The arid zone of West Pakistan: geographical aspects of aridity in West Pakistan.

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Geographical Aspects of Aridity in West Pakistan.

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Abstract of Thesis

In West Pakistan aridity has for long been considered from many separate aspects, climate, hydraulic engineering, irrigation engineering, crop selection etc, and there is a considerable volume of unrelated findings. This thesis represents an attempt to relate and correlate the various approaches by establishing some of the aspects of the geographical relationship between man and various aspects of the land.

The basic environmental elements of physique, geology, structure and climate are first established, a selective approach being based on relevance to the central point of climatic aridity - Chapters 1-3. In Chapters 4, 5 and 6, are considered those elements which are physical in character, directly influenced by climate, but whose present characteristics are to a varying degree the result of the human response to dominant aridity. Thus, in considering Hydrography one must look at elements such as river-regimes and underground water partly as fundamental parts of the landscape

and also as units having a two-way reaction with man's works in irrigation, cultivation etc. Similarly Soils, and Plant Ecology are regarded as parts of a whole complex in which climatic aridity is dominant and as complexes of natural and man caused factors. The concluding Chapters 7, and 8 are devoted to a consideration of the direct human response to environment, in the past and present. Archaeological, historic and present settlement patterns not only illustrate this response, but clarify our picture of the environment itself.

Aridity finally is more than a deficiency of rainfall. The most simple human response is to live on the qualities of drought-resistance possessed by some livestock, but extensive pastoralism in arid areas itself brings into focus some more complicated implications of climatic aridity, i.e. overgrazing, deforestation and their ecological consequences. Man as cultivator can move away from direct contact with climatic aridity, but since pre-historic times this has merely extended the range of the effects of total aridity on himself, and extended the range of meaning, in the landscape, of the factor of aridity i.e., canals and increasing salinity, floods and barrages, wells and commercial crops.

THE ARID ZONE OF WEST PAKISTAN

Geographical Aspects of Aridity in West Pakistan

By

Maryam Fazal Ahmad Khan

Thesis submitted for the Degree of Doctor of Philosophy in the University of Durham

May, 1961.

TO MY

FATHER AND MOTHER

CONTENTS

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Introduction

In West Pakistan, aridity has for long been considered from many separate aspects such as meteorological and climatic, irrigation and hydraulic engineering, crop selection and pedological. However the diversity of independent studies has meant that each approach has usually ignored closely related but not obviously relevant facts. Many of the reports thus appear to be contradictory of each other, and much repetition exists. Different agencies and bodies have approached a common problem in such different ways that development works sometimes cancel each other out. A clear example appears in the way in which in the past, the calculation of the amount of water to be applied in irrigation, a need created by aridity, has been made differently by workers responsible for reclaiming land from the desert on the one hand, and for reclaiming land ruined by irrigation on the other.

This thesis is a pioneer attempt to integrate the different approaches geographically, to provide for the first time an assessment of the factors involved in the delicate balance imposed on the life of West Pakistan by aridity. The pivotal theme throughout is water and its relation with other physical and human elements.

Taking such a theme, the main reliance has had to be on personal observation rather than direct fieldwork and on scattered but considerable published and unpublished works. The writer is directly familiar with all the regions of West Pakistan except for the Divisions of Quetta and Kalat, and has thus been able to translate reports in terms of direct experience. The purpose of the thesis therefore is to consider the geography of aridity as a whole and to present some evaluations and judgements which otherwise could not be made; the main such conclusion being that of the increasing precariousness of reliance upon increasingly complicated ways of living in conditions of aridity. This precariousness affects everything, including human society, in the ecological complex. If this is appreciated, as it can be geographically, then a new balance of human life, climate, river regime, soils and terrain can be established. As will appear the need is urgent and the true balance hard to find.

For this purpose an inventory of the relief and geologic stratigraphy becomes important, therefore the physiographic setting form the beginning of this thesis. The first two chapters reveal the physical personality of the area and a cursory comparison has been made between the topography and the processes shaping the topography. Desert evolution is also considered.

Chapter 3 emphasises the importance of precipitation as the principal element controlling the climatic regime and the destiny of man. West Pakistan lies on the fringes of both Summer Monsoon and Western Depressions. Both these rain bearing influences fade out over this land. Most of the country receives rainfall which is late, meagre and extremely capricous. The influence of rainfall in general and particular of the monsoon is so marked that the agricultural calendar and seasons are defined by its incidence. The variable incidence of rainfall has been explained in terms of various aspects of its volume. The average annual rainfall decreases from 40" in the extreme north east to below 5" in the south west. Variability increases with the decrease in the annual amount of rainfall. The areas of least rainfall show highest degree of aridity and highest variability. No formula or mathematical calculation can be applied as in the present circumstances we cannot rely on any basic formula for rainfall which is extremely fickle. The temperature variations have also been discussed and also their effects along with sporadic rainfall in producing the aridity. Finally, the aridity has been treated by defining it with reference to classification schemes, and De Martonne's formula has been adopted to express the degree of aridity of West Pakistan. Almost all the causes of aridity accounted by various authors has been reviewed.

While, Chapters 1 to 3 to a large extent deal with the inter-relations of unchangeable physical elements, in Chapter 4, we turn to a consideration of the first of the basically physical phenomena in which human action has increased the complexity of the function of aridity, i.e. hydrography and water-resources. It is seen that water resources derived from externally originating rivers and underground bodies are as inadequate as rainfall. The ecological dangers as well as benefits of irrigation are examined particularly as regards waterlogging. The hydrographical history of the region is discussed together with the implications of political divisions of hydrographic units. Similarly, in Chapter 5, the Soils of West Pakistan are considered. They represent natural processes in specific environmental conditions but are also partly products of human actions in an arid region. Thus soil salinity is directly and indirectly a result of sub-tropical aridity. Ecological work in this field is examined along with policies of soil control and improvement.

Chapter 6, has been intended to show how the physical factors of orography, climate, water and soil influence the plant cover and cultivation of plants is affected by these factors. Throughout the study the interaction of human and physical factors has been blended. Every chapter shows the geographical limitations imposed by shortage of water, climate, soil and traditions. The existing land use pattern is finally fully governed by the rainfall regime, and the provision that has been made for artificial irrigation. Sample studies in the discussion of various plants for 3 stations is examined in terms of the climatic amplitude of the stations. The degree of irrigation intensity and suitable techniques are also considered. The oscillation of food production is explained and related to the causal factors. The means and measures which may be adopted to increase the food production for the alarmingly increasing population, when the major handicap is limited water, are discussed.

Chapter 7, is a historical inventory which throws light upon the evolution of cultures and environments since 5,000 B.C. Once this area supported an advanced agricultural civilization, which maintained trading and commercial relations with the contemporary civilizations of Iraq and Iran. From 1,500 B.C. to the annexation of this part of the sub-continent by the British sovereignty in the 18th century, West Pakistan remained practically a "cross road" for foreign incursions. Some important points emerge very clearly. First, there is some evidence that climate during early human occupation was less arid, and that even in early historic times the Indus plain was ecologically more attractive than at present. Secondly, the Indus plain remained throughout attractive to primarily pastoral groups from Central Asia, their movements into the sub-continent being topographically canalised through the Indus region. West Pakistan has thus been a region of new successive human appraisals, and a region of conflict rather than one of slow indigenous development. In the particular environmental circumstances this has had specific effects on settlement.

In the final chapter, an attempt is made, by using the landscape evidence rather than by social and economic analysis to show how settlements in their form and distribution, reflect aridity as it appears in the minds of men.

Every aspect of this study has been consistently related to the water resources and aridity. The striking fact that arises from this study is acute poverty of the available water resources. Pakistan is facing an acute shortage of food and an economic breakdown in the face of a rapidly increasing population. There is always an apprehension of food shortages and at the same time people are desirous of raising their standard of living. To achieve this end, substantial and consistent attempts are needed to find out better methods for the economic use of water and drought resisting crops.

Every inch of Pakistan, particularly the utterly neglected Divisions of Quetta and Kalat await basic research and offer an immensely interesting field of study of geographical control. It needs application of field work, science and capital.

In this age of space exploration nature is apparently being controlled by scientific progress, by application of technology and automation and the needs of the modern man are thus assessed. In spite of all this advancement, the natural forces still remain dominant in the development and the rehabilitation of a country; here the inherent character of an area - aridity - determines the limitations.

As previously pointed out, with a study of this kind, main reliance must be on documented evidence supplemented by personal observation. Chapters 6 and 8 are based almost entirely on the writer's own personal work.

The candidate regrets to state, that the obtaining of basic data direct from some of the Pakistan Government Departments was virtually impossible. That information so asked for was finally only acquired indirectly. That information which could be obtained inside Britain was easily afforded. The information office and the Education

Division in Office of the High Commissioner for Pakistan must be singled out for their helpfulness which is here acknowledged gratefully.

Mention must be made of the great help given by Professor A.J. Zuur and R.H. Messemaeck Van de Graaff of the Netherlands, who were visiting experts to Pakistan during 1957-58. The information related to salinity and waterlogging reproduced here, is based mostly on material obtained from them through personal correspondence. The writer in this context feels highly obliged to them. Her thanks are also due to Mr. H.E. Hayward of the Salinity Laboratory, Riverside, California; who arranged an introduction to Professor Zuur; and explained the most recent views accounting for the prevailing salinity, by personal communications.

Every possible effort has been consistently applied for the acquisition of recent information on West Pakistan. In this respect foreign experts have proved very responsive, and have answered many enquiries with great interest. In spite of their overwhelming business they replied promptly, which is highly appreciated. The writer feels indebted to the F.A.O. authorities at Rome and Unesco authorities at Paris. They have very willingly acceded to her every request and supplied her with all the available literature produced by the experts deputed by the F.A.O. and Unesco under the auspices of the Arid Zone Committee. Mention may be made of the obligations which she owes to Professor C.W. Thornthwaite and his staff of Laboratory of Climatology, Centerton, New Jersey, who pleasingly supplied her with the literature they produced on the south west Asia on the evaluation of aridity. Through these media the writer received a bulk of information, also from the Unesco News letter received regularly since December 1958.

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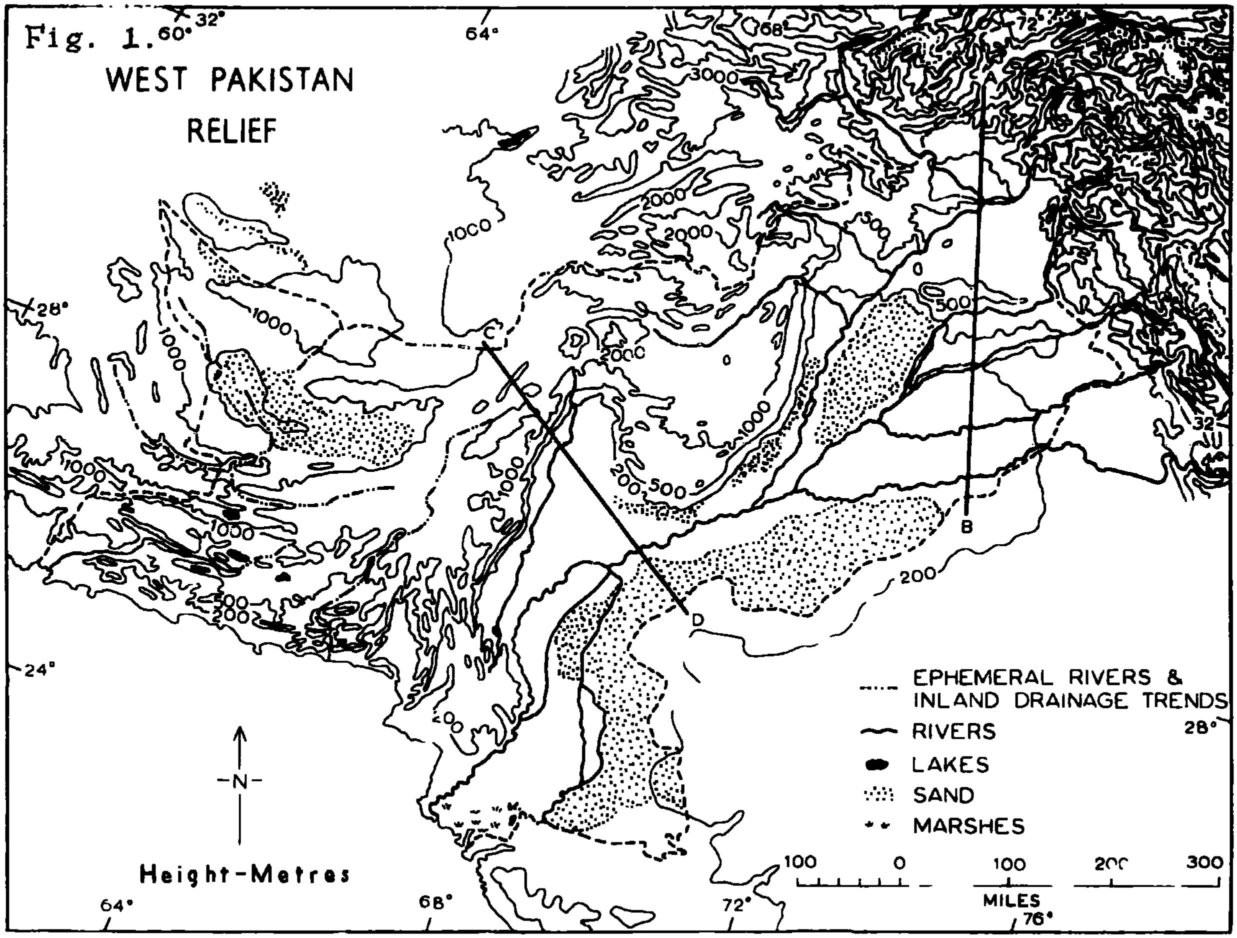


Fig. 1.
WEST PAKISTAN
RELIEF
60°
32°
64°
68°
72°
28°
24°
30°
32°
28°
64°
68°
72°
76°
3000
2000
2000
1000
1000
1000
1000
1000
1000
1000
500
500
500
500
200
200
200
0
0
A
B
C
D
EPHEMERAL RIVERS &
INLAND DRAINAGE TRENDS
RIVERS
LAKES
SAND
MARSHES
N
Height-Metres
100
0
100
300
MILES

Part I

Physiographic Setting

Chapter 1

Physical Features

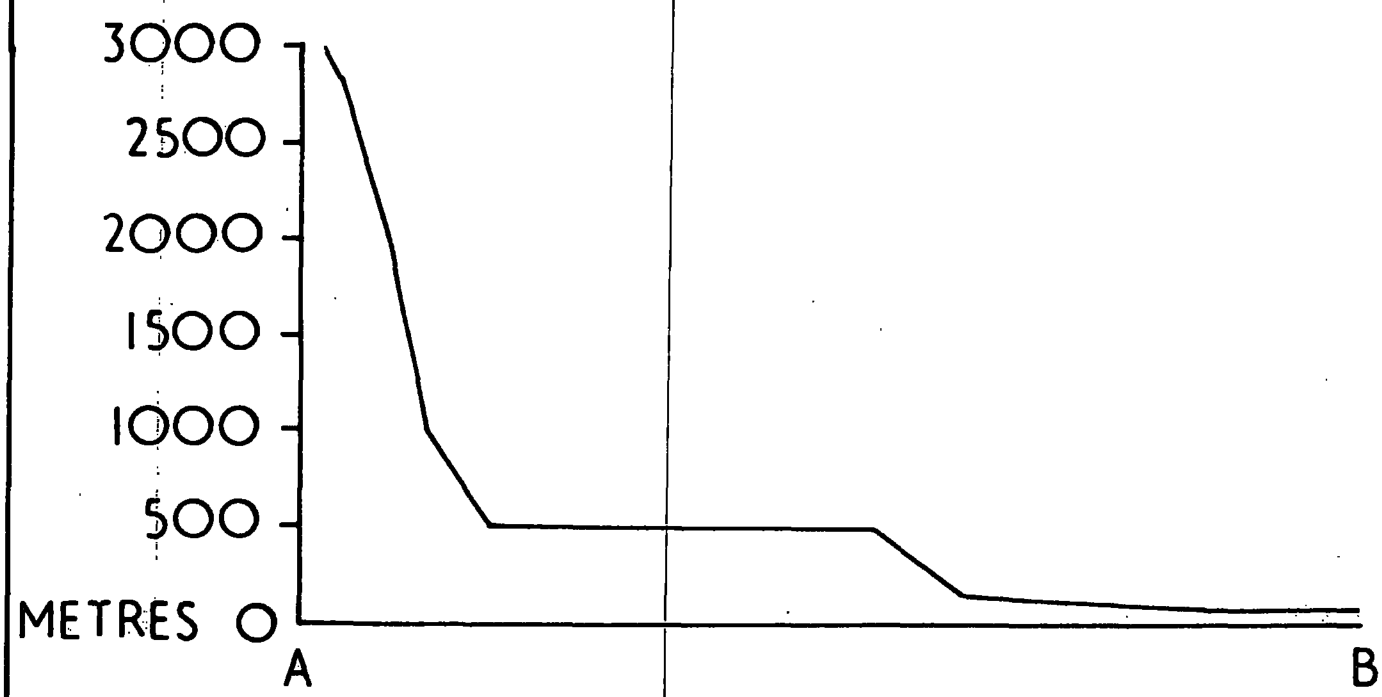
The diversified topographic pattern of West Pakistan is well illustrated in Fig. 1. Most striking is the contrast between the rugged high mountain land of the North and West and the relatively level aggraded lowland of the South East. From the region of the Pamir Knot, where the amplitude of relief lies between 6,000 and 8,000 metres above sea level, great mountain ranges fan out to the South West, with gradually concentric arcuate dispositions. In the mountain lands are thus enclosed great highland basins, while between the outflung marginal minor ranges lie lowland basins pockets. Outlying highlands form isolated fragmentary eminences.

In the North-East, between the Indus and the Jhelum rivers, descent from highland to lowland is via the Potwar Plateau, situated just under 500 metres above sea level. (Fig. 2A.). The southern edge of this plateau region is defined by the east to west line of the Salt Range. The south facing escarpment of the Salt Range, marked by the 500 metres contour, is the southern-most edge of the arcuate bold major relief forms. South of this, the land drops away quickly to some 200 metres above sea-level, the level of the

FIG 2B SECTION WEST - EAST

FORMALISED RELIEF SECTIONS

FIG. 2A SECTION NORTH - SOUTH



Upper Indus Plain, which, then, with only slight undulations, gradually descends to sea-level more than 500 miles to the south.

The western edge of the lowland is met more abruptly by the highland edge. The arcuate swinging ranges of the Sulaiman and the Tobakakar rise to 3,000 metres above sea-level, enclosing between them the medial Lora-Zhob basin. The outer edge of the Sulaiman range then falls abruptly eastward to the main lowland level. (Fig. 2B.). Beyond the Kirthar Range, which walls off the Lower Indus Basin, the Makran and subsidiary ranges are aligned east to west; rising precipitously from a narrow coastal plain. In the Kalat Division lie alternating mountain blocks, depressions and basins.

To the east, the Indus Plain is bordered by the Thar-Parkar Desert, topographically relieved only by a slight rise to some 200 metres above sea-level, in the extreme south-east.

Physical Regions:-

A schematic zoning of West Pakistan into component parts, each having natural as well as political unity has not yet been devised by anybody.(1) There are however, a few analytical groupings of natural regions of the Pak-Hind Sub-Continent; recognised both by foreign and national geographers.(2) Geographers more or less differ in their schematic analysis of the Natural Regions of the Sub-Continent, suggesting a number of major, secondary and further sub-divisions. Of these geographers, Baker proposed 4 major regions, while Stamp envisaged 5, whereas the number of major divisions as advocated by Ahmad and Pithawalla are 7 and 5 respectively. Recently, Spate has attempted a regional division of the Pak-Hind Sub-Continent. Though he has treated the sub-Continent as a single unit, yet in his scheme, West Pakistan is very clearly identified with a group of independent natural regions. According to his approach, West Pakistan includes two Macro Regions and 5 Regions of First Order with Micro divisions. In Spate's scheme for the sub-Continent, the Regions of First Order comprising West Pakistan are I, II, III, IX and a part of IV.

All the major or macro regions listed by various authorities are large divisions having within them great topographic variations, for the explanation of which they have resected them into a number of minor regions.

After examination of the previous literature mentioned above, and in the light of personal observation the present writer has devised her own scheme of regions, more similar to Spate's scheme than to the others.

Broadly speaking the physical features of a country are an expression of the character of land-forms, which are an outcome of collective and continued efforts of "epigene"(3) and "hypogene" processes. There are no hard and fast rules for the demarcation of natural regions, only that they are best based on main orographic features. The regions are commonly based on the physiographic elements of 1. mountains, 2. plateaus and plains, 3. valleys, 4. basins and lakes, and 5. coast line.(4)

The physical delimitation adopted here, is strictly based on these natural lines of differentiations and variations in the disposition of mountain ranges, valleys, water-sheds, plateaus, plains, doabs, deserts and coast.

The zonification basis used here is that of the Topographic Sheets of 1:1,000,000 scale. Each region is homogeneous in its physical features. Its recognition as an independent whole does not depend on its extent. The regions so defined are described below since they form the basis for all future physical, ecological and human references in this study.

As there will be separate chapters on the aspects of geology, climate, hydrography, soil, ecology of cultivated plants and settlements, the present context has been restricted to orography and structure and very few passing references have been made to other aspects of West Pakistan.

<u>The Macro Regions</u>:-

In a strict orographic sense, Fig. 1, clearly shows the division of West Pakistan into two Macro Regions: I. The mountainous country in the north, north-west and south-west and II. The plains flanking the mountain belt to the south and south-east. The same divisions may be adopted both for structural and stratigraphic studies of West Pakistan: I. The Young Folded Tertiary Highland which forms the western sequence of the Himalayan chain, and II. The Quaternary Lowland. The two Macro Regions are clearly defined in the two profiles drawn from north to south and west to east. (Figs. 2A and B.).

The two Macro sections are dissimilar both in the mode of their constitution and conformation, as explained in Chapter 2. Both types of region have different histories of formation and their evolutionary cycles determine their present topography, which in turn chiefly control their climate, hydrography, soil and the native fauna and flora.

I. Highland:-

The structural development of highland building, briefly, is that, initially the surface configuration has been created by orogenic movements, by which an ancient sea floor has been exposed and lifted high to form the present mountain ranges and plateaus of varying size and magnitude, which "depend on the amount of uplift that it has suffered".(5) These from their inception, were subjected to modifications caused by "exogenic" or external processes". As the highland was being raised up into high mountain chains, the land was folded, and faulted.

Referring again for a moment to relief map, Fig. 1, a distinction can be made between the northern and southern highland. In the north, the relief of the country, in places reaches extremes of 6,000-7,000 metres above sea-level. Folding is severe and the ranges radiate to the south-west. In the opinion of Pascoe the greatest warping in the high Hindu Kush, Hazara and adjacent mountains ..... occurs along a line where the north coast of the northwardly moving land-mass would first have met the south coast ..... or rather the marine sediments off the coast ..... of the Angara Continent. Here the buckling, thrusting, and mountain formation would have been most intense".(6) This suggests that the northern part of the existing highland was sandwiched between the two rigid masses of Gondwanaland and Angaraland as they moved northward and southward respectively. Hence, the elevation and complexity correspond with the amount of pressure and disturbance.

In the southern highland, the mountains rise to 3,000 metres above sea level only. Their folding is comparatively slight. Their relatively low elevation and "simple structure"(7) are thus explained by Pascoe.(8) "On each side of this line the rock-waves of the invaded continent and its coastal sediments would have eddied past and spread out in a wider belt of less concentrated and less intense folding and faulting". The nodality of Quetta, "between the consecutive mountain arcs ..... appear to have coincided in a general way with headlands projecting from the drifting Gondwanaland mass". The present strike of the southern mountains is attributed to the N.N.E.-wards movement of the Deccan Mass.

The recurrences of these orogenic storms is clearly witnessed in the presence of folding, thrust and dislocation of rock strata in isolated blocks between the mountain ranges.

As the rocks, of which the highland is composed originated in a Mesozoic Ocean they are predominantly of rocks of relatively recent marine origin. Except for the Siwaliks, they are made up of fluviatile debris and consolidated mud deposits. In marked contrast, the underlying solid geology in the lowland region is obscured by a thick overlay of water and wind-borne material ranging from fine silt to coarse gravel. The surface is pocketed by saline depressions and waterlogged areas and raised in a few low eminences.

Finally, rivers in the highland are antecedent, and flow in deep and precipitous valleys. They cut vigorously through the mountains to reach the plain, and very active corrasion is in progress. The rivers in lowland zones lead sluggish courses governed by local base levels and they are in the state of "aggradation".

II. The Lowland:-

The lowland is defined as a "geosynclinal depression"(9) or "trough",(10) extending from the foot of the highland in the north to the coast in the south. The Indus plain, (like the whole of the Indo-Gangetic plain), as commonly believed by geologists, originated structurally from a "fore-deep" formed in front of the high crust waves of the Himalayas as they were checked in their southward advance by the inflexible solid land-mass of the Peninsula".(11) This hypothesis holds,that,the whole geologic history not only of West Pakistan but of the whole Pak-Hind Sub-Continent has been controlled and regulated by the movements of the Deccan mass. The lowland thus,occupies a medial or an intermediary location between the two adjoining areas of structural significance and bold topography.

Actually, the lowland of West Pakistan is composed of two troughs. The first is the "Indus" trough, the second, the "Ganges" trough occupying the area between Lahore and the Salt-Range.

The developmental history of this Plain is simple and brief, beginning at the dawn of the Quaternary Era. It is an area of prolonged aggradation and all previously existing features have been concealed under the mantle of superficial deposits laid down by exogene processes. The tremendous amount of detritus with which it is filled has lead to sinking. The lowland owes its surface details to the work of water and wind and to the desquamation caused by a high range of temperature. The depth of alluvial sediments is not confirmed, but is estimated approximately to be of the order of 1,300 feet. These deposits become considerably finer further away from the highland. Over these thick sediments flow the rivers originating in the mountains.

The almost homogenously constituted plain is amazingly vast and predominantly gentle in slope. Some low local terrain features break the monotony of its level slope and uniformity of character. They are the "exhumed"(12) outliers of the Aravalis at Kirana, Chiniot, Sangala, and Shurkot, which protrude to a height of 1,000' above the surface of plain.(13) At some places low valley swells produced by river deposition at flood time, or the subdued mounds of settlement sites of the by-gone days, also add character to the landscape.

The consequence of the flatness of this is that a very slight change in the level of land or water may lead to the affluents of one river to flow into another. In the present day the rivers are accustomed to overflow their channels in the rainy season. Every year the intensity of floods surpass the previous year. "The river Indus, which has been on the rampage for some days, suddenly changed its course today some 25 miles from Dera Ismail Khan and submerged more than 25 villages. About 14,000 villagers had to flee from their collapsing houses, and were evacuated in boats, but many villagers are missing. Several thousand houses have collapsed".(14) The verbal picture may be visualised in plate 14 , in the Chapter on hydrography.

The compact entity of the lowland, visually conspicuous by virtue of its relative smoothness, further stands out in terms of its utility to man. It offers a greater amount of land favourable for human use than the terrain of highland. In it are situated the major nucleations of settlement, because the land is largely capable of tillage with readily available water. Moreover, this is the area where there is great competition for land and water for various uses, for instance agricultural, settlements, factories, educational and amenities. The desert tracts are sparsely inhabited by pastoral nomads, but sedentary farming is made possible by irrigation in the alluvial tracts of the arid and semi arid zones.

There then, are the two macro-regions, structually disturbed highland and aggraded lowland. Not only in their relief and structure are they contrasting in character, but also largely because of these contrasts they are different in most other ways, not least in all the factors associated with aridity and its impact on human life.

The main characteristics of the sub-regions are now outlined in order to provide a firm basis for latter discussion. In the absence of any single study, other than that of Spate, which considers the character of the many sub-regions, it has been thought appropriate to include this series of short sketches if only to illustrate the great variety of physique. Table 1 Fig. 3.

Table 1

The Topographic Zonation Scheme for West Pakistan

Macro-Region	Region of First Order	Region of Second Order	Micro-Region
A Highland	I North and North Western Mountain	(1) Hazara hills	
		(2) Zone of longitudinal ridges and valleys	a. valley of Swat b. valley of Panjkora c. valley of Chitral

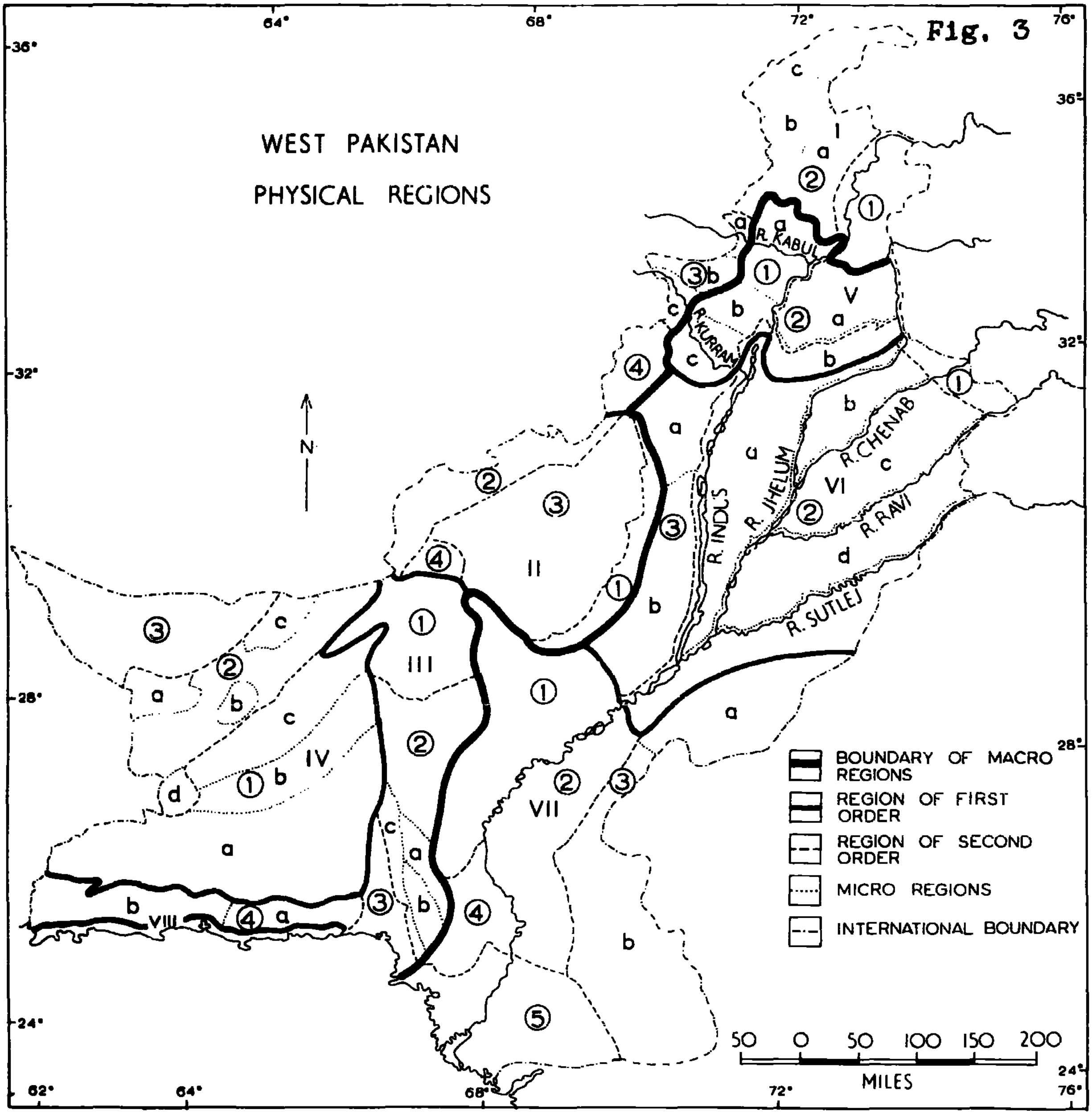


Fig. 3
WEST PAKISTAN
PHYSICAL REGIONS
N
R. KABUL
R. KURRAM
R. INDUS
R. JHELUM
R. CHENAB
R. RAVI
R. SUTLEJ
BOUNDARY OF MACRO REGIONS
REGION OF FIRST ORDER
REGION OF SECOND ORDER
MICRO REGIONS
INTERNATIONAL BOUNDARY
50 0 50 100 150 200
MILES

Macro-Region	Region of First Order	Region of Second Order	Micro-Region
		(3) Zone of transverse Ranges and valleys	a. Kabul Valley b. Safed Koh Range c. Kurram Valley
		(4) Mountainous maze of Waziristan	
	II Western Mountain Rim	(1) Sulaiman Range	
		(2) Tobakakar Range	
		(3) Zhob-Lora Basin	
		(4) Quetta Node	
	III Southern Mountain Rim	(1) Sarawan country and Central Brahui Range	
		(2) Kirthar Range	a. Khude Range b. Pab-Range c. Chaper Range
		(3) Hab and Porali Valleys	
		(4) Makran Coast Range	a. Eastern Makran with Hingol valley b. Western Makran with Dasht-valley
	IV Central and Northern parts of Kalat Division	(1) Central Ranges	a. Central Makran Range b. Rakhshan Range c. Sihan Range

Macro-Region	Region of First Order	Region of Second Order	Micro-Region
		(2) Inland Drainage Basins	a. Hamun-i-Mashkel
			b. Hamun-i-Margho
			c. Hamun-i-Lora
			d. Parom Kaps
		(3) Chagai Hills	
	V Sub-Mountainous zone	(1) Trans-Indus plains	a. The Vale of Peshawar and Mardan plain
			b. Kohat plain
			c. Bannu plain
		(2) Cis-Indus	a. Potwar Plateau
			b. Salt-Range
B Lowland	VI Upper Indus Plain	(1) Sub-Siwalik zone	
		(2) Doabs	a. Sindsagar doab
			b. Chaj doab
			c. Rechna doab
			d. Bari doab
		(3) Derajat	a. Dera Ismail Khan
			b. Dera Ghazi Khan
	VII Lower-Indus Plain	(1) Sibi-re-entrant and western Nara doab	
		(2) Eastern Nara doab and Salt Lakes	
		(3) Desert	a. Cholistan
			b. Tharparkar

Macro-Region	Region of First Order	Region of Second Order	Micro-Region
		(4) Kohistan	
		(5) Delta	
	VIII Makran Coastal Plain		

I. North and North Western Mountain Rim.-

The bold orographic outlines are determined by the parent structure, by combined efforts of the multiple processes of orogenesis. The country of staggering and gleaming heights, with a series of alternating deep valleys, falls into four natural regions of second order.

1. Hazara Hills:

Excluding the south-eastern extremity the whole region lies in the Division of Peshawar. Climatically, it is the most humid part of West Pakistan.

This is the zone where the Outer or Sub-Himalayan or Sub-Siwalik Ranges, and the lesser or the Mid-Himalayan ranges meet.(15) Hence, the area has been treated as a separate component. The Cis-Indus or Western Hazara ranges descend from the altitude of 10,000 ft in the north to about 4,000 ft in the south. It is noticeable that the profusion of spurs increases as the surface falls in height. In the east the Dunga Gali Range runs along the right bank of the Kagan (Kunhar) river, and the Jhelum river flows in the south of this range, making a water-parting between the two rivers.(16) The range varies greatly in its elevation from about 15,000 ft in the north to about 4,000 ft in its middle, finally, terminating in the plain in the south. The south eastern spurs form the Rawalpindi hills which rise from 2,000-4,000 feet and form bad-land topography. Erosion is active owing to deforestation and over-grazing, and also to the unconsolidated material of which the hills are composed. Numerous streams, larger on the western slopes, smaller on the eastern, dissect and water this region. Plate 1.a, illustrates the character of the river pattern. Between the eastern and western Hazara hills, lies the Central Hazara Country, which consists of a formation of solitary hills along with a patch work of plains. This tract of low elevation is a dividing zone between the eastern and western Hazara ranges.

2. The Zone of Longitudinal Ranges and Valleys:

The whole zone lies in the Peshawar Division, and forms a northern periphery of the semi-arid zone. This is an area of lofty mountains and gorge-like river valleys corresponding to the ranges they flow through. Plate 1.b portrays a gushing mountain stream entering a small fan, and the

Plate 1

a

b

Plate 2

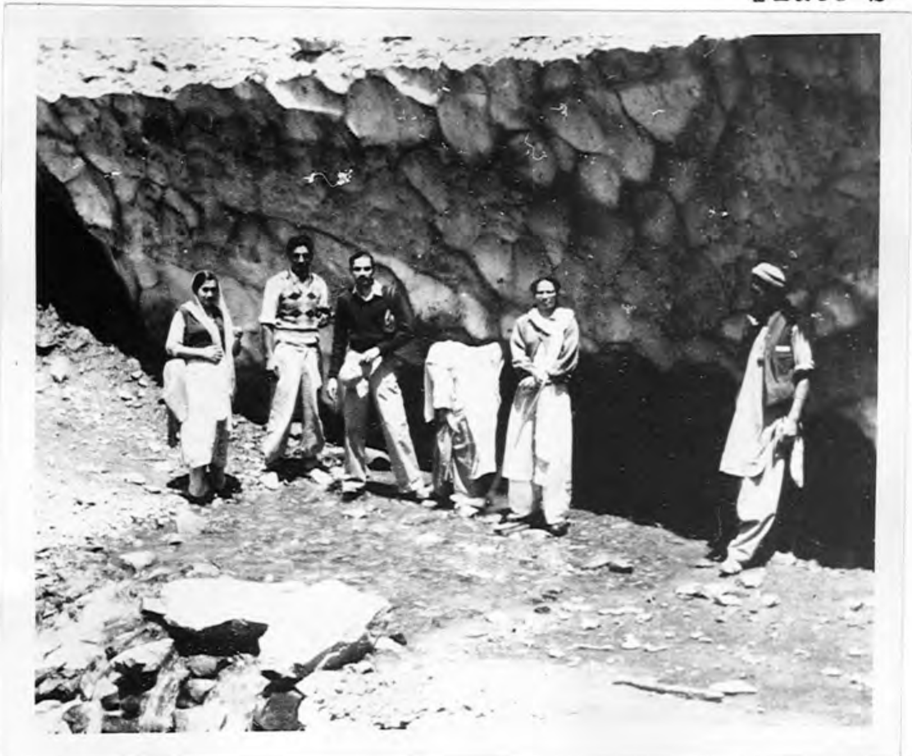


Plate 3

Plate 5

Plate 6

1. Potwar peneplain over Middle Siwalik beds west of Chauntra, with Khair-i-Murat ridge in background.

Plate 7

FIG. 1. HILLS OF DHOK PATHAN CONGLOMERATES AND SANDSTONES, NORTH OF MALANGI, NEAR BANK OF INDUS.

a

..3. Loess landscape in Potwar silt.

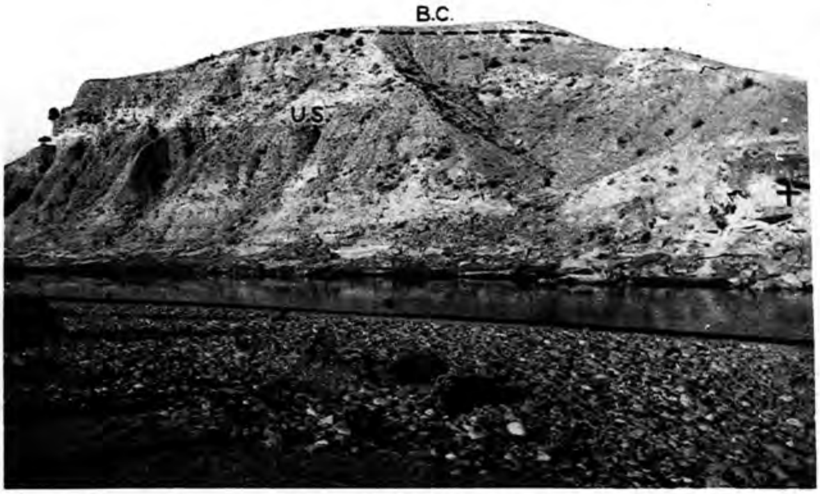
B

Plate 8

FIG. 1. GORGE OF THE INDUS BELOW ATTOCK. THE HILLS ARE OF ATTOCK SLATE

Plate 9

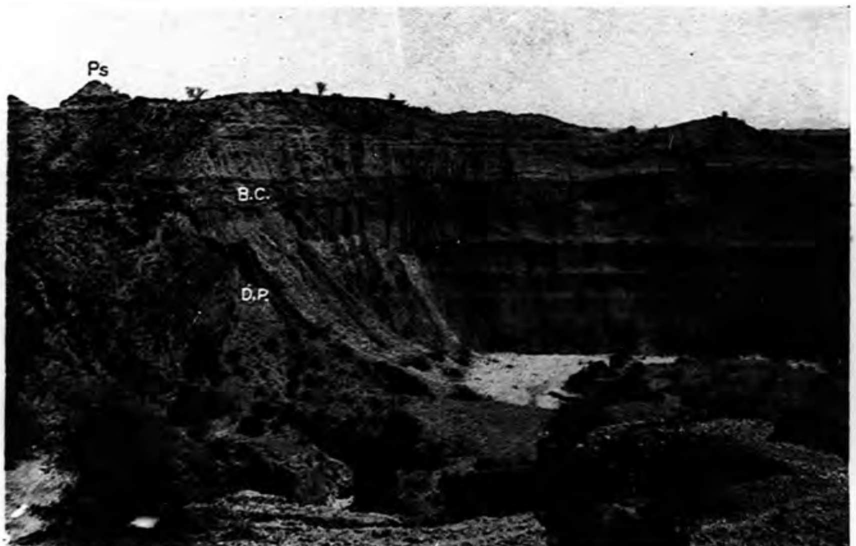
3. Erratic boulder on T2 near Campbellpore. Pecked petroglyphs on surface.



2. Boulder conglomerate with erratics (B.C.) on tilted Upper Siwalik beds (U.S.) with bone bed (+) on Haro River near Campbellpore.

Plate 10

Plate 11



3. Pinjor silt overlain by Boulder conglomerate (B.C.) and Potwar loessic silt (Ps), unconformable on folded Pliocene Dhok Pathan beds (D.P.) in Soan Valley.

Plate 12

4. Fault escarpment of Khair-i-Murat with dissected pediments.

Plate 13

unevenly wooded slopes. These longitudinal ranges form many local watersheds, but the whole section forms a watershed between the Oxus System and the Indus System. Within this section the Hindu Kush mountains provide the premier water-parting, between the Chitral (Yarkund) and Panjkora rivers. The Hindu-Kush is a bifurcation of the Pāmir Knot and it impinges on the western extremity of the Himalays. In fact the territory is a continuation of the Himalayan system. The other ranges provide the water-divides between Panjkora, Swat and the Indus Valleys. In this way the linear pattern of each ridge forms a single natural entity. (Table 1.). The average elevation in the extreme north is 27,000 feet. The chief peaks are covered with perpetual snow which feeds the rivers of this area throughout the year. Plate 2 was taken during the month of July about 10,000 feet above sea level in the Dir state territory, and the magnitude of the snow cover is clearly seen.

One of the earliest European travellors in this area portrayed the extremely mountainous terrain as follows: "It is an entirely mountainous country, with never a stretch of plain more than 3-4 miles in length. The valleys are deeply cut and the lowest mountains are 13,000-14,000 feet in height, while some rise to 25,000 feet. Except in lower

Chitral and in some secluded valleys they are perfectly barren and bare".(17) This desiccated, barren and wildly eroded country is illustrated in plate 3. In contrast to this bleak picture of the mountains, a bright and lively portrait of the lower portion of valleys is drawn thus, "..... surrounded by extensive maize and wheat fields enclosed by walnut, mulberry, apple and apricot trees. The hillsides are clothed with deodar and chir, the cedar and common pine trees and water is plentiful".(18) There is no dearth of such picturesque spots in regions 1-III and V.

The above two contrasting views are remarkably illustrated in Plate 4. Barren mountains are replaced in their foot hills by orchard groves and fields. The highest range in the far distance is snow capped, and it is followed by lower and barren mountains and narrow valley defiles, which terminate into the lower ground, where the banks of the stream are clothed with fruit trees.

In the south, the Hindukush ramifications are involved in shaping the Malakand and Utmankhel ranges. Their altitude varies from 5,000-6,000 feet. This compassable elevation has offered opportunities for the location of a power station at Malakand to generate electricity by harnessing the Swat river. In the south-east, the water divide between the Indus and Swat rivers descends into the Bunneer plateau with an inset transverse valley, the whole area draining into the Indus.

3. The Zone of Transverse Mountains and Valleys:

This forms the south western portion of the Division of Peshawar, and the zone of spring rainfall of semi-arid conditions. Unlike the region 2 the mountains and valleys run transversely, approximately W.N.W. to E.S.E. The longitudinal and transverse zones are separated from one an other by the W-E valley of Kabul river. Hence, the northern boundary of this transverse zone is formed by the Kabul valley, which rests on the spurs of Safed Koh.(19) Safed Koh runs in west-east, and is of considerable height. Its loftiest pinnacle is Sakaram 15,620 feet. The average elevation from the west in the vicinity of Piewar Kotal, and in the east in the neighbourhood of Ghora is about 10,000 feet.

The Safed Koh follows a zigzag path to the east, where many off-shoots depart from it which "are remarkable for their parallelism with each other and with the parent range".(20)

4. The Mountain Maze of Waziristan:

This forms the north western portion of Dera Ismail Khan Division. It obtains most of its rainfall in spring and forms the north-western extremity of the semi-arid region. The orography of Waziristan is confused and complex, dominated by several dry hummocky ridges. The general alignment of the ranges is west to east. Waziristan is a country of numerous "Raghzaies" and "Kutzas".(21) The former are flat-topped stony plateaus of great extent and of varying heights, from 50-200 feet. Unlike them, the latter are rich fertile basins. The most prominent peaks are Shuidar 10,936 feet, and Preghal 11,556 feet. "The outer spurs of south Waziristan hills are to the eye utterly barren and desolate, though here and there the soil nourishes a few stunted wild olive trees."(22) The Waziristan ranges coalesce into the Bannu plain in north-east and in Dera Ismail Khan in the south-east.

The other peculiarity of this area is the absence of any dominant grain or trends in topography and drainage systems. General alignments are mainly from West to East, both of relief forms and of river valleys. In the north the area is traversed by north west to south east flowing Kurram and Tochi rivers. All the rivers join the Indus directly or indirectly, and the whole area is bounded by the gorge which ends in the fertile Wana Plain.

Important Passes in Region 1:-

There are many passes in this section of West Pakistan. These passes are extremely narrow in the high Hindukush at the heights of 13,000 feet. The comparatively wider passes are Khyber, Tochi, and Gomal. Throughout the human history of the Indus Plain, these passes provided relatively easy paths through the difficult terrain of the region. Historically the most famous is the Khyber pass, owing to its broad size and situation on the head of the Indus Plain, hence forming a gate way to the fertile inviting plains. More details are recorded at the end of Chapter 7.

II. Western Mountain Rim:-

The whole region is contained in the Quetta Division, and forms a part of arid Pakistan. Unlike region 1, there is more regularity in the orographic character of this Region. The structural elements of Hindukush proceed southward and westward in the shape of crescents and loops. Within their arms lie numerous small and large river basins.

As the Divisions of Kalat and Quetta have had more comparative study, the shape and schematic arrangement of the orographic lines have been explained, in general agreement by modern writers.

Wadia refers to the relief patterns of Baluchistan as "of a more simple geological structure" with a "succession of anticlines and synclines ..... especially the mountains reveal a very simple immature type of topography. Here the hill-ranges are anticlines with intervening synclines as valleys".(23) Erosion and aridity have dissected the limestone areas with precipitous gorges and steep slopes. The signs of maturity, broad valleys, gentle slopes and subdued appearance of the topography, are here non-existent.

The shape and general layout of the mountain ranges have been expressed thus: "The general configuration of the mountains resembles the letter S"(24) and another, "parallel or rather concentric ridges roughly an arc of a circle".(25) Another verdict, "a land of contradictions and contrasts".(26)

The topographic and structural complexities associated with arcuate ranges and valleys enclosed by them may be summarised as follows. The orographic lines are tapering elongated, swinging southwards and northwards, assuming crescent shapes, with ridge summits of varying altitudes, 6,000-11,000 feet in the Sulaiman and Tobakakar Ranges. The Sulaiman Range falls in a convex slope to the plain and it forms a striking western limit to the lowlands. Numerous transverse valleys breach the mountain wall and divide the country into separate natural compartments. The area widens out between the Tobakar and Sulaiman Ranges, where the intervening Lora-Zhob basin nestles and the Tobakakar Range converges on this medial depression. The mountain ranges are tangled in a knot round Quetta. The whole region abounds in small plateaus, mesas, precipitous crags, and "damans" littered with boulder clay. Among them a few green alluvial basins are located. Plate 5, shows this typical immature landscape.

III. The Southern Mountain Rim:-

Regions III and IV lie in the Division of Kalat, and are extremely arid areas. For consideration the southern mountain rim may be divided into 4 parts:

1. Sarawan Country and Central Brahui Range:-

This consists of a number of enclosed valleys. The general slope of the country is to the north. The average altitude is 5,000-8,000 feet. The chief range, the Central Brahui, and Nagau and Unalath ranges have an average height of 7,000 feet.

2. Kirthar Range:-

Kirthar is the main range and numerous minor ranges run parallel to it in the common alignment of north to south. The immature characteristics of Kirthar Zone are striking. The massive limestones of Cretaceous to Oligocene times is accompanied with small Deccan lava intrusions in the anticlines. The anticlines have been attacked by erosion but owing to desiccation erosion has not progressed far, hence the anticlines and synclines persist as ridges and valleys respectively. The most prominent feature is Kirthar range with an altitude of 4,000 feet in the south to about 8,000 feet in the north. This range is breached at places by deep gorges, for instance, the Mula and Gaj.

3. Hab and Porali valleys:-

Both are triangular valleys and drain into the Arabian Sea. The Hab flows through a narrow defile between the ranges of Hamalig and Lakhan and joins the sea in an estuary.

Porali river drains most of the flat triangular plain of Lasbela, which is set in the scarps of surrounding ranges of Pab on its east and Hala on the west. It has been conjectured that the lower Porali valley once was part of the sea in Recent geological times.(27)

4. Makran Coast Range:-

This consists of a series of minor ranges, from east to west, the Kulbit, the Taloi and the Talar Hills. These ranges lead a tortuous course parallel to the coast, with a steep slope to the coastal plain and relatively gradual slope inland.

At places the terrain swells into a continuation of hills with an average height of 2,000-3,000 feet about sea-level. The enclosed synclinal valleys; the triangular transverse Dasht and Hingol valleys are fertile spots of panoramic beauty.

IV. The Central and Northern parts of the Kalat Division:-

This region is divided into four parts:

1. Central Ranges:-

An area of vast wilderness and a mosaic of north to south and south-west lying ranges and valleys. The average elevation of the mountain uplands is 5,000 feet. These mountains diverge from the Sarawan country. There are numerous subsidiary fragmental elevations scattered here and there. The river valleys become broader to the south as the elevation decreases. These mountains are supposed to be the south eastern extension of the Iranian orographic system.(28)

2. Inland Drainage Basins:-

The south western and northern slopes of the Central Ranges sink into the depressions known as 'Hamuns' or Kaps'.(29) These Hamuns are skirted by the Dasht-i-Tahlab and sandy deserts. The height of these Hamuns and Kaps is about 3,000 feet. Further north lies the Hamun-i-Lora and Dalbandin plain, between the Chagai hills and Raskoh mountain.

The largest of the Hamuns is Hamun-i-Mashkel, with a length of some 54 miles and width varying from about 8-20 miles. The river Rakhshan-Maskhel drains into it. The rest of the streams draining here are seasonal torrents and carry water during the rainy season only.

Pishin area drains into Lora-Hamun. Evaporation in these Hamuns is constant and their surface is turned into a salt sheet, except during floods.(30) The area between Nuski to Chagai forms a large level tract of alluvial and lacustrine soil. The Chagai Hills are littered with talus-fans and rocky decay forming terraces, the levels of the former lakes. They contain saline water during rainy season.

3. Chagai Hills:-

These hills form a border along the Afghan territory. They are a series of recent volcanic hills. The eastern Chagai is laced with terraces. The landscape is dominated by volcanic mountains, Koh-i-Sultan the most outstanding among them all. Vredenburg visited this area and produced a fascinating account of volcanic mountains.(31) About the size of Koh-i-Sultan he writes, "The Koh-i-Sultan is an oval shaped mountain whose larger axis striking west-north-west is about 17 miles, the transverse width being 10 miles. It is an extinct volcano....of three distinct cones"; which is its chief distinguishing feature.

The Regions I-IV described above "have one thing in common. They are all mountainous, or very hilly, or consist of high plateaus surrounded by mountains".(32) The common human characteristics associated with Regions III and IV as we shall see, are based on for their dependence on underground water resources of water supply.

V. Sub-Mountainous Zone:-

The transitional sector is situated between the lowland in the south and the highland in the north. The whole zone, climatically is semi-arid. It is divided by the Indus into two Regions of the Second Order. 1. Trans Indus and 2. Cis-Indus. The highland descends sharply on the Sub-mountain zone, and in turn the sub-mountain zone ends abruptly against the lowlands. The further divisions in small zones adopted here is based on the diversified constitution of relief features.

1. Trans-Indus Plains:-

The area embraces the plains of (a) the Vale of Peshawar and Mardan, in the Peshawar Division (b) Kohat plain and (c) Bannu plains, the latter two plains lying in the Division of Dera Ismail Khan.

(a) The Vale of Peshawar and Mardan plain:-

It is a plain of "an almost perfect ellipse" with an opening to the south through which the Kabul river makes its way to meet the Indus.(33) Structurally the plain is referred to as a 'lacustrine hollow'(34) and littered with superficial deposits of 1,000-1,200 feet thick, which lies on the Attock slate in the exposed depths of a breached and eroded dome. The area rises from the Indus bank, 1,000 feet to 1,500 feet in the north. The south western portion is an interfluve built by the Swat and Kabul rivers.

(b) Kohat Plain:-

The vale of Peshawar is separated from the Kohat plain by the hills of Adam Khel. Kohat is seated on a high dissected plateau and it is higher than the Bannu plain in the south, and Peshawar plain to the north. The grain of the country is west to east, and the high summits lie at the elevations of 4,700-4,900 feet. Being a limestone mass it is very jagged and desolate except in the river valleys and at spring points.

(c) The Bannu Plain:-

It is a horse shoe-shaped plain drained by the Kurram and Tochi rivers and numerous affluent streams coming from the Waziristan hills. Like the Peshawar Vale it is also encompassed by high hills but has two exits towards the south and east. The plain lies at a height of 1,000 feet in general.

The Vales of Peshawar, Bannu and Kohat with their verdant landscapes offer a striking contrast to the surrounding desolate high ground.

2. Cis Indus:-

Includes the Attock district of Peshawar Division, Mianwali forms a part of Dera Ismail Khan Division and north eastern portion of Rawalpindi Division.

a. Potwar Piedmont Plateau:-(35)

Structurally, the Potwar Plateau occupies a synclinal location between the limestone and sandstone anticlimes of

Kalachitta and Khari-Murrat Hills in its north, and the Salt-Range in its south. It is generally referred to as the "Potwar trough".(36) De-Terra and Patterson have recognised it as a "peneplain", its undulating surface shaped by the age long processes of erosion and deposition.(37) Plate 6 is an illustration of this peneplain backed by the Khair-i-Murrat-ridge.

The plateau stretches over an area of 4,000-5,000 square miles. It extends over the Attock district and occupies Rawalpindi and Jhelum districts. It expands over the area between the Jhelum and the Indus rivers. The site for the new capital of Pakistan has been selected in this region and from the point of view of a planner the area has been tentatively delimited and defined as "Murree, inclusive of Galis, inclusive of Abbotabad. Haripur to Hazara to Campbellpor to Pindi Gheb to Khaur to Dhudial to Sohawa, Bathor-north along the river Jhelum until it meets Murree Road Muzaffarabad".(38)

Geographically the northern boundary of Potwar is clearly formed by the southern slopes of the Kala-Chitta, Khair-i-Murrat and Margalla hills. The plateau disappears gradually in the northern slopes of Salt-Range and has an ill-defined border.

It presents a variety of landscapes in its different sub-regions. In the west, Attock area facing the Indus is seamed by ravine land known as Makhad Jandal country. Its central portion is occupied by a "Broad Geosynclinal valley of Soan, filled with latter Tertiary deposits".(39) It's average height is 1,500 feet. The Soan and its tributaries flow through an abandoned course of the former Indo Braham River. The present river has re-excavated its course through the former channels, therefore the land has been terraced.(40) The general appearance is of typical 'bad-land' locally known as "Khuddera".

The altitudes of Khair-i-Murrat and Kala-Chitta Dhar varies from 1,300-1,500 feet, the highest summit of Kalachitta being 3,521 feet only. (Plate 7a.) The north west and south eastern parts of Kalachitta range exhibit different types of landscapes. The small level plain of Chach lies in north west, while the south eastern slopes are scarred by a number of seasonal nallas.

A great part of the plateau is overlain by a wind blown mantle of loess which is readily influenced by erosion. (Plate 7b.). It is one of the most erosion affected areas in West Pakistan.

The land of rivers, ridges, ravines, hills and fertile parcels of land with great mineral potentialities has been given the honour of having the new Federal Capital named Islamabad.

b. Salt Range:-

This region lies in both the Cis-Indus and Trans-Indus districts. The Range is situated south of Potwar Plateau and lies east to west in direction; and spreads over an area of 250 miles. The Salt Range is an example of a dislocation mountain in the extra-Peninsular region and structurally is known as orthoclinal. "Its orthoclinal outline, i.e. its steep southern scarp and the long gentle northern slope, suggests that the Salt-Range is the result of a monoclinal uplift combined with a lateral thrust from the north, which has depressed the southern part of the monocline under the Punjab plain, while the upper part has travelled some distance over it along a gentle plane of thrust".(41)

The average elevation is 2,000-3,000 feet, and the Range consists of several parallel hills enclosing small fertile patches and plateaus such as Malot, Nurpur, Dandot and Son-Sakesar. The range is also punctuated by numerous salt lakes, the important lakes being Kabaki on Son Plateau, and Kalar Lake on the meeting point of Salt Range and Potwar Plateau.

The origin of these lakes has been studied by many geologists, first observed by Andrew and associates.(42) Locally known as "Kahars", their origin is considered to be due to local subsidence by deformation of surface, but Wynne has found no evidence of subsidence.

The present configuration of the lakes derives from an uneven accumulation of loess deposits in the hollows created by tectonic movements. Some of these lakes are taken to be "aeolian basins". All these lakes are very shallow and flat bottomed.

Among the hills, the important are Barkrala ridge in the north east which is followed by Mount Jogi Tilla ridge in the south. The northern gentle slopes of the Salt-Range is covered with loess deposits. The deposits of Potwar and Salt-Range suggest, that the area surrounding these tracts must have been a cold desert or a glaciated area, and being devoid of trees provided the raw material for wind deposition of loess. (Plate 7b).

VI. Upper Indus Plain:-

This comprises the Divisions of Lahore, Multan, southern portion of Dera Ismail Khan and Rawalpindi Divisions, and the Bahawalpur Division, forms the lowland heart of the Arid Zone of Pakistan.

The region may be divided into three divisions:

(1) Sub-Siwalik zone,

(2) Doabs and

(3) Derajat.

(1) Sub-Siwalik zone:-

This occupies a narrow belt which includes north-eastern parts of Lahore and Rawalpindi Divisions. It forms the north-eastern extremity of the upper Indus plain, and it is listed as a separate section owing to its comparatively steep gradient and relatively humid climate. It forms the foot hills of higher mountains made of Siwalik deposits. The area rises to over 1,200 feet, and it is traversed by the great rivers, Jhelum, Chenab and Ravi with a number of seasonal streams, such as Ujh, Degh, Aik and Tavi. As the area is located right at the foot of the humid mountains, there is a constant seepage of water in this area. This is an area of copious rainfall as compared to the rest of West Pakistan. The combined phenomena of seepage and relatively heavy rainfall has caused a high water table hence irrigation by wells is feasible and common.

(2) Doabs:-

The dominant features of the Upper Indus Plain are the plateau-like interfluves lying between rivers which have deeply excavated their valleys. These flat-topped interfluves have a north to south trend. They may be considered as the water-shed zones between the rivers. All these doabs are roughly equilateral triangles in shape with their bases in the north in the Sub-Siwalik Zone, and apex in the south in the sandy arid country, the apices created at the points where rivers subsequently converge on one another.

With the exception of a small area the elevation of the Indus plain above sea-level is under 1,200 feet, and most of it is under 600 feet, the plain falling below 250 feet in its extreme south east.(43) The fall is steepest, where the lowland meets the Sub-mountainous zone, 15' per mile, but usually 1 foot over a large area and only 6 inches in the south-west is general. Figs. 1-2A and B illustrate this.

The imperceptible flatness is broken by minor variations created by the rivers themselves. The surface of the Upper Indus Plain is marked by numerous scars left by ancient river valleys. In each doab or interfluve the slope rises smoothly from the immediate vicinity of the river or from the riverine tract. In a transverse section the following divisions are observable. (Fig. 68 Doab Settlement of Chapter 8).

1. The moist belt is analogous to a flood plain and contains two main elements. The first, "Sailaba", "Bet" or "Kachha" as locally known in different localities, (At present the name Sailaba is in vogue), is the lowest portion in the proximity of the river channel hence it is flooded frequently. (44) It contains one or two rivulets and at places their

course is dotted by small islands. Here lies the land most suitable for rice growing, since rice is a hygrophitic plant. The Sailaba is replaced on the higher portion of the flood plain by the second element, "Khadir" or new alluvium, also subject to flood. This is an area of high water-table because of percolation from the river beds, thus wells are a common method of irrigation. Both Khadir and Sailaba are valuable agricultural lands, because of their high content of silty loam, but they are liable to floods.

Khadir is bounded by the belt of:- 2. bluffs, known at different places under local names as "Bangar", "Pakka", "Manjha" and "Dhayas". They rise to over 20 feet and often are deep gullied. This belt forms the settlement zone, being situated at higher levels. Agriculture is a profitable pursuit, because of the presence of fertile soil accummulation, but the water-table and river lie far below this level. The Dhayas are succeeded in turn to the centre or top of the doab, by a zone popularly known as, 3. "Bar". This is a small scale upland area and before the innovation of modern canal irrigation, Bar had the appearance of a desolate, barren, waste, like a true desert. Now there are four bars which now possess green fields, blooming orchards and freshening parklands. From west to east the bars are:-

(i) The Kirana Bar, the centre of top of the Doab between Jhelum and Chenab.

(ii) Sandal Bar, between Chenab and Ravi.

(iii) Ganji Bar or "bald" Bar between Ravi and Beas and

(iv) Nili Bar, between Beas and Sutlej, lying in India.

The above analysis demonstrates how the level of each doab rises in stages from the river bank to the centre of the doab, and again falls on to the bank of the other river. Hence, the right and left sides of each doab are similar in topography and consists of systematic terraces excavated by rivers, these terraces have been named differently in different localities. This conformation of the doabs has assisted irrigation works also.

Sind Sagar Doab:- This is the western-most doab lying between the Indus on its right and the Jhelum, Chenab, and the Punjnud on its left. It is the largest and driest among all the doabs, and is generally known as Thal.(45) In length, the doab is 150 miles from the base of Salt-Range to Muzaffargarh district (inclusive). The doab includes within its limit Mianwali district in the Division of Dera Ismail Khan, Muzaffargarh in Bahawalpur Division, and Shahpur district of Rawalpindi Division. Thal is considered to be of a uniform terrain, "but the northern Thal has a

sub-stratum, which is covered by a succession of low sand-hills, with a general North-west direction and its appearance is that of a sandy rolling prairie covered in the rare years of good rainfall with grass and stunted bushes".
The natural water table is 40 feet deep, grain is extensively grown in winter as a dry farmed crop. In its eastern part it is known as Thal Kalan or Greater Thal and is shrouded with a "line of high sand hills from N-E and S-W". The proportion of sand decreases as the height of the Thal Kalan decreases towards the west. Grain and melon are dry farming crops. In Mianwali from Fatehpur to Mihran the country is known as Daggar in the north and Jandi Thal in the south. The Daggar and Jandi form a fertile fringe parallel to the Indus and the surface is virtually free from sand dunes. As the water table here is high, water is obtainable at shallow depths. Daggar is considered to be a deserted channel of the Indus. This is a flat surface land of sandy loam. Winter wheat and fodder are main crops.

Another topographic feature of the Thal is Powah on the west of Daggar area. Powah is an upland strip about 3 miles broad, forming the high bank of the Indus. The height decreases from 40 feet in the north, decreases towards the south and finally disappears at Kot Sultan. Although settled, here rainfall is a casual phenomena, and cultivation is precarious depending on the floods only. The

Powah tract is replaced at lower levels by numerous water bodies, left by the floods. They are known as dandh, or flood hollows or lakelets. It is desirable to draw the attention of the authorities to drain off stagnant water from these pools, as they are accentuating the twin local maladies of salinity and waterlogging.

The most uninviting and desolate part of the Thal is the tract lying between the Salt-Range and the Indus. The sea of sand dunes and rock debris is underlain by hard soil impregnated with salt. This part is known as "Chachh", the area being like a mirage.

With the construction of Jinnah Barrage on the Indus river in the vicinity of Kalabagh in 1949, the desert area is being transformed into green fields which produce good crops of wheat, cotton and sugarcane. It is an effective example of the control of aridity in West Pakistan.

Speaking generally, Chaj, Rechna, and Bari doabs are similar in their topography. These three eastern doabs constitutes the most fertile area of West Pakistan, and are traditionally considered to be the granary of the subcontinent. Besides its agricultural productivity the area carries a dense concentration of population, a net of railways and roads, the chief centres of industries and education. In fact this is the most developed and highly urbanised modern part of West Pakistan.

The reasons for the advancement of these doabs and the under development of the Sind Sargar doab are two fold, (a) natural and (b) cultural.

(a) The natural:- As far as topography is concerned these doabs are similar in many respects. Both eastern and western doabs exhibit a terraced landscape. All these doab regions are arid but the eastern doabs, especially the Bari Doab, receive more rainfall, which means better chances of agriculture. Lahore annual rainfall is 19", Layallpur 12" and Thal 10" and Mianwali 10". Hence aridity has been the major obstacle which is only recently been attacked. Again, Lahore region geographically occupies a medial position between the Ganges plain and the Indus plain. Hence it was desirable and possible to develop the Bari doab at this link between the Ganges and the Indus plains. The first canal was constructed in this region.

(b) Cultural:- Culturally, Lahore and Multan have been always classical cities, and this area has long been a centre of urban life. All rulers since 1200 AD have developed Lahore because of its vicinity to Delhi. Delhi has been a Capital City almost continuously throughout the history of the Sub-Continent, and Lahore has always served as a provincial capital. The past history of the sub-continent reveals that the Lahore region has always held a key position between Delhi, the Chief ruling seat and Peshawar the main gate of entrance for the foreigners. From the dessiccated mountainous terrain of Peshawar the invaders always came across a level and cultivable land with plenty of river water in Lahore region, and here a relatively stable and prosperous centre could either be established or successfully defended.

With the development of the Lahore region by the construction of canals, population increased, and more and more land was required for further expansion of the settlements. Thus the periphery of the Lahore region or the Bari-Doab extended to Multan. The new cities of Lyallpur, and Montgomery at an average distance of 90 miles from Lahore were established. Lahore has always been the chief centre of learning and with an old University (opened in 1882) attracted more and more population and satellite towns and villages thus ensued. Lahore remained a source of spiritual, cultural and industrial energy.

The Sindsagar has been developed only since 1949. The chief reason is to bring the wasteland under the plough to grow more food for the rapidly growing national population. The Sind Sagar doab with the application of irrigation water now produces food for the nation as well as supporting new modern settlements. The Doab is not now at all neglected in any respect. It is provided with Colleges, schools, with all economical possible amenities; good roads and efficient means of communication are being introduced. Now Lahore occupies a marginal position as a border town, and its future advancement is less obvious; hence now the western doabs stand more and more chances of development, especially after the final decision of the canal dispute between Pakistan and India. (See too Hydrography).

(3) Derajat:-

The Trans-Indus territory consists of two districts, Dera Ismail Khan in its own Division in the north and Dera Ghazi Khan, situated in the Division of Bahawalpur in the south.(46)

The territory lies between the Daman of Sulaiman mountain and right bank of the Indus. The braided land along the Sulaiman mountain is known as Pachad. It is an area of precarious rainfall, and deep gullies have been cut out by ephemeral torrents.

The name Sindh is applied to the land fringing the right bank of the Indus. Between the Pachad and Sindh lies an upland known as Danda Land. As it is out of reach of canals and streams, cultivation is dependent on wells. Here are some patches of saline efflorescene called "Reh" or "Kallar".

VII. Lower Indus Plain:-

The area has been described thus, "Sind consists of a broad, dry, alluvial plain stretching from the edge of the Baluchistan plateau (the Kirthar Hills) on the west to the Thar desert on the east. Running through the centre of this plain its life and soul - the Indus River. Just as Egypt is the 'Gift of the Nile' so may Sind be described as the Gift of the Indus".(47) After receiving the water of the rest of the rivers at Mithankot, the Indus flows over a level plain until it enters the narrow and the higher stony ground at Sukkur and Rohri, eastern limestone outposts of Kirthar. This narrow point has been of great advantage in the construction of Rohri railway bridge and is the site of one of the largest irrigation dams in the world. This elevated ground forms a natural divide between the Upper and the Lower Indus plain.

The Lower Indus channel bed is higher, owing to deposition, than the neighbouring lands, hence there is a constant fear of flood. The channel is lined with protecting bunds for long distances.

The Lower Indus plain is traversed by a single river, in contrast to the Upper Indus Basin. The Upper Indus region is characterised by the convergence of many streams and tributaries at Mithankot. The lower Indus Basin by contrast has divergent channels of small outflows. This divergence occurs not from a single point but from a series of points. Between these effluents the river has formed small intervening interfluves, different in character from the northern doabs already described. We may regard this region as composed of five sub-divisions based on the interfluve units.

1. Sibi Re-entrant and Western Nara Doab:-

The area includes the north west of Khairpur Division and west of Hyderabad Division. This plain is a westward continuation of the Indus plain set under the curvature of the Sulaiman mountains. The plain is traversed in the north by a number of small streams including the Bolan and Nari which rise in the Kirthar and Sulaiman mountains respectively. These rivers are insignificant ameliorators of the prevailing aridity. The water table is very low, rainfall is inadequate, surface water is seasonal, therefore agricultural is not an economic proposition, and a pastoral economy prevails.

The Sibi or Kachi plain consists of clay desert, which is known as "Pat" between Jacobabad and Sibi. The Pat gives way to a mixed sand and loam plain to the south.

In the south west the land consists of a fertile doab of old alluvium between western Nara and the Indus river. The land is also studded with small salt lakes. The western Nara is believed to be a deserted course of the Indus. The doab stretches south to the large Manchar Salt Lake in Sehwan, where West Nara drains. The classical agriculturally rich tracts of Larkana and Dadu lie in this doab.

2. Eastern Nara Doab:-

It includes the eastern portion of Khairpur Division and in its south lies the Division of Hyderabad.(48) The land is confined between the Indus and the Eastern Nara rivers; and consists of new alluvium. The Nara doab is thought to be the old delta of the Indus, and its northern extension is known as Hakra in Cholistan. This area like the rest of the doabs abounds in channels of lost rivers, and the abandoned hollows are filled with saline water, known as "Dhands". The causes of formation of these saline lakes have been studied by several geologists, notably Halland and Christie, when they made a detailed survey of the Samber Lake in western India.(48)

La Tochi believed that the saline lakes are due to the "possible sub-terranean percolation from the Punjab rivers". The accumulation of ordinary rain water further helped the concentration of salts already existed in the parent sediments. According to Walter's theory, salts from marine formation are "brought to the surface to form superficial efflorescenses". Halland and Christie found it difficult to accept such mechanisms of the salt origin as satisfactory; remarking that there are neither inflowing large rivers nor traces of ancient rock salt and saline springs.(48)

Many experiments on hot weather winds which help the formation of these salt lakes by increasing evaporation rates have revealed that salt concentration conditions are optimum in regions of inland and obstructed drainage, and where there is a strong in-draught of hot drying winds. As far as the lower Indus Basin is concerned it is neither a region of inland drainage nor an area of obstructed drainage. It fulfils the one condition of a strong in-draught of hot drying winds which in the absence of other forces proves an insufficiently effective causative factor.

Cotter has also studied the Salt Lakes of the Lower Indus Plain. He regarded their origin as due to the local percolation of water. "The water which percolates through the basal layers of the desert sand where it rests upon the impermeable alluvial clays of the Sind plain, emerges in many low lying places to form marshes or lakes", known locally as dhands. In 1952 Godbole's (48) studies led to the conclusion that the salt is due to percolation phenomena as well as to the receding Tethys sea. Thus all that may be said at the moment is that the formation of the present dhands in the Lower Indus Basin owes something to the local percolation, geological history and recent climate.

The process of interest to us is that of percolation. Water is held up by an impermeable strata beneath the sand covering. This water near the salt lake shore or "Sim"is sweet. This water can be used for agricultural or domestic uses, if it is brought to the nearby villages through pipes. The dhands might be connected with the existing canals to provide extra flood storage for use during drought. This might help in the elimination of water shortage to some considerable extent, as there is a mosaic of such dhands. The value of such a scheme finally depends on whether dhand water will remain sweet and on whether a build up of salinity might occur.

3. Desert:-

This includes the desert of Cholistan or Rohi which forms the south eastern [illegible] strip of the Division of Bāhawalpur. It continues southwards through the south east of Khairpur Division, to the south east part of the Hyderabad Division, where it is called Tharparkar.

1. Cholistan:-

The north-east of this sandy country consists of "pools and backwaters of the rivers".(49) The alluvial irrigated strip formed by river deposits is called Sind. The Cholistan desert is separated from the Sind alluvial tract by the course of the lost Hakra river. Hakra or Wahin is a subject for dispute as there are different notions whether the lost river was the Ghaggar or Jamuna or Sutlej. The whole of Cholistan is now covered with a thick aeolian deposit laid down in dry conditions, a western extension of the Rajputana desert. "It's surface is a succession of sand dunes rising in places to a height of 500 feet". The depth of sand is so deep that "wells fail to reach the substratum". Such high elevation of sand heaps is the result of persistent and constant winds.

ii. Tharparkar:-

The sand hills are known in Sindhi as "Bhits". Oldham the geologist has given a very detailed survey of sand dune hills of the lower Indus Plain.(50) Based on their shape, he has observed two types of sand heaps:-

1. The longitudinal ridges correspond to the parallel direction of monsoon winds.

2. Transverse ridges are aligned across the direction of prevailing winds. He opined "that the restriction of the longitudinal type of sand-hills to the sea-ward and western margins of the desert appears to show that they are connected with a greater wind force than the transverse type". Hence the two types depend on the degree of permanency of the winds.

The main extent of sand desert is described thus, "the Registan or desert tract consists of nothing but sandhills; many of them however, derive picturesqueness from their bold outline, and are sometimes even fairly wooded. The several ranges of sandhills succeed one an other like vast waves".(51)

The wooded sand dunes might prove a source of underground water if they are exploited, as trees are a true indication of moisture or water resources.

Throughout the lower Indus Plain barkhans are a common phenomena. Only the alluvial tract is free from sand dunes to some extent.

4. Kohistan:-

This forms the south-west portion of Hyderabad Division. Its rocky terrain consists of north to south anticlines of limestone akin to the Kirthar hills.(52) They vary in their height from 1,200-3,000 feet. Near Sehwan the most eastern spur the Laki hill, stands on the Indus with a perpendicular face of rock 600' high.

The face of the hills is cut by a number of "Nais" or hill torrents, with quite broad, level beds, covered with sand and silt. The 'nais' drain to the Indus. The general appearance of the country is barren, broken and covered with occasional barkhans. A discussion of desert evolution is deferred to Chapter 2.

5. Delta:-

The Indus has a well defined delta whose apex lies in Tatta, which is the northern extremity of tide waters, 60 miles inland. In the south-west the right arm of the delta reaches to Cape Monze and the left arm almost merges with the Rann of Kutch. The base of the triangle is 125 miles long, and it contains a number of creeks and inlets, which have extensive mangrove swamps. During the monsoon the delta is flooded to an extent of 20 miles inland, because the tide is high at the same time as the Indus is in spate.

The chief characteristics of the delta:-

i. It has been formed recently, most probably during the development of paleolithic and later cultures and is still in the process of creation.(53)

ii. The Khadar and Bhangar alluvia are not separately distinguishable, owing to the irregularity of channels formation.

iii. Like the Ganges delta it is not suited to cultivation nor to habitation, because it has not achieved any true stability; it is neither land nor sea.

iv. It's formation is 'normal' and high banks hem its channels behind which the ground slopes to the swamps.

VIII. Makran Coastal Plain:-

This is a longitudinal narrow strip of land flanking the Arabian sea.(54) Structurally it is created by submergence owing to tectonic activity, therefore, the coastline is crenulated and there are many "hammer head peninsulas", for instance Gwadar and Ormara. It is traversed by the lower courses of the rivers Dasht, Hingol and Porali, which join the sea, making small estuaries. The second peculiarity of the coast is that it is laced with groups of mud volcanoes.

From the above it may be concluded that West Pakistan is a country of vast contrast in its topography. It consists of high altitudes of perpetual snow in the Hindukush, and the table lands of Potwar and Kalat which merge into the great expanses of the Indus plain and deserts. The plains of the Indus are encircled by the lofty mountains on the north west and south west. These mountains are broken by numerous passes and corridors which provided an incentive to the western Asiatic races to encroach upon the Sub-Continent of Pak-Hind since time memorial. The chief gate way of Khyber provided an opportunity for the construction of the Grand Trunk Road from Landi Kotal to Calcutta by Shershah Sori, an easy path and an attraction for subsequent invaders. Through these lofty and generally dry mountains the invaders have been always fascinated by the flat cultivable plains beyond, provided with oceanlike rivers. This "land of milk and honey" had to survive invasions frequently, and West Pakistan has always remained a battle field through its cultural phases, and partly for this reason remained neglected and undeveloped, no invading group being given sufficient time for maturing. The people of the whole of West Pakistan except for the Sind provinces, have been renowned for their martial characteristics. The Pathan regiment, the Baluch regiment and the Punjab regiments have been reared in West Pakistan.

Because of this political inconstancy the whole of highland and sub-montane region has been settled by numerous tribes, some nomadic, some refugee groups, some invaders. Even at present the cultural landscape of the highland is built around small scattered nucleations of tribal villages.

In the lowland political conditions have been always relatively more constant hence settlements are more stabilised based on arable agriculture. Under periodically peaceful conditions art of agriculture, education, and industry tended to advance fitfully using the plenty of available river water and the level fertile plains.

The rampart of the lofty mountains has played the prominent part in creation of the present climatic conditions. They provide an obstruction between the Central Asiatic air masses of the lower atmosphere and West Pakistan. The winter and spring rainfall which helps the production of wheat, the staple product of the country is due to the orographic effects of the extensive rim of high mountains. The perennial rivers maintain their flow because of their sources in the perpetual mountain snows. The gradual slope of the plain and doabs help the construction of distribution canals. The soft detritus of the plain debris has facilitated canal construction and the alluvial soils respond well to irrigation, and the deep soil detritus of the plain in its sub soil layers form the underground water reservoir for the rain water which, sinking through the porous alluvia of the plain can be tapped by wells.

Chapter 2

Geology

In order more completely to understand the fundamental characteristics of the physical landscape, the hydrography and ecology of our region, it is necessary to examine the geological elements of which it has been composed.

A fair amount of literature exists on the geology of West-Pakistan. Generally the areas of Quetta, Kalat, Kohat, Attock, Hazara, Makran, Khairpur and particularly the Salt-Range are best known by geologists. A fairly abundant knowledge about these localities has been built up since 1870. The reasons for our knowledge covering the Salt-Range in particular are portrayed by Wynne, "The Salt-Range is the most important locality ..... for the study of physical as well as stratigraphical geology. Since very early times it has attracted the attention of geologists, not only because it contains a very large portion of the fossiliferous stratified record of the ..... region, but because the easily accessible nature of the deposits and the clearness with which the various geological formations are exposed in its hills. Besides the stratigraphical and palaeontological interests, there is incribed in its barren cliffs and dried gullies such a wealth of geodynamical and tectonic illustrations that this imposing line of hills can fitly be called a field-museum of geology".(1) A more recent comment runs, "It offers one of the most instructive groups of geological sections".(2) The Salt Range is a unique area for the field work and it has been explored more than any other part of the whole Pakistan.

Though there is an accummulation of references to the geology of western unit of Pakistan, these are scattered in numerous publications of the Geological Survey of India, and specialist papers produced by leading geologists such as Oldham, Blanford, Wynne, Vredenburg, Pascoe, Davies and Wadia. Nowhere as yet are, there authoritative syntheses and therefore still much of the developmental work, particularly concerned with irrigation, proceeds on an inadequate basis of fundamental fact.

The preliminary geological writings of the area concerned date back to 1870. Since then great advances have been made in the different fields of geology. Since 1950 the Government of Pakistan have taken effective measures to explore the country intensively and to tap potential mineral resources, solid fuel and particularly the underground water reservoirs, as water is the crying need of the dominantly arid and semi-arid West Pakistan. West Pakistan has been surveyed from the air under the Colombo Plan by Canadian experts in 1954. At the moment, a photo-Geologic Survey of

Waziristan is being carried out in order to locate the underground water areas. Under Ground Water Development Organisations have been set up recently in the Divisions of Lahore, and Quetta-Kalat.

The material presented in the present chapter has been derived from the scattered primary sources.

Geochronological Sequence:-

The sequence of geological formations as now recognised has been set out and arranged in the geological time-scale. Appendix 1. Briefly, we may outline the geochronological sequence thus. In the sea of Tethys marine deposits of considerable thickness were laid down, limestone being of great importance. Particularly during the Armorican and the Alpine Orogenesis these beds were uplifted, folded and faulted.

Finally, in recent geological times the area has been subjected to Glaciation and the lower lying affected areas have been overlaced by superficial deposits. This has been followed by erosion and deposition under normal and arid conditions. The most significant product of the Quaternary period is the Indus Plain.

The chief characteristics of the geological formations as depicted by Appendix 1 and Fig. 4 may be considered.

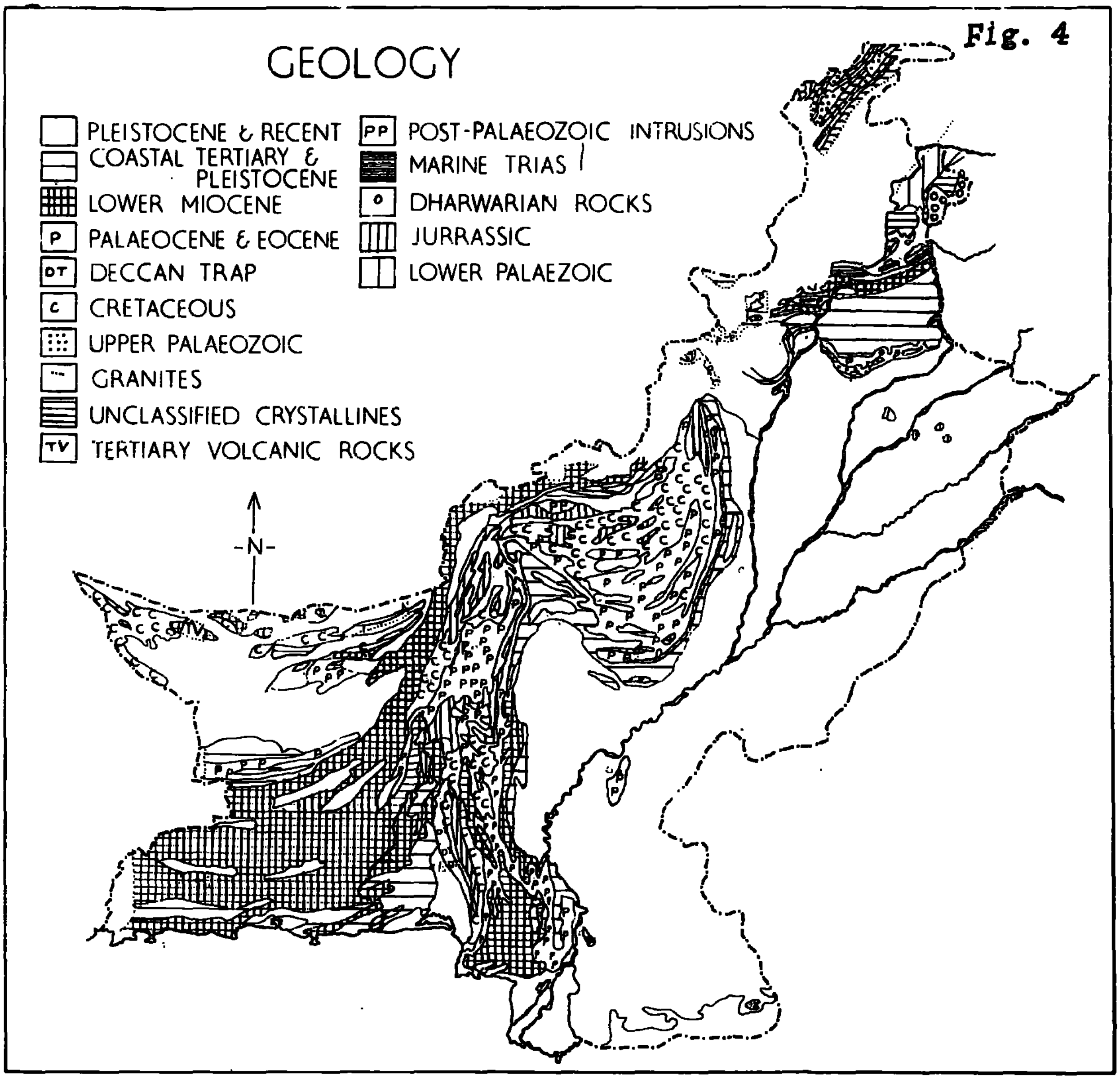


Fig. 4
GEOLOGY
PLEISTOCENE & RECENT
COASTAL TERTIARY & PLEISTOCENE
LOWER MIOCENE
PALAEOCENE & EOCENE
DECCAN TRAP
CRETACEOUS
UPPER PALAEOZOIC
GRANITES
UNCLASSIFIED CRYSTALLINES
TERTIARY VOLCANIC ROCKS
POST-PALAEOZOIC INTRUSIONS
MARINE TRIAS
DHARWARIAN ROCKS
JURRASSIC
LOWER PALAEZOIC
-N-

briefly as follows:-

1. The major highland parts of West Pakistan were formed during the Tertiary era,during the structural storms of the Alpine Orogeny. The Tertiary hills of the Hyderabad-Kalat frontier make such a perfect sequence that it has been considered as a 'type' for the Pak-Hind Sub-Continent.

2. The Divisions of Kalat and Quetta possess a large tract of "stratified marine geological record which helps to fill up the gaps in" the Pak-Hind succession.(3)

3. Makran coast exhibits subsequent records of marine transgressions.

4. Mesozoic formations are comparatively inconspicuous and they are accompanied with volcanic intrusions, and contain economic minerals of coal and iron. The Mesozoic deposits may be observed more or less in a complete order in the Trans-Indus-Salt Range.

5. The most important strata of the Products Limestone of the western part of Salt Range were transformed into solid dry land above the sea-level in the Paleozoic Era, immediately after the Armorican Orogeny slackened. These are excellently developed deposits and by virtue of their perfect development are "a type reference for the Permian

system of other parts of the world".(4)

6. There is a noticeable break between the Cambrian and Devonian as no deposits of Ordovician and Silurian have been developed. Devonian is represented only by insignificant deposits in Chitral only.

7. The appendix indicates also the minor remnants of Eozoic or Pre-Cambrian rocks at two localities, the Kirana Group and the Tharparkar rocks.

Thus the geological episode of the area is bound up with two great movements, and it shows the passage of many geological times and processes, the rocks belonging to almost the whole geological system.

A brief idea of the geological architecture has been furnished in the foregoing paragraphs. There follows a fuller picture of the gradual construction of the country during the subsequent periods, a picture which helps to explain what aridity finally means in the different regions of the country. (See Appendix 1).

I. Primary or Palaeozoic

Cambrian:-

The Attock and Hazara Slate is a disturbed series and its age is an unsettled problem among the geologists. Whether it belongs to the Pre-Cambrian, Lower Cambrian or Cambrian has to be ascertained finally.

The Cambrian System is perfectly developed in the eastern extremity of the Salt Range, descending order as shown in the appendix. The saline series form the basement of the Cambrian Strata and their age has been a point of great controversy among the geologists. Recently researches of Dr. Gee have confirmed their date of origin as Cambrian, and these ancient portions seem to have remained undisturbed since their formation. As noted subsequently the Salt-Range series was alternately locally covered beneath the transgressional sea and uplifted to be exposed to erosion. The Salt Range demonstrates this frequent phenomena of emergence and submergence since Cambrian times. It exhibits subdued features of topography, and it presents the "exhumed" or "resurrected" landscapes.(5) Plate 8 illustrates exhumed landscape formed of Attock slate, through which the Indus could carve out only a narrow exit.

Devonian:-

The fragmentary formations of this age have been traced in Chitral and Hazara. Due to great fault systems the Devonian strata is thrown directly against the Cretaceous.

Carboniferous:-(6)

During this period of geological evolution the whole of West Pakistan like the rest of the Extra-Peninsula was occupied by the great Geosynclinal Sea, the Tethys. This sea persisted from the Cambrian to the Eocene during which time a great variety of marine life flourished and formed enormously thick deposits. The persistence and continuity of this extensive sea was interrupted and disrupted by several intervals of uplifts and erosion, each uplifted portion subjected to the denuding agencies.

The areas lying west and east of the Himalayas were occupied by the arms of the Tethys but the actual sea was best developed in the area which has at the present the most elevated ranges of the Himalayas. The present Divisions of Kalat and Quetta were occupied by its south-western arm and an outlet of the sea also extended towards the Salt-Range, but this extension was non-continuous in time. The sea was disturbed frequently and the coastline fluctuated considerably as the waters advanced and retreated, least of all in the relatively stable northern side. As a consequence the geological strata exposed in the Salt-Range, and its vicinity, includes estuarine and brackish water deposits in various strata. These shallow estuarine and brackish deposits laid down on the margins of this ancient sea have contributed to the present salinity.

The persistence of the Tethys was first seriously disturbed with the advent of Middle Carboniferous movements. During the Carboniferous certain localities of the Salt-

Range, Hazara, Quetta and Kalat Divisions were raised up. Appendix 1.

Since the Cambrian the Salt-Range had attained a position above the waters and was subjected to the agents of denudation. It was again included in the zone of sedimentation, under the tensions produced by the Late-Carboniferous period.

An exact and nearly parallel continuation of the outcrop of Permo Carboniferous is traceable in the western part of the Salt-Range, with a base of glacial deposits. These were formed in the glacial age during the upper-Carboniferous, which affected the whole sub-Continent. The glacial boulders are akin to the boulders of Hazara boulder bed, Simla, Rajputana, Bihar and Orissa. Their glacial origin has been proved by their polished, faceted and striated appearance.

Permian:-

The whole Permian system consists of two types of sediments laid down at different stages.

1. Lower Permian:-

This is clearly defined in the Salt-Range at two different horizons, a. The Katta stage of brown sandy limestone and, the Amb Stage, b. Calcareous beds of sandstones, clay, grey and blue. They are succeeded by the, Middle Permian, clearly distinguishable at Kalabagh and Virgal stages. These rocks are crinoidal limestones, with marls and dolomites and cherty limestones. In turn they are covered by the Upper Permian Strata.

2. Upper Permian:-

The final section of conformal sequence has been identified at three distinct horizons:-

a. Chidru Stage was confined to the layers of marls and sandstones.

b. Kundghat contains sandstones.

c. Jabi is constituted of cherty limestone.

This fascinatingly complete Permian sequence gave origin to the Products Limestone which has been named differently owing to the peculiarities exhibited by the local groups, the whole system formed by the subsequent gradual local submergence of the Salt Range.

Fig. 5A illustrates the position of land and sea in West Pakistan during the Lower Permian. It shows that except for a few localities, the whole lowland and highland were occupied by ancient seas. Small portions of Hazara and Waziristan and a large section of the eastern Upper Indus Plain were islands in that sea. It is noticeable that the north eastern extremity of the present Thar Desert was dry land during Lower Permian.

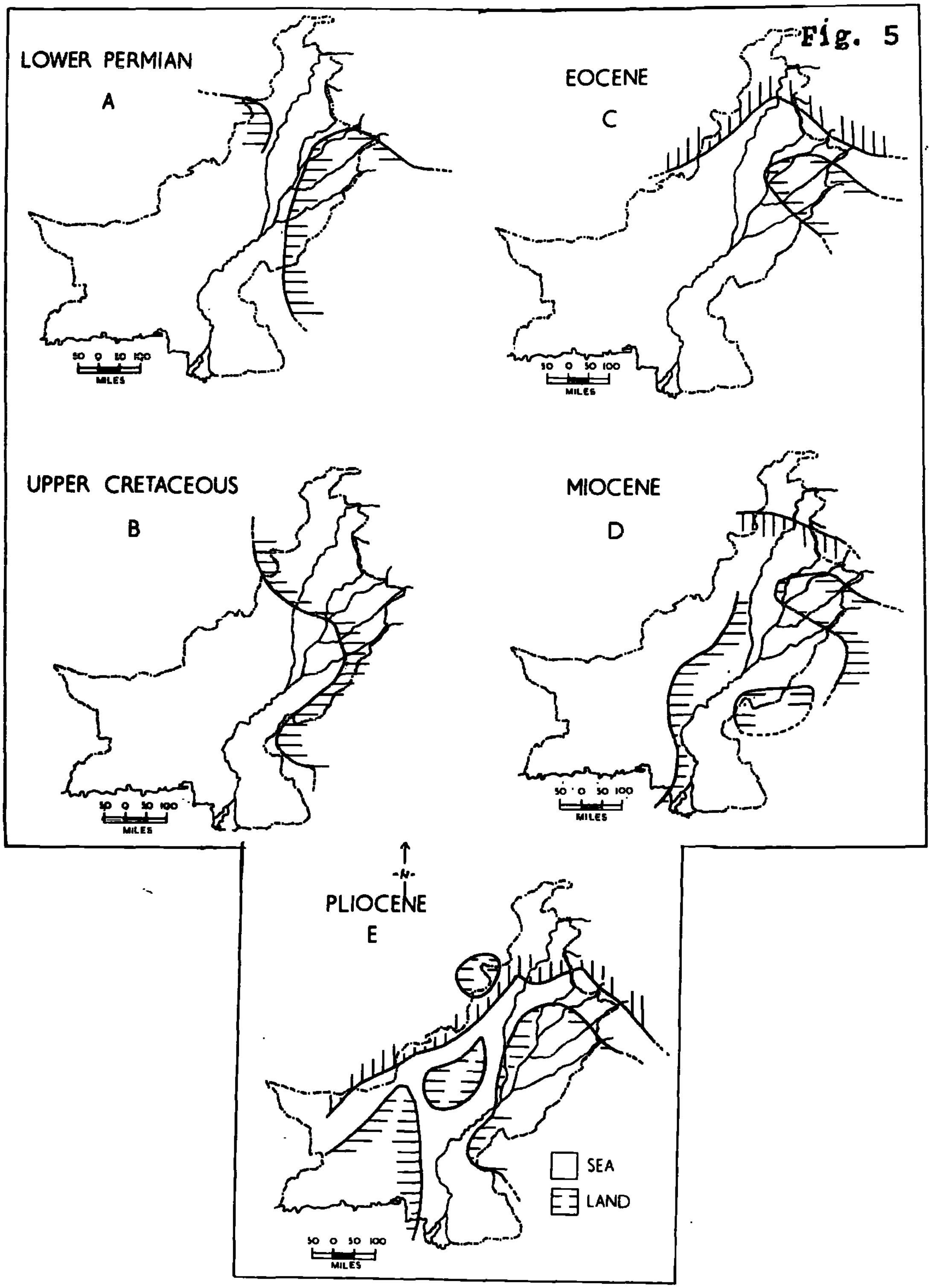


Fig. 5
LOWER PERMIAN
A
EOCENE
C
UPPER CRETACEOUS
B
MIOCENE
D
PLIOCENE
E
N
SEA
LAND
50 0 50 100
MILES

Secondary or Mesozoic

Triassic Systems:-

1. Lower Triassic:-

At the opening of the Mesozoic, the Lower Triassic were laid down in the Kalachitta range of Potwar zone, and in the Salt Range. These horizons consist of argillacous facies, shales and slates. This deposition continued to the end of middle Triassic in both localities.

2. Middle Triassic:-

The whole Triassic system is found in the Trans-Indus Salt Range, but in the Cis-Indus the sediments are confined to the middle and the lower Triassics.

3. Upper Triassic:-

The parallel deposits of the Upper Triassic are found in the Hazara, Kalat and Quetta Divisions. The Quetta-Kalat Triassic rests directly upon the Fusulina limestone of the Middle Carboniferous, creating a non-conformity.

Jurassic Systems:-

This system is best developed in the eastern part of Quetta and Kalat Divisions. These deposits were laid down in the south west arm of the main Tethys sea.

1. Lower Jurassic:-

The Oolite horizons of Hazara were developed during that period.

2. Middle Jurassic:-

After the middle Triassic the sea was temporarily withdrawn from most of the sections of Salt Range, Quetta and Kalat, hence there is a gap in the continuity of deposits. In Kalat, Quetta and the Salt Range the Middle Jurassic follows in normal transition.

The rocks of region III-IV are explained thus. "The rock-system of Baluchistan are capable of classification into two broad divisions, comprising entirely different types of deposits. One of these, the Eastern, is mainly characterised by a calcareous constitution and comprises a varied geological sequence, ranging in age from Permo-Carboniferous upwards. This facies is prominently displayed in the mountain ranges of E. Baluchistan, constituting the arenaceous and comprising a great thickness of shallow-water sandstone and shales, chiefly of Oligocene-Miocene age. The latter type prevails in the broad upland region of W. Baluchistan, stretching from the Makran coast northwards up to the southward confines of the Helmand desert. The differences of geological structure and composition in the two divisions of Baluchistan have determined in a great measure its principal physical features".(7)

In the Salt Range the Jurassic shale is highly variable, which suggests that the sedimentation process, might have been interrupted by oscillation of the sea or changes in river regimes. The eastern Salt Range succession, was affected by vigorous disturbances and the strata illustrate the recurrences of folding and faulting, the natural order of stratigraphy being utterly disturbed, "the faulted and tilted blocks lie against one another in the most intricate disorder imagineable".(8)

<u>Cretaceous Systems</u>:-(9)

With the advent of the Cretaceous, culmination of the Jurassic, the physical order of the country was further changed. The Salt Range, Kalat, Quetta and Western Hyderabad Divisions were immersed again under the deep water of a gulf extended from the Tethys. Thick and widely distributed deposits of Cretaceous along with an enormous volcanic outburst have been determined. According to its normal transition the Cretaceous is sub-divided into the following ascending order:-

1. Lower Cretaceous:-

These sediments survive in the Chichali hills of Cis-Indus Salt Range; Quetta, Kalat, and Hyderabad Division. The deposits are of white and yellow sandstone, and shales in the Salt Range, and Parah limestones and Belemite shales in the rest.

2. Middle Cretaceous:-

This may be distinguished in Hazara Spiti shales and narrow faulted bands of limestone with igneous intrusions.

3. Upper Cretaceous:-

Beds are preserved in Kalachitta, Hazara, Kohat, and the Division of Quetta, Kalat and Hyderabad. Their mode of superposition is non-conformal with lower and middle Cretaceous series, as these areas emerged from the sea during the middle Cretaceous and were exposed to erosional processes.

During later marine transgressions there were laid down the varied sediments of Gault sandstone in Kalachitta, Kohat, and Hazara, whitish limestone, Pab sandstone with volcanic tuffs in the remaining areas affected by the Lower Cretaceous Sea.

Evidences of widespread igneous activity in West Pakistan are available in Kohat, Bannu, West and South Waziristan, in the hill tracts of Quetta and Kalat and Hyderabad Divisions. These volcanic intrusions of the Late Mesozoic periods are a significant feature among the predominantly limestone sediments. The Cretaceous limestones are phenomenal sources of underground water.

Fig. 5B, shows the progress of land formation at the culmination of the Cretaceous. Almost all of the humid and sub-humid West Pakistan with a small portion of the present desert came into existence. The north eastern portion of the Thar Desert continued to be land.

Tertiary or Cenozoic Era

The three first parts of the geological timescale have now elapsed and the fourth chapter commences with the remarkable phenomena of the Tertiary Era. During these times, occurred the Alpine orogeny which was initiated during the middle of Eocene, and persisted till the end of the Tertiary. Thus the prodigous vulcanicity of the Cretaceous was followed by earth movements, which introduced the greatest alterations in the relief of the country, and henceforth the area possessed in the main the present orographic outline.

The outstanding characteristics of the Tertiary deposits is that they show a general passage from marine beds to the river deposits of the Siwalk series.

Eocene

1. The Lower Eocene beds rest conformally upon the Laki strata in the Divisions of Hyderabad; Kalat and they are known as the Ranikot series. The beds consists of clay, soft sandstone, Carbonaceous and lignite shales. The Ranikot series of the Salt Range and Hazara correspond with them; but the later strata lie in a nonconformal position.

The Hazara deposits contain nummulitic limestones and the Salt Range possesses shale ferruginous and limestone.

2. The Middle Eocene Series in the Salt Range are restricted to the Bhadur beds, forming the summit of the Salt Range, of massive limestone and Sakesar Beds. These beds correspond to the Eocene deposits of Laki series which are seen in the Divisionsof Quetta, Kalat, areas of Kohat, Attock, Mianwali and Hazara districts.

3. Above the Middle Eocene, the Upper Eocene is represented by the conformal Kirthar series of nummulitic limestone in Hyderabad and Kalat Divisions. They occur simultaneously in Hazara also.

Fig. 5C shows that the proportion of land has been again reduced. The land which was discernable during the Upper Cretaceous was partially drowned again in this figure.

Oligocene:- These shallow water formations are entirely absent in West Pakistan except for a few traces of fossiliferous marine limestone beds at Nari in Hyderabad Division and Kojak shales in Quetta and Kalat Divisions. This suggests that only a few small portions of West Pakistan was invaded by the sea during the Oligocene, and most of the region was subject to aerial erosion.

Miocene:- Unlike the previous system Miocene formations have been traced out over large areas. These beds have varied types of formation in different localities. The whole system may be split up into various sub-divisions.

1. Lower Miocene:-

These formations are perceptible in the Gaz and Nari series of the Hyderabad Division, and the fresh water deposits of Bugti Beds and the Murree series of Potwar, Hazara, and eastern Salt Range. The chief contents of these deposits are shale and limestone. The fresh water deposits are composed of clay sandstone and conglomerates.

2. Middle Miocene or Lower Siwaliks:-

It has been deduced from the constituents of the Siwalik deposits that they had been laid down by rivers, in the same way as the rivers are depositing detritus at present in the Indus Basin. The difference is this, that, the Siwalik deposits have been upheaved and involved in the making up of the Siwalik chain of the Himalayan System. The lithological character of these deposits is varied, semi-nodular, clay, shales, sandstones, purple shale and conglomerate. In West Pakistan the Lower Miocene is observed in the Salt Range, Kalat and Hyderabad Divisions.

3. Upper Miocene or Middle Siwalik:-

The most conspicuous formations belonging to this time are the Makran series in Kalat Division. Contemporaneous beds are found in the Salt Range, containing the white sandstone and pale-coloured shale. The whole Siwalik system is comprehensively developed in the Potwar Plateau and in the Kamlial stage of the Salt Range. Fig. 5D shows vast portions of land in the present area of West Pakistan at the close of the Miocene time. Water still persisted over the lowland, Salt Range, Potwar, Waziri territories and the sub-Siwalik region.

Pliocene or Upper Siwalik:-

These are confined to the points of emergence of the large rivers and intervening areas. As in the case of the Pliocene boulder-clay of the Salt-Range, this period shows evidence of large scale glacier formation in North of West-Pakistan. The other beds of the Pliocene are the Manchar system of Hyderabad Division. Fig. 5E illustrates the maximum extension of the contemporary land areas. The major features of the highland were almost completely located in present day locations, the sea completely eliminated from the Divisions of Peshawar, Multan and Kalat. Most of the present desert area was however still occupied by the sea.

With the close of Pliocene the Tertiary Era terminates, and the formations of solid geology of the area cease to be of significance.

Before examining the Quaternary period the salient features of the preceeding eras may be summarised here. During these eras the parent rocks of West Pakistan came into being. The common characteristics of these movements was either to uplift the sediments which were deposited in the ocean floor at some places or to submerge land areas at other places. The whole of West Pakistan may be re-garded as having been generally occupied by sea since the Paleozoic, this general marine occupation being but occasionally interrupted.

The recurrence of uplift is reflected both in Appendix 1 and Fig. 4, showing the Pre-Tertiary uplifted areas and it is believed "that the Himalayas were probably first folded in the Cretaceous and latter in the Eocene and Miocene, but their present elevation was not attained until the Pliocene and most of the topographic detail is Pleistocene or later in age ".(10) Fig. 5E.

It is again evident from the appendix that though the uplift process has been of an intermittent duration through-out the earth's history of West Pakistan, it was violent and continued over a great span of time from the Miocene to the early Quaternary, during which time large areas acquired the present position. The final upheaval was preceded by the volcanic activity during the Cretaceous.

As already stated the sequence of evolution is complete at many places. In addition to Salt-Range, Kalat, Quetta and Hyderabad Divisions the Potwar Plateau also demonstrates nearly a complete Tertiary succession. It can be traced from the Eocene to the Pleistocene with the exception of Oligocene.

The immense formation of limestone throughout the area stands a witness to the existence of widespread uniform conditions for calcareous formation under the repeated process of transgression of seas at various times. The occurrence over wide areas of limestone and sandstone strata which are permeable to varying degree have considerable effects on drainage and water supply, and therefore on human activity. The relationship between rocks and hydrography will be considered later.

Quaternary Era:-

The drift geology or superficial deposits of the area results from processes of deposition from the Pleistocene until now. The deposits form the surface geology of the second Macro Region of West Pakistan. These deposits have infilled the Indus depression to the depth of thousands of feet, so completely that the solid geology of the plain is entirely obscured beneath these deposits.

During the Pleistocene time a great many changes occurred in the pattern of hydrography of the sub-continent

(See Chapter 4). This was partly a result of Pleistocene Glaciation and partly of earth movements.

Pleistocene Glaciation:-(11)

The main testimony of an early Ice Age is provided by the Talchir series of Salt Range, formed during the Upper Carboniferous. The main depositional evidence of the Pleistocene glaciation is provided by the boulder conglomerate and erratic blocks embedded in the alluvium of the Potwar region. (See Plate 9). The origin of erratic blocks has long been disputed by the geologists, some writers attributing their origin to normal flood effects, but the most tenable theory is that they were moved by mud avalanches or directly by glaciers, as they bear the signs of glacial action on their striated and smoothed surfaces.

According to De-Terra and Patterson, there was no continuous glaciation during the Pleistocene Period, but ice sheets and glaciers advanced and retreated, leaving their marks in the terraces formed during glacial and inter-glacial periods. De Terra has observed four phases of Pleistocene glaciation in the Soan Basin (Chapter 7).

The Quaternary accumulation in the plain, falls into two categories, fluviatile accumulation, the debris transported and deposited by river water and aeolian material.

The unconsolidated superficial fluviatile material is perceptible predominantly in the Indus Plain. These deposits do not form distinct horizons as the whole detritus forms a continuous sheet, but the three types of deposits have been determined by the geologists. They have been recorded in the following order of superposition:-(12)

1. Deltaic deposits.
2. New alluvium or "Khadar".
3. Old alluvium or "Bhangar".

These formations contain "Bhaber", "KanKar" and "Reh". They are unconformal to the Kirana outcrops of the Aravalis, which intrude here and there in the Upper Indus Plain. The Deltaic deposits are the continuation of new alluvium and they are still in the process of aggradation, at places rising to the height of 70 feet above sea level; much higher than the surrounding country. New alluvium consists of the lowland deposits of recent age through which the rivers flow. At present they occupy the low ground. Quite different is the "Bhangar" or older alluvium. This belongs to the Upper and Middle Pleistocene and occupy the plateau high ground and is free from the effects of recent inundations. The Bhangar is not common in the Indus Plain, forming a few patches only in the lower basin.

The other drift deposits are gravel talus known as

"Bhaber", lying on the border of the hills. In these gravels and conglomerates many of the ephemeral rivers disappear without entering the plain.

In the dry alluvium,vast areas have been covered by "Reh" or "Kallar" formation. Their origin is associated with the chemical disintegration of the rocks. Soluble salts have been dissolved by percolation and through capillary action carried to the surface. The Kallar salts are a mixture of various elements, for instance carbonates, sulphates and chloride of sodium with calcium and magnesium salts.

Windborn material:-

In the arid areas, the wide bare expanse of desert is punctuated with ripples of sand dunes of different shapes and altitudes. These deposits conceal the parent rock underneath them. Origin of these desert tracts is attributed to their inland situation and to the prevailing winds.(13) These desert expanses occupy a critical position that they lie almost out of the monsoonal tracks in the west and almost beyond the Western periphery of the monsoon regime. Hence the precarious and capricious rain, they obtain. The Thal moreover occupies a leeward position in the foot of Sulaiman Range. (See Chapter 3).

Desert evolution:-

Studies of the origin of deserts will certainly prove pre-requisites in the search for and location of underground water. The following are some of the most important arguments put forth about the origin of the deserts.

Wadia points out that the deserts of Thar and Rajputana are the result of a long process of mechanical rock decay, owing to prevalent droughts, extremes of temperatures, and strong insolation accompanied by wind action. He further states that, "This change has been brought about by the great dryness that has over come this region since Pleistocene times leading to the intensity of aeolian action on its surface".(14)

The gist of a long treatise contributed by La Touche on the Geology of Western Rajputana is this that the present deserts have been produced by gradually silting up of the water courses, conjoined with an accelerating sand drift. His conception is allied to that of Wadia.(15)

As described later in the history of hydrography of West Pakistan the present rivers represent a transformation of the early river systems, and the present desert zone was previously traversed by many rivers. Blanford's theory concerning the origin of the present desert pattern was based on the eccentric distribution of dunes. He opined that the Runn of Kutch was a part of a sea, which was gradually filled with the deposits carried by Luni and Ghagar rivers. He further believed that these rivers flowed in long estuaries separated by extending spits which provided the raw material for wind action and that the present desert is largely formed of such material.

The physical evidence, supporting folk tradition, indicates that there existed a river valley between the Deccan penninsula and the present sandy country of West Pakistan. Up till the 6th century B.C. Indus had 6 tributaries, namely Jhelum, Chenab, Ravi, Beas, Sutlej and the Saraswati which flowed on the left of Sutlej. It is supposed that the Saraswati "having ceased to join Indus, it made for itself an under ground connection with the Ganges and Jumna near Allahabad. Over a vast space of the now desert country east of the Indus traces of ancient river beds testify to the gradual desiccation of a previously fertile region, and throughout the deltaic flats of the Indus may still be seen old channels which once conducted its waters to the Rann of Cutch, giving life and prosperity to the past cities of the delta, which have left no living records of the countless generations that once inhabited them".(16) (See too Chapter 4). The present desert is obviously a barrier to communication, but "prehistoric immigrants, who crossed the frontier mountain barriers in successive waves to search for the golden plains, did not meet such obstruction to their slow movements towards the east and south as would be encountered in these later days".(16)

Recent researches on arid zones of the world have concluded that the origin of deserts attributed to a combination of factors. The primary case is their location in the tropical and sub-tropical anticyclonic regions for the greater part of the year, and in the subsiding air masses the moisture content is low and rainfall sporadic. Their immediate vicinities are also affected by the same but less powerful atmospheric conditions which in a sense isolate the nuclear centres from disturbance.(17)

In West Pakistan the whole of the lowland is a vast expanse of desert but for the great perennial rivers and the modern canal system. At present extreme arid conditions persist in three tracts. The first two being the Thal desert at present under the process of reclamation, the Cholistan in the Bahawalpur Division the western extension of the Rajputana Desert, and its continuation to the south east, the Tharparkar desert. The parent rock of these areas have been obscured by these windborn sandy deposits. In the Tharparkar alone solid rocks belonging to the Precambrian have been identified. The dry sand drifting winds sweep over these tracts and accumulate sandhills of varied shape and size. The third tract lies in central and north west Kalat Division, the stony desert.

These areas experience large seasonal and diurnal ranges of temperature which result in a large scale desquamation of the rocks in the adjoining hilly areas. The loose material produced thus forms a raw material for the winds to carry it and deposit it in the sand heaps and dunes forming the vast wildernesses. Near the river courses the sandy desert merges with the alluvial deposits. These sands are further encroaching on the fertile land. In the accompanying Plate 10 the recent encroachment of the sand is shown.

The origin of the present sand accumulation is now considered to be derived from:-

1. Sub-areal denudation of the sedimentary and Metamorphic rocks of the hills.

2. The sand brought by the south-west monsoon wind from the coastal region of Cutch. (But as noted in Chapter 3, the S. West monsoon winds do not enter West Pakistan via Cutch in the present post glacial period).

3. The ancient estuarine beds as envisaged by Oldham in 1893, stretching inland in the Indus plain.

The sand ingredients are quartz, felspar and hornblende which indicates that the main source area of sand must have been the highland region.

Thus the latest geological phase in the history of West Pakistan is the occurrence of desert formations, characterised by strips of dunes, and pitted by shallow depressions of salt water already mentioned in Chapter 1.

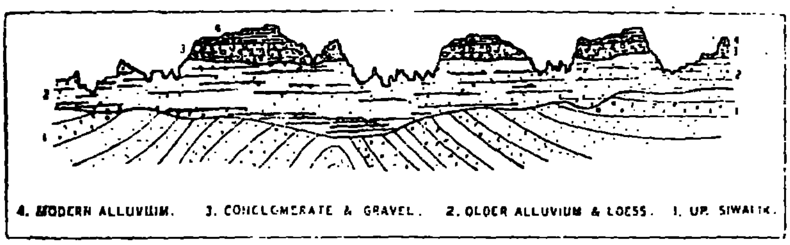
The picture of gradual submergence of the solid geology by later unconsolidated deposits may be exemplified by the Potwar sequence, illustrated in Fig. 6. The parent rocks of the north east Potwar are completely obscured by these accumulations (18) lying in the following stratigraphic order, 4, gravel, 3, gravelly conglomerates, 2, loess, (Plate 11) 1, older alluvium, representing a high level of rivers.

A gradual and smooth passage from Pleistocene to Recent into Prehistory is depicted in the Quaternary deposits. (see Chapter 7). The Quaternary is finally marked by the presence of man. Dozens of sites have been explored in the Potwar region where the human emergence and existence has been testified in the presence of artifacts.

Of particular relevance to this study, and as the preceeding account reveals, certain geological phenomena in West Pakistan have favoured the creation of under ground

Fig. 6

PLEISTOCENE AND SUB-RECENT OF THE POTWAR.



—Pleistocene and Sub-Recent deposits of the Potwar. Approximate Scale 1 inch = ½ mile.

water bodies. The most conspicuous feature of this kind is the frequent occurrence of faults and thrusts planes, as a consequences of earth movements; (19) Fig. 4 and Plate 12, Khair-i-Murat. Under such circumstances regions of porous recent rocks have often been sealed off by tectonic contact with earlier rocks which are impermeable. This phenomena is of very common occurrence in the Regions II-IV and the Salt-Range.

In the Regions III-IV, wherever the sub-recent sediments are thrown against the older sediments very suitable conditions have been created for formation of perennial springs. The springs in Nushki and Loralai are related to such incidence where the sub recent porous rocks are thrown against the Khojak shales, Triassic sandstones against shales and limestone, and Cretaceous limestone against Ghaj shale in the Loralai district.

In Region II the same arrangement of the strata led to the formation of springs in the districts of Kohat and Waziristan. Water escapes through the exits generously provided by faults, joints and bedding planes in the limestone strata. Such springs eventually supply streams, of great importance in the highland zone in that they can be used to support for agriculture. Plate 13 is an illustration of a spring which is utilised for irrigation at Urak, near Quetta.

Wherever the Eocene limestone is thrown down against shales, water percolates through the shales and is ultimately absorbed by limestone. Such localities are utilised for the construction of "Karez", which is an indigenous means of obtaining irrigation water. Evaporation loss is prevented as the water is obtained through pipes sunk into the gravels, and protected by the direct rays of the sun, where a great quantity of water is lost to atmosphere. The most common use of Karez is found in the Regions of Quetta and Kalat, owing to the presence of suitable natural conditions.

The folded structures themselves provide conditions where several layers of synclinal water-bearing strata are found, as for instance in the Chagai district and Waziristan.

Lastly, the alluvial material is a great reservoir of under ground water, where water percolates from the river beds as well as dissipates from the hills as is common in Regions VIa and VI 1. A detailed account of under ground water is given in Chapter 4.

In summary form we may say that the geological character of West Pakistan as thus outlined is of significant importance in that other environmental factors especially climate are modified or emphasised as far as man is concerned by geological factors. In a region mainly arid or semi-arid in character the presence of elements such as mechanically weak shales, thick loess, and structure-controlled aquifers can tip the balance for or against human occupation.

Chapter 3

Climate

West Pakistan's dominantly north-south alignment is climatically important in that a considerable range of latitudes breaks down the uniformity resulting from the country falling almost completely within the great Afro-Asian Arid zone. Extension in latitude in combination with those geographic elements already considered, gives variety and distinction to the mainly arid climatic regimes observable.

The diversity of climate is manifested in the rainfall pattern, temperature distribution, wind direction and the march of humidity. As noted below, these are controlled more by regional orography than by any other single element. Thus, we find that structure and relief patterns have not only extended direct influences on human life, but have also indirectly influenced human life by their critical influence on climatic regimes, hydrography and water availability (see chapters 4-6).

The late Indian Meteorological Department adopted for purpose of climatic analysis a scientific scheme reasonably based on the onset and offset of the monsoon over the Pak-

Hind sub-continent, and advanced a conventional division of the climatic year into four seasons:(1)

(1). The season of the north-east monsoon.

(a) January-February cold weather season.

(b) March-Mid-June hot weather season.

(2). The season of the south-west monsoon.

(a) Mid-June to Mid-September.

(b) Mid-September to December, retreating monsoon season or Autumn. These four seasons of the year correspond with the agricultural year, as climatic conditions govern the crop production to a great extent. (Chapter 6).

Of the two transitional stages (1)b, the hot season and (2)b, the autumn season, the former precedes the monsoon and the latter follows it. Over most of West Pakistan, these two transitional periods are relatively dry and therefore the first significant point that must be emphasised is the marked rhythm in the occurrence of rain and drought.

An introduction to the understanding of this seasonal rhythm must be based on an examination of the four periodic states of the pressure systems, and the weather accompanying them. This brief study is not concerned primarily with the mechanism of air mass climatology. Hence, the treatment is restricted to that of the surface and low

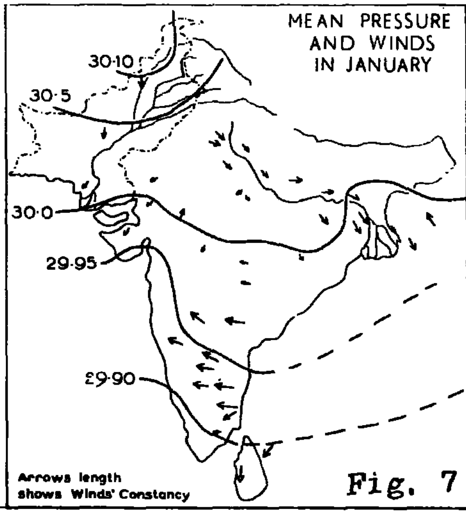

MEAN PRESSURE
AND WINDS
IN JANUARY
30·10
30·5
30·0
29·95
29·90
Arrows length
shows Winds' Constancy

Fig. 7

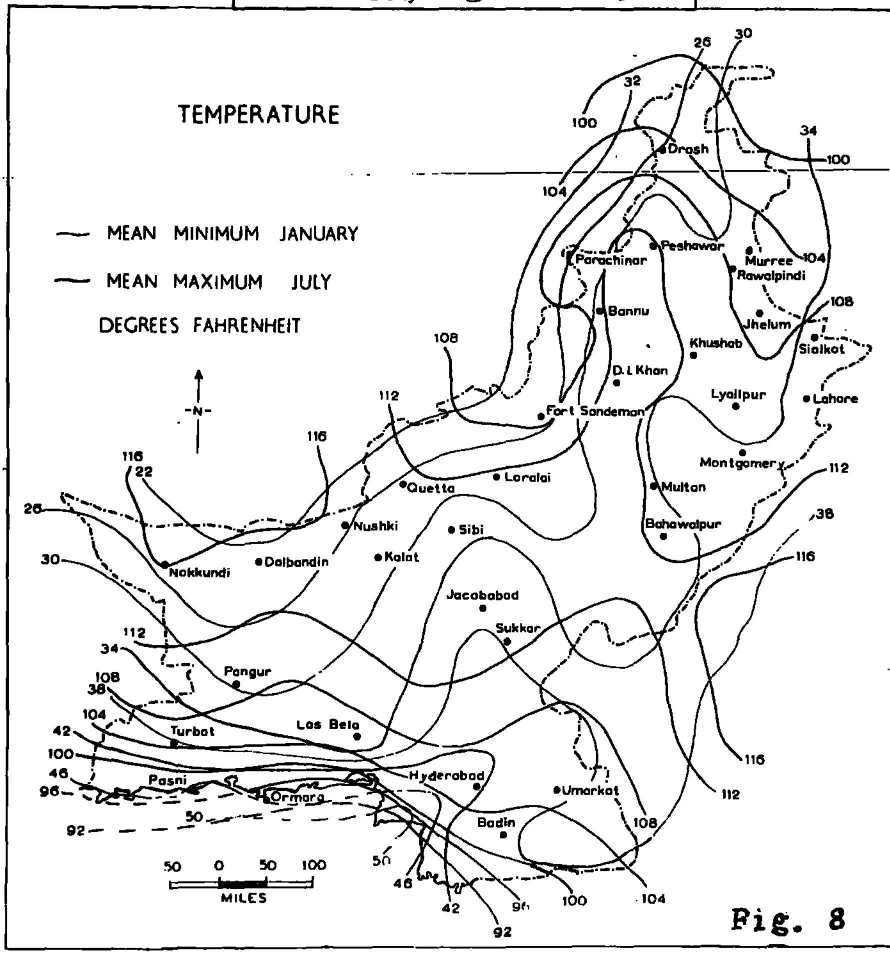

TEMPERATURE
MEAN MINIMUM JANUARY
MEAN MAXIMUM JULY
DEGREES FAHRENHEIT
N
Drosh
Parachinar
Peshawar
Murree
Rawalpindi
Bannu
Jhelum
Khushab
Sialkot
D. I. Khan
Lyallpur
Lahore
Fort Sandeman
Montgomery
Multan
Loralai
Quetta
Nushki
Sibi
Bahawalpur
Nokkundi
Dalbandin
Kalat
Jacobabad
Sukkur
Pangur
Turbat
Las Bela
Pasni
Ormara
Hyderabad
Umarkot
Badin
MILES

Fig. 8

altitude atmospheric pressure "build up" and wind movements, and of course the resulting weather.

Winter Season:-

With the advent of winter the rapid cooling of the interior Indus plain, which as we shall see is largely isolated from surrounding climatic regions, encourages the cooling of at least the lower layers of air and an increase of atmospheric pressure to a mean of 30.10" in January (Fig. 7). Relatively low pressure conditions lie over the ocean south of the Equator and the pressure gradient decreases uniformly from the Upper Indus plain to the south, West Pakistan naturally coming under the dominating influence of air outflowing from the landmass. Temperature almost equally uniformly decreases from south to north indicating an influence of both latitude and altitude. It appears from Figure 8, that the Isotherms of January generally run closely parallel to the coast, distorted only by the effects of altitude. The lowest temperature occurs in the north-west and south-west where the temperature falls as low as 22°F, mean minimum. Prevailing winds mark an air movement towards the south and south east. Fig. 7.

A contemporary high pressure settles over Central Asia, which has no bearing on the production of winter conditions experienced over the sub-continent. Previously it has been thought that the Pak-Hind sub-Continent is directly influenced by the cold air which outflows from the Central Asian High pressure. Recent studies have proved this to be an erroneous view. Investigations have revealed that the actual air mass movement leads to the formation of a high pressure locally over West Pakistan. The cold air settling over Central Asia is completely shut-off from the south by the heights of the Himalayas and by the vast up-land expanses of Tibet plateau. On the north and western peripheries of West Pakistan the continuing wall of mountains is nowhere less than 6,000 feet; and the Hindukush itself towers more than 20,000 feet. These eminences form in depth, line after line of impediments to the lower levels of air circulation and the sub-Continent is entirely cut-off from the out moving air of Central Asia, this air movement finding rather an outlet towards China. The high pressure which is established over West Pakistan must, hence, be regarded as local in origin. The resulting winds are continental in origin, have little moisture and their direction of movement from the north west and west, is directed by the Indus trough and attracted by the equatorial low pressure zone. They are slow blowing winds with an average speed of 2-3 miles an hour over the plains, (there is hence no possibility of obtaining wind power.) Their speed is rapid but not strong in the south near the coast. In the Regions III-IV the constant cold bitter wind is locally called as "gorich".(2)

The anticyclonic regime is characterised by low humidity, invigorating bright sunshine, high day temperatures and a calm atmosphere. These conditions favour a high daytime insolation and rapid progressive nocturnal cooling and consequently the diurnal ranges are striking. For instance the difference between mean January maximum and minimum at Lahore in 28.7°F and at Peshawar 22.6°F. (The temperature range and its affect on crops are treated later). The occurrence of frost and water freezing is frequent in the highland, but only of occasional incidence in the lowland.

The serenity of weather is disturbed by the passage of Western Depressions, across the north western highland to the south eastern lowland between December and April. Every year their occurrence is recorded 4-6 times in a month in the north-west region and in the Upper Indus Plain. The Makran region is usually visited by these depressions with surprising regularity on 5th November, 6th December, 8th February and 6th March.(3) Their stay is accompanied by cloudy spells, rain, hailstorms, cold waves, wind and the temperature falls sometimes below freezing point. As this disturbing weather comes with a marked regularity, precautions need to be taken for crop protection along the Makran coast where small river valleys are fertile crop producing areas. Heavy snow fall occurs over the mountains which is of vital importance to the maintenance of the glaciers which feed the perennial rivers. In the Kalat and Quetta Divisions the snow is of even greater value as it replenishes the 'Karezes'. The rain that these depressions release depends on their intensity. Sometimes they pass over mildly without shedding considerable rain. The agricultural effectiveness of precipitation is reduced when it comes in erratically heavy rainstorms, but snowfall more slowly and regularly releases water for agriculture. The excellent fruit producing areas of Quetta and Kalat are maintained with the utilisation of such water.

Many meteorologists have studied the origin and structure of these climatically and agriculturally important western Depressions since the late 19th century.(4) The earliest idea was that the western Depressions originate locally either over the north west of West Pakistan or that, they are developed over the Baloch-Persian plateau. Later theories suggested that the original source of the Western Depressions was the Mediterranean sea. More recent studies have been able to shift their source region further westward in the Atlantic, and in the opinion of the latest investigations the Western Depressions belong to the family of the Depressions which originate in the extra-tropical region of Atlantic, at the meeting place of the Equatorial and High Latitude air masses. These developed instabilities travel towards the east and in their journey develop secondary depressions over the Persian Gulf and regain strength and advance forward to West Pakistan, where they eventually die. Their track from west to east is appreciably controlled by local terrain and atmospheric conditions. These centres of instability are, as already noted, responsible for the violent thunderstorms which are sometimes injurious to the standing crops. This "outside influence" is of great significance as it causes rain especially since the indigenous anticyclonic calms are naturally periods of aridity, and alone make possible the economic growth of cereals such as wheat and barley. Its benefit is enhanced under conditions of feeble winter evaporation. Moreover run off during this period is less than during monsoonal rain owing to the less torrential nature of rain. Hence the highest proportion of rain is available for agricultural purposes. The failure of these rains may result in crop failure.

During winter and spring the north-west part of West Pakistan receives rain, while dry cold persists over the most of south east. The amount of rainfall decreases in the following order. During spring at Darosh and Peshawar 7.81" and 8" respectively and Bannu and Quetta 2.76" and 2.44" respectively. During winter Darosh and Peshawar receive 4.12" and 3.64" respectively and Quetta and Bannu receive 4.93" and 5.8" respectively. Lahore 230 miles south east of Peshawar receives only 3.8" from November to April covering both seasons winter and spring. (Appendix 2.)

Hot Season:-

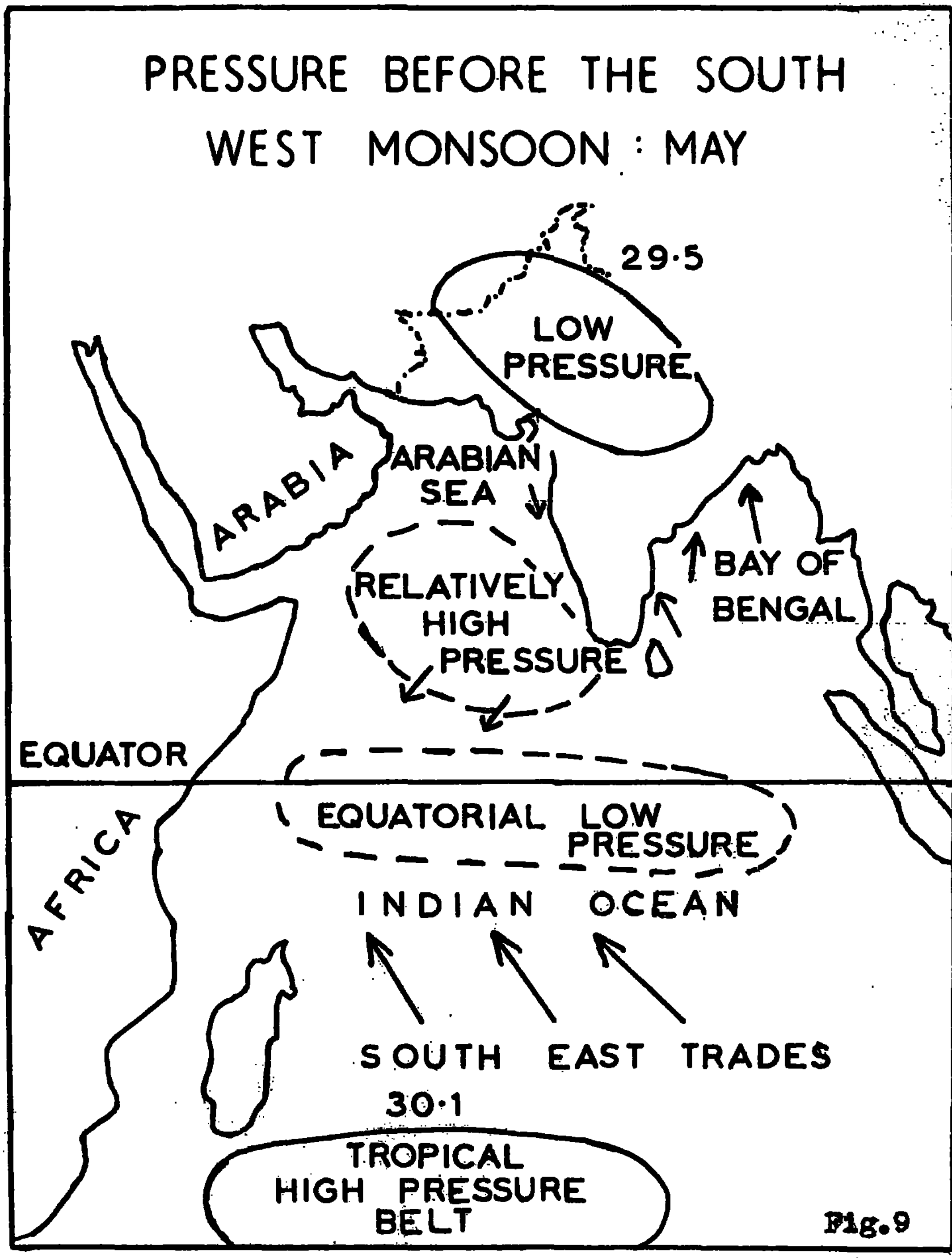
A complete reversal of air circulation takes place with the apparent movement of the sun towards the north. The high pressure disperses gradually and eventually by May it is entirely replaced by a trough of low pressure formed over the rapidly heated landmass. Consequently temperature rises rapidly and wind direction is reversed altogether. Winds become inblowing "inshore" winds in general. The cooling affect of the north-east monsoon dies out and the atmosphere becomes very dry and relative humidity has been registered as low as 1%. The temperature increase is ameliorated along the coast by sea breezes.

During the alteration of pressure conditions, "Air circulation is cyclonic and feeble and conditions are ideal for the generation of local thunderstorms".(5) The land is heated quickly by active insolation during the day, which induces air convection of local extent. In-drawn air heated and desiccated, is particularly associated with the hot day wind known as "Lu". Air movements such as this are able to build up on a large scale over the great low-lands. Their dryness adds positive physiological drought effects to the negative absence of rain. Humanly speaking, the only amelioration is felt as these winds die away in the evening to be followed by a momentarily exaggerated coolness.

In May Isobars run in approximately a north-west to south-west direction and in the east clearly following the orographic pattern of the country. (Fig. 9). A deep low pressure centre, encloses more than half of West Pakistan and stretches to Jabalpur in Central India.

The South West Monsoon Season:-

The suffocating heat of early summer months ends with the "burst" of the monsoons. Their time of arrival and departure vary irregularly from place to place. Their mean date of arrival in West Pakistan is July 1st and departure prolonged from 14th to 21st September. The chief characteristics of the onset of the monsoon is the arrival


PRESSURE BEFORE THE SOUTH WEST MONSOON : MAY
29·5
LOW PRESSURE
ARABIA
ARABIAN SEA
RELATIVELY HIGH PRESSURE
BAY OF BENGAL
EQUATOR
AFRICA
EQUATORIAL LOW PRESSURE
INDIAN OCEAN
SOUTH EAST TRADES
30·1
TROPICAL HIGH PRESSURE BELT
Fig.9

of torrential rain associated with electrical storms,indicating extreme atmospheric instability and turbulence.

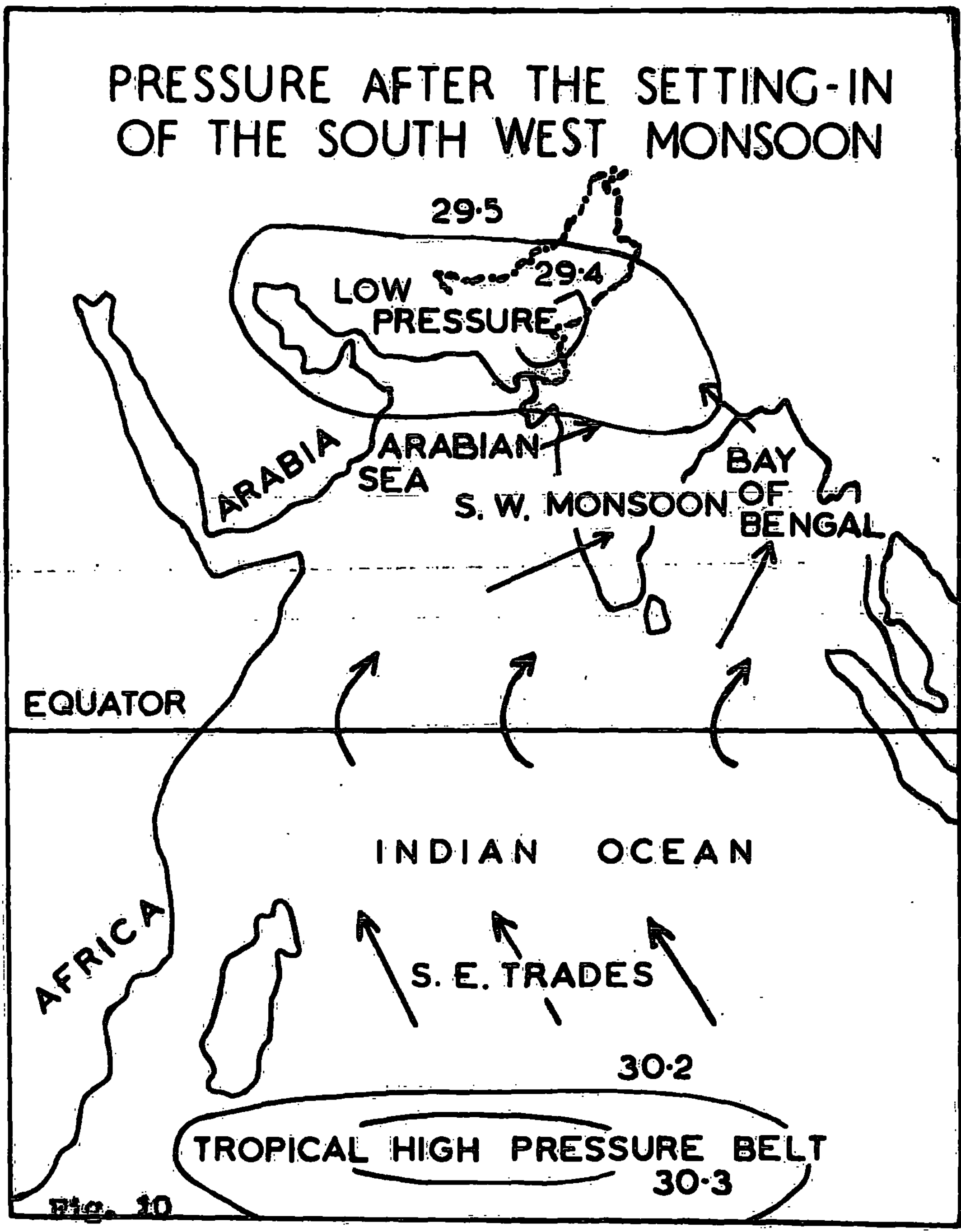
The deep low of May contracts in area and slowly deepens to an average pressure of 29.40" in July (Fig. 10). Near the sea and in the highland periphery,temperatures rise to high July maxima but in the central lowland the cummulative heating raises temperatures to an extreme. For example at Darosh in a valley in the high mountains the July extreme is 110°F, Lahore in the lowland recorded 118°F. and at Karachi on the coast the extreme maximum temperature was 98°F. With the advent of heavy showers of rain at irregular intervals, a considerable reduction in the temperature follows immediately owing to progressive conduction and evaporation. The high humidity however often makes the heat physiologically unpleasant.

The structure and origin of the south-west monsoon has been subjected to close examination for the last 50 years but many anomalies crop up in every argument. Even now there is no completely satisfactory hypothetical explanation of 3 phenomena associated with monsoon:-

1. The seasonal regularity of large scale reversal of air movement.

2. The suddenness of the onset of monsoon.

3. The characteristics of monsoonal precipitation in West Pakistan.


PRESSURE AFTER THE SETTING-IN OF THE SOUTH WEST MONSOON
29·5
29·4
LOW PRESSURE
ARABIA
ARABIAN SEA
S. W. MONSOON
BAY OF BENGAL
EQUATOR
INDIAN OCEAN
AFRICA
S. E. TRADES
30·2
TROPICAL HIGH PRESSURE BELT
30·3
Fig. 10

There are two groups of experts who have investigated the origin of south-west monsoon current. During the researches undertaken by pre-1930 experts, namely Blanford, Walker, Simpson, Hemraj and Normand, air-masses climatology was neglected. The succeeding experts, namely Thomson, Sawyer, Naqvi and Bannerji, have viewed the origin of south west monsoon current from the stand point of air masses and their approach is more elaborate.(6) After studying the various hypotheses the writer tends to support Elliott and Naqvi. The following statement mainly derives from their studies although as Naqvi states "The basic causes of the south west monsoon of our region though usually claimed to be understood even by school children, are as yet not quite clear and fully agreed upon, even amongst specialists".(7)

Figures 9 and 10 give impression of the Isobaric conditions,which generally occur during the month's of May and July and the coming of the monsoon.

In May an intense low pressure is occupying a great areal extent, covering West Pakistan and Central India. Simultaneously an Equatorial belt forms an ill-defined trough. The intervening passage between these localities of two separate lows is a ridge of relatively high pressure.

Again contemperaneously a well established high pressure is located south of the Equator, where from,the South East trade winds rise and outflow to the north. Thus, over the sub-Continent and the Indian Ocean lie two lows and two highs of varying intensity. The low over West Pakistan and the high over the tropical zone south of the Equator over the vast ocean are very strongly developed, but the Equatorial low and its nearby high pressure are relatively less developed. Large scale air motion can only set in,if the feeble Equatorial low and high have been eliminated completely.

In July the picture is entirely changed. Quite simply the land-sea contrasts in heating reach their climax. The weak low and high have been completely vanished, and the ocean is covered with an even higher pressure belt of upto 30.3", and the Pak-Hind Sub-Continent is covered with an even more definite and intensified low pressure falling to an average of 29.4 inches primarily over West Pakistan. The landward advance of the trades was previously hampered by the presence of the Equatorial low and the "ridge of high pressure"; these have now cleared and the South-East Trades, turned to the right as they cross the Equator by the deflection received by rotational motion, become the south-west monsoons. The pressure gradient over the ocean is steep but more gradual over the land.

As the south-west wind inflow to the land increases, the mixing of cold and warm air in the resulting turbulence reaches a critical point and lead to the "bursting" of the monsoon, the dominating south-west monsoon winds having travelled over the ocean for a great distance become saturated. We may say that the south-west monsoon "burst" is an activity associated with the junction of two air currents, a land originating current developed over West Pakistan and ocean current originated over the southern hemisphere, their paths directed by the pattern of land and sea relief. The low pressure of West Pakistan has no connection with the low, lying over Central Asia, but is independent, generated locally.

The bursting character of the monsoon is not valuable for the land. The excessively heavy downpours of monsoon rain encourage soil erosion, run off resulting in floods, and the formation of channels and ravines takes place. (See also Chapter 5). The river beds, and reservoirs get choked and silted up and eventually they overflow the low-lying areas. Indirectly, the water reservoirs are insufficiently replenished as a large quantity of the rain water flows rapidly to the sea in the form of floods, instead of being absorbed by the soil.

The south-west monsoon air-movement affecting the Pak-Hind Sub-Continent forms two branches - the Arabian Sea and the Bay of Bengal, but West Pakistan falls out of the direct influence of both branches. As illustrated in Figure 11, the rain bearing current of the Arabian sea branch does not enter West Pakistan, its northern limit lying in the Gulf of Cambay.(8) Figure 10 shows low pressure as centred over the Lower Indus Basin, but as far as the precipitation is concerned this region receives only a trickle of it. The factor responsible for this phenomenon is the arrival of the air currents not from the sea but from the Afghan-Baluch plateau towards the Lower Indus region. These originally S.W. monsoon air masses already having lost much of their moisture become still drier in their descending process to the plain, hence no rain incidence. The Figure showing the limit of moisture bearing winds also indicates that these finally west to north-west winds become on-shore near Karachi but have absorbed only a small amount of moisture during their short journey over the Arabian Sea near the coast, which amount is both insufficient and ineffective. This amount of rain again fluctuates from year to year, which depends on

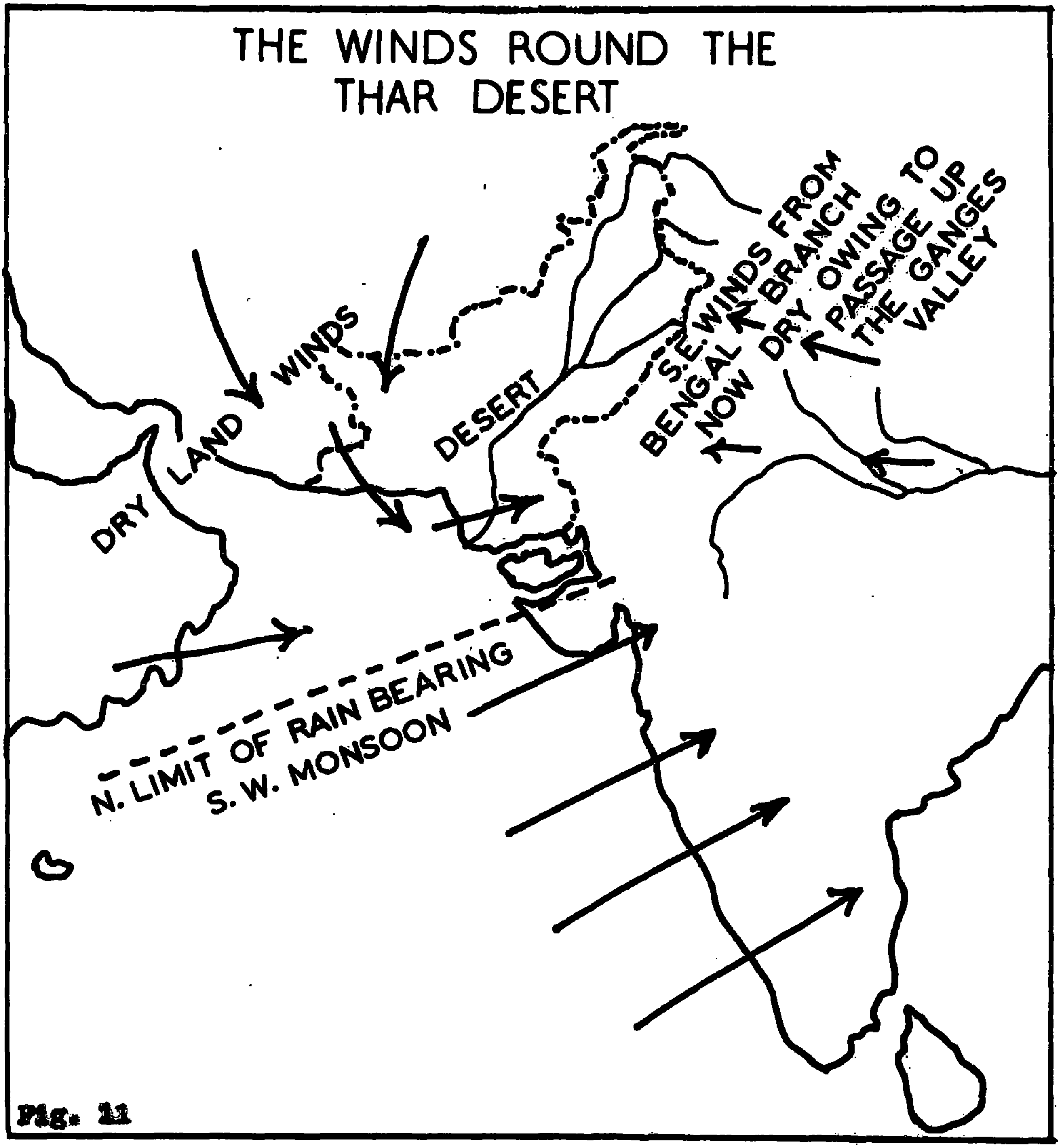

THE WINDS ROUND THE THAR DESERT
DRY LAND WINDS
DESERT
S.E. WINDS FROM BENGAL BRANCH NOW DRY OWING TO PASSAGE UP THE GANGES VALLEY
N. LIMIT OF RAIN BEARING S.W. MONSOON

Fig. 11

the strength of monsoon.

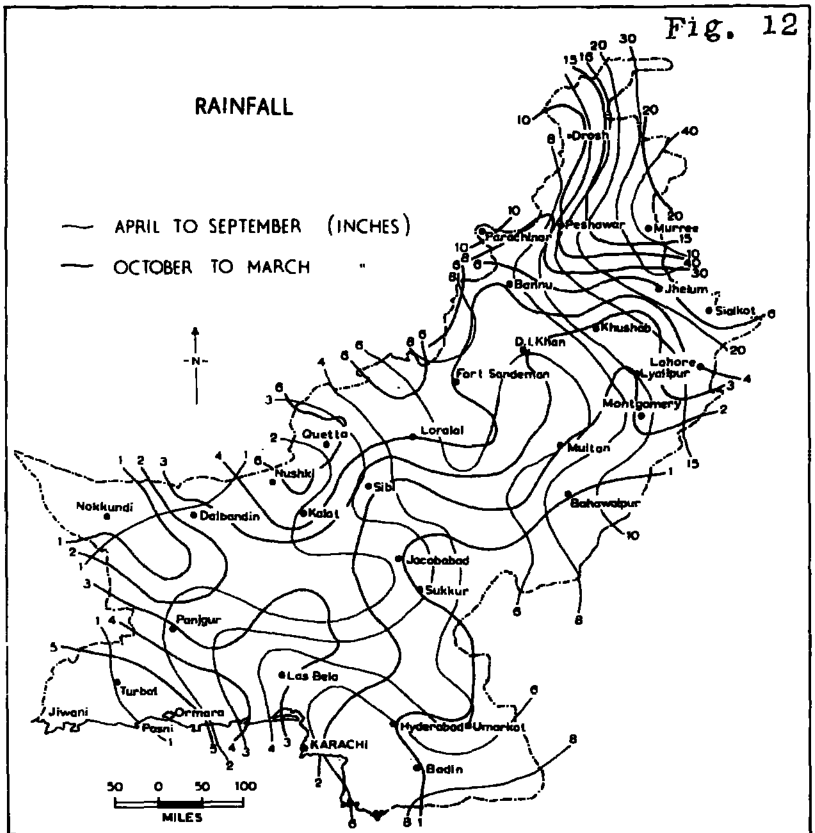
The inflow of the Bay of Bengal current on the east and north-east of Pak-Hind, confers bountiful moisture on East Pakistan and Assam. It then turns to the west up the Ganges Valley, and its moisture is nearly lost by the time it reaches West Pakistan. It becomes even more dry as it descends on the Upper Indus Plain, and West Pakistan receives only a scanty amount from this branch also. In the Indus Plain heat convection develops local turbulence but this ascending air is encountered by the dry inward moving upper currents before it reaches the point of condensation. Such are the meteorological reasons for the general aridity of West Pakistan.

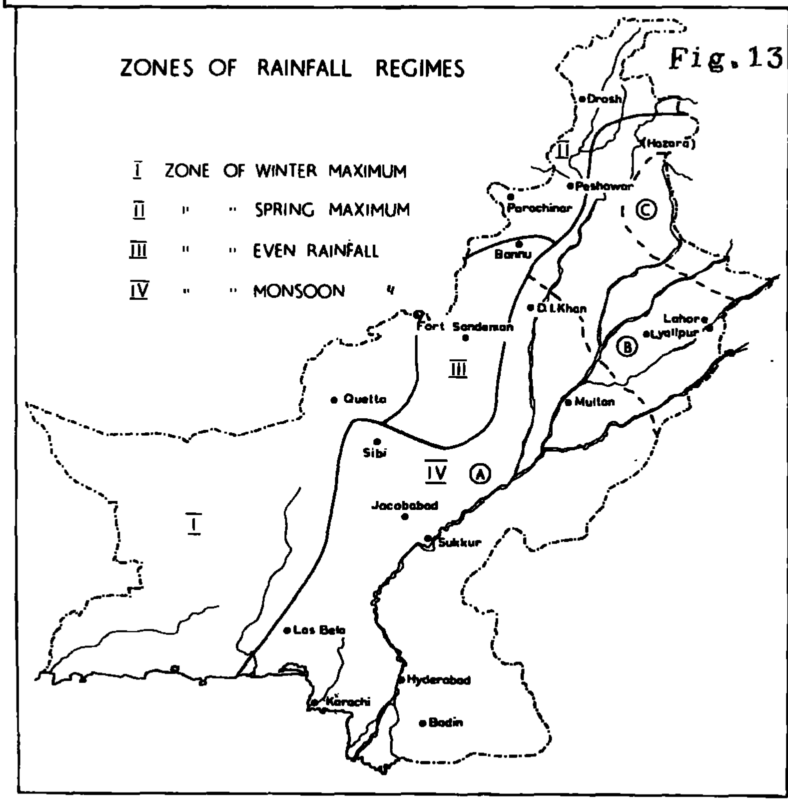
The decrease in rainfall from east to west is very pronounced; for instance Allahabad and Delhi get 33 inches and 22 inches respectively, Lahore 16 inches, Multan and Hyderabad 5 inches each; Peshawar and Quetta 3.29 inches and 0.46 inches respectively. The data Appendix 2 indicates that summer rainfall is restricted to the east of West Pakistan, and in the west it becomes too meagre to support even good grass and eventually desert supervenes.

In the opinion of some authors, though the monsoon current originates in the southern tropics, its components are augmented substantially north of equator.

Some workers maintain that "Much of the North Indian

Westerly current undoubtedly originates in the southern hemisphere, crossing the equator in the West Indian Ocean, but nevertheless a large portion is probably of northern hemisphere origin".(9) Riehl is of the same opinion: "Doubt has also been expressed that all the air moving with a westerly component at lowlevels over the Indian Ocean is really of southern hemisphere origin". Thomson further stresses that North Indian westerlies travelled over a large area north of Equator hence,it is not justified to label them of entirely southern hemisphere origin. Thomson on the basis of the study of air flow at the levels of 2,000, 5,000, and 10,000 feet, refuted the idea of an intertropical front and states that "The use of climatological records of surface winds on which to base the traditional theory of the intertropical front was a very bad mistake. Tropical winds are notoriously fickle and light, and there is much danger in using light surface winds in meterological analysis; it is fantastic that the theory of intertropical front built on such a foundation can have so persisted".(10) To conclude we may say that the monsoon origin is still a controversial point. The gist of a vast amount of research is that,the monsoon current is the result of interaction of atmospheric conditions of both upper layers and lower, their air source region lies in the south of equator and


RAINFALL
APRIL TO SEPTEMBER (INCHES)
OCTOBER TO MARCH "
N
Drosh
Parachinar
Peshawar
Murree
Bannu
Jhelum
Sialkot
Khushab
D.I.Khan
Fort Sandeman
Lahore
Lyallpur
Montgomery
Quetta
Loralai
Multan
Nushki
Sibi
Nokkundi
Dalbandin
Kalat
Bahawalpur
Jacobabad
Sukkur
Panjgur
Las Bela
Turbat
Jiwani
Ormara
Pasni
KARACHI
Hyderabad
Umarkot
Badin
50 0 50 100
MILES
Fig. 12


ZONES OF RAINFALL REGIMES
I ZONE OF WINTER MAXIMUM
II " " SPRING MAXIMUM
III " " EVEN RAINFALL
IV " " MONSOON
Drosh
(Hazara)
II
Peshawar
Parachinar
I
C
Bannu
D.I.Khan
Fort Sandeman
Lahore
Lyallpur
B
III
Quetta
Multan
Sibi
IV
A
I
Jacobabad
Sukkur
Las Bela
Hyderabad
Karachi
Badin
Fig. 13

air masses are modified on their long voyage to West Pakistan. The differential heating and cooling of both the sub-continent and the Indian Ocean during different periods explain the generation of gigantic air masses of differential nature in thermal and moisture content; the areas over which they reside are areas of active conflicting air throughout the year. The critical triggering off, of cycles of turbulence gives to monsoon weather its significantly peculiar character.

The Isohyets of high April-September rainfall embrace the greater part of the north-east, east and south-east. The amount of rainfall and concentration of isohyets grow less towards the west. The rainfall from October-March presents altogether a reverse picture. These isohyets tend to concentrate towards the north-west, west and south-west with the greater value of rainfall. They deconcentrate to the opposite direction showing lesser values. Both types of Isohyets are evenly spaced over a small area roughly lying between Las Bela, to Sibi then to Bannu. The gist of Figure 12 is that the monsoon contribution to the annual rainfall is higher in the east and winter contribution to the rainfall is higher in the west.

In both types of Isohyet pattern the influence exerted by relief needs comment. The highlands in the north and north-west owe much of their precipitation to orographic control. The Isohyets over the south-west highland again reveal the differences in the amount of rainfall over the Kalat and Quetta Divisions. The rainfall increases towards the north and decreases to the south and west, and is directly related to the layout of the mountain ranges. The ranges become higher and valleys narrower to the north, this arrangement of relief outline provides an opportunity to the convergence of south-west winds, hence there is more rain in Quetta and Urak than in their south at Kalat.(11) The Bolan Gap, a break in the continuity of Sulaiman and Kirthar allows the monsoon winds to pass through, but the inflowing air already of low humidity gives little rain after ascending the high passes.

This is a general areal distribution of rainfall interpreted with an eye to relief. The rainfall zones have been demarcated which conveys the idea that West Pakistan is never rainless. (fig. 13) It obtains rain at one place or other through out the year. The other feature illustrated by the diagram is the overwhelming periodicity of rainfall. Thirdly, more than half of the Western Unit of Pakistan is benefitted by the south-west monsoon precipitation, when the rainfall is more general and more abundant.

In the sample studies it will be seen that though monsoon rainfall is greater in quantity than winter precipitation it is less effective, as hinted already in the account passed.

The Autumn:-

This term of the year is characterised by the retreat of the south-west monsoon, and manifests the "most settled weather of the year, the serenity of the climate is seldom disturbed".(12)

By the middle of September the activity of the south-west monsoon ceases, and it is followed by another dry spell and calm for three months. The land is often flooded and waterlogged in the former rainy months which maintains high air humidity and temperatures tend to equalise. Some storms and rainfall occur owing to the local changes of temperature in this post monsoon period. Then temperatures tend to decrease, diurnal range grows higher, eventually cold weather prevails again with the re-establishment of high pressure as explained in the beginning.

A Regional Analysis of Rainfall:-

In West Pakistan, as is clear from the preceding treatise, exist significant regional differences in rainfall regimes. These may be classified by periodicity of fall, incidence of maxima and absolute amount, Fig. 13 illustrates such a classification.

The relatively small number of recording stations makes it impossible to establish precisely the limits of regions indicated. Thus from observation the author would extend the area of the humid zone (See Fig. 21A Aridity), - which in Fig. 13 is approximately equivalent to the area, of monsoon rains of longest duration - to include the Hazara District [illegible], but this cannot be proven by statistical records. There are similarly other gaps and blanks in the record. Although the map is based on fragmentary statistical evidence, ecological and human support for the classification is sufficiently strong.

As already noted, the pulsatory character of the monsoon and regional variations in resulting precipitation, and the differing seasonal characteristics of all precipitation is of great importance in determining the effective ecological and human value of the precipitation. The following descriptive analysis must therefore be regarded as a key to further consideration of the problems of aridity.

I Zone of Winter maxima.

II Zone of Spring maxima.

III Zone of even rainfall.

IV Zone of monsoon maxima.

I. The Zone of Winter Maxima:-

Cold season rainfall is characteristic of a very large area where an average annual rainfall is less than 6" and extreme maxima are under 10". The proportion of mean monthly received in winter from November to February at Quetta is 5.21"; and its annual rainfall is 9.44". At all the stations representing this zone the highest amount of rainfall occurs in February except at Nokkandi where the maximum occurs in January (less than 1"). Agriculture is primarily dependent on underground water which is replenished both by snow and rain. Fig. 12 illustrates that the scarcity of rainfall is particularly marked in the west of this zone.

II. The Zone of Spring Maxima:-

This covers a very small area, has relatively highly effective rainfall and it is very balanced in its rhythm. The whole zone receives 5"-10" rainfall during this season. Peshawar, Darosh and Parachinar acquire their maxima in two months. March-April, 4.20", 7.81" and 8.37" respectively, while their annual rainfall is 13.56", 18.04" and 29.25" respectively. March is the wettest month of the year at Peshawar and Parachinar and April is the wettest month of the year at Darosh. The recognisable blandness and precipitation effectiveness resulting from gentle showers is restricted to a small areal extent. Besides this valuable rainfall, crop production is supplemented both by surface and ground water resources.

III. The Zone of Even Rainfall:-

This is a region in which rainfall is likely to occur throughout the year, because it lies on the periphery of the winter, spring and monsoon zones. The representative stations for this region are Bannu, and Fort Sandeman, they obtain their maxima in July, 2.21", 2.14", and their annual rainfall is 11.11", 10.83" respectively, and having well spread rainfall over the year. There is no rainless month at Fort Sandeman, and Bannu. Cultivation is again depending on all sources of water as there is availability of both surface and ground water.

IV. The Zone of Monsoon Maxima.

A further sub-division of this zone must be made, based on the duration of the rainy season, the total amounts of precipitation and the period of maximum rainfall. The 3 divisions are:-

A Areas of 2 very wet months.

B Areas of 4 very wet months.

C Areas of 8 very wet months.

In the sub-region A of the monsoon regime, 7 stations are included, they obtain their maximum rainfall in two months July-August but the highest amount is recorded in July - 2.01", 2.29", 0.95", 1.44", 3.20", 2.98", and 3.97" for Multan, Dera Ismail Khan, Jacobabad, Sukkur, Karachi, Hyderabad, and Badin, respectively. Their westward location and amount of rainfall they receive, suggest that they only obtain rainfall when the monsoon is in full strength. After the waxing of the monsoon current the rainfall starts dwindling and these stations receive an insignificant amount in September, as compared to July-September rainfall is 0.52", 0.63", 0.89", 0.02", 0.17", 0.11" and 0.54" for Karachi, Hyderabad, Badin, Sukkur, Jacobabad, Dera-Ismail Khan and Multan; and their annual rainfall amounts to 7.70", 7.09", 9.7", 3.7", 3.60", 9.09" and 7.05" for Karachi, Hyderabad, Badin, Sukkur, Jacobabad, D.I. Khan and Multan respectively. This is an area where the monsoon arrives late and retreats early and it forms the western limit of the monsoon intensity. Agriculture entirely depends on canal irrigation or floods. Sibi and Las Bela, on the western periphery have 2 rainless months, October and November.

The second sub-region B, is comprised of the stations where the monsoon commences in June and rainfall continues over to September, though the amount recorded for September is highly variable from place to place. The representative stations are Montgomery (very meagre in June 0.98"). Lyallpur, Lahore, and Khushab. Their wet period spreads over four months; June-September, (except Montgomery, wet term lasts for 3 months only); whereas the former sub-region A has a wet term for 2 months only. This pronounced difference is related primarily to the location of the region A, and to the commencement and ceasation of the monsoon which is governed by the strength of the monsoon current. Montgomery and Lyallpur obtain their primary maxima during August, 2.90" and 3.58", Lyallpur gets a considerable amount in September 1.49". While the primary maxima recorded at Lahore and Khushab was in July 5.45" and 3.90" respectively. The rainfall occured during September at Lahore and Khushab was 2.20" and 1.38" respectively. It is now clear from the difference in duration of monsoon rains and their rainfall incidence as between sub-regions (A) and (B) that the critical limits between aridity (sub-region A) and semi-aridity (sub-region B) result from the erratic, pulsatory character of monsoon activity. This oscillation may be related to the year to year fluctuations in the monsoon strength, this aspect further demonstrated in Fig. 14.

Group C constitutes, Murree, Rawalpindi and Sialkot. This region, highland in case of Murree and sub-montane

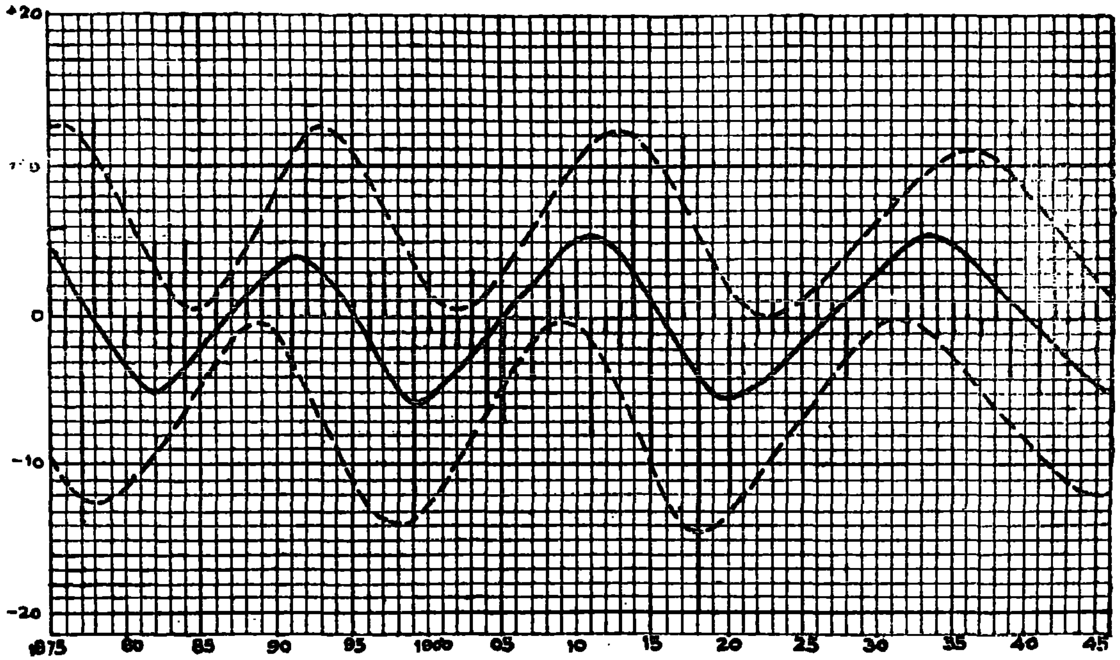


Fig. 34 Fluctuations in the strength of the monsoon from year to different parts of the Indo-Pakistan sub-continent from 1876 to 1946 /The vertical lines show the number of sub-division (out of 30 in the whole region) which recorded flood and droughts in each year /

terrains in case of Rawalpindi and Sialkot, is one where rainfall is adequate for plant growth. Murree for example, receives a mean monthly of over 1" of rainfall in every month except November. Rawalpindi acquires a rainfall less than 1" only in October and November and Sialkot obtains a rainfall less than 1" for 4 months namely, May, October-December. Hence,these 3 stations examplify the humid zone of West Pakistan, with the maximum precipitation in the hot season derived from the monsoon. The high level of underground water promotes the use of well-irrigation for cultivation requirements.

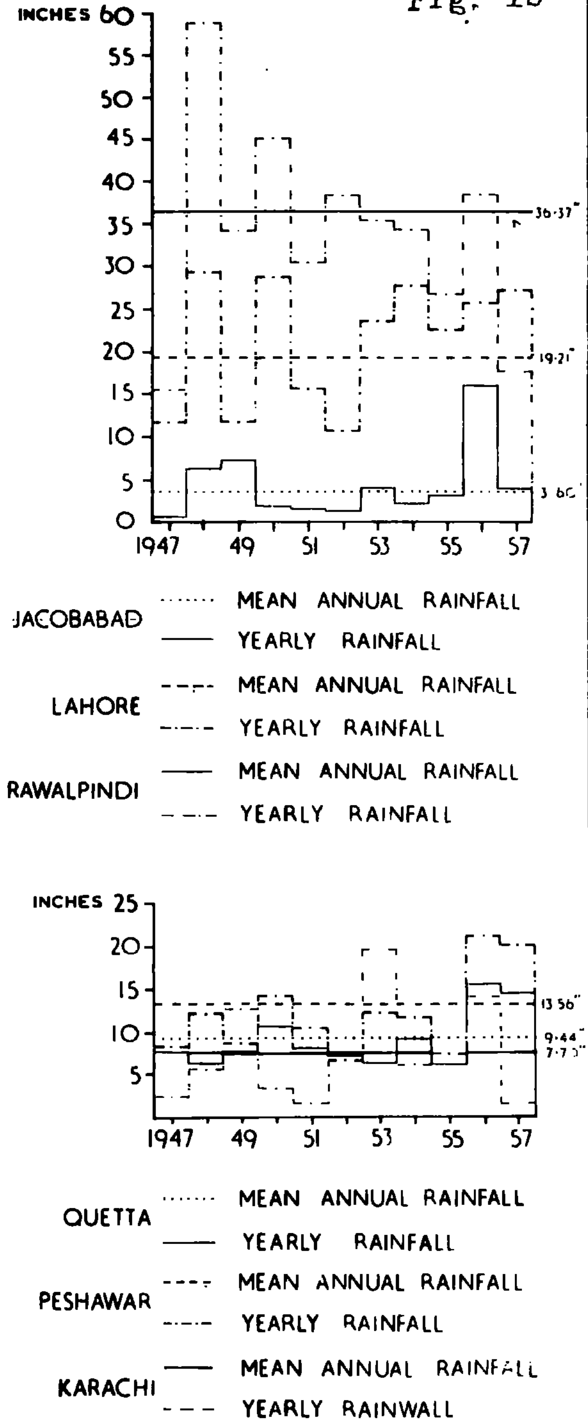
Thus,the differences of distribution in time and space may be recognised as associated with fundamentally different types of rainfall regimes.

From the above description of seasonal conditions and the regional analysis of rainfall regimes, we now return to a closer examination of general and particular climatic conditions which in the final analysis,are responsible for the problem of aridity in West Pakistan.

First,it is clear that West-Pakistan remains a principal seat of barometric minima and maxima at different stages of the year. The circulation factor controlled by the relief patterns regulates the rainfall distribution. The position of pressure centres fluctuates periodically,

11 YEARS RAINFALL VARIATIONS

Fig. 15



their extension and intensity affect the wind direction in turn, and finally, periodic storms are also produced by pressure convergence and divergence.

The present writer has studied numerous climatic accounts which are full of generalised statements, but day to day realities are very different especially in the incidence of rainfall. Yearly data for 11 years is shown in Table 2 and plotted in Fig. 15 for 6 stations. The graphs conspicuously show the sporadic nature of rainfall. Within 11 years the amount of rainfall at each station in each year has varied considerably. The rainfall data plotted here are far above and below the mean annual rainfall for respective station in 11 years.

In 1956 Jacobabad received 16" of rainfall, 5 times more than its mean annual rainfall, while in 1947 rainfall was .66", 1953 being the only year with rainfall approximating to the mean annual 3.72" (mean annual is 3.60").

The mean annual rainfall for Karachi is 7.70", but during 1953, rainfall was excessive as it reached to 19.95", more than twice than the mean annual. During 1957, on the other hand it totalled only 1.46". Out of the 11 years, 6 years remained with a rainfall below the mean annual and 3 years recorded rainfall above the mean annual; as 12.74", 19.95", and 14.20" for 1949, 1953 and 1956 res-

Table 2

11 years Rainfall in inches at Selected Centres

	Karachi (Manora)	Lahore	Rawalpindi	Peshawar	Quetta	Jacobabad
Height in feet above sea level	13	702	1676	1155	5490	183
1947	2.33	11.99	15.47	8.13	7.90	0.66
1948	5.59	29.07	58.84	12.02	6.30	6.05
1949	12.74	11.57	34.7	8.70	7.97	7.91
1950	3.38	28.84	45.01	14.01	10.72	1.99
1951	1.67	15.58	30.39	10.49	9.19	1.77
1952	7.55	10.92	38.11	6.84	7.09	1.31
1953	19.95	23.84	35.33	12.23	6.48	3.72
1954	6.03	27.86	34.35	11.82	9.36	2.20
1955	7.47	22.62	26.75	7.30	6.24	3.03
1956	14.29	25.99	38.16	21.06	15.69	16.00
1957	1.46	27.32	17.77	20.0	14.69	3.85

Source: West Pakistan Year Book, p. 172. 1959

pectively. In the opinion of one writer rainfall is "the phenomena of least occurrence at Karachi".(13) The abnormal values stated in the table extend this statement; the rainfall character is a phenomena of least certainty or unpredictable phenomena, not only at Karachi, but throughout the arid and semi-arid West Pakistan.

The mean annual rainfall for Lahore is 19.21", but during 1947, 1949, 1951-52, rainfall was only 11.99", 11.57", 15.58" and 10.92" respectively. Years 1947 and 1949 followed by years of as much rainfall as 29.07" in 1948 and 28.84" in 1950. The years 1953-1957 had been years of copious amount of rainfall much above the mean as, 23.84", 27.86", 22.62", 25.99", and 27.32".

At Rawalpindi the mean annual rainfall amounts to 36.37", but rainfall diminished to 15.47" in 1947. Within the 11 years from 1947-1957, 1947 remained the driest year throughout West Pakistan. At Rawalpindi, 1947 followed by 1948 the year of the highest amount of rainfall 58.84". During the rest of the years the rainfall had been neither much below the mean annual nor much above it. The degree of uniformity in the rainfall incidence is higher than at Karachi, Lahore, Peshawar, Quetta and Jacobabad, which places Rawalpindi out of the zone of aridity.

At Quetta, rainfall reached to 15.69" in 1956 and it followed with little decrease in 1957, 14.69", whereas the mean annual rainfall is recognised as 9.44". The rest of the years do not show well marked deviations from the mean.

The data for Peshawar show, 1956 as the year of highest rainfall 21.06", in the following year rainfall was 20.01", while the mean annual for Peshawar is 13.56". Year 1952 had been an utterly dry year, 6.84" rainfall.

The above 11 years rainfall picture shows that out of these 6 stations, 3 stations, Lahore, Jacobabad, and Karachi show high variability of annual rainfall, but the extremes are shown by Jacobabad, and Karachi, where the rainfall can only be termed utterly fickle. For purposes of analysis, we may regard the range of deviation from recorded means for the low rainfall stations to be so great as to make statistical manipulation quite pointless. The sporadic characteristics of monsoon rainfall as noted, and emphasised in the preceding pages, is very well explained in the sample study of rainfall at Lahore, Karachi, Jacobabad and Rawalpindi which are typical as representing the region of monsoon rainfall. The unreliability of monsoon rainfall is truly attested.

The least variability is expressed by Quetta and Rawalpindi and is only slightly greater at Peshawar. The data further show that the contrary conditions i.e. of high and low rainfall occurred simultaneously at different stations for instance Lahore recorded 27.32" during 1957, while the rainfall registered at Karachi for the same year was 1.46", utterly defficient. 1957 was a year of low rainfall at Rawalpindi; but like Lahore, Peshawar, Quetta and Jacobabad had large amounts 20.01", 14.69" and 3.85" respectively.

All these years of copious rainfall were years of high floods. Thus the dual problem in space confronting West Pakistan,is that of non-regularity of rainfall and non-uniformity in space and time, particularly during the summer monsoon rains.

From the fluctuations of mean annual rainfall from 1947-1957 as plotted in Fig. 15. we can visualise an overall tendency for the whole country, (leaving aside the zone of winter rainfall) to reveal first a downward trend and latter on,a rapid increase, and the turning points of the curves from a downward to an upward trend occurs simultaneously. The trend at Quetta, which belongs to the winter rainfall region, is different from the rest of the stations, i.e. was non-synchronous, with other stations, but occasionally these peaks have shown slight similarity to those of Peshawar.

The fluctuations are smoothened in 1951-52, at Jacobabad; and they are rather high at Lahore for that period. At Rawalpindi variations tend to be mild in 1952-54; at the same period variations at Karachi are rather appalling; at Quetta they are mild and at Peshawar they are not frightening.

It may be emphasised here, that the fact of the rainfall being above or below the mean values does not have any obvious or direct significance from the agricultural point of view. The crops may fail with the mean annual amount of rainfall when its incidence is not normal. The chief importance of rainfall for the plants lies in its timely arrival and suitable distribution, which is the chief drawback of the rainfall of West Pakistan. An average fall of 10" rainfall is adequate for wheat cultivation in some parts of west Australia, but 19" of rainfall for Lahore is inadequate for a wheat crop, because of its erratic and torrential incidence.(14) In the same way the wheat cultivation both at Quetta and Peshawar is possible with 9.44" and 13.56" of rainfall respectively for these and this is only slightly supplemented with extra irrigation, but at Lahore it is very much dependent on artificial irrigation.

The year to year variability of rainfall as explained by specifying 6 sample stations has a drastic affect on agriculture as the peasants' programme of sowing and harvesting corresponds to the timely arrival and departure of rainfall. If the winter rain benefiting the growth of cereals, is below expectation the crop is uneconomic.

The winter rain is followed by the dry spell during which Rabi crop (wheat) is harvested; and the fields are left in fallow during the hot weather, like the Egyptian Charaqui.(15)

The Kharif crops rice, maize, cotton and millet are grown as the monsoon sets in. These crops are watered by rain and ripened by the summer heat, and are harvested as the monsoon waxes. If the monsoon is late this sowing will be delayed. If the monsoon is prolonged the ripening is retarded, in both ways the resultant crop is unprofitable. This is important because the fundamental point which must be remembered concerning agriculture in West Pakistan is that while in the Upper Indus exists one of the largest areas of irrigation agriculture, for the country as a whole rainfed farming is predominant.

Further the only foreseeable freeing of agriculture from the control of rainfall incidence lies in the further extension of irrigation, and the importance of setting the allocation of water in the mountain catchment areas. (See Chapter 4). Hence regularity in the approach and departure of monsoon is of vital importance for the crops as a "premature cessation of the general rains is particularly serious, whilst a delay in their commencement, though not so serious, is at the same time likely to cause considerable economic loss".(16) Thus the problem lies in the small degree of reliability and uncertainty of monsoon rainfall not in the meagre amount of it.

In the pages following, an effort has been made to describe the monthly conditions of both temperature and rainfall during a period of 60 years, in order to indicate the meteorological factors responsible for aridity, and to show that what determines the aridity is the type of rainfall.

Data

Systematic recording of climatic values was initiated with the establishment of Meteorological Organisation by the Government in 1865.(17) Therefrom the compilation of rainfall and temperature data was carried by each province. Since then masses of literature on the sub-continent has been produced more especially on the characteristic of rainfall incidence. New ideas and theories have been produced, but still the network of observation stations requires to be extended. A larger number of observation stations will provide a better opportunity to study the occasions of rainfall incidence and its variability over the greater part of the country. This will be the greatest assistance in the solution of climatic vagaries of floods and droughts.

Reliable data employed in the analysis of temperature and rainfall extends over the 60 years, 1881-1940. The case studies are all meteorological stations, typical of the rainfall regions. The data used here reveal the critical characteristics of rainfall and extremes of temperature. To illustrate the eccentricities of climate the study has been conducted by selecting sample stations of varying amplitudes of rainfall and temperature. The chief aim is to ascertain the changeability of rainfall and extremes of climate that cause the aridity and affect the agricultural pursuits.

Both temperature and rainfall data have been plotted in the graphs and histograms for a better expression of aridity. In each case study each group demonstrates several aspects of rainfall, for instance:-

A Mean monthly rainfall.

B Heaviest fall in 24 hours - the intensity of rainfall.

C Mean number of rainy days - effectiveness of rainfall.

D Fluctuation of rainfall - Total in wettest month and total in driest month.

In the same way temperature graphs depict the extremes of minimum, maximum, and ranges which have a biological significance. Both rainfall and temperature studies have been related with humidity, winds, clouds fog and precipitation; as the combined action of all these factors produce the present climate. By such analysis of data, this section clearly shows that the mean values of both temperature and rainfall are meaningless as they give erroneous impressions of the arid climate which is essentially the product of extreme thermal and moisture conditions.

Temperature:-

In a country like West Pakistan where there is a delicate adjustment between the available water and the water requirements, temperature stands as a very important climatic element for agricultural economy as, "Temperature in relation to the amount of aqueous vapour present in the air and the rainfall determines the character and abundance of the staple crops".(18)

In the previous passages it has been made clear that West Pakistan is never rainless, one part or the other is wet in some part of the year. The greater part of West Pakistan is affected by the south west monsoon as previously noted. Spring rainfall lasts for 2 months and the winter rainfall lasts for 2-3 months. The monsoon has a paramount effect in producing the climatic characteristics of

West Pakistan, with well-defined seasons, and moisture increase and decrease. Thermal conditions can easily be taken into account by the farmer but water-availability is a less amenable factor.

During winter the air-mass and pressure movements develop as noted earlier in this chapter. Generally the winter temperatures decrease from the coast inland and with increasing altitude. The penetration of oceanic influence is evident in the pattern of Isotherms, (Fig. 8). The inland temperature changes slightly when the constancy of the 'high' is shaken by the impact of the depression from the west. It appears in the Fig. 16, that winter is the season of great temperature contrasts, and in consequence high ranges. The greatest swings in day and night temperatures have been recognised in winter. (Appendix 3).

In summer, as already stated one finds a rapid thermal build up. The distance from the sea is again conspicuously important as the temperature along the sea is tempered (Karachi Graph) and the high altitudes again indicate relatively modified temperatures. Jacobabad has become proverbial for its constantly highest recorded temperatures. "In seventeen out of the last twenty years the highest day temperatures ranging from 117°-126°F were recorded at

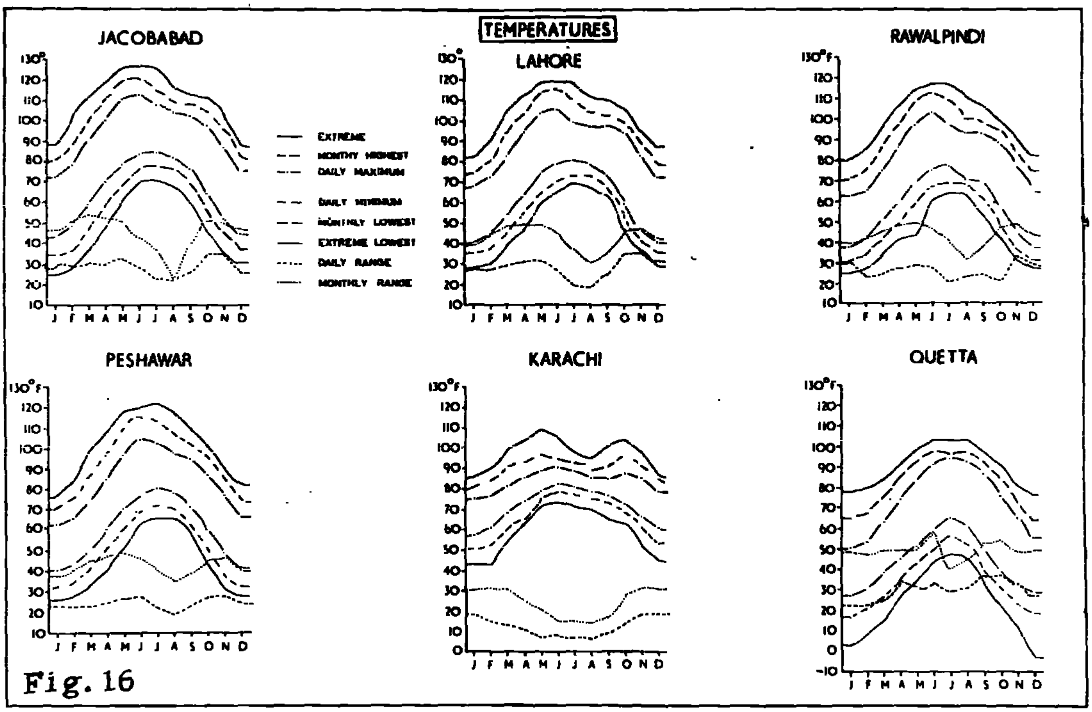

TEMPERATURES
JACOBABAD
LAHORE
RAWALPINDI
PESHAWAR
KARACHI
QUETTA
EXTREME
MONTHY HIGHEST
DAILY MAXIMUM
DAILY MINIMUM
MONTHLY LOWEST
EXTREME LOWEST
DAILY RANGE
MONTHLY RANGE
130°F
J F M A M J J A S O N D

Fig. 16

Jacobabad".(19) It is also recorded that the maximum temperature surpassed 120° at Jacobabad, Hyderabad, Montgomery, Dera-Ismail Khan, Multan, Khushab and Lahore. It is note-worthy that these high maxima are recorded inspite of the large extent of irrigated land surrounding all these towns except Dera Ismail Khan. The temperature lowering effects of irrigated fields and tree crops are not obviously apparent.

Thus the annual march of temperature which corresponds with the northward and southward journey of sun, produces the vigorous land and sea winds in winter and summer respectively.

As a result of high temperatures, with no considerable rain even the rivers dwindle away. All types of vegetation wither. In the pastoral areas results are still more discouraging, for animals are sadly affected by drought. The irrigated areas, at this time, provide a strong contrast with their verdurous landscape adjoining the areas of no irrigation. The extreme temperature is accentuated by drought as no water is present for evaporation or transpiration. During winter and summer temperature shows considerable ranges except near the coast where temperature does not reach extremes. The range tend to increase from the coast to the interior.

The seasonal contrast in the temperature distribution has great bearing on agricultural produce. The period of copious monsoon rainfall is always accompanied by uniformly high temperatures and under such conditions the growth and maturity of the Kharif crops are accelerated.

The transition from summer to winter provides a chance for the peasant to sow the winter or Rabi crops (mainly wheat), before the soil moisture, accumulated during the monsoon, dries up. By March the temperature rises rapidly and the maturation of crops is adversely affected by sudden changes of temperature. Even time distribution of both temperature as well as rainfall are most conducive to good crop yield, and, for instance, the long days of weak sunshine in high latitudes seem to produce better quality of grain than the short hours of more strong sunshine of the lower latitudes. Canadian wheat is of better quality in terms of protein content, than the Pakistani and Egyptian.(20) In the same respect Italian rice is superior to ours.

Both temperature and rainfall are best further examined by discussing 3 sets of different categories of temperature values for representative stations, Quetta, Peshawar, Karachi, Lahore, Jacobabad and Rawalpindi. Appendix 3, Fig. 16.

The temperature for sample stations covers the period of 1881-1940. The 3 sets of temperatures may be explained herewith:*

1. In each case, and here taking the example of Quetta the temperature during July rises by day to an average of 94.0°F (column mean of daily maximum) and falls to an average of 65.0°F (column-mean of daily minimum) during night.

2. In the normal July the highest temperature to be expected by day is 96.0°F (column-mean of highest in the month) and the lowest temperature to be expected by night is 56.0°F (column mean of lowest in the month).

3. A temperature as high as 103°F on 8th July in 1933 column-extreme highest recorded) has however been recorded by day and the one as low as -3°F (column-extreme lowest recorded) has however been recorded by night during 21st December 1929.

Quetta:-

Occupies an elevated position, 5,490 feet about the mean sea level, between latitude 30°10', longitude 67°01'E.

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* 1. All the temperatures are in Fahrenheit, unless stated otherwise.

2. For purposes of analysis the author has taken a climate year extending from March.

The data reveal that the temperature regime is unvarying with July or June the hottest months and January the coldest month throughout the period. The graphs illustrate the different values of temperature and ranges occurred during the 60 years. Eight different curves denote the respective values.

1. Monthly Mean of Daily Maximum and Minimum:-

The maxima rise regularly from March 63.6° and the monthly mean daily highest maximum of 94.0° occurs in July. The downward march of temperature occurs rapidly after the peak of July and it decreases regularly from October, until it reaches 50.2° in January. This lowest maximum corresponds to the lowest monthly mean daily minimum registered 27.6° in January. Highest mean daily maximum of July corresponds to the highest mean daily minimum of the same month 65.0°. Hence the increase and decrease of mean daily minima follow the trend of mean daily maxima, both curves rising and falling parallel with their crest at July.

The curve illustrating the mean diurnal range differs strikingly from the temperature curves, in shape and trend. This irregularity derives from the great difference in the night and day temperatures in every month. The range curve indicates two maxima. The primary occurs in October-

November 36.5° and 36.8° respectively; a well defined secondary maximum forms in April 34.8°. The range tends to rise in June also. It is noticeable that ranges are higher during the transitional period owing to the rapid increase and decrease of temperature with the penetration of cold winds in October-November and hot winds in April. [illegible] of [illegible] and minima for 11 years [illegible] the [illegible] range.

The minimum range occurs in January and February 22.6° and 22.8° respectively, the wet months when rain modifies the day and night temperatures. The ranges start declining from December onward when the cold weather regime is completely established; they show a rise towards an April maximum as winter atmospheric conditions break up. Hence the curve shows 2-3 rises and an equal number of falls in the diurnal range.

The highest relative humidity occurs in January (Figs. 17-18), when the number of overcast days with cloud, the number of foggy days, and the number of rain days are highest, accompanied with the highest frequency of precipitation, with a mean wind speed of 2-3 miles per hour. Quetta occupies an exposed position for the cold winds, which brings its temperatures low, further diminished by winter rains.

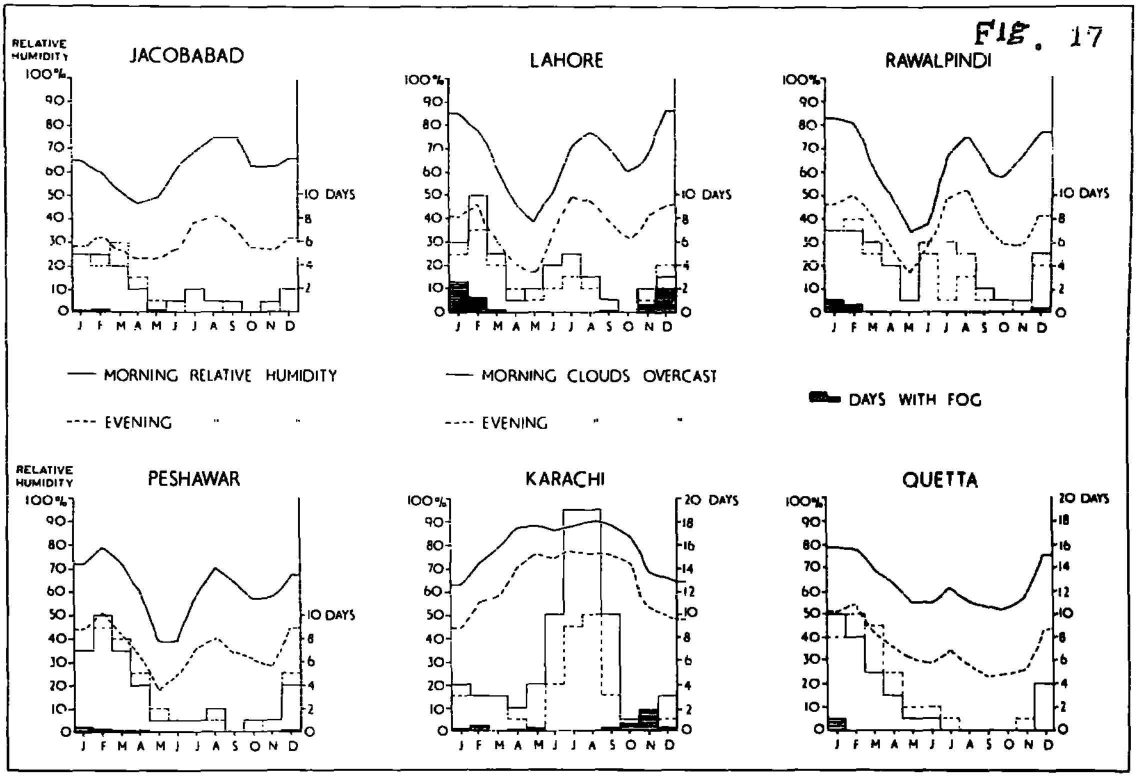


Fig. 17
RELATIVE HUMIDITY
JACOBABAD
LAHORE
RAWALPINDI
PESHAWAR
KARACHI
QUETTA
10 DAYS
20 DAYS
J F M A M J J A S O N D
MORNING RELATIVE HUMIDITY
EVENING " "
MORNING CLOUDS OVERCAST
EVENING " "
DAYS WITH FOG

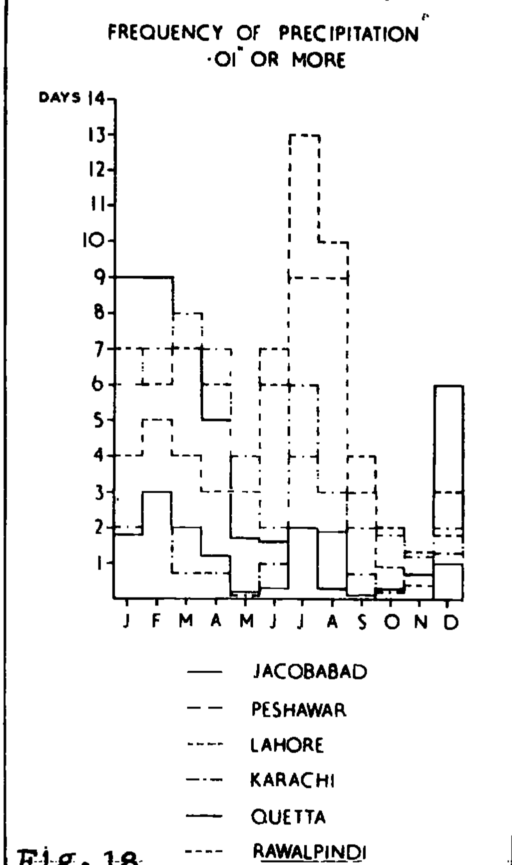
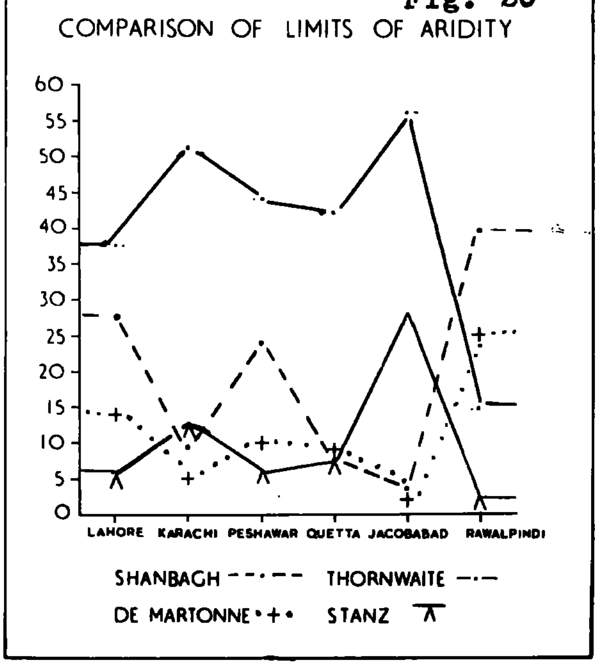

FREQUENCY OF PRECIPITATION
·01" OR MORE
DAYS 14
13
12
11
10
9
8
7
6
5
4
3
2
1
J F M A M J J A S O N D
JACOBABAD
PESHAWAR
LAHORE
KARACHI
QUETTA
RAWALPINDI

Fig. 18

Fig. 20


COMPARISON OF LIMITS OF ARIDITY
60
55
50
45
40
35
30
25
20
15
10
5
0
LAHORE KARACHI PESHAWAR QUETTA JACOBABAD RAWALPINDI
SHANBAGH
THORNWAITE
DE MARTONNE
STANZ

2. Means of Monthly Maximum and Minimum Temperatures:-

Considering the curves of the means of the highest and lowest recorded in each month, the curve of mean monthly highest rises above the curve of mean daily maximum. The curve illustrates the fact, that temperature marches smoothly from February 67.4° and the highest expected was recorded 97.7° in June, falling to 96° in July and again rising to 97.1° in August. This small absolute difference reflects larger day to day variations related to the local instability of the atmosphere, resulting from the succession of different air layers in the monsoonic "waves". Thus, different from the monthly mean daily maxima, the hottest months in term of mean monthly maxima have been June and then August. The temperature tends to decrease by October.

The lowest mean monthly minimum follows a smooth curve with a crest at July, of 56.0°. It is very interesting that the highest lowest of the year is registered in July, not in June or August. The reason seems to be the lesser afternoon cloud cover during July, (Fig. 17), accompanied with high humidity which lead to less active radiation so the night temperature does not fall below 56.0°. Moreover clouds are rapidly dissipated in allowing early morning radiation and temperatures rapidly to rise. There has been more rainfall in July which also helps to equalise the day and night temperatures, so that at night the atmosphere tends to be hot and damp.

The absolute monthly range curve is very illustrative of the contrasting mode of temperatures. The range forms an abrupt prominent peak in June which is followed by a very deep trough in July, which is an obvious influence of the summer rainfall. As compared with the July minimum and the maximum the rise and fall of the range in the first 5 months is insignificant. It exhibits a secondary maximum in October, the month of low humidity and less clouds. The heat is absorbed during the day and radiated quickly during the night under the clear skies. The lowest maximum of July truly corresponds to the lowest minimum of range as clearly depicted in the graph.

3. Absolute Extremes:-

A temperature as high as 103° has been recorded for three consecutive months, on 13th August 1931 and 22nd June followed by 8th July 1933. The years 1921-1936 were hotter than average and 1933 was the hottest year of the period as appeared in both table and graph. The second maxima were not well pronounced, 98° on May 31st 1936 and 97° on 19th September 1936. The lowest extreme maximum in the period was recorded on 6th December 1904, 76°.

A temperature as low as -3° has been recorded by night on 21st December 1929. The graph shows that the highest extreme minimum reached 47° on 1st July 1938. The lowest temperature marches rapidly upward by April and drops steeply by October. The chief minimum is -3° and the second minimum is 3° on 17th January 1910. Notable extreme variations have been ascertained in 1923 when the lowest recorded on 30th September 33° was much lower than the monthly mean daily minimum for the month 49.7°, and on 5th November of the same year when temperature rose to an extreme of 81°, whereas the mean daily maximum for November is only 65.4°.

These temperature anomalies are determined by both local and externally-derived conditions, which every spot of the country is liable to be suddenly affected as noted subsequently.

The curves of 3 sets of maximum temperatures run fairly parallel to each other in smooth curves, but there is no such correspondence between the curves of the maxima and the curves of the minima temperatures, explained by the fact that in all respects there is a great difference between the day and night temperatures. This appears from the curves drawn for ranges. Large ranges are characteristic of dry climates hence one factor of the Quetta climate is thus explained. This combined with other factors accentuates its aridity.

Peshawar:-

Latitude 34°01'N, Long. 71°35'E. height above mean sea level is 1164 feet. (Figs. 16-18 and Appendix 3-5.)

Monthly Means of Daily Maximum and Minimum:-

At this station also March is a month showing a striking rise in temperature, the steep curve rising to 105.0° in June. This forms the single primary maximum, and the single lowest mean maximum is found in January, 63°. The highest mean daily minimum is recorded in July 80.2°, when the maximum is noted 102.5°. This is similar to Quetta where the mean highest maximum was reached in June, but the mean lowest maximum was read in July. At Peshawar July is more damp which tempers the day and night temperatures. Again the mean monthly daily minimum is higher (78.9°) in August than in June (77.2°), because the former follows the month of monsoonic rainfall, and the heavier rainfall has a moderating influence on both day and night temperatures. June remains comparatively dry because the monsoon current never reaches Peshawar before July. In consequence August shows lowest range, 19.3°. Other contributory factors for the low range are high relative humidity and the high number of cloudy days in summer months. Fig. 17 shows three maxima of both morning and afternoon percentage of relative humidity. The chief is revealed in February, 79% in the morning and 51% in the evening, with two subsidiary maxima in January and March. The second well defined maximum is in August, which is followed by trough in September-November, and December delivers a third maxima of 67% and 44% for morning and evening. The humidity has been lowest in May 39% (m. and e.) 18% (e).

The maximum number of days with cloud overcast was in February, and maximum fog prevailed in January. The maximum frequencies of precipitation and number of rain days occur in March. There has been no cloud overcast recorded in September Fig. 17.

Means of Monthly Maximum and Minimum Temperatures:-

June is again the hottest month, showing values of 115.3°. The order of increase and decrease of temperature under this category is similar to the swing of monthly mean daily maximum and minimum. January remains the coldest month; with a temperature as low as 32.1°. The highest minimum was reached in July 72.4° for the same reasons as stated above. The lowest range 35.5° is shown in August and the highest range 49.8° is appeared in May. Thus the range shows a single principal maximum in May, and a single principal minimum in August. Generally the range is low in the first 2 months of the year, when cloudy weather is frequent. These ranges convey an actual picture of both diurnal and periodical contrasts. The difference between the mean highest in January and the mean highest in June is 44.3° and the difference between mean lowest in January and mean lowest in June is 37.0°. These high ranges between the coldest and hottest months express the continentality of the station also.

Absolute Extremes:-

The 5th July 1920 was the hottest day at Peshawar during the period of 60 years with 122°. The second hottest day was 17th June, 120°. The maxima of third order appeared on 31st May 1911, 118°, and the same on 9th August 1915. This shows that the second decade of the present century remained the hottest era. The lowest maximum was recorded on 7th June 1890, 77°.

The coldest day during the period was 22nd January 1934, when the temperature went as low as 26°. The highest minima recorded in two years, 66° on the 1st of July 1881, and 13th August 1893.

The swing of 3 types of temperature resembles a little the Quetta regime. The difference lies in the values of temperature of all categories, accounted for by the altitudinal and latitudinal differences of both cities. Because of its lower elevation all type of temperatures recorded at Peshawar, are higher than that registered at Quetta. Appendix 3. The ranges are higher at Quetta which is indirectly a measure of its greater aridity. The water vapour content at Peshawar is more than that at Quetta, which tends to keep the balance between the day and night temperatures. Moreover vegetation cover is more extensive and dense in the environs of Peshawar which also modifies the atmosphere, while Quetta lies in barren surroundings.

Karachi (Manora):-

Latitude 24°48'N. Longitude 66°59'E; 13 feet above mean sea level. Karachi offers a contrast in the course of temperature curves of all categories. The curves for Quetta and Peshawar show symmetrical paths with a single prominent peak in each case and there is more divergence between the minima and maxima values. (The same is exhibited by the curves for Lahore, Rawalpindi and Jacobabad). There is inconsiderable divergence between the set of curves of minima and maxima at Karachi, and their gradients are gradual not steep like the others.

Mean Daily Maximum and Minimum:-

June remained the hottest month 90.4°, and the lowest maximum occurred in January 75.5°. There is a small range between the hottest month and the coldest month, 14.9°, showing clearly that the difference between the monthly temperature is not as high as shown at other places. The Daily maxima show a regular and marked rise from March at all stations, and there is a difference of about 10° between the daily maxima in February and March; except at Karachi where it is only 4.9° and at Jacobabad 12°. The low range at Karachi is owing to oceanic influence. Again the maxima for January and February are 75.5° and 76.9° with a difference of 1.4° only, while the maxima of 90.4°, 88.6° and 88.5° for June, May and July also only differ by an amount which is altogether ecologically negligible, as compared to the well pronounced differences at these seasons at other stations.

The Daily minima also illustrate the constant temperature, the difference between January minimum and June minimum being 24.9°. The ranges in the daily minima and maxima are also low throughout the year, the lowest recorded in August, 7.3°. The ranges are highest during November to December the dry months.

The explanation of low ranges and relatively low, regular temperature values lies in the fact that Karachi is situated in the tropical maritime belt. Throughout the year temperatures are moderated by the sea breezes, and ranges are mitigated. Under the influence of the sea breezes the relative humidity observed for 80 years, has never dropped to less than 40% in the afternoon and never less than 63% before noon. Morning humidity as high as 90% has been recorded in August, owing to moisture carried in the atmosphere by monsoon air and a high degree of forenoon cloudiness (an ironic contrast to rain paucity). Appendix4. The humidity curves reveal a gradual fall and rise, with no peaks or steep gradients. Fig. 17.

Mean Monthly Maximum and Minimum Temperatures:-

The highest reveals two maxima of 96.3° in the transitional periods of pre-monsoon in May and the post-monsoon in October, and these months are the hottest as far as the mean highest for the month is considered. This is the most interesting aspect of the temperature fluctuations. The graph illustrates the October maximum is more well-defined than the May maximum. Fig. 16. The high values shown by these months is an unusual phenomena. The highest minimum was attained in June 78.9°. January remained the coldest month 50.9°. The day temperatures of May and October are similar but they are not followed by the same changes during night; which is 75.1° minimum for May and 68.1° minimum for October. The factors accounting for this include afternoon clouds overcast and fog, while precipitation frequency and shorter nights further bring the temperature down. The highest range appears in February, 31.5°, owing to clear sky and low humidity which favours insolation followed by rapid radiation at night. The low ranges are shown in the wet months June-August but lowest in August. 14.3°, during which the clouds and humidity remain highest and frequency of precipitation high.

Absolute Extremes:-

The curve of extreme highest is similar to that showing the monthly highest. May remained the hottest month in 60 years, 109° on 9th May 1938. The second hottest day occurred on 8th June 1916, 105°. The data reveal that on the whole, the period remained much hotter at Karachi during the 3rd and 4th decade of the present century (Appendix 3). These decades were interrupted by cold years. For instance 13th April 1932 was the 3rd extremely hot day in the period with 104° while in the same year 12th July showed 98° of temperature, followed by an extreme lowest of 47° in December. During 60 years the coldest day was 17th January 1935, 43°.

The chief characteristics of Karachi climate are as follows. The coldest month in all respects has been January, while the hottest month remained inconstant; between May-October. Both the temperature and ranges are low because of its littoral position. Again Karachi is situated between two entirely different environmental regions. It faces an ocean and its hinterland is formed by a desert, which is dominated by high pressure during winter and low pressure during summer. The hot winds are generated inland affecting the climate particularly in the way the range of hot months is extended. The temperature data for Karachi do not in fact give a true physiological picture of its climate which we may describe as being dry warm temperate.

<u>Lahore</u>:-

Latitude 31°35'N and Longitude 74°20'E and 702 feet high above the mean sea level, occupying a land locked location in the eastern extremity of the Indus lowland, on the windward side. Appendix 3-5 and Figs. 16-18.

Mean Daily Maximum and Minimum:-

The temperatures start increasing by March, 82.6° to a single maximum in June, 105.9°. The rise from March to June is steep while the fall is gradual from June to October. The difference between February maximum and March maximum is 10.5°. The difference between the lowest maximum in January and highest maximum of June is 37.9°. From July the temperatures are reduced mildly owing to the highest amount of monsoon rainfall, high morning humidity, high morning cloud overcast and the highest amount of precipitation frequency of 0.1" in July.

As is evident from the graph the lowest minimum occurs in January when the radiation is at the highest in long nights; 40.1°. The minima rises rapidly again by March, as pointed out by the steepness of the arch showing the mean daily minima. It reaches to the highest point 80.1° in July. In this case also the highest maximum of June does not coincide with the highest minimum, like previous stations, and for similar reasons. The lowest, January temperature 68.0° is associated with winter showers and a high percentage of morning relative humidity-85, which keeps the temperature low. The highest percentage of relative humidity was obtained in morning of December. The humidity is lowest in May and in October before and after the monsoon.

While at Karachi humidity is fairly well distributed over the year and does not show considerable variations, Quetta, Peshawar and Lahore being continental in their location show great variations in humidity, and the curves showing the humidity follow an opposite course to that of temperature curves and are in harmony with rainfall incidence. Another feature of humidity is, that it is low in the months which show high range of temperature.

These aspects are well demonstrated by Figs. 16-18 and the data, Appendices 3-5.

Mean Monthly Maximum and Minimum Temperatures:-

The month of June is again identified as the hottest month, 115.2°. Temperatures are very high from April to September, and temperature rises rapidly from February, tending thereafter to be uniform. Rapid variations again are visible in November. The transitional periods are the times of great fluctuations in temperature. January remains the coldest month (54.7° was registered). The highest minimum does not correspond with the high June maximum. The crest of the curve is formed by the two lowest maxima with a negligible difference occurring during July 73.2° and during August 73.3°.

The monthly ranges are considerable and they develop several well defined maxima, with a well marked single minimum in August, 30.7°. The primary range maximum is in April 49.6° differs only slightly from the 49.0° in May. In winter the maximum range appears in November - 47.3°. On the whole regularly high values of range are more frequent than the regularly low values during the year.

Absolute Extremes:-

The 28th June 1929, with 119°, was the single hottest day in 60 years. The temperature variations are very small from May to July, and they are not large from March to October, with a constant high temperature. The largest group of hot years was concentrated in the end of last century. In general 1892 proved the hottest year, with temperatures of 106°, 112°, and 118° recorded on different days from March to May. The absolute minimum was noted on 19th January 1935, 28°. The highest minimum was noted on 9th July 1934, 69°. The greatest number of cold months appear to occur in the first decade of the present century.

The temperature indices for Lahore show that June had been constantly the hottest month during the period of 60 years observations. The extreme highest was 119°, the highest for the month was 119° and the daily maximum was 105.9°. The January values similarly prove it incontestably the coldest month at Lahore.

Jacobabad:-

Latitude 28°17'N, 68°29'E, 186 feet above the mean sea level.

Mean Daily Maximum and Minimum:-

On the whole temperature indices are very high. There is little difference in the mean daily maxima observed at Jacobabad than the mean of the highest in the month noted at Lahore. (Appendix 3). For example in January highest in the month is 74.2° at Lahore and mean daily maximum for the same month at Jacobabad is 72.7°. In the same way meagre differences are shown in the remaining months, and the same variations are visible in the absolute maxima at both stations. The hottest month throughout the period has been June, with 113.9°. The curves shown are similar to those of Lahore and Rawalpindi. The maxima swing between May-June with the dominancy in June. The lowest daily maximum occurred in January 72.7°.

The lowest daily minimum of 43.8° was recorded in January. The curve of daily minimum is a perfect dome. The rise of temperature in the first two months of the year is smooth; it is rapid till May, and in the rainy months it is equalised. From September the minima fall but comparatively less acutely.

The percentage of relative humidity in the morning is highest, 75%, in August and September. The humidity indices are lowest in the pre-monsoon term. July is the month of highest, mean wind speed miles per hour 4.2. The most calm month is November with a wind 1.2 miles per hour. The number of overcast cloudy mornings is highest in January and February 5 days for each but the evening clouds are highest in March 6 days.

The mean daily ranges for each month are considerable, and they rise gradually at the beginning and recession of monsoons. 32.6° in May and 34.6° in October. The lowest range is during August 22.1°.

Mean Monthly Maximum and Minimum Temperatures:-

The highest temperature was read in June 120.7°, preceded by 120.0° in May. The path of this curve follows the mode of the daily maxima with two projected zones. The rise of temperature is also rapid in the first 3 months, but temperature falls abruptly in November to December with a penetration of cold wind from the north and west.

The lowest was exhibited in December 37.0°. The minimum for both December and February was 37.5°. The highest range was shown at March 54.2°, the lowest ranges as a rule again formed in August, 23.0°.

Absolute Extremes:-

The extreme highest readings was observed on 12th June 1919; 127°. The second maxima is revealed on 27th May 1914, and 6th July 1901 of the equivalent indices 126°. The variability is however shown by 1st November 1909 appearing as the hottest day, 103°, for the year and 7th May as the coldest day, 61°, for the same year. Similarly in 1938, when the 16th September was the hottest day for the year and was rapidly followed by the 30th November as the coldest day with 36°.

The thermal climate of this arid station in January is very well seen if we make the following comparison:

The mean daily maximum:	72.7°
The mean monthly maximum:	81.7°
The extreme maximum:	89°
The mean daily minimum:	43.8°
The mean monthly minimum:	34.6°
The extreme minimum:	25.0°

The range in the maximum temperatures is small, but the range in the minima is high, together exerting a great influence on the plant growth; wilting point is reached on most days [illegible], but under desertic conditions when the dew is formed by rapid cooling at night, plant growth is inhibited mainly by temperature. The range between the mean daily and the extreme temperatures is vast in both maxima and minima which is why mean values become useless for arid climates.

If we consider the range of temperatures for the month of June the effect of evaporation and transpiration becomes clear.

Mean daily maximum:	113.9°
Mean monthly maximum:	120.7°
Extreme maximum:	127°
The mean daily minimum:	84.9°
Mean Monthly minimum:	76.8°

Extreme minimum 70°

The difference between the mean daily maximum and extreme is 13.1° and the daily minimum and extreme is 14.9° and the extreme maximum and extreme minimum show a wide range of 57°. These differences in the extreme temperatures affect the plants, stock and human beings and here again mean values prove inadequate.

Such variations are part of the general geographical complex. The extreme temperature, and general high temperatures are owing to its location in a desert region in the low latitude lying in the path of trade winds. The hottest places are found near the tropic of Cancer where "the vertical rays strike down somewhere for 85 days, May 10-August 3," between 17°35'-23°30'N. Thus "the sunbaking of land and ocean towards the tropics".(21) The intensity of sun baking is further accentuated "Because of the transparency of atmosphere, the insolation of the high sun-period near the tropics gains in relative intensity, since sub-tropical land masses are among the least cloudy areas of the world".(22) Consequently the hottest places of the earth occur between latitudes 16°-36°N. The highest temperatures recorded on the earth is 136.4° at Al-Azizya (32°N) in the Libyan desert. West Pakistan experiences high temperatures for its situation between 24°N to nearly 37°N.

The highest ranges are owing to a rapid cooling at night which is equally a characteristic phenomenon of arid climates. At present Jacobabad is very much irrigated but it has a typical climate of desert areas.

Rawalpindi:-

Latitude 33°36'N and longitude 73°07'E, and elevation above the mean sea level is 1674 feet.

Mean Daily Maximum and Minimum:-

Temperature, as at Lahore and Jacobabad, starts conspicuously rising by March, and after a quick rise it reaches a peak in June 103.5°. It is fairly uniform in the wet months of July-September. A decrease of about 10° is shown by the end months. The highest minimum was recorded in January 62.3°. The difference between the June and January temperature is 41.2°. These seasonal ranges are responsible for the main climatic periodicity. There is less range in the months of January and December maxima; 4.5°.

The lowest daily minimum was recorded in December 37.8 which succeeded by 37.9 in January. At the rest of the 5 sample stations January has been always the coldest month. The ranges in the daily minima and maxima are higher than Peshawar but lower than the rest of the stations. Unlike the other (except Karachi) sample stations the lowest range was reached in July, 20.7° the highest range was noted in November, 33.3°, corresponding with the range at Quetta for the sample month.

Mean Monthly Maximum and Minimum Temperatures:-

The temperature adopts the same path as shown in the previous category. It marches swiftly upward after March to a crest in June (113.0°.) Temperature is uniformly high from May to October, followed by rapid reduction in November. The difference between the highest of June and January is 42.4°.

The lowest is noted in January 30.8° and the highest minimum occurs in July 68.7°, again a vast difference - 37.9°. The ranges show a lowest minimum of 31.9° in August. The transitional and dry months of May and November exhibit the highest ranges 49.8° and 48.9° respectively. The course of monthly ranges shows rapid variations which are more acute than the mean daily ranges.

It must be noted here that the low ranges related to July and August are accompanied by high monsoon rain; and high humidity during the morning - 75% and 67% in August and July. The highest morning humidity occurs during morning in January 83%, accompanied by low wind speed which discourages evaporation, high precipitation frequencies and a high number of cloudy days. The highest precipitation frequencies occur on July-13th.

Absolute Extremes:-

The highest absolute maxima were recorded on two days, 117° on 1st of July 1912 and 4th June 1929. The curve showing these values runs in an ill defined dome. The 1st February 1929 was the coldest day 27°, followed by the hottest day on 4th June in the same year. The absolute difference between these two absolutes for February and June shows a remarkably defined cold and hot season. This aspect is noted in 1940 also, when 27th May was the hottest for the year, 114° and the coldest day for the year occurred in September 53°, a great deviation from the normal cold month of January, noted in 1905, 1918, and 1938. These not uncommon variations are entirely related to the micro-climate of Rawalpindi as affected by proximity to Murree hills and thermal winds.

The absolute lowest for the period occurred on 14th January 1937, 25°, and the highest minimum in July on 30th, 1901, 64°. The table indicates that the hottest and coldest years are distributed over the whole period and are not concentrated in any one decade contrary to Lahore and other stations; Rawalpindi in this respect as in rainfall is a non-arid region. The month of greatest absolute range is May, 71°, and the lowest range is assigned with August 48°.

The extreme ranges at Rawalpindi are very high.

On the whole the shape of curves showing the maxima are very similar for Jacobabad, Lahore and Rawalpindi. They form a high plateau of primary maxima and which is followed by a low plateau in the post monsoon period. There is a little difference between the temperature values at Lahore and Rawalpindi.

The above account may be summarised thus. The seasonal distribution of temperature is governed by the multiple action of altitude, latitude, continentality, rain, winds, clouds, humidity and precipitation, micro-climate, surrounding environs and plant cover. It is clear that latitude dictates the amount of heat corresponding to the Solar Journey. That the influence of altitude is many times more important than that of latitude, is fully supported by the values shown by Quetta and Peshawar.(23)

The anomalies are not analysable by any known law, nor is the estimation of their evaluation hypothetically possible. Temperature is modified by sea influence in the case of Karachi, by altitude in Quetta, by cold winds at Jacobabad and Lahore, by vegetation and cold winds at Peshawar and Rawalpindi. The temperature tends to show in general Jacobabad, Lahore and Rawalpindi (the zone of monsoon rains) have two maxima before and after the onset and offset of the monsoon, and in these cases the temperature is modified by summer rainfall. This is generally true for the whole Indus plain. The highlands away from the monsoon tracks, as indicated by Quetta and the Sub Montane Trans Indus plain as demonstrated by Peshawar, show only one maximum.

In West Pakistan the general hottest month is June while January is the coldest. The ranges are accorded and controlled by the amount of rainfall, cloud, and wind-speed. The lowest minima occur in the highland, because of low insolation and the effect of cold winds. August remained the month of lowest range in the region of monsoon and spring rains. January is the month of lowest range in the zone of winter rainfall. Conversely August exhibits the highest percentage of humidity in the regions of summer and spring rainfall whereas the highest humidity percentage is confined to January in the zone of winter rain. The months of high humidity July-August in the Indus plain and Trans-Indus plains are very uncomfortable owing to wet and suffocating days of low wind speed.

The above survey of the temperatures demonstrates that the extreme maximum temperatures are high and uniform over West Pakistan. The highest extreme is nowhere less than

100°, even at coastal Karachi reaching 109°. Under such high temperatures evapo-transpiration is at a high rate leading to an acute water deficiency. The areas where the lowest temperatures have been observed are located in high altitudes in the heart of land masses as exemplified by Quetta. The extreme minima are less uniform over these stations. The extreme ranges are exhibited by Quetta: 75° in January. The stations which are in the lowland and on the windward slopes exhibit two maxima, the highest in spring and one in autumn. The values are directly affected by pre-and post-monsoonal conditions. Both monthly and diurnal ranges are higher in June at Quetta. These amplitude of the ranges are of great significance for the inhibition of biological and ecological processes.

The 6 sample studies are homogeneous in exhibiting high values of temperature which points to the degree of heat, but do not give a true picture of aridity. The temperatures at Rawalpindi are quite similar to those of Lahore, but Lahore is generally placed by climatologists in the semi-arid zone; while Rawalpindi occupies a transitional position between the humid and semi-arid zones. The temperature in the case of Rawalpindi like Karachi has been proved a bad index of its climate. On the whole the temperature values give a partial and less precise impression or definition of the climatic environs.

The final and the most significant remark about the study of temperature amplitudes which is delineated by Figs. 16-18 is that both maxima and minima show the greatest possible fluctuations and they are not likely to surpass these limits.

Rainfall

As this is the factor of paramount importance for the study of arid climates, many scholars have approached its different values from many different viewpoints. A mass of literature has been produced since 1886. Blanford directed his attention to the rainfall features of the sub-continent and produced a voluminous and most informative account in 1886.(24) The subsequent literature is primarily based upon his treatise as it is quoted and referred to frequently. The rainfall is remarkably periodical in its incidence and it is concentrated in few months of the year. Its distribution is uneven both in time and space. Bearing this in mind the areas with seasons of precarious and copious rainfall have been distinguished. With such circumstances the recurrence of periodical floods and droughts are inevitable. Hence, the economic value of the rainfall is lessened when it is of such variable nature. Blanford also estimated that "quantity of rainfall as well as cholera epidemics and other variable conditions of the social well-being are subjected to triennial rotations".(24) It means the years of copious and meagre rainfall occur and recur every three years.

In the following few pages we can see to what extent this statement is applicable in West Pakistan. As appears in Table 2 of 11 years rainfall and in Fig. 15 which shows the plotting of the data, there is no fixed rotation. We cannot fix the limit of years after which low or heavy rainfall recurs.

At Karachi as the data show the year of pronounced high rainfall occurs and recurs at the intervals of 2, 3 and 4 years. Blanford's belief is barely supported in this respect. The years of low rainfall have tended to occur in consecutive groups of 2-3 years.

Some examples will serve to indicate the type of sequences observable. Thus at Karachi two years of low rainfall 1947 and 1948 were followed by one year of heavy rainfall in 1949. This in turn was followed by low rainfall in 1950, 1951 and 1952. 1953 showed an increase over the previous three years. At Jacobabad 1948 and 1949 had high precipitation while from 1950 to 1952 low rainfall persisted.

1953 here too was a period of almost average rains. Not until 1956 did abnormally heavy rainfall return. In these cases, the irregular short term alternations are observable. At Lahore on the other hand such alternation is absent. Heavy rainfall may persist for a long period as from 1953 to 1957 inclusive. Mean rainfall is practically never recorded in any single years.

The interpretation of data at Peshawar leads to the donclusion that the normal incidence of rainfall is rare, it is either very much below normal or very much above normal, but the years of very much below normal occur and recur very regularly at the short interval of two years. For instance such rainfall has been noted for 1949, 1952, and 1955. There is no regularity in the occurrence of abnormally high rainfall, it may occur on two consecutive years as in 1956-1957. The examination of data shows that the general tendency is for a more frequent deficiency of rainfall than the mean. Irrigation water is very much wasted in the areas where no cycle of rainfall can be envisaged, and a balance in the use of water cannot be most easily maintained if some rhythm can be postulated. At Peshawar, Rawalpindi and Quetta a water balance can to some extent be maintained as the rainfall occurrence tends to be cyclical. There is, however, no real regularity in the occurrence of dry and wet years. They may occur in a group of consecutive years over a vast territory or small area. It is clear that the "triennial rotation", the belief held by Blanford is very much over generalised a statement for West Pakistan.

An equally informative account is compiled in the Imperial Gazetteer. Droughts and floods are very well treated in relationship to seasonality of rainfall.(25)

Clark and Williamson have computed the annual variability of rainfall for the sub-continent. They have defined variability "as an average percentage departure from normal".(26) The same authors have propounded the zonification of Pak-Hind sub-continent into rainfall regions demarcated on the basis of normal rainfall, its variability and effectiveness. They used an index based on the fall of .01" of rainfall in every month as implying an 'effective' rainfall.(27) Clark has evaluated the changeable nature of rainfall and its departure from normal over the Indo-Gargetic plains, his arguments based on the monthly and seasonal rainfall. He has also recognised regions based on the periodical variation in rainfall.(28)

The annual as well as the seasonal intensity of rainfall is computed by Holdaway. "The average intensity of precipitation defined as mean precipitation per rainy day. A 'rainy' day is one with 0.1 inch or more rain" and the recognised "mean intensity is 0.83 inches".(29)

Roy and collaborators have made an appreciation of characteristics of both winter and summer rainfall of Quetta.(30) After making an observation of hourly distribution of data for 1926-31, they reached one specific conclusion that winter rainfall is of even distribution during each 24 hours, so that the likelihood of the comparative atmospheric changes proceeding regularly enough for the development of snow is increased. As opposed to this the summer rainfall is concentrated in one part of the day often in the afternoon and early evening. There is in this sense less stability.

C. Ramaswamy and associates conducted the study of rainfall periodicity at Peshawar, and the influence produced by these rains. They found that spring rainfall is copious and most favourable for the crops, the driest months being October and November. They found that for these months out of 17 years, 11 years remained without rain: "not even one cent of rain was recorded in 24 hours in the first half of November".(31) Other studies include that of Naqvi who concluded that there is a 50 year cycle of rainfall at Karachi,(32) and L.K. Sinha who classified the nature of rainfall whether it is 'local' or 'widespread' or 'few falls' in its incidence during each period.(33)

These notes illustrate the changing pattern of analysis and the way in which different elements in the incidence of rainfall have been considered significant. For West Pakistan as a whole, the candidate has had to rely on basic data and examine it in sample detailed studies. On this basis the following scheme has been devised by the writer.

1. Mean Monthly Rainfall:-

This is self explanatory in that mean annual figures give too crude a time lapse picture of rainfall, while at the other extreme mean daily figures for our purposes are too distorted by secular variations.

2. Mean Number of Rainy Days:-

The criterion for distinguishing rainy days is a measurable amount of rainfall i.e., more than 0.01" falling in 24 hours.

3. Total in Wettest and Driest Months:-

This indicates the extreme fluctuations in the amount of rainfall from month to month.

4. Heaviest Rainfall in 24 Hours:-

This is the maximum rainfall recorded for a period of 24 hours. In general the rainfall comes in sudden downpours which is the common feature of tropical and sub-tropical areas. This is also known as the intensity of rainfall. It determines the degree of run off and evaporation and very largely the effectiveness of precipitation.

These values have been adopted as "The real key to conditions in the rain is the number of rainy and windy days. Total rainfall and mean monthly temperatures are altogether misleading".(34) Moreover, "The yield of crops depends not only on the total annual rainfall but also on the distribution of the rain by season and even by days".(35) It has great implications in Pakistan where the cultivation schedule corresponds to the timely arrival of rainfall in each season.

Quetta:-

One distinguishing feature of Quetta is its position in the intermont basin of Pishin, an ephemeral river. The success of agriculture depends entirely on the receipt of sufficient amount of rainfall or the availability of underground water.(36) The precarious rainfall affects the supply of ground water and it becomes inconstant in supply. As earlier noted Quetta lies in the lee of the Sulaiman Range during the period of the South West monsoon and only during winter when westerly depressions cross the passes to the North West, is there any inflow of moist air.

As representing a zone of winter maximum rainfall Quetta has been chosen as an example for the statistical analysis of data. Moreover, in the zone of winter rainfall Quetta is the only place possessing data for 1881-1940.

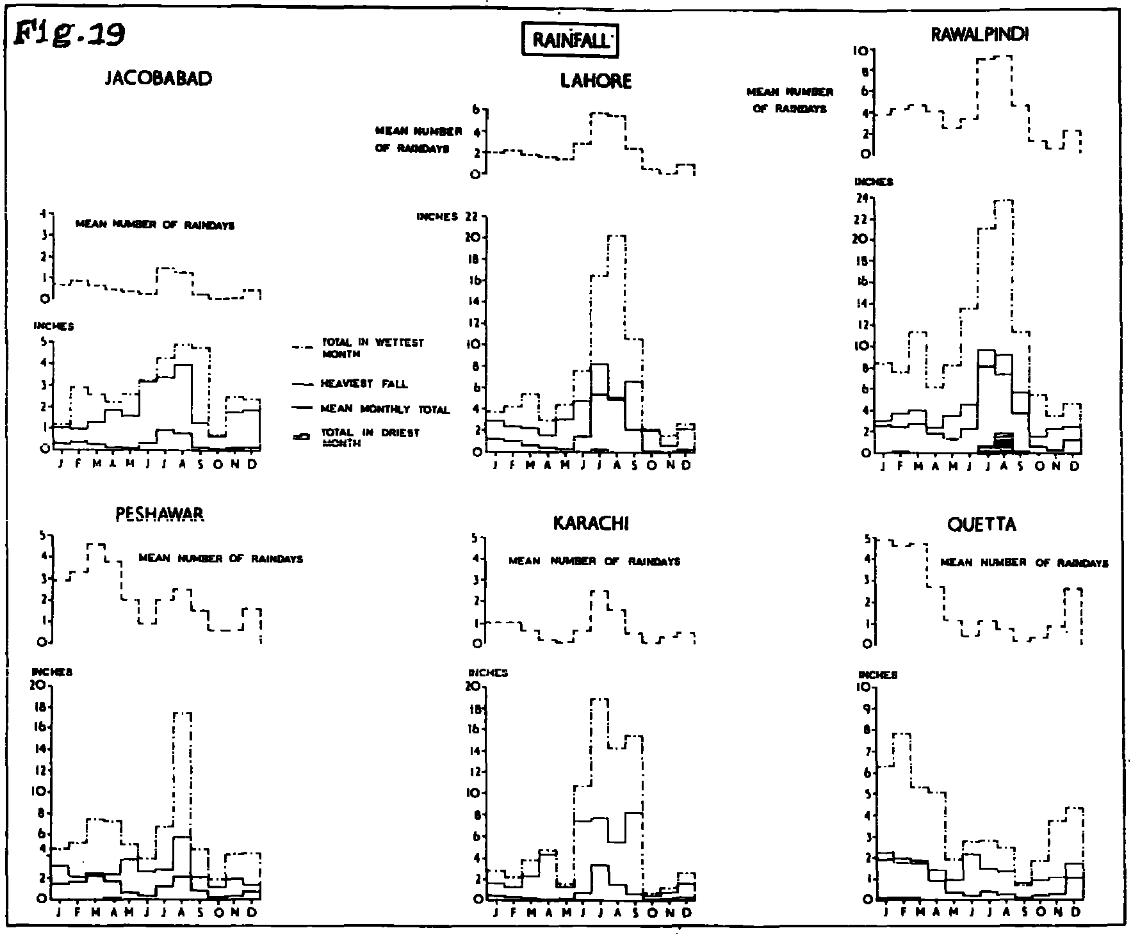
The general impression gained from the accompanying Fig. 19, is that a very distinct maximum of rainfall falls in winter in the months of December-March and a less distinct maximum during the monsoon months. This appears in records of mean monthly values, number of rain days, intensity of rainfall and degree of variability. The same impression is conveyed by the column of precipitation frequencies. Fig. 18.

These primary and secondary maxima correspond to the months of high humidity both in the morning and afternoon. This is associated with morning and afternoon cloud overcast, and the prevalence of fog, all of which reach a maximum in January. Finally, the maximum rainfall corresponds with moderate wind velocity. Winds are high during the transitional period of spring when the range of temperature is high.

Mean Monthly Total:-

These values show February to be the month of highest rainfall 1.98", while the lowest rainfall occurs in September, 0.04". September to October forms a pre-winter dry

Fig.19


RAINFALL
JACOBABAD
LAHORE
RAWALPINDI
PESHAWAR
KARACHI
QUETTA
MEAN NUMBER OF RAINDAYS
INCHES
TOTAL IN WETTEST MONTH
HEAVIEST FALL
MEAN MONTHLY TOTAL
TOTAL IN DRIEST MONTH
J F M A M J J A S O N D

period with total rainfall of 0.16". It is drier than the post winter from May to June; 0.56". The latter period is one of the slow and irregular disappearance of the instabilities of the westerly depressions while the post monsoon period has a small number of weak monsoon depressions which reach as far as Quetta.

The highest mean number of rainy days occur in January 4.9" but highest mean monthly rainfall in February 1.98". It shows the heavier the rainfall the higher its intensity. The mean number of rainy days in a year is 24.0 during which 9.44" of rainfall was received. Out of these 24 days 19.5 days occurred during December-April with 7.65" of rain, about .39" of rain per day. During July-August the total monsoon rainfall was 0.79" in 1.8 days, about .42" per day. During winter the amount of rain in each fall tends to be smaller than the rainfall amount per occasion in monsoon period. It shows the imbalance in the incidence of rainfall and relates that monsoon rain comes in heavy downpours, but is less in total amount than winter rainfall which comes in light showers but persists over longer period.

Heaviest Fall in 24 Hours:-

The intensity of rainfall is more strikingly illustrated, if we examine the columns showing the heaviest fall in 24 hours. 25th January 1888 had the highest rainfall of 2.20". This is followed by 28th June 1934 with 2.17". This shows the uncertainty of rainfall in that as a general rule June is [illegible] the driest months. Thus during one period of 24 hours in June 1934 as much rain fell as would be expected an average during the whole month. Such incidence of rainfall confirms the truth of the statement that "the yearly average may fall in a single storm".(37) The foreign influence of western depressions is almost absent and June is too early for monsoon rains at Quetta. These heavy downpours during June are the result of local convectional disturbances. Sinha has calculated the number of days of such local showers for the old province of Baluchistan as 2.5 and Holdaway has computed the mean annual precipitation per rainy day for the same province as 0.48", and 0.60" for the monsoon period, July-August.

Total in Wettest and Driest Months:-

Seasonal fluctuations of rainfall are shown by the length and steepness of the histograms. Thus the most drastic aspect of rainfall the "variability" needs emphasis. February 1893 proved the extreme wettest month, when 7.77" was recorded. The difference between this monthly total and the mean annual for Quetta is only 1.67". Again 7.77" is more than the normal amount received in December-April, 7.65". On the other hand, in February 1908 rainfall fell to the meagre amount of 0.03". This type of range is a common characteristic of each month of the year. The nature of rainfall is so pulsatory that each month of the year could equally be expected to obtain a copious amount of rainfall as well as a scanty amount. The wettest months are likely to be followed or preceded by a dry month. For instance a fall of 5.08" occurred in April 1885, followed in May by 1.96" in the same year. The wettest year 1885 was preceded by the driest year of 1884 with 0.68" in September. September seemed to remain the driest month of the period. For these characteristics it is truly said "that the variability of rainfall is increased where its average amount is diminished, and ... if the rainfall extends over a great part of the year it will be much less likely to have a wide range than when it falls in a short season".(38) As appears in Fig. 19 precipitation higher than mean is more likely to extend over a period of some duration, while the low rainfall is less extended.

From the above rainfall features a tangible conclusion may be drawn. On the whole rainfall is inadequate for successful agriculture, and its distribution is confined to certain periods. There is a vast variation in maximum and minimum amount recorded and its quantity is never reliable. It is quite possible that a years rain may fall in a month or a dry month like June can obtain rainfall in 24 hours which is 10 times more than its mean. The rainfall is subject to great oscillation owing to local and external conditions. Such rainfall is of little effectiveness as it is lost by rapid run off and may be positively damaging by its erosive power and in floods. The effectiveness of rainfall depends on the vegetal cover of the area, the type of soil and the degree of evaporation. If the area is rich in vegetation a large amount of rainfall water will be consumed by this covering and the evapotranspiration process will slow down. If the area is coverless the water will end in run off and high degree of evaporation especially when the winds are steady and dry. If the soil is pervious water will be accommodated by it, while if it is impervious silt the water will not sufficiently rapidly penetrate through it.

The observations made from the 11 years statistics do not enable one to suggest any probable cycle for Quetta. We can say that there is no evidence of increasing and decreasing rainfall. The rainfall seems to be constant but with remarkable variations.

The mean annual rainfall as calculated by Auden for Quetta was 9.04" (1881-1909 and 1911-1942, no records exist for 1910), and the rainfall interpolation for 1881-1940 is 9.44", indicating an increase of .40".(39) Disparity crops up in the amount of annual rainfall calculated for the same number of years.

Peshawar:-

Contrary to Quetta, Peshawar and its environs are watered by the considerable flow of perennial rivers such as Kabul, Swat, Panjkora and Chitral. Thus its agriculture benefits from river water, rainfall as well as underground water as there is a considerable amount of spring flow in the limestone areas, whereas Quetta depends on rainfall 'Karezes', surface flow being almost absent.

As inferred in the first chapter the Vale of Peshawar is encircled by a "horse shoe shaped ring of hills" with openings to the east near Attock and Khyber on the west. The depressions penetrate the plain through the Khyber pass and Peshawar receives its highest amount of rainfall in March. The essential feature of the Peshawar climate is that it is influenced by the eastward track of the western depression. These depressions which start their activity from December are already rapidly degenerating before their entry to Peshawar region. In the beginning i.e. December, the area affected by the depressions stretches from Kalat-Quetta to Darosh but from March their effect is contracted to the north west highlands and the Vale of Peshawar only.

Mean Monthly Total and Rainy Days:-

The total annual rainfall is 13.56" occurring in 26.3 days with March 2.44" as the wettest month and both June and November as equally dry months.0.31". The rainfall improves after these months. As compared to rainfall at Quetta, the rainfall amount as well as occasions of rain are better distributed. The examination of periodicity of rainfall reveals that spring rainfall is abundant in amount as well as in occasion, whereas the monsoon rainfall is less in quantity as well as in incidence. During the former period the rain amounts to 7.17" (January-April) in 14.16 days, while in the latter period rain amounts to 3.29" in 4.5 days (July-August). If the rainfall were evenly distributed in each case the daily proportion of rainfall would come to .49" in winter and .73" in summer. To see even greater discrepancies between even distribution of rainfall in one period and uneven distribution in another, we can compare the rain received during March which is the peak month 2.44" in 4.6 days to 2.03" in August in 2.5 days. This shows that though rainfall brought in the monsoon is less in amount but it is heavy in its manner and of short duration. The rainfall in March is less heavy and of long duration. These variable natures of seasonal showers bear variable values. The March showers improve the wheat quality and August downpours are lost in run off. Along with this the frequency of precipitation of over 0.01" is highest in March, and highest humidity, clouds and fog also occur then. (Figs. 17-18).

Heaviest Fall in 24 Hours:-

The intensity of rainfall is illustrated in the amount of rainfall transmitted within 24 hours by the monsoon on 4th August 1892, 5.94". The fickle nature of monsoon is particularly convincing here because Peshawar forms the zone of spring maxima. 1892 has been a year of peculiarities because August was preceded by July 29th in the same year with 2.75".

Total in Wettest and Driest Month:-

The variable nature of rainfall is adequately illustrated by the quantity of rainfall in the wettest and driest months. The wettest month, August 1892, reached a peak of 17.75" and it is noted above the 4th August 1892 was the wettest day of the period. In the same year in reverse to this in April rainfall fell to 0.03". The variability of rainfall is further illustrated as follows:

April 1885 had been the wettest month of that year with 7.35" with 1st April as the wettest day of the same year 2.42". The deviation from the normal is extremely distinguishable either in the months of monsoon or in the driest months which are transitional in the seasonal regimes. The range of fluctuation is similar to Quetta but the amount of rainfall is more.

Karachi:-

Situated on the fringes of a tropical sea and a desert, its climate is both affected by the sea as sea breeze modifies its temperature and by its desertic hinterland with adverse conditions for rainfall. The surface flow of Indus and Malir rivers are the main source of water and rainfall is both insufficient and uncertain.

Fig. 19.

Mean Monthly Total and Rainy Days:-

The data in hand gives out 7.70" as annual mean rainfall, which disagrees to the annual rainfall of 7.75" according to the investigations of Naqvi, which he acquired from the interpolation of 100 years data for rainfall.(40) July is the month of relative abundance with 3.20" and October being the month of the least occurrence, 0.02". The monsoon rain (June-September) is 6.00" which again does not correspond to the figures quoted by Naqvi for June-

September 6.16". These figures are stated for comparison's sake because the annual rainfall as computed by Naqvi infers an increasing rainfall, but the data which candidate has quoted infers an opposite trend.

Karachi offers a far more erratic incidence of rainfall (as a strong contrast to its temperature conditions) than Quetta and Peshawar. The sporadicity of rainfall in the latter areas is less evident because of their fairly scattered rainfall over the year. The receipt of annual rainfall of 7.70" at Karachi is in 9.0 days, and its per day occurrence comes to .85". Out of the 7.70", 6" forms the monsoon portion released in 5.2 days. Appendix 5 and Figure 19 show the high variability of the amount attained in each month as well as in each season. This variability of rainfall does not occur in the rainy season at Peshawar and Quetta, representative of spring and winter rainfall zones.

Heaviest Fall in 24 Hours:-

The variability of rainfall is even more striking if we observe the statistics for intensity. An exceedingly high rainfall delivered on 6th September 1926, 8.11", is extremely unusual in type because normally the monsoon leave the sub-continent especially West Pakistan by 14-21st of September. 1926 seems to be the year when monsoons took a long time to retreat from the coastal area, and there is no evidence of heavy rainfall during 1926 at the other 5 stations, all inland. In 1902 a great contrast occurred, on 13th May, normally the second driest month when 1.21" rainfall fell, this followed by 7.17" in June (normal rainfall for June always remains below 1"). The fluctuations in rainfall from May 1902 to June 1902 is a measure of unpredictability of arid zone rainfall.

Total in Wettest and Driest Months:-

During July 1894 the rainfall was as high as 18.63" and it was the primary wettest month of the period. September 1926 was the second wettest month of the year with 15.35", this caused by the slow progress of the monsoon departure. The south west monsoon winds linger on until the area is completely taken by the northerly cold winds. At this time of the year the cold off shore winds proceed steadily to the south and the south west monsoons leave the sub-continent with the same steadiness. Both these currents are feeble, but the cold northern current grows slowly stronger as it expands over a larger cooling area and the out-going south west monsoons grow weak slowly. Ultimately dry cold incoming winds overcome the departing monsoon winds and anticyclonic weather prevails once again. Abnormal rain may be attributed to fluctuations in the normally steady process.

Lahore:-

The noticeable characteristics of the city are: it lies in the heart of irrigated land in the Bari Doab, it occupies an inland location in the Indus plain on the windward side, and it lies in the monsoon region B. Fig. 19.

Mean Monthly Total and Mean Number of Rainy Days:-

July is the wettest month with 5.45", while the total annual rainfall at Lahore is 19.21", occurring in a mean number of 27.6 days. On the other hand, out of 19.21" annual total amount 14.44" occurred in June-September both inclusive, when the monsoon activity is highest. The bulk of the rains is obtained in the months of monsoon and they come in heavy showers, as compared with gentle incidence of rainfall in January, 1.04" in 2.0 days, and in December 0.47" in 1.0 days. The driest month is November, 0.10".

Total in Wettest Month:-

The erratic incidence of rainfall may further be noted by the analysis of the data for the wettest months in the duration of 60 years. The histograms conspicuously indicate the periodicity and vast fluctuations in the mode of rainfall. The mean annual rainfall for Lahore is 19.21", but it rained 20.39" in the month of August in 1908. The mean rainfall for August is 5.15", the wettest month during 60 years. The vagaries of rainfall are confirmed by the fact that May proved the wettest month in the year 1885, with a recorded rainfall of 4.38", while May is normally the second driest month of the year, with only 0.59" in 1.3 days. According to the mean monthly rainfall, November is the driest month in the year; 0.10" rainfall and 0.3 rainy days, but it was the rainiest month, 1.52" in 1928. The statistics show that variability is remarkable from not only season to season but also from month to month, and the mean driest month can be expected to be for some specific year the wettest month. The causes for the wettest month of May in 1885 are related to the persistance of the Western disturbance, this is confirmed by the simultaneous wettest month of May at Rawalpindi, both April and May at Quetta, and April at Peshawar. The persistent activity of western disturbances of 1885 did not affect Jacobabad and Karachi. The total for the driest month was 0.32" in July 1918.

Heaviest Fall in 24 Hours:-

On 28th July, 1924, 8.27" fell in 24 hours, which is an indication of the strength of monsoon bursts. This amount exceeds the mean monthly total for July of 5.9". The table shows that in each month of the year the fall in 24 hours has been very heavy as compared to the mean monthly total. These heavy falls concentrate during the summer months. In this case May again stands out for its exceptional rain. As a rule May obtains 0.59" mean rain, but on 27th May 1883 3.00" came in heavy downpours in 24 hours. The intensity is less concentrated in the spring and winter months.

Jacobabad:-

This lies in the heart of an area which is enclosed by a dry upland rim on N.W. and desert on the east with the aridity index below 5. (Fig. 21A).

Mean Monthly Total:-

There is not a single month with a receipt of rainfall as much as 1", even the wettest, July receiving only 0.95". The total annual rainfall is 3.60" falling in 7.3 mean number of days. The data show that the trivial amount of 3.60" is also concentrated in the summer months. The total summer rainfall from June-September is 2.26" in 3.4 mean number of days, which gives .6" per day. When the annual amount is examined the rain per day comes to .4", the heaviest showers coming with the south west monsoon rains. The relatively even distribution of winter rainfall is clear from the data, January 0.23" in 0.7 days, and February 0.33" in 0.9 days.

The Total in Wettest and Driest Months:-

Fig. 19 is a true reflection of seasonality of rainfall as well as its extreme aspects of positive and negative. In 1917, August was the wettest month with as much as

4.97", succeeded by 4.79" in Sept. in the same year. In 1914 the wettest month was October .68", and this amount came in one heavy fall on 29th October 1914; generally October is reckoned to be the driest month. Still another striking fluctuation is seen in June 1930. It was the wettest month 3.25", but the whole rain came in one day's showers on 30th June, a little less than the annual mean coming in this 24 hours. The most interesting example of the rainfall variability for this station may be observed by considering the values for 2nd August 1884, when 4.00" was registered in the heaviest fall of 24 hours, exceeding by .40" the mean annual amount, while during 1884 there was no rain during any other month. The typical characteristics, precarious and erratic rainfall as recognised for the arid region are well supported by the rainfall incidence at Jacobabad. It is so uncertain that any amount from zero upward may fall at any time. Such conditions utterly inhibit rainfed cultivation and have a great influence on irrigation crops, because unpredictable rain cannot usefully supplement irrigation water. The concentrated amount, above the mean values, is largely lost to run off, while it would have been proved beneficial had it come evenly distributed in summer months. It shows how the rainfall is most delicate and complicated climatic element, aridity becoming much more than a simple total deficiency of water.

Rawalpindi:-

Rawalpindi occupies a submontane position in the Murree foot hills, this exerting a significant influence on the climate particularly on the rainfall.

The graph distinctly shows the periodicity of rainfall and its high concentration in the summer months. The mean monthly values show that August is the wettest month, 9.17" occur in the mean number of 9.1 days. The driest month is November with 0.5 mean number of days. The total mean annual amounts to 36.37" in 49.5 mean number of days. The rainfall intensity is well demonstrated by the amount of rainfall for the summer months, from June-September 23.44" in 25.8 days, amounts to .9" per day. To show the well scattered winter rainfall incidence the following may be observed; the total amount of winter rainfall December to February is 23.44" in 25.8 mean number of days with the average intensity of .5".

The Total in Wettest and Driest Month:-

The rainfall values of all categories for Rawalpindi are highest among the six case studies, as is observable by graphs and data. Though the receipt of rainfall is considerable throughout the year except from October-November, yet the periodicity of concentration of rainfall are conspicuous. In August 1916 rainfall as high as 23.58" was released; which is more than the mean total for the four summer months. Commonly, October-November are the driest months but 5.35" in 1914 and 3.42" in 1883 was recorded for these months respectively, and out of 3.42" 2.22" occurred on 12th November as the heaviest showers in 24 hours. The heaviest in the driest month was received in August 1928 - 1.92". The values showing the heaviest fall in 24 hours for the winter months are lower than the one showing for summer months; 3" in 24 hours released on 7th January 1885, this being noted as the year of highest and prolonged activity of western disturbances.

The above survey emphasises that there is a remarkable general variability of rainfall throughout West Pakistan but the variability is particularly high in the zones of monsoon rainfall. The highest variability is demonstrated by Jacobabad and Karachi situated in the monsoonal zone, A. In addition to this the variations have been indicated in the incidence of wet and dry months. July and August are the wet months for the area of monsoonic regiment and January being the wettest month for the zone of winter rainfall, March standing as the wettest month for the zone of spring rainfall. May and October are generally dry months throughout West Pakistan. This is how drought and wet conditions precede and succeed one another. The salient features may be summarized as:

1. High concentration in one period with:
2. High intensity resulting in:
3. Low effectiveness.

Aridity:-

We have established some of the fundamental physical characteristics of West Pakistan in the preceding discussion. In particular we have noted how the region falls in a transitional position between and marginal to the two great air instability systems, the Western depressions finally fading out after their long journey from the Atlantic and the south west monsoon too. This marginality is in part, a consequence of two dimensional position and in part an effect of topographic control of lower atmospheric air movement. Position and topography as we shall see also largely determined human destinies in West Pakistan and as noted in Chapter 7, in traditional society a precarious response to political, social and economic conditions themselves environmentally conditioned, has had to develop under the ultimate control imposed by water-availability.

Only during the last century and a half has it been possible to see the changing of traditional responses to social and physical factors. Only in very recent years have scientific studies of the moisture factor been developed. Having established the necessary background we may now turn to a direct examination of this factor in terms of aridity.

Many scientists have approached from different angles the first analytical problem - the methods of measuring aridity. These exponents have adapted different values for their purposes, but they do not agree in their results. No measurement has proved to be of all purpose value and most of them involve laborious and elaborate calculations, based on detailed records. Four types of measurements by various authors are considered below.

De Martonne derived the following formula to ascertain the degree of aridity:

$$A = p : (T + 10)$$

T = mean annual temperature in centigrade.

P = annual precipitation in millimeters.

He believed that "such a combination of temperature and rainfall explains the character of the vegetation cover adequately".(41) From the point of view of plant cover and hydrography, he recognised desert conditions when the indices drop below 5, indices between 5-10 demarcating the semi-desert conditions. The indices 10-20 characterise Savanna and Steppe land. The dry cultivation of grain is practicable but irrigation proves more useful when the index is over 10. Irrigation becomes obligatory for a successful farming below the 10 index.

The formula computed by Thornthwaite for the purpose of differentiating humid and arid areas is as follows:-(42)

$$Im = \frac{100s - 60d}{N}$$

Im = Moisture Index.

s = water surplus.

d = water deficiency.

n = water need.

Based on these notations positive values signify the humidity index and negative values express the aridity index. This measurement of aridity is based on the rate of potential evapotranspiration, and the climate is regarded as dry when evaporation/transpiration exceeds precipitation. Hence the theme of this theory is "precipitation effectiveness", which is positively high only in the temperate regions and very low in West Pakistan as in some other tropical and sub-tropical countries. Based on the above hypothesis, he propounded the following climatic types:-

Climatic Type		Moisture Index
A	Perhumid	100 and above
B_4	Humid	80 - 100
B_3	Humid	60 - 80
B_2	Humid	40 - 60
B_1	Humid	20 - 40
C_2	Moist subhumid	0 - 20
C_1	Dry subhumid	-20 - 0
D	Semi-arid	-40 - -20
E	Arid	-60 - -40

Edward Stanz has designed a "dryness index" in terms of evaporation and rainfall, while studying the climate of Afghanistan and vicinity.(43) He is of the opinion that greater evaporation signifies lesser precipitation which gives a high index of aridity. Thus he framed the formula as - D = E/R where D = Dryness Index, E = Evaporation and R = Rainfall. If the manipulated values are below 6 the climate is moderate. 6-20 values delimit the semi-arid or Steppe and when they exceed 20, desert conditions prevail. His decisive factors are rainfall and evaporation not the potential evapotranspiration as the countries in which his research was based lack continuous plant cover, so that transpiration is not pronounced.

Lastly, Shanbhag, in the determination of aridity has developed a formula symbolised as E.G. the Effective Growth Index.(44) It is obtained first by computing the "monthly effective growth index". When monthly precipitation is divided by mean monthly temperature and multiplied by 100, the sum of the 12 months will give the "Effective Growth Index". The indices 0-20 denote arid climate, 20-40 for semi-arid, his thesis based on the following formula:-

$$E.G. = \sum_{n=1}^{n=12} \frac{100\ (P)\ \ e^{o.24t} \times 118.8^{2}}{(168.0)(118.8)(0.24)(e^{o.24t}} \quad n$$

He laid stress on the role played by the degree of temperature for optimum growth of plants. There are certain limits below and above which the rate of maximum plant growth diminishes or stops. The optimum temperature for the maximum growth is standardised as 86°F (30°C), though this varies with different plant species and soil. In the same way the growth of plants is inhibited when the minimum and maximum temperatures are 32°F, 0°C and 104°F, 40°C respectively.

By comparing the values of aridity as advocated by the four authors, we realise great differences in their evaluation and assignment of the grading of aridity.

It is noted, that those who have computed indices using the combination of temperature and rainfall obtained more or less similar index grades. Those who have employed evaporation have realised more or less equal grades. All but Shanbagh have graded the aridity into three categories, he having two notations only, arid and semi-arid.

The indices as proposed by these authors for the sake of comparison have been computed for the six stations which have been selected for sample study, and charted in Fig. 20 and Table 3. The discrepancies in the values by

Table 3.

	Shanbagh	Thornthwaite	De Martanne	Stanz
Lahore	27.6	-37.6	14	5.4
Karachi	9.36	-52.3	5	12.1
Peshawar	24.0	-44.0	10	6
Quetta	7.70	-42.0	9	7.3
Jacobabad	3.82	-56.6	2	28
Rawalpindi	39.82	-14.7	25	2.0

Stanz are considerable. He places Rawalpindi and Lahore both in a humid classification when by observation and the examination of rainfall and temperature data they differ considerably. In all but the Stanz's gradation, they are both subhumid and differ considerably from each other. The values for Peshawar are true, and Jacobabad indices also reflect the desertic nature.

Shanbagh's indices convey a picture of the areas which are borne out both by commonsense and ecological observations. The indices computed by his formula place the six stations in different respective climatic type. The same picture is gained from the indices of de Martonne. The indices limit as proposed by Shanbagh is very flexible, as compared to the limits of the others.

The indices of Rawalpindi as interpolated by the method proposed by de Martonne and Thornthwaite suggest its climate as humid and dry subhumid respectively. On the whole there is no agreement in the values of these workers in the field.

The candidate has used as the basis for the measurement of aridity in West Pakistan the formula devised by de Martonne. It is appreciated that in many ways it is a less refined instrument of analysis, than that of Thornthwaite for instance, and it is the latter which is mainly used by Pakistani climatologists; but it is the simplicity of the de Martonne formula which recommends it in this case. As already noted the magnitude of deviations of rainfall and humidity from the mathematical means is so great that such mathematical means become of low value for delicate statistical manipulation. When one also realises the spatial coverage by meteorological stations is poor, and that, the duration of observation is limited, then the danger of using highly elaborate processing techniques becomes obvious. Such techniques may be valuable for suggesting working hypothesis for specialist climatic study. For this thesis which is concerned with the question of aridity in West Pakistan in general geographical terms, it is more suitable to use an analytical process possessing the same degree of crudity as that contained in the statistics available. Moreover, and this is crucial, in the candidate's experience the De Martonne classification is better supported by regional observations in the field than are the others. (Table 4).

Table 4.

Aridity Indices

	Place	Aridity
1.	Badin	6
2.	Bannu	8
3.	D.I. Khan	6
4.	Darosh	17
5.	Hyderabad	4
6.	Fort Sandeman	9
7.	Jacobabad	2

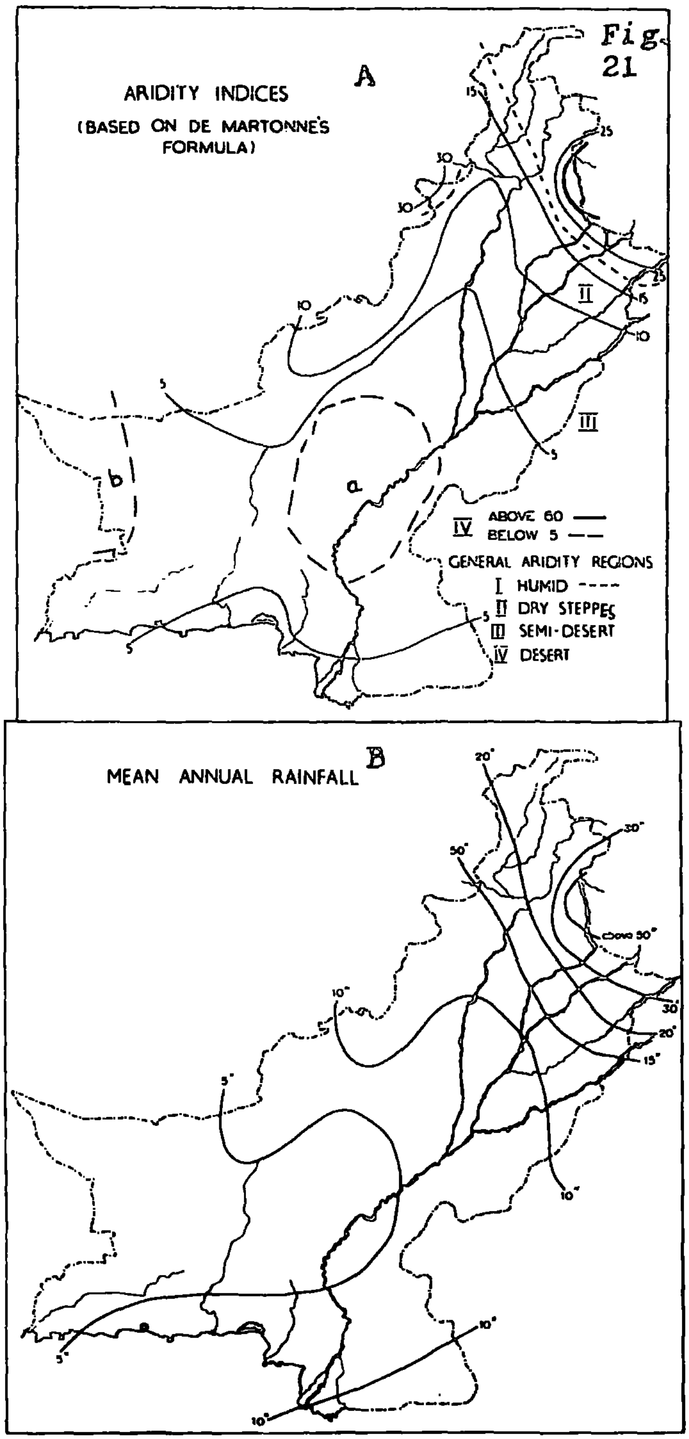


Fig. 21
A
ARIDITY INDICES
(BASED ON DE MARTONNE'S FORMULA)
IV ABOVE 60
BELOW 5
GENERAL ARIDITY REGIONS
I HUMID
II DRY STEPPES
III SEMI-DESERT
IV DESERT
B
MEAN ANNUAL RAINFALL

	Place	Aridity
8.	Kalat	7
9.	Karachi	5
10.	Khushab	11
11.	Lahore	14
12.	Lasbella	5
13.	Layalpur	9
14.	Montgomery	7
15.	Multan	5
16.	Murree	68
17.	No Kundi	1
18.	Panjgur	3
19.	Parachinar	29
20.	Pasini	4
21.	Peshawar	10
22.	Quetta	9
23.	Rawalpindi	25
24.	Sialkot	24
25.	Sibi	3
26.	Sukkur	2

The following impression is obtained comparing Fig. 21A with the mean annual rainfall Fig. 21B. It is seen that the arid zone limited by the isopleth of index value 5 covers a smaller area than that covered by the Isohyete of 10". Similarly the isopleth fixing the boundary of dry semi-arid lies between 10"-15" isohyetes; and that for Steppes encloses the area corresponding roughly to the 20" isohyetes.

Leaving aside a narrow strip of land forming the territory of Parachinar in the south west (Region I and the territory of the Outer Himalayas of the Murree hills in the south east of Region I), the aridity indices show dry conditions dominant over West Pakistan.

The highest intensity of aridity is found in the two localities enclosed by the lowest indices (below 5) which corresponds with their utterly desertic conditions. Firstly, area (a) of the Lower Indus Plain including Sibi, Jacobabad and Sukkur. Here maximum rainfall remains below 5" always and extreme temperatures rise as high as 125°, 127° and 118° respectively. The aridity diminishes very irregularly outwards from this circle. (b) The second zone lies north-west of Region IV or the Kalat Division, including Nokkundi and Panjgur. These stations receive even less rainfall than the section (a) and their extreme temperature rises as high as 120° and 114° respectively. The isohyete of 5" corresponds very closely to the Aridity Isopleth of value below 5.

The areas confined between the isopleths of indices 5-10 may be termed the semi-desert areas. The trend of isopleths shows how aridity increases towards the north east. Quetta, Fort Sandeman, Lyallpur, Bannu, Montgomery and Kalat occupy marginal or transitional positions with their indices of 9, 9, 9, 8, 7, and 7 respectively. They lie on the margins of semi-arid and arid areas. The annual rainfall in this belt varies from 7-15", from south to north-west and north-east. The Isohyets of 10" and 15" very closely correspond to isopleths of 5 and 10. The extreme temperatures vary from 121°-103°. Irrigation farming is very concentrated in the eastern portion of this belt and the great reclamation programmes of desert have been successfully carried on here. This zone covers a large portion of the Upper Indus Region and a considerable area of Region II, and only a fraction of the Trans-Indus Submountainous Region and Region III. More or less a replica of this tract is found in the strip constituting Badin, Karachi, and Lasbela; with an aridity index of 5.

The remaining area has index values between 10-15 and 15-25. The former encloses Lahore and then sweeps to the north westward and encloses Darosh, which according to De Martonne forms the Steppe region. The isohyets of average annual rainfall of 20" coincides almost exactly with the isopleth of 15. Similarly, the isohyets of above

30", 50" and 30" rainfall coincide with the isopleths of 30, 60 and 25. The small areas enclosed by the isopleths of 30, and more form the true humid region of West Pakistan as derived from the de Martonne's aridity index.

Aridity decreases mainly to the N.E. as illustrated by the swing of the isopleth trends. In N.W. in Parachinar mountains the humidity of the high N.W. ranges is clear. The closer examination of isopleths over the north east shows how the degree of aridity here changes rapidly over short distances. This aspect is directly related to the amount of annual rainfall and the elevation of the area. Isohyet patterns are similarly developed in the same way the area rises abruptly from the 600-1,200 feet level to 1,500 feet and over. (See Fig. 1). Thus the contributary factors are annual rainfall and altitude above sea level. The same factors account for the variations in the area around Parachinar.

While, in the extreme north there exists this striking contrast between relatively dry lower land and relatively wet highlands, as one progresses southwards this contrast diminishes. Thus the arid low country around Quetta is backed by only slightly more humid mountain country. Further south in Baluchistan prevailing climatic aridity is only very occasionally slightly modified by topographic influences or fluctuations in weather.

The Indus plain apart from the north eastern strip has an extremely slow rate of index change. In this land of subdued relief and minimum rainfall, uniformity of climate over a vast area is the most significant characteristic.

Fig. 21A illustrates very clearly how in the regions with an aridity index value below 15, i.e. the desert, semi-desert and part of the dry steppe, the areal transition between degrees of aridity is slight and slow. Where values rise above 15 then local regional differentiation becomes much more marked, a result of greater topographical diversity. This contrast is of particular significance in emphasising the critical nature of very small differences in humidity between the different regions of West Pakistan. As noted in Chapter 6, plant response to very subdued diversity in the general uniformity of the drier regions is equally subdued. The limits between desert, semi-desert and dry steppes are extremely difficult to demarcate.

The implication of this aridity will become more revealing in the chapters dealing with ecology of cultivated plants, and settlement pattern. The human response through irrigation to aridity and the cultivated crop response to aridity becomes more important than natural climatic phenomena and natural plant ecology in forming the landscape variations.

A theoretical picture of aridity which corresponds closely to field reality may thus be constructed with De Martonne's indices of aridity. This delineates the several degrees of aridity namely desert, semi-desert and steppes. Speaking broadly a delimitation of boundaries in terms of rainfall only can now be made. South of the 10" isohyet lie the deserts (the arid zone) and the areas with rainfall between 10" and 30" are semi-arid.

The chief characteristics of the arid zone are high temperatures, high diurnal ranges, high evaporation and extremely low rainfall with extreme rainfall uncertainty, which is insufficient for crop production; irrigation is a necessity, but it is only readily developable in the Indus Basin.

The temperature fluctuations during the day have been noted by Miles around Paujgur. "In November at 6 a.m. thermometer was 46° and at 1 p.m. 86°".(45) Such extraordinary mercurial changes arise from simple differences between isolation and radiation. Dewfall at night is considerable. Various people have carried out investigations on dew as helping plant growth in the deserts at night when the evaporation is almost nil, for example investigation by the Department of Geography, Durham in

Libya. Israeli researches in dewfalls have confirmed that dew falls on 26-28 nights during every summer month in Israel. "They may amount in some areas to the equivalent of ½" in a month".(46) Such investigations are in their infancy in Pakistan. After a few years the estimates of dew which is being studied may prove a help in the growth of some food crops or forage in Pakistan.

The semi-desert merges with the desert in the south and with the semi-humid in the north. There is no hard and fast boundary between any climatic zone, each zone merges imperceptibly with the other, having a broad transitional zone on either side, the natural boundaries never being defined sharply. The most important guide to transitions becomes the natural and cultivated vegetation. The semi-desert region contains pockets of desert areas such as the northern portion of Thal desert.

In the semi-arid zone as noted under rainfall and temperature vicissitudes of climate do exist but on relatively a smaller scale. "The rainfall is sufficient for certain types of crops and grass is an important element of the natural vegetation unless overgrazing has replaced it with brush".(47).

The semi-arid may be considered as the zone of relatively less uncertain rainfall, hence relatively less complete dependence on irrigation for agriculture. On the other hand the arid zone is the most uncertain of rainfall and agriculture is uneconomic without irrigation. Thus the present and future vast and efficient irrigational works become necessary and worthwhile devices to combat the aridity.

The causes of aridity:-

The aridity of 36% of the world area has lead to the investigation of the causes of its dryness and the possibility of amelioration.(48) Hence desiccation has become a debateable point for the last few decades, attracting the world wide attention of modern geographers, biologists, climatologists, geologists, archeologists and historians. In the following pages it is endeavoured to trace the factors rendering nearly the whole of West Pakistan climatically an arid country.

The geological and geomorphological evidence in shape of river terraces, dry river-beds, and dried up lakes, archaeological remains dating back to c.5,000 B.C., and historical literature testify,that,the climate of West Pakistan was more genial and uniform during antiquity than it is today.

Considering the world as a whole deserts have existed throughout the time with varying magnitude and with non permanent location. "But during most of the warm periods and especially in the Mesozoic, they expanded greatly, extending from the sub-tropical region far into the present temperate zone".(49) The location of deserts fluctuate with the pulsation of the atmospheric conditions. In the present times West Pakistan along with the adjoining vast expanse of deserts is under the sway of major desert forming conditions.

In the arguments concerning the development of the aridity of West Pakistan, it appears however that the agents responsible for present aridity are both natural and cultural. The field evidence provides testimony for both natural and cultural forces, but the cultural or human agency is at present particularly emphasised.

Natural Factors:-

In the opinion of Quaternary glacial geologists, modern arid and semi-arid regions had pluvial regimes during the Pleistocene period; ascribed to the relatively low latitudinal extension of the Ice Sheet, ... "the entire belt of eastward moving cyclonic storms was shifted" about 15^{o} southward, "from the position it occupied at present".(50) Humidity decreased as the recession of glaciers took place. The contracting glaciers meant the contraction of the Polar climate, which in turn lead to the retreat of the cyclonic zone of mass juncture to the present positions. H.V. Ficker,(51) calculated that at the time of the maximum glaciation of the north-west Pamir the rainfall was four or five times as great as at present. The pluvial character of Quaternary West Pakistan is borne out by the character and distribution of river and lake terraces as explained in chapters 1 and 7.

It is held by some,that West Pakistan was generously watered by the south-west monsoons during the period of 3,000-2,000 B.C. but more recently the main tracks of the south west monsoon disturbances shifted to the east,and thus, West Pakistan lost the moisture bearing winds.(52) This explanation seems to be inadequate. As far as the track of monsoon current is concerned, it probably did not shift as much as to bring about such a drastic result. No storm belt follows rigidly a mathematically correct path, but changes slightly from year to year. As explained in the beginning of the present chapter,that amount of rainfall which depends on the strength of monsoon is affected by numerous factors. The following are the most probable factors accounting for the low rainfall and aridity.

1. The Bay of Bengal monsoon current is fully de-prived of its moisture during its long journey from East

Pakistan to West Pakistan. The Arabian sea monsoon current meets an extremely hot region after crossing the warm sea and its relative humidity quickly drops from c.90-c.55%.

2. The relative aridity of the inmoving western air is further strengthened by the presence of the static hot dry air in the upper levels over the adjoining region of Iran, Afghanistan and Rajasthan. Moisture is further lessened by the burning solar heat and intense evaporation. Refer Fig.(11)

3. West Pakistan is permanently a "seat of indraught to land winds in a far larger measure than to those from the sea".(53)

What of the past? The evidence provided by the presence of boulder clays in the environs of Potwar Plateau points to glacial conditions dominant in that area during the Pleistocene. In post-Pleistocene times the evidence of humid hydrographic developments in West Pakistan is plentiful, in the dry wadi beds traversing the Kalat Division, in the now dry beds of the Indus and the lost Saraswati in Bahawalpur Division. The Dasht of Kalat Division regarded as relics of the furious floods of days when the area enjoyed a Boreal climate.(54) The whole lowland stands testimony for such changes.

Further evidence is found in the presence of vast stretches of beds and terraces of ancient lakes, which are now either dried up entirely or left in as salty marshes. The divisions of Kalat and Hyderabad do not lack such proofs. (ref. Chapters 1-2). A substantial reduction in the Karez supply and drying up of Karezes also lead to the conclusion that climate has tended and possibly is still tending towards greater aridity. It is probable that man's extraction of water has not caused, but has exaggerated the decline in subsurface water which results from progressingly lessening rain supplies. This is clearly still an active process in the Kalat Division. (Ref. Chapter 4).

So far the archaeological evidence of recent trends goes it confirms the inferences of meteorology. When Europe was largely ice bound, the belt of storms at the junction of Polar and tropical air was displaced southward and laid approximately over the latitudes of area where civilization first dawned.

The excavations both at Mohenjodaro and in the vicinity of Quetta are proof enough of a moist climate during prehistory. The climate gradually became dry as the glaciers relics of much earlier ice sheets steadily retreated.

Marshal and Hutton point out that "Everywhere in southern Baluchistan there are remains of enormous dams and bands, proving that at one time the land was elaborately irrigated and pointing perhaps to the period at which its natural waters began to fail on account of climatic changes involving the undertaking of conservancy on a larger scale, and we are probably justified in picturing Baluchistan, a land of hills and valleys indeed but now barren and arid swept, as 5,000 years ago (period of Mohenjo Daro climate), a good land of fountains, drinking water of the rain of Heaven".(55) The opinion held by Stein (56) is that the divisions of Quetta, Kalat, Hyderabad and Khairpur have experienced similar climatic change.

Mrs Mackay has framed a conclusion in the favour of moist climates based on the prehistoric relics of the Indus civilization.(57) "From evidence of the seals found in the cities of Mohenjodar and Harappa, it seems certain that the climate of the Indus Basin was far moister 5,000 years ago than it is today. On their seals the craftsmen portrayed with the faithfulness of familiarity those denizens of moist, lush jungle, the elephant, tiger and rhinoceros which are no longer known in Sind. The lion, a lover of dry open country, has not yet been found on seal, amulet, or painted pottery. He was evidently almost unknown. Moreover it must have taken immense quantities of wood to burn bricks required in the construction of a city so large as that which excavation has revealed at Mohenjo Daro - a fact which argues a more thickly wooded condition than there exists at present".

All field archaeological investigations support this conception of a past more humid and genial climate. At the same time, the remarkable preservation of archaeological remains since the final decay of the Indus cities suggests an early onset of an arid climate. Stein maintains: "The climate of the Indian Desert, dry enough nowadays is far removed from the extreme aridity of the true desert, which in Chinese Turkistan has allowed relics of ancient life to survive in such a remarkable preservation. But observation of topographical features along extensive stretches of dry river beds, locally still well-known, and the study of old sites on their banks might throw some light on the period when water permitted there continuous agriculture and thus perhaps on the chronology of the process, which led to water ceasing to flow in the beds".(58)

The interpretation of Rigveda by Unakar shows that, probably from 5,000-2,000 B.C. climate was characterised by very well-defined seasons. First, a term of cool weather with a quite evenly distributed rainfall accompanied by few thunder storms. The second term, was of heavy rains which caused by winter depressions, finally followed by a long drought.(59)

These climatic features are comparable in regime type with the present climate especially in terms of periods of drought, but it was probably wetter during winter than it is at present, and the monsoons would seem to have become stormier and more associated with high temperatures.

Evidence of large irrigational works, bands and tanks clearly suggest a marked seasonality of rainfall. Therefore the inhabitants of the prehistoric time i.e. pre-Alexandrian, presumably had to take precautionary measures to collect water to face the drought period. The other conclusion which can be drawn is that, elaborate drainage systems and culverts suggest the heavy rainfall; which watered the area generously in its season, and made the disposal of surpluses on balance more regularly important than now.

The amount of rainfall was sufficiently heavy to allow the growth of vegetation which served as plentiful fuel and supported much wild life. Animals like the elephant could easily find a refuge. On the other hand an analogous faunal situation was formed in North Africa during the Carthaginian period and conclusive evidence of desiccation is in this case not easy to find.

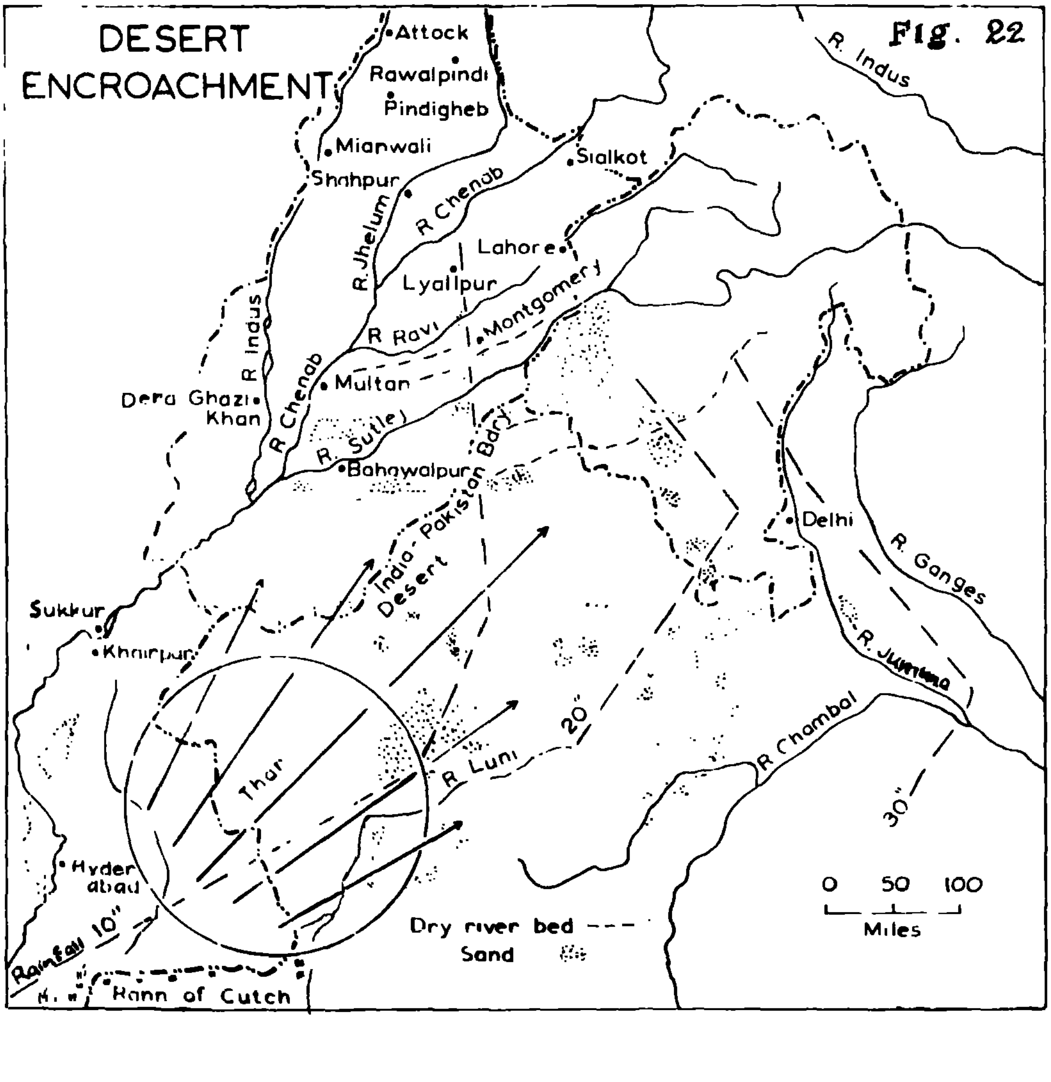
A generalised curve of rainfall prepared by Brooks shows that 2,250-2,500 B.C. was the period of maximum rainfall in the Indus Valley.(60) Other evidences in this direction have been carefully sifted by him and he supports the theory of climatic change all over the world. Most subsequent evidence suggests that the climatic conditions of West Pakistan have been more or less stable in historic times.(61) Natural aridity has become an extremely complicated problem and much controversy still rages over conflicting evidence.

Cultural Causes:-

The descriptive accounts of the early travellers have an important contribution to our knowledge of the early geography of West Pakistan. This literature contains the description of landscape and climate from the time of Alexander to the end of Moghul Empire, for example:

"Alexandar and his army had marched through vast areas of virgin forest where now only desert was to be found".(62) "The accounts of ... Moghul hunt bear witness to considerable forest growth".(63)

All the experts on the arid zones unanimously agree that the present desert conditions of West Pakistan are finally the outcome of man's action along with his stock. "The man made desert is a stern reality which so far has rarely been faced up today. Man has been the enemy of the forest



DESERT ENCROACHMENT
Fig. 22
Attock
Rawalpindi
Pindigheb
Mianwali
Shahpur
Sialkot
R. Indus
R. Jhelum
R. Chenab
Lahore
Lyallpur
R. Ravi
Montgomery
R. Indus
Dera Ghazi Khan
Multan
R. Chenab
R. Sutlej
Bahawalpur
India-Pakistan Bdry
India-Pakistan Desert
Delhi
R. Ganges
R. Jumna
Sukkur
Khairpur
Thar
R. Luni
20"
R. Chambal
30"
Hyderabad
Rainfall 10"
Rann of Cutch
Dry river bed
Sand
0 50 100
Miles

and of vegetation ever since he learnt to grow crops for food and to pasture flocks and herds on the countryside".(64) Human extension of aridity has also resulted from increased population densities, migrations and wars . All these reasons are particularly applicable to the case of West Pakistan, as this part of the Sub-continent has been a corridor zone for migrating races, cultures and communities particularly since the incursion of the Aryans.

To provide reliable evidence of the desiccation process resulting from human action now going on in the divisions of Lahore, Multan, and Bahawalpur, Gorrie has reconstructed the movement of shifting sand.(65) Cartographic evidence was first prepared by Major Wright in 1870, and again later in 1935. Gorrie concludes that "inspite of irrigation developments shifting sand has increased alarmingly". The accompanying map (Fig. 22) illustrates the direction of sand advancement since 1870 towards Lahore at an average rate of ½ mile per year, and the sand is still encroaching upon the highly fertile plains with considerable speed. Gorrie believed strongly that soil seldom naturally degenerates into sand. The cause of fertility degradation, he had attributed to bad farming methods, failure to conserve moisture, lack of manure, and too many grazing animals all helping to create a condition in which deterioration takes place. The scenes produced by sand encroachment are visible in Plate 10 Chapter 2.

Over grazing has played havoc in turning West Pakistan from a dry into an arid land especially in the uplands and mountains, as is later considered in Chapters on soil and plant ecology. The present extreme state of affairs results mainly from negligence on the part of the man. Man is such a powerful agency in the production of deserts that not only in the areas of meagre rainfall but even in warm temperate rainy climate such as that of south Brazil and cool temperate South Island, New Zealand, arid conditions have been established by the practising of incorrect agricultural methods.(66)

Stebbing has precisely enumerated the causes of present desiccation in the case of West Pakistan.(67) It is held to be due "primarily to the over utilisation of the vegetation covering of the soil under which productivity is reduced, the decrease of water supplies in the springs, streams, rivers and wells, the sinking of the water-table in the soil strata, and decrease in the rainfall. It may be due to (a) the presence of neighbouring deserts and sand penetration. (b) erosion in varying forms through over utilisation of the soil and the combination of (a) and (b) accompanied by dry, hot and cold winds". J. Phillus is also an emphatic advocate of the idea that expansion of the deserts is owing to the human negligence.(68) In his survey of the Great Pak-Hind Desert Glennie reported on the basis of field evidence that it is not a true climatic desert.(69) Aurel Stein similarly reported fundamental differences between the true desert of Gobi and the partly cultural desert of Pak-Hind.(70) Even in the early nineteenth century conditions were not as extremely arid as they are now. Elphinstone in 1808 described the desert when he rode through it as "during and just after the rains it wore a very different green pasture land covered with the richest and most succulent grasses".(71) The incidence of rain was then sufficient to keep the pasture ready to support more livestock than at present, which is the main contention of Glennie. The bulk of direct evidence supports the belief that while the area during historic times has been at least semi-arid, the degree of ecological aridity has been increased by man.

In his early study about the climatic changes Walker (72) maintained: 1. that man is not responsible for the introduction of present aridity, it must be attributed to the large scale abnormality in the atmospheric movement, which results in a small amount of monsoon rainfall. 2. that the available rainfall data suggested that precipitation was tending to increase rather than decrease over a period of time. In the light of records of longer duration it is impossible to hold with Walker's hypothesis. No clear trends are discernible.

From the above inferences, one can say that as far as meteorological conditions are concerned climate has been stable in West Pakistan since historic times. Man is directly held responsible in bringing about local changes. The decrease and increase in the amount of monsoon rainfall depends on the fluctuating strength of monsoon air currents. The monsoon rain is "greatest when the general circulation of the atmosphere is weakest".(73)

The investigations carried out in India do not give any clue to climatic change.(74) The impoverishment of climate there has also been considered as a cultural factor. All we can finally say, is that, the assembly of archaeological and meteorological material here too argues in favour of stability of climate, and points to a diminishing effectiveness of precipitation since antiquity.

Apart from obvious consequences of human action and the question of past climatic change, the question still remains open as to whether there is any perceptible cyclical change observable at present. As noted earlier, certain short-term periodicities appear in the rainfall records of individual stations. The lack of correspondence between these separate observation patterns makes it impossible to draw any general conclusions.

On the other hand,Tixeron has concluded after studying the historical, botanical and archaeological evidences in Israel and the sub-continent of Pak-Hind, that climate is slightly changed during the last 80 years.(75) The need remains for combined meteorological, archaeological and ecological studies to establish the nature or even existence of a historic process of desiccation and to ascertain whether such a process is still continuing.

The Control of Aridity:-

One traditional and modern method is to conserve rain water as much as possible by building tanks and dammed reservoirs. One great difficulty arises from evaporation loss from the resulting water surfaces. This approach is examined in the following chapter.

Lately, experiments concerning artificial rainfall in Australia and Mexico have attracted the attention of the other countries towards this man-made phenomena.(76) At present there are three possible methods of producing artificial rain.

1. The cheapest and simplest method is to induce droplet

formation in the clouds, by making the local clouds "so cold that the temperature drops below the natural freezing point of super-cooled water condensed initially from the water vapour in the air".(77) Such conditions are induced by feeding the undercooled clouds with Dry Ice (solid carbondioxide which vaporises at a temperature of 78.5°C).

2. Rainfall has also been successfully chemically induced by seeding silver iodide crystals in the clouds.

3. The formation of precipitation has been attempted with the process of condensation spraying water drops into these "non precipitating clouds".

For all these methods the essential pre-requisite is the presence of cumulus and cumulo-nimbus clouds with at least a thickness of 5,000 feet, and a base height not exceeding the cloud thickness. As appears from Fig. 17 that cloud cover is normally developed in non-monsoon seasons not suitable for an economical formation of artificial rain in West Pakistan; nor is it possible to seed the thin, infrequent fogs or mist.

In West Pakistan studies in the synoptic survey of hygroscopic nuclei concluded, that apart from the coastal region the clouds in various parts of West Pakistan are capable of producing artificial rainfall. In this direction six experiments have been conducted since 1953, by seeding both cold and warm clouds.(78)

A. Seeding of warm clouds during monsoon:-

i. in the sub-montanous trans-Indus plain of Mardan in 1953.

ii. in the Upper Indus plain and adjoining hills from ground in 1954.

iii. Trial ii was repeated in 1955 and 1956. A seeding of cold clouds in the winter season.

iv. in the vicinity of Quetta from the hill top in 1955.

v. Trial iv was repeated in 1956.

The chemicals used were common salt for warm clouds and kerosene oil burners used for producing the silver iodide in warm and cold clouds. These experiments were quite successful technically but had to be shelved because of high cost.

Considering the climatic conditions as described, the main possibility of increased rainfall is by seeding the winter clouds. As winter rainfall is less in amount relative to atmospheric water vapour and comparatively stable in its incidence, it can be made copious and more effective especially since evaporation is low. Successful seeding of clouds in summer is not likely to be as easily carried out during technically suitable conditions. Moreover summer rains are in any case likely to be torrential and they often produce floods, which are wasted by run off to the sea. The need in such circumstances is to control and save this surplus water for the drought period.

The real necessity is for Pakistan to act first upon the methods of conserving rain water and to adopt economical and judicious means of its utilization. The new scienti-fic discoveries like artificial precipitation and use of Krilium to create gardens out of deserts cannot be proved economical. Such adaptations come last. The cheapest long term schemes like afforestation, building of bunds and maintenance of soil by vegetal cover are the most ecologically stable and ultimately the most valuable means.

Chapter 4

Hydrography

Hydrography is an essential part of the physiographic character of a country, and it has great direct influence on man's activity, both in rural and urban areas. In West Pakistan like the rest of the tropical and sub-tropical lands, where rainfall is remarkably seasonal, and characterised by droughts of 4 months or longer, a knowledge of water resources is of the utmost importance.

The rainfall characteristics show clearly that West Pakistan requires much more water than is supplied by rainfall for successful agriculture and other purposes.

An analysis of hydrographic resources of West Pakistan is here introduced by the zon... ation of the area into the following hydrographic regions. Fig. 23.

1. Indus System.
2. Drainage of Makran Coast.
3. Inland Drainage Basin.
4. Under Ground Water.

The Indus System

The Indus Basin stretches over an area of about 348,000 square miles, and out of that 204,000 lie in Pakistan.(1)

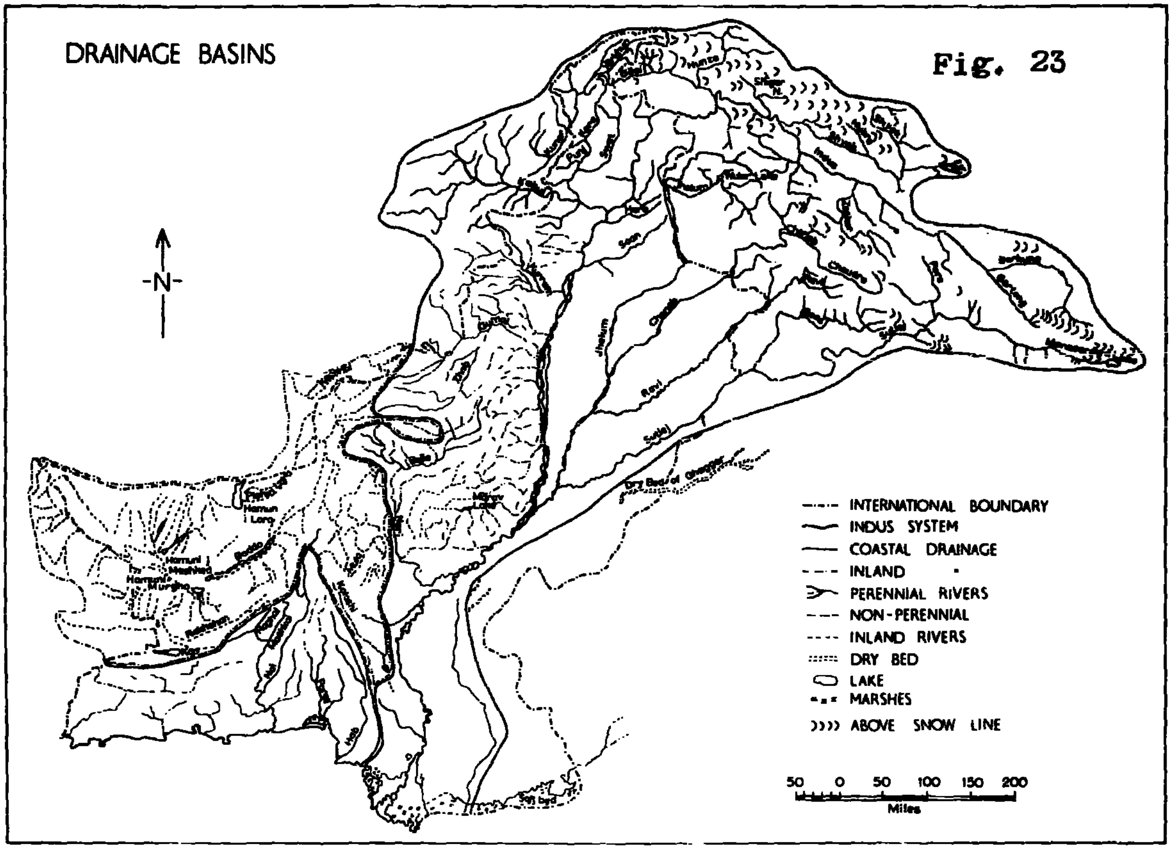

DRAINAGE BASINS
N
INTERNATIONAL BOUNDARY
INDUS SYSTEM
COASTAL DRAINAGE
INLAND
PERENNIAL RIVERS
NON-PERENNIAL
INLAND RIVERS
DRY BED
LAKE
MARSHES
ABOVE SNOW LINE
50 0 50 100 150 200
Miles
Jhelum
Chenab
Ravi
Sutlej
Soan
Dry Bed of Ghaggar

Fig. 23

This system of rivers includes the master Indus itself with its major eastern and western tributaries, the Sutlej, the Beas, the Ravi, the Chenab and the Jhelum on the east and the Kabul, the Kurrum and the Gomal on the west. The Indus system is one of the great river systems of the world. Its annual flow is twice that of the Nile and three times that of the Tigris and Euphrates combined. It amounts to almost 170 million acre-feet or enough water to submerge, to a depth of one foot, the whole area of the Texas state or the whole area of France.(2)

The Himalayan portion of the Indus System excluding the Kabul in Afghanistan covers an area of over 100,000 square miles, bigger than the whole basins of most of the European rivers. The Sutlej alone drains 20,000 square miles.(3) The vast extent of the catchment areas of the Indus and its eastern associates is shown in Appendix 6,(4) and that of the Himalayan associates of the Indus catchment basin area is:-(5)

Shyok	13,000 square miles.
Gilgit	10,000 square miles.
ZasKar	10,000 square miles.
Singhgie	7,000 square miles.
Dras	5,000 square miles.
Shigar	5,000 square miles.

On the west the Kabul drains 35,000 square miles.

The parent river Indus along with its tributaries are snow fed. The KaraKoram Glaciers are considered to be relics of the Ice Age and are the greatest ice flows of the world outside the Polar region. To these enormous glaciers the south running rivers owe their perennial flow, which has been utilised from the time immemorial for irrigation purposes, and the regime of these rivers is controlled by the factors of seasonal rainfall and snow-melt. At present besides irrigation uses, the rivers have been harnessed for the generation of hydroelectricity. These rivers also furnished a cheap water transport before the advent of the present canal system. In respect of food, rivers give a supply of fish which supplement food from the soil. The trend of the upper Indus plain is north east to south west sloping away from the Himalayan foot hills. The five rivers flow obliquely towards the main river Indus which flows closely to the base of the Sulaiman range. (Fig. 23). The reason for this pressure to the south west is the large volumes of water and detritus brought by the five rivers, the water and sediment from the west being relatively insignificant. The rivers follow the topographic grain and align themselves along the asymmetrical axis of the Indus structural trough. Contrary to this irrigation expansion is towards east and south east owing to relatively soft deposits.

The study of the topography shows that the Indus Basin rivers exhibit a variety of braided, meandering and fixed channel patterns. The river course is braided whenever the deposition is excessive; and channels are fixed at the points where deposition is small, and the process of meandering dominates when the circumstances are intermediate. These rivers have maintained their fixed channels whereever they are tectonically controlled. These characteristics of the channels of each individual river are of great importance in the training of their flow and flood control. All these rivers enter West Pakistan and ultimately unite with the Indus after flowing over a vast lowland.

The political fact of the division of the upper reaches, of the Indus rivers by political frontiers has had deplorable hydrological and economic consequences. Lack of cooperation between Bharat (India), Tibet and Pakistan has prevented the unified treatment of this great catchment basin. Pakistan has suffered greatly from her inability to obtain meteorological and water flow data for the whole area, because without this, necessary annual flood forecasting cannot accurately be carried out. Further as we shall see, flood prevention and catchment basin management is prevented by the partition of the area. According to Ferrel's law rivers move to the right bank, and their ancient beds are still traceable in the east. Therefore all the big cities have been built on their left bank, such as Lahore, the city of Ravi and Sialkot the city of Chenab.

The common trait of both eastern and western tributaries and the Indus itself, is, that, they journey through the mountainous terrain for a long distance before their embouchment on the plains of West Pakistan. The highland section lying within the boundaries of West Pakistan form striking topographic features, such as the 100 miles long gorge of the Jhelum at whose mouth is now built the new Mangla Dam.

In the highlands the rivers are in a large measure structural strike streams occasionally breaking transversely through the ranges in great gorges of rejuvenation. Their youthful dissection gives way suddenly to deposition as they enter the flat plains of the basin. (Fig. 23). At this point of suddenly decreased gradient most of the rivers have to deposit the load previously borne by their high velocity. At some points in the Siwaliks this change in 'thalweg' is effected in the presence of softer foothill rocks. Everywhere alluvial deposition becomes dominant in valley formation and the streams cut their braided and meandering beds into deep alluvium and flood detritus. This maturity exists in basins separated by structurally caused changes in local base level. They produce a contraction and deepening of valley forms as at Kalabagh, Sukkur and Kotri on the Indus. All these points have been used for river regulation as by the Jinnah, Sukkur, and Kotri barrages. Similarly the resistant Precambrian rocks of the Kirana hills at Chiniot form a bottle neck and local base level in the flow of the Chenab. This succession of open plains and narrow gorges is very significant from the point of view of river use, and flow regulation, and of course results from the main tectonic altitudinal changes of Tertiary and Recent times, and from the increased post Quaternary volume of snow derived river water.

Indus:-

Indus has a total length of more than 1,800 miles as compared with the Ganges 1,550 miles,(6) while the Nile has a course nearly 3 times longer than Indus, viz. 4,161 miles.(7) The volume of water in the system is equal to the Columbia River in the United States and Canada, more than three times as large as the Nile, and about ten times as large as Colorado river in the United States and Mexico.(8)

Indus originates near the Manasarowar lakes in Tibet at an elevation of 15,000 feet. About 850 miles of the Indus course lies in the mountainous region while for the rest it flows through the plain area.(9) The length of the river within the Pakistan boundaries is about 1,000 miles. It commands a catchment basin of 118,400 square miles with 14,415 square miles under glaciers, but the mean annual rainfall incidence is only 17.74", the lowest among all.

After its rise the Indus immediately flows in north westerly direction in a very long transverse valley in the heart of the main Himalayas, and on its way it receives Zaskar which occupies a catchment area of 10,000 square miles at its left bank.(10) Innumerable rivers and torrents dissipate themselves in the Indus on its both right and left banks. After traversing the mountainous country for about 500 miles below Gol Indus joins its largest affluent of the mountainous stage the Shyok river. In this upper catchment area the Indus is both rain and snowfed. At altitudes of the order of 10,000 feet the bulk of precipitation falls as snow, changing to a predominance of rain between 5,000-6,000 feet. Precipitation is well distributed throughout the year,hence,volumetric fluctuations are mainly the consequence of snow melt and snow accumulation. The height of the permanent snowline is some 13,000 feet. Figs. 23 and 1.

In its upper east-west structure conforming section, the Indus is controlled by local base levels produced by normal differential erosion and relatively small scale tectonic effects. The silt load although varying along this course is relatively low. When however the Indus turns south in its antecedent course cutting through the Tertiary folds, its erosive effects are increased. The silt load increases potentially in relation to, in general, the southward increasing mechanical softness of the rocks through which it cuts. When the river leaves its antecedent gorge sections this silt load is then deposited. The zone of deposition is extended southwards during the flood seasons as the increased volume of water increases the load carrying capacity. The silt helps in building up the river bed, and consequently silting of canals takes place. Along with other factors silting also contributes to the flood occurrence. Table 5 illustrates the character of detrital transportation:

Table 5

Site	Year	Discharge	Total	Sand	Silt	Clay	Percentage
Indus at Durban	1954	43856	48074	23540	15842	15286	0.109
	1955	62633	85737	45881	24570	15285	0.137

Indus pursues a chequered course as it crosses the Hazara country. The whole drainage of Regions I-II is absorbed by the Indus, consisting of both perennial rivers and ephemeral torrents.

From the Mianwali district southward the river enters the infilled structural depression of the Indus Plain. There in braided channels, it swings from bank to bank in a 10 miles broad course, above the confluence of Kurram. These non-perennial channels in the braided course provide an opportunity for the construction of inundation canals.(11) The braided [illegible] course is continued and elaborated as the river "rolls a volume of water equal to that of all the other five rivers taken together".(12) The Zhob river with a basin of 6,000 square miles drains into Gomal river which drains the adjoining part of Afghanistan also, and ultimately finds an outlet into the Indus at Dera Ismail Khan through a break in the Sulaiman range. Besides, a myriad of storm rain torrents periodically join from the Sulaiman range. The whole course of the Indus making the western boundary of the Sindsagar doab is "broken by islands and sandbanks but beautiful scenery is afforded along its banks, which abound with date, acacia, pomegranate and other trees".(11)

In the plains the Indus course is one of aggradation.

This results in periodic overflows of water which lead to serious floods in the period of excessive flow. In this respect the Indus has been regarded as "less manageable than the Nile. Its main channel is constantly shifting and at only 3 places Sukkur, Jerruck and Kotri the river banks are permanent".(11) South of Mithankot the confluence of the Indus and the Panjnad, the Indus advances as a single stream with no permanent tributaries on its right or left banks. Aggradation increases and the river bed is raised above the surrounding area. The intensity of high floods have only been brought under control by the 50 miles long Kashmor (11) embankment. Some seasonal rivers enter from the water-divide formed by Central Brahui mountains.

The width of the river from bank to bank ranges from 480-1,600 yards, while the average in the dry season drops to 680 yards. During floods the river channels expands to over a mile in width, and maintain a depth from 4-24 feet. Its minimum discharge is as low as 19,000 cusecs and maximum as high as 820,000.(11)

Utimately it ends the long journey flowing sluggishly into the Arabian Sea, dividing itself into outlets and effluxes on both banks such as Fuleli, locally known by various names as Guni, Pharan, and the Kori, and the Pinjari known differently from place to place as Gungra, and Sir, diverging near Jerruck.(13) The prominent effluxes are Ochitoo on the west and Haidari on the east.

Jhelum:-(14)

The upper waters of the Jhelum converge in the tectonic depression of the Vale of Kashmir, from the surrounding mountain slopes. This upper catchment basin is small and compact with those of the Indus and Sutlej, 12,445 square miles, with 142 square miles of Glaciers, which is bigger only than that of the Ravi. In the Vale of Kashmir it passes through the lakes of Dal and Wular, small relics of a larger post glacial lake. Alluvial deposition by the Jhelum and its tributaries have largely filled the depression. The vigorous youthful mountain streams on entering the Vale are transformed into generally sluggish low gradient rivers meandering in part through shallow lake and marsh. This perched basin to some extent serves as a flow regulator for the Jhelum.

The Jhelum then breaks across the NW-SE structural and topographic grain first westward, and then southward in the 100 miles long Mangla gorge. The full geomorphological history of this area has not yet been worked out, but for our purposes we may accept the general theory of antecedent drainage to account for the direction and form of the Jhelum. At Mangla the river enters the lower foot-hills zone to the north east of the Salt Range, in which section is received the seasonal water contribution of non-permanent streams such as Kahan. At Miani the Jhelum enters the Upper Indus lowland plain and aggradation becomes dominant.

From the human point of view the main points of significance are political and technical. Following the 'de facto' partition of Kashmir, the main regulatory basin of the Vale of Kashmir has lain in Indian territory and the antecedent gorge section forms the boundary between India and Pakistan. The consequences are made more important by the fact that flow regulation for power-generation, flood and irrigation control is rendered technically easy by the changing valley character, but political difficulties neutralise the technical advantages.

Chenab:-

It is served by a catchment basin of 11,399 square miles, greater than that of the Ravi and the Beas, with an area of 1,475 square miles under glaciers or permanent snow. Like the Jhelum its flow is confined to the outer ranges of the Himalayas. The union of two glacial fed streams Chandra and Bhaga gives origin to this river. In its catchment basin the river flows through long trenches and deep antecedent gorges, and these features as in the case of the Jhelum are maintained up to the point of entry to Pakistan territory below Akhnur. (Sheets 1.1000,000)

As the Chenab leads a longer course through the glacier carrying mountains and its upper basin has more rainfall (47.24") than the Jhelum, it carries a bigger volume of water and flows through a wider bed making numerous islands which are formed by divergent and convergent channels which first diverge from it and then converge on it. This process is very marked between Marala and Chiniot. The size of these divergent channels is as big as the main stem of the river.

There is also a net work of seasonal hill torrents which join the river between the point at which it enters the Indus trough at Khanki, particularly on the right bank. In July 1959 the inundation in Aik and Palkhu nullahs submerged 100 villages in the Sialkot district.(15)

Chenab's water has been generously used for irrigation works, because of its large volume of water, and its long passage of the plains. It feeds two headworks at Marala and at Khanki, both on its left bank.

Ravi:-

The Ravi has the smallest catchment area 3,562 square miles with a 100 square miles of glacial covered area and with the highest precipitation, rising to 93". It originates from Bara Bangahal glacier in the Sub Himalayan region (in Indian territory) in the Kangra hills. Its chennel is comparatively narrow and more twisting than the preceding rivers. It also joins the Indus depression abruptly as it leaves the antecedent valley. There are many seasonal streams joining the main river chiefly on its right bank. The largest tributary is the Degh which flows parallel to the Ravi for a considerable distance eventually joining the parent river a little below Sharqpur. Degh is a troublesome stream and every year it brings havoc to Pasrur Tehsil. In July 1959 its water "flowed through villages with a level of 10-11 feet at some places".(15)

Throughout its journey over the low plain, the Ravi maintains a regular course; there are a few and small sand banks and islands. It flows through relatively hard sediments and has high banks, and so less extensive sedimentation of the flood plains and less dangerous overflows take place.

Ravi forms part of the boundary between Pakistan and

Bharat for a distance of over 70 miles. The present head-works fed by the Ravi in Pakistan territory are at Balloki and Abdul-Hakim. These heads have been affected by the latest decisions of the World Bank, (discussed under irrigation).

Sutlej:-

This big river is the peripheral water-course of the Indus Basin in the east. This largest tributary of the Indus river emerges from the Manasorowar lake in the Kailas mountains. Sutlej drains 23,400 square miles in its upper reaches, with an area of 2,468 square miles of glaciers, and an average 19.71" of precipitation. It is noticeable from Appendix 6, that the greater the glacial extent smaller the rainfall incidence as in the case of the Indus and Sutlej; in the main Himalayas medium high precipitation is mostly in the form of snow, and it is replaced by heavier rainfall in the outer or sub-Himalayan regions. The Sutlej leaves the mountains at Rupar gorge which point has been utilised for the erection of a dam for the Sirhind canal.

At the south eastern corner of Kasur Tehsil the Sutlej enters the Pakistan plain and like the Ravi it also serves as a boundary line for about 80 miles until it enters the Division of Bahawalpur. This river makes a less wide flood plain as compared to Chenab and Jhelum. The banks of Sutlej are relatively high which have proven less liable to the floods.

A study of the river courses points the following characteristics:-

The Indus Basin is drained by big surface rivers as well as by seasonal streams. The Indus itself and its large perennial tributaries are at first fed by snowmelt and the rate of discharge in the source areas mainly depend on the melting of snow; contribution of summer rain is comparatively of less significant particularly in case of Indus and Sutlej. At lower altitudes monsoon rainfall augments the volume of rivers and the rivers now draw water from two sources, snow and rainfall. The Indus drainage system shows many variations, in the dominantly a dead level plain; local bad lands are created by the flood plains, high interfluves, and incised meanders. Alluvial fans of immense size are formed at the points of debouchment to the plain.

Quite different are small streams like Siran, Pounch, and Soan, which have their sources at lower elevation and their discharges are low for the whole year. They draw their water either from melting of limited and seasonal snow or from seepage, and during summer they pass high discharges for very short periods.

The last category of the streams consists of flash nullahs which swell high during the summer monsoon, and dry up for the rest of the year. Except for the Indus and Jhelum all the Five Rivers leave their mountain stages in Indian territory, hence their upper reaches are beyond Pakistan's territorial control of construction of control works or hydroelectric power from the natural high heads of water of the upper rivers, or even to maintain good watershed management. Such opportunities are confined to the Indus and Jhelum, to a limited extent.

Evolution in hydrographic pattern:-

A study of the evolution of the drainage system of the Indus is necessary to the understanding of the location and wealth of ground water resources.

Geologists have postulated various hypothesis about the existence of a proto-Indus river which spread over a vast area of the sub-Continent during the Eocene period, the existence of this river being largely based on geological and faunal studies, but the complicated history of the

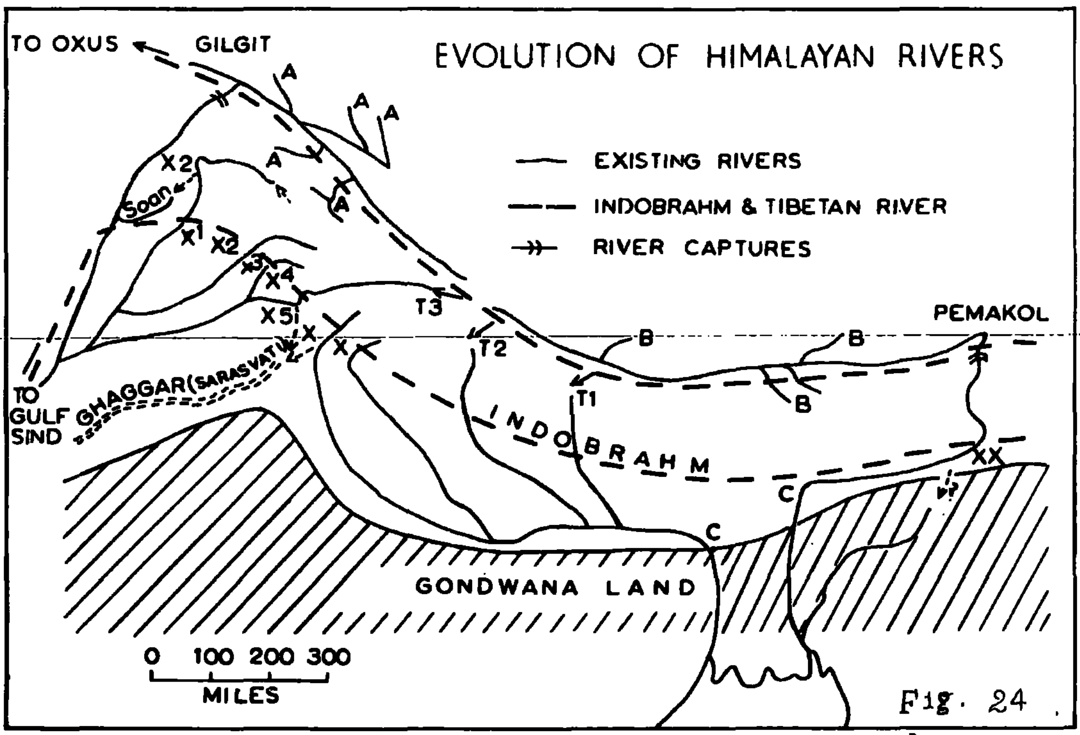

EVOLUTION OF HIMALAYAN RIVERS
TO OXUS
GILGIT
EXISTING RIVERS
INDOBRAHM & TIBETAN RIVER
RIVER CAPTURES
PEMAKOL
Soan
TO GULF SIND
GHAGGAR(SARASVATI)
INDOBRAHM
GONDWANA LAND
0 100 200 300
MILES

Fig. 24

river systems remains still a debateable point. Here only the most significant points can be mentioned.

Oldham, Pascoe, and Pilgrim unanimously agreed that the existing three river systems of the northern sub-continent, namely Indus, Ganges and Brahmaputra, led a combined westward and north westward course in pre-Siwalik times, and they deposited their debris brought down from the partially elevated Himalayas over the area which now form the Siwalik hills, encircling the Himalayas at their foot. (Fig. 24).

Oldham remarks that this Eocene river "once found its way to the sea by a single delta, instead of two, and this must have been at the head of Arabian sea or of the Bay of Bengal. The indications of the sea having extended up the Indus valley within the recent period, and the absence of any similar indications in the delta of the Ganges, make it probable that the former was the original outlet of the drainage".(16)

Pascoe, in his study of the oil belt of the former Punjab advanced a similar theory regarding the origin of the present river systems of the Pak-Hind sub-Continent. He maintained that the modern river systems are the result of the dismemberment of a former river which he named Indobrahm, and "the head waters of which consisted of the Brahmaputra flowing through Assam. This river flowed westwards and north-westwards along the foot of the Himalaya as far as the north-west Punjab, where it turned southwards along a line not very different from that of the modern Indus, and emptied itself into the Arabian Sea. In other words, the Assam Brahmaputra was once the headwaters of the Indus".(17)

Simultaneously, Pilgrim framed a conclusion about the history of the rivers, based on a field study on the Boulder conglomerates in the Siwalik. After an examination of the enormous thickness of these deposits, he opined that they could only be laid down by an enormously big river, which he named the Siwalik.(18) His view is similar to that of Pascoe, that, the Siwalik River carved out its valley parallel to the modern Himalayas in a westward and south westward direction, between the then rising Himalaya and the Deccan Trap and eventually it merged into the Gulf of Sind. Most probably it flowed more towards the west than at present over the area now covered by the Kirthar and Sulaiman mountains. In fact a genuine explanation has not been forwarded by both Pascoe and Pilgrim about the Siwalik beds of the Sulaiman and Kirthar ranges.

Below Kalabagh for some distance the Indus has certainly continued in the same course which it adopted in the Eocene times. The area below Kalabagh is known as Thal, which consists of massive detrital deposits. In the opinion of Davies the conglomerates "near Thal seem to indicate river action in that vicinity from early Cretaceous times onward".(19) He considers that, the river might have been the combined Chitral and Kurram, and the delta of this river receded and advanced according to the marine transgression and regression. Ultimately this river may have been captured by the Kabul river in its upper course. According to this theory, in the Eocene an Indobraham river flowed in the previous course of Kurram. It is certainly probable that the present Thal was an area of river deposition in post Cretaceous times. Later on rivers shifted their courses westward which leaving an apron of alluvium. The evidence about the ancient course of the Indus through the present Thal is provided by the presence of a long lake Basira in the Muzzuffarghar district.(11)

The postulated Indobraham or the Siwalik river was broken by the intensified Himalayan upheavals in the post Siwalik times. The unity of the one big river was severed and the modern drainage pattern thus came into being as:(20)

1. The Indus from north-west Hazara.
2. The five tributaries of the Indus.
3. The Ganges system.

Thus the present drainage is antecedent to the structure as it existed before the final uplift of the Himalayas and these rivers continued to cut their passages through the rising ranges and pour down to the plains.

The origin of the Jhelum, Chenab, Ravi, Beas and Sutlej corresponds with the upheaving of the upper Siwalik stage and resulting dismemberment of the Indus from the Ganges. In the meanwhile the uplift of Potwar plateau caused a rejuvenation of the small streams which previously dissipated into the lower Indus, and now they were enabled to capture the remaining arteries of the Siwalik river which passed through the Potwar to join the Indus. Fig. 24. "Ultimately, the head-waters joining up with the youthful torrents descending from the mountains, these rivers grew much in volume and formed these five important rivers, ... having their sources in the snows of the Great Himalaya Range and deriving their waters from as far east as the Manasarowar lake on the Kailas Range. The western portion of the broad but now deserted channel of the main river, after these mutilating operations has been occupied today by the puny ..... stream the Soan; a river out of harmony with its great basin and the enormous extent of the fluviatile deposits with which it is choked".(20)

In the sub-recent geological interlude,slight shifting of watershed between Jumna and Indus System brought changes in the courses of the easterly affluents of the

Indus and the western tributaries of the Jumna. Both physical and historical evidences exist to illustrate that Jumna used to discharge into the Indus System even in early historic times, then known by the name of Saraswati. The present Eastern Nara is regarded as a remnant of the old Ghaggar. Stein has propounded two causes for such a radical change in the hydrographic pattern.(21) "As regards the upper portion of the ancient bed, archaeological evidence attests a drying up during historic times, which is likely to have been at work in pre-history. It might have been hastened by the diversion of flood waters for irrigation brought about by more settled conditions and the resulting pressure of population. 2. Lower down on the Hakra, the main change was due to the Sutlej having in late pre-historic times abandoned the bed which before had joined the Ghaggar. The result of a law affecting all rivers whose course lies over alluvial plains". The extinction of the Sarawati led to a severe decrease in the surface water and the area became desiccated.

The accompanying Fig. 24 illustrates the views of Pascoe and Pilgrim as reconstructed by Spate.(22) The figure demonstrates the captures of the Tibetan river by Attock, Indus and Dihang; T1, T2, T3, possible outlets of the Tibetan river by Photu pass (Kali Gandak), Karnali, and Sutlej; A-A, northern Shigar, Nubra, Shyok, southern Shigar, Zaskar, suggesting south east flowing Indus (De Terra); B-B, tributaries suggesting possible a western-flowing Tsangpo, C-C, possible disruption of Indobrahm by proto-Gages and proto-Brahmaputra; X1-X5, successive captures of Indobrahm by Punjab rivers, XX, possible capture of Meghna waters by Indobrahm after former had captured head waters of Tibetan river, XY, XZ, possible captures of Upper Jhelum by Chenab and Upper Soan by Jhelum; X,X captures by Ganges (reversed) Indobrahm cutting back westwards.

The most recent discussion has been opened by Geddes.(23) He accepts a possible Tibetan river, but no Sub-Himalayan Siwalik or Indobrahm. On morphological and hydraulic grounds, he maintains, it is most unlikely that a mountain foot river would flood along the depression and carry detritus of the type found in Siwalik pebble beds. His alternative hypothesis is that the pebble beds represent a zone of coalesced fan deposition from N-S streams. Also, Geddes believes there is no real evidence for the river captures noted on Fig. 24, apart from the Jumna case. Krishna and Aiyangor together with Geddes see no need for involving the presence of an Indobrahm river to explain the character of the Indo Gangetic plain.(24)

The final outcome of this controversy remains in doubt although it is probably more accurate to postulate a Tibetan river and to ignore the possible existence of an Indobrahm.

<u>River Regimes</u>:-

The monthly normal discharges of the Indus and its eastern affluents have been charted in Figs. 25, A-F.(25)

The Figures illustrate vividly how all the rivers have seasonal variations in flow, but each is markedly individual. The common feature of all the rivers is the small volume of water in winter. The volume of water increases steadily as the snow in their catchment areas starts melting as the summer draws near. During this time of the year there is practically no rainfall therefore the volume of water depends entirely on the geographical conditions of the catchment area, such as the size of the catchment area, their average elevation with regard to the snow line and their situation in relation to monsoon air movement (See Appendix 6).

Ravi occupies the smallest catchment area, which commands a small extent of glaciers 100 square miles only, but there is a higher average rainfall 93" than in any other catchment basins. The minimum monthly discharges in its catchment recorded as 2,086 cusecs. The vast

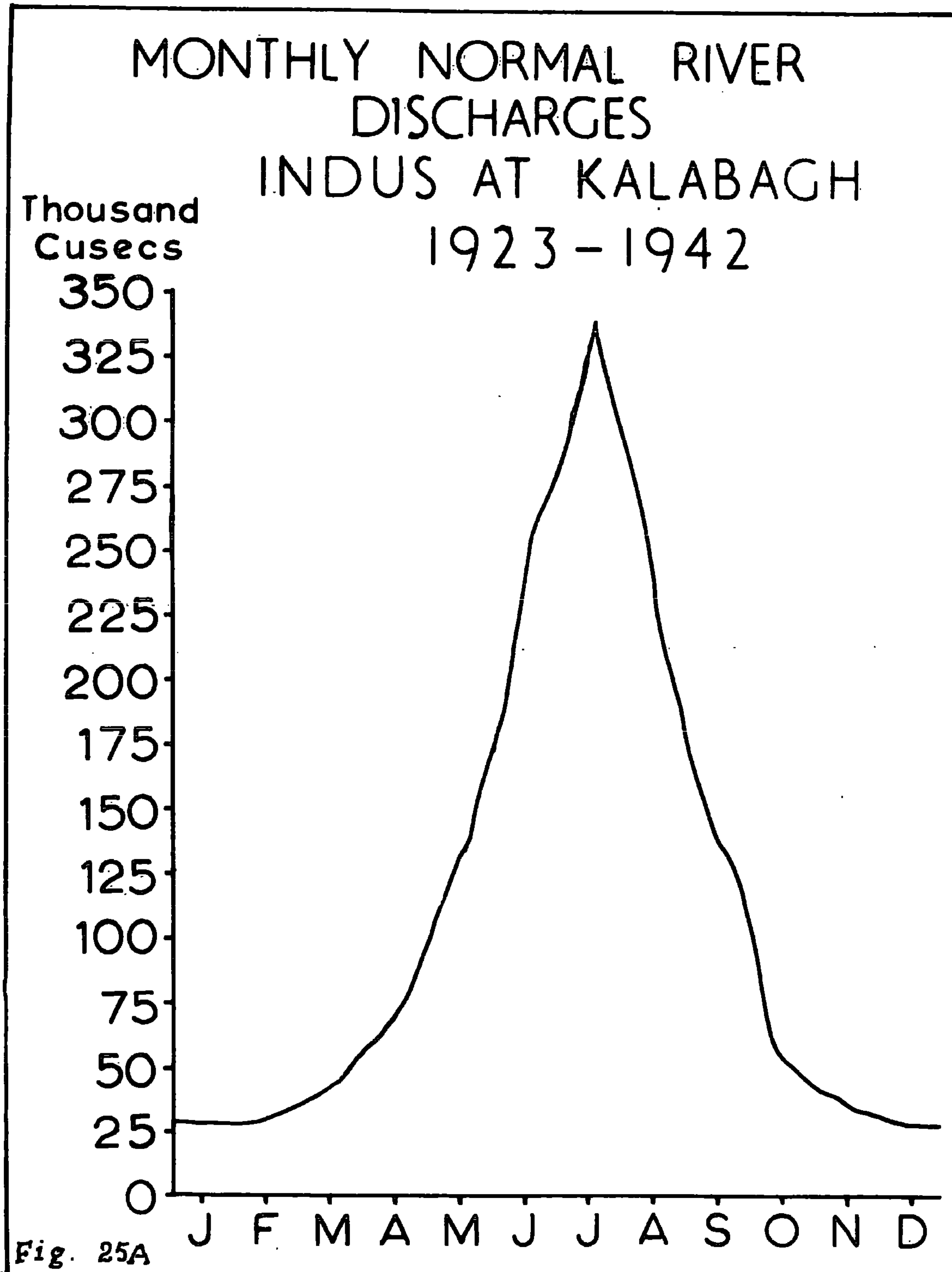
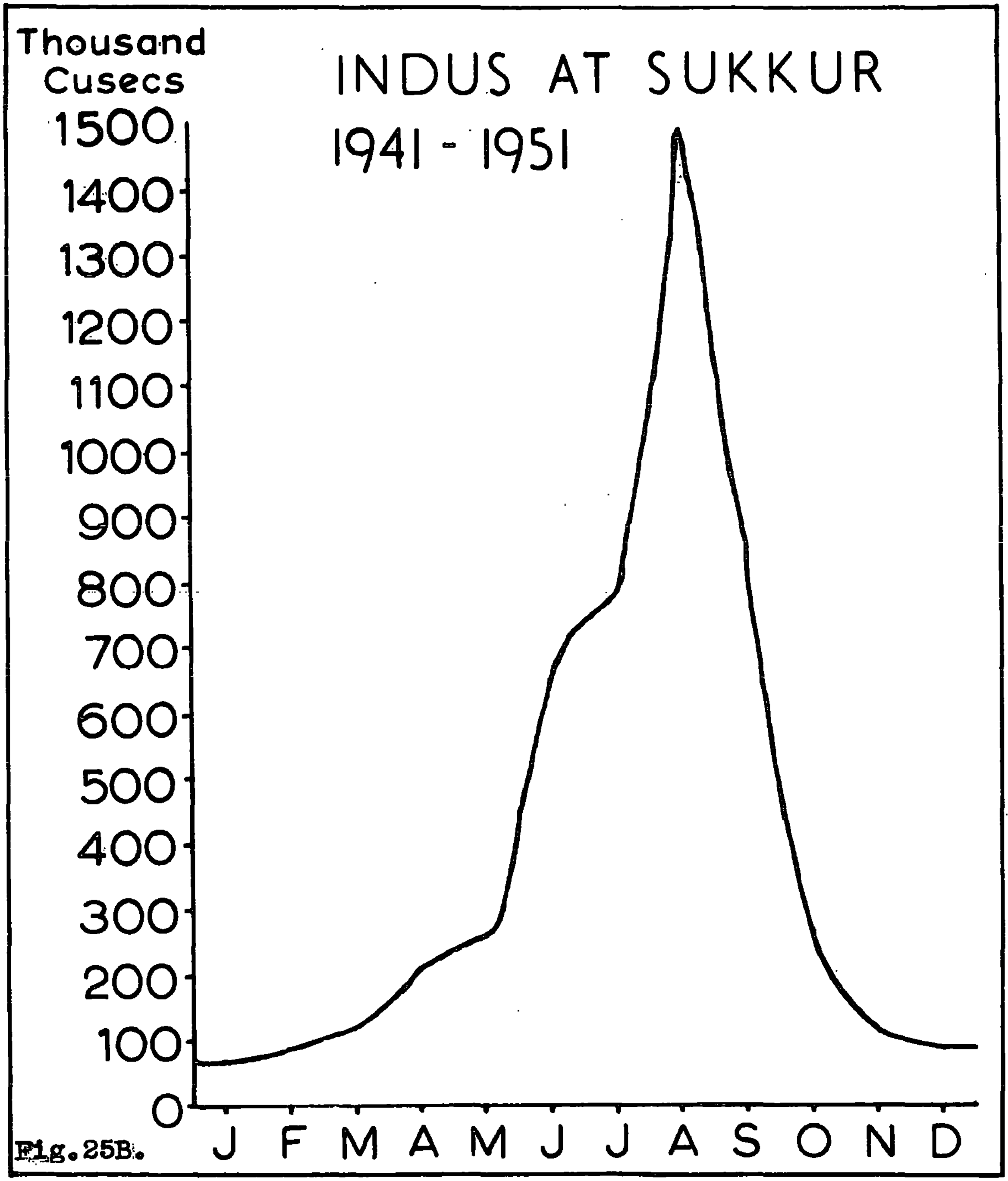

MONTHLY NORMAL RIVER DISCHARGES
INDUS AT KALABAGH
1923 - 1942
Thousand Cusecs
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
J F M A M J J A S O N D

Fig. 25A

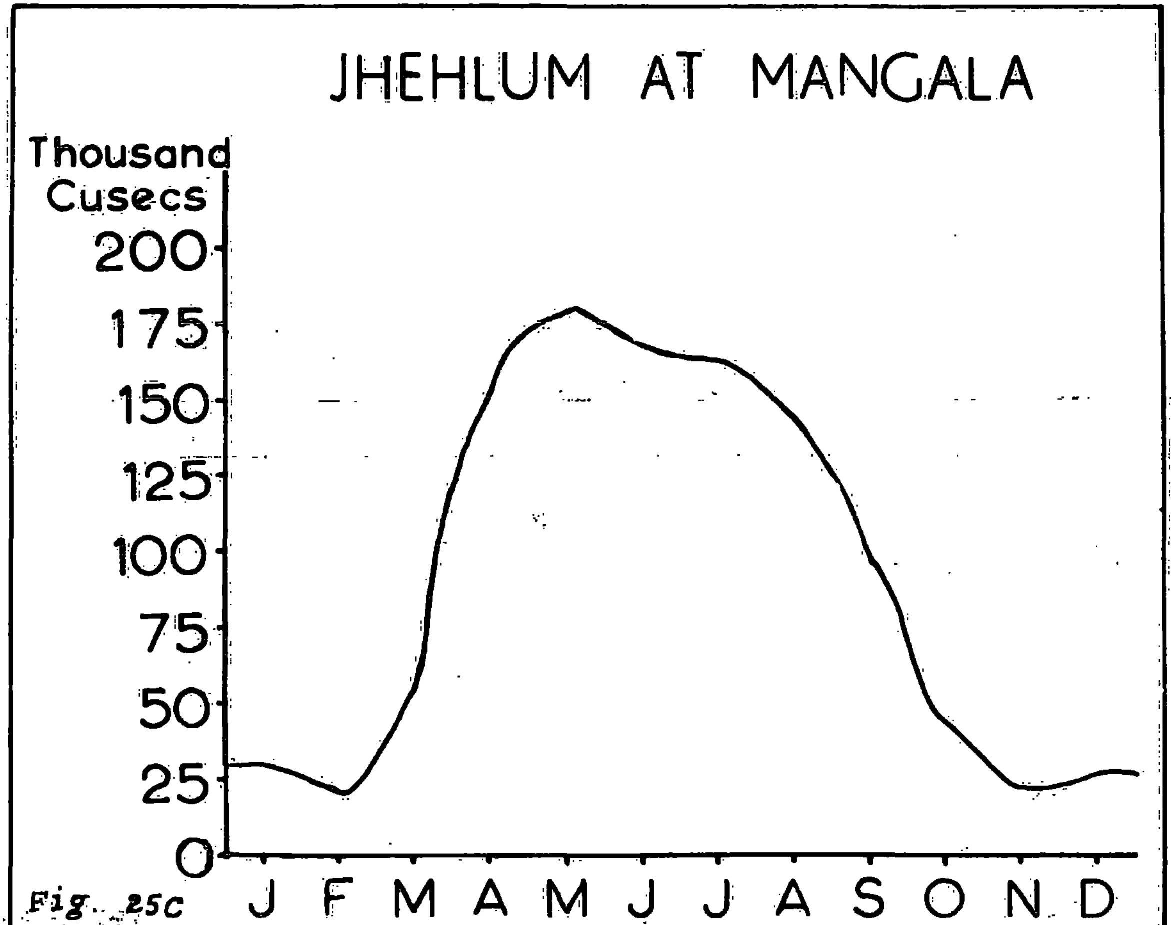


Thousand Cusecs
INDUS AT SUKKUR
1941 - 1951
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
J F M A M J J A S O N D

Fig. 25B.

extent of glaciers is more important than the amount of rainfall in producing a greater volume of water in case of the Indus river, where the mean annual rainfall, falls to 17.74", the glacier area of the Indus catchment being more than hundred times greater than that of the Ravi. The minimum recorded discharges in the catchment of the Indus is 18,870 cusecs. The heavy rainfall produces a great volume of water only for a short time, but the large contribution of the glaciers keeps constant flow of water to the rivers.

The graphs showing the seasonal changes in the volume of the rivers, Jhelum, Chenab, Ravi and Sutlej indicate the interplay of snow and rain in contributing to river flow. In the case of Jhelum, a rapid early snow melt results in the first maximum occuring in May. This heavy flow is maintained by the monsoon rains and decreases relatively slowly as the rains die away. In the case of the Chenab, the spring snow melt is slower and the rise in volume steady until during July and August a short high maximum results from the coincidence of the rains and snow melt. The fall is rapid. In the Ravi and Sutlej snow melt gives relatively small increases in volume and only with the bursting of the monsoon in the mountains comes the immense increase to flood maximum.



JHEHLUM AT MANGALA
Thousand Cusecs
200
175
150
125
100
75
50
25
0
J F M A M J J A S O N D

Fig. 25c

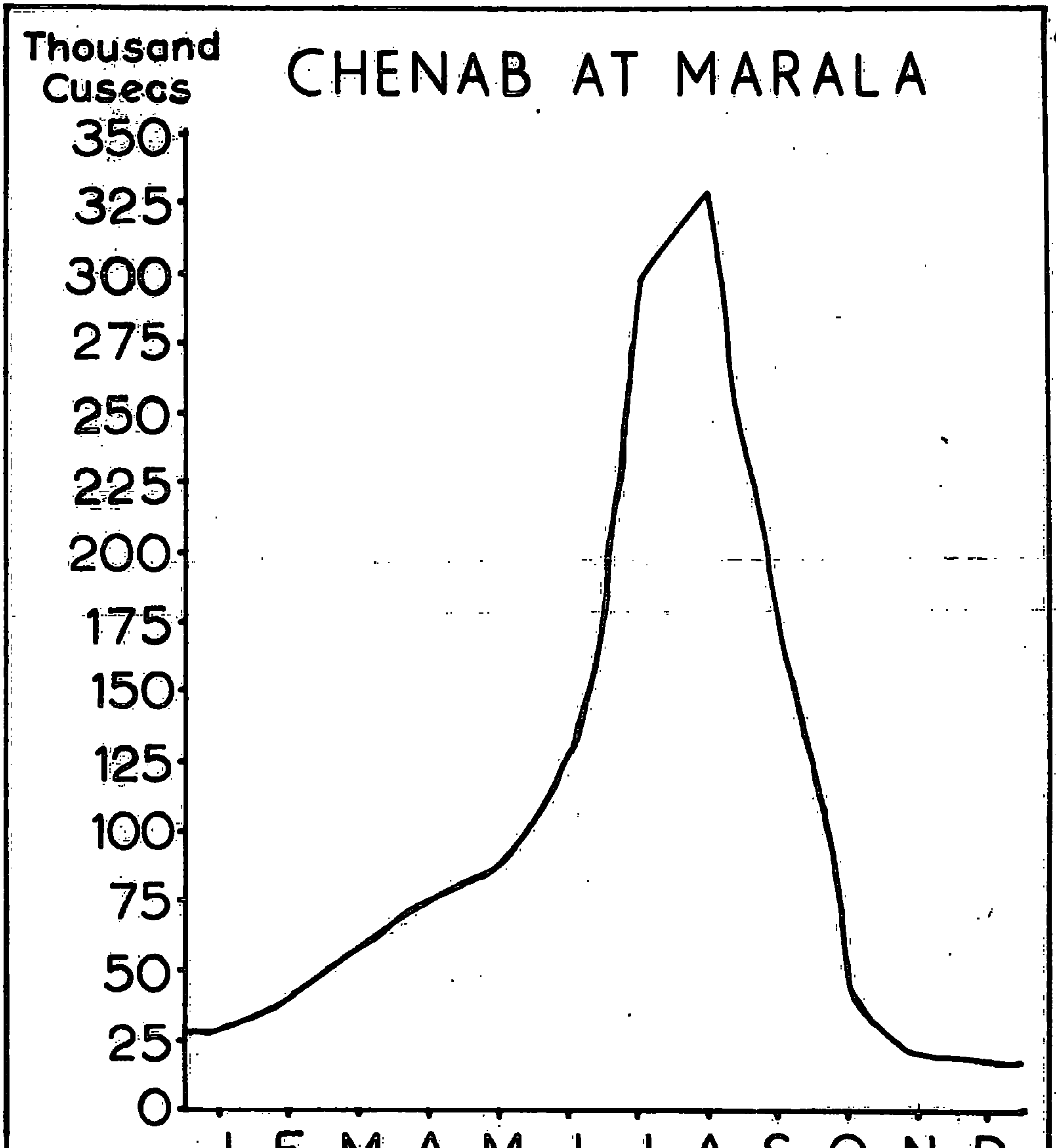

Thousand Cusecs
CHENAB AT MARALA
350
325
300
275
250
225
200
175
150
125
100
75
50
25
0
J F M A M J J A S O N D

Fig. 25D

Where the increment from the glaciers and snowfed hills is great as in the case of Chenab, the flood season is prolonged. Where the monsoon rains alone are of importance the spate is sudden and short. Problems of control and utilisation, as noted below, will obviously differ.

Table 6

Normal monthly discharge
Indus

	At Kalabagh	At Sukkur
January	26,584	65,003
February	29,128	39,601
March	41,707	113,543
April	70,040	213,041
May	193,536	250,045
June	253,115	671,226
July	337,077	792,612
August	297,023	145,998
September	135,287	767,285
October	52,169	266,309
November	33,690	121,204
December	28,169	95,712

In order to describe the Indus regime, graphs for flow at two places have been drawn, the purpose being to show the volume of water of the Indus before it collects the

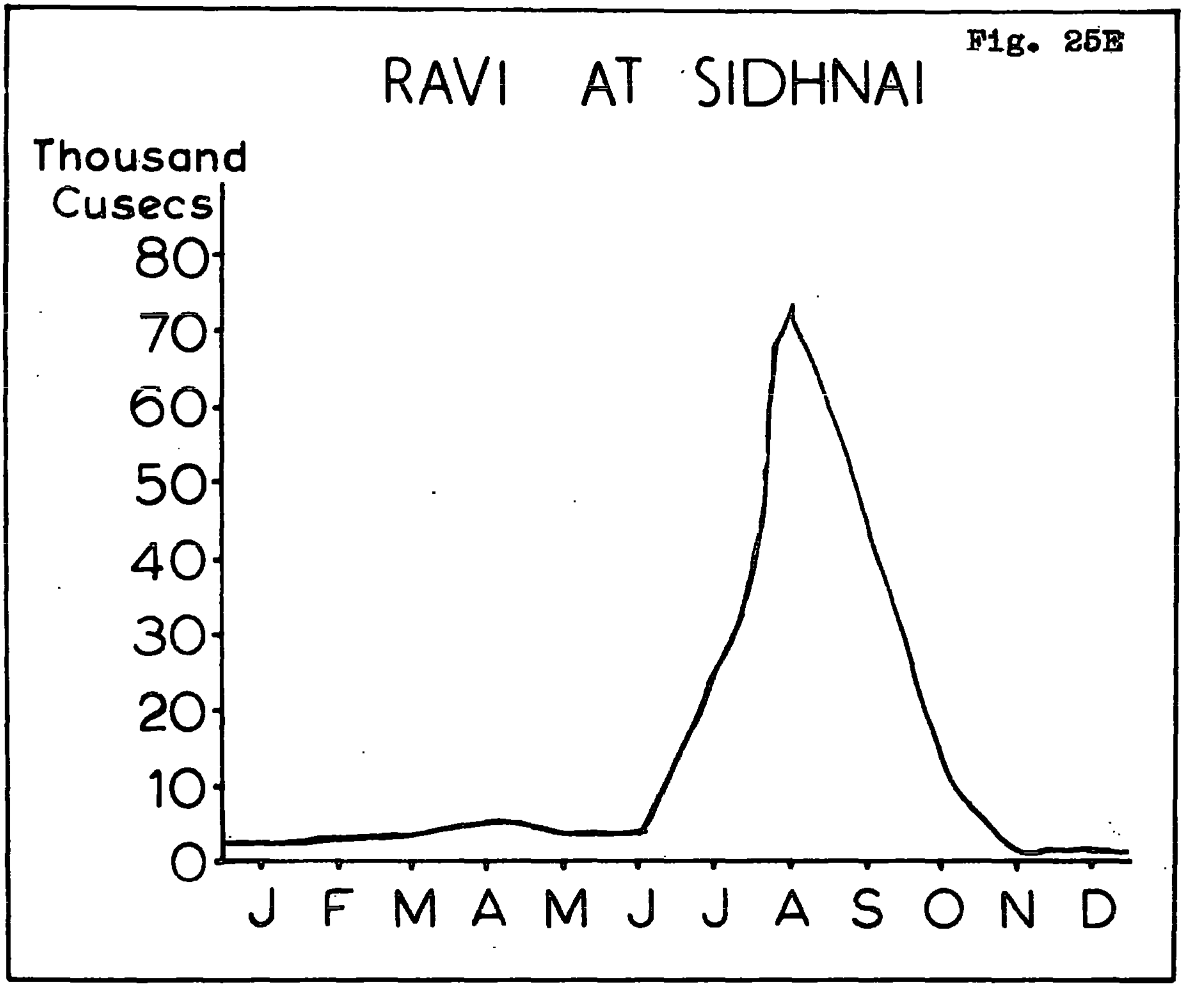
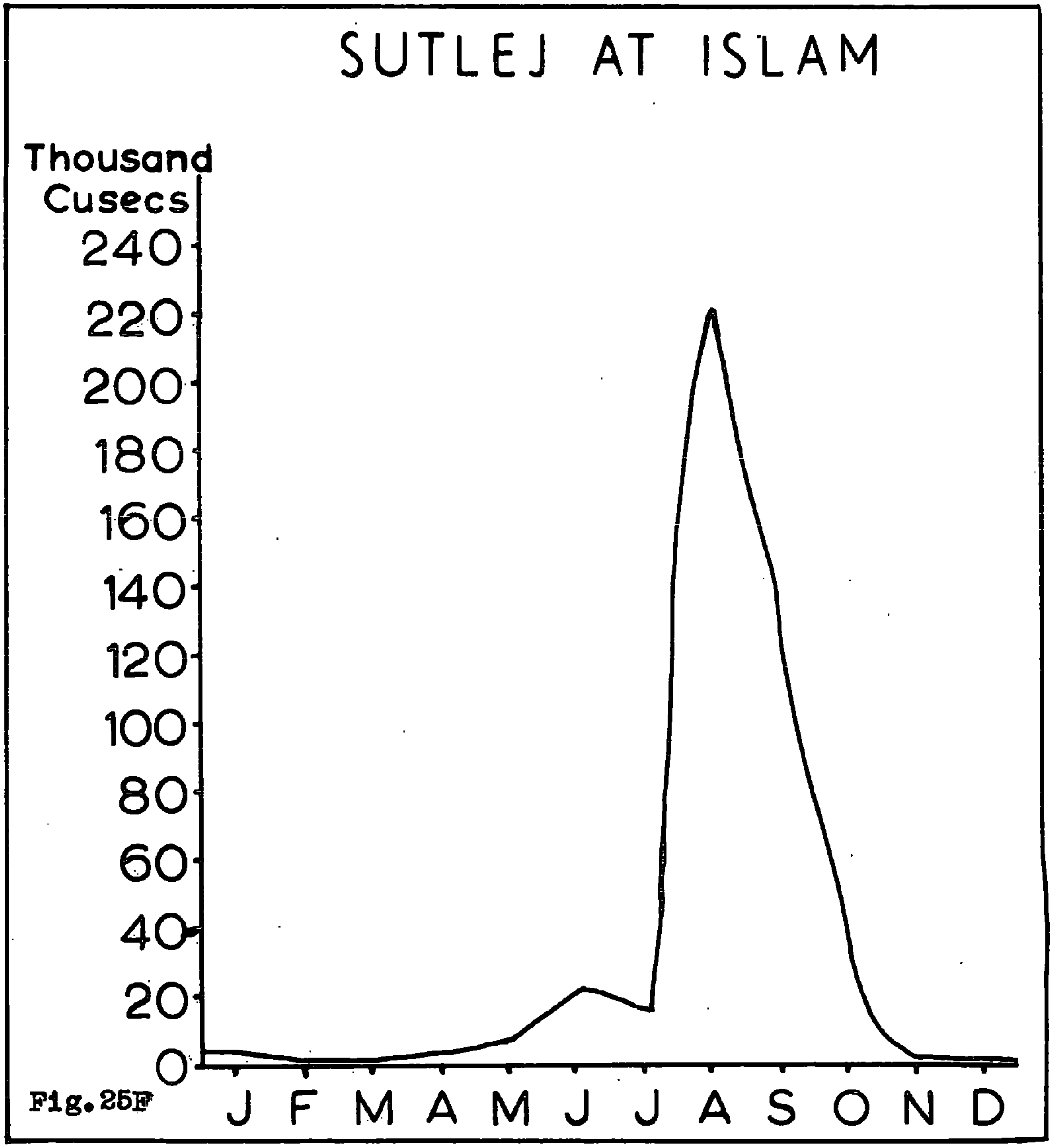


Fig. 25E
RAVI AT SIDHNAI
Thousand Cusecs
80
70
60
50
40
30
20
10
0
J F M A M J J A S O N D


SUTLEJ AT ISLAM
Thousand Cusecs
240
220
200
180
160
140
120
100
80
60
40
20
0
J F M A M J J A S O N D
Fig.25F

waters of its eastern tributaries, the Jhelum, Chenab, Ravi, and Sutlej, the Kalabagh (25) example, while Sukkur was selected as a point at which the Indus is joined with the combined waters of its eastern associates. Both Kalabagh and Sukkur are similar in their topographic dispositions. At Kalabagh the amplitude of river is very similar to that of the Chenab. (Table 6). Water begins to rise steeply by March until the crest is reached in July. The rise is caused by the melting of enormous glaciers in the vast source region of the Indus, and is maximised by July-August rainfall. The magnitude of the volume of water decreases rapidly after August. Fig. 25A.

At Sukkur the volume of water is very large throughout the year, but it gains more after May. It attains the highest magnitude in August. Compared with the rise its fall is very steep during August-November.

The striking differences in regime pattern at the two places, shows the difference between single river flow and the complex effects of the combination of different streams.

The graphs for all the rivers show that flow is extremely changeable. Table 7.

Table 7

	Jhelum at Mangla	Chenab at Marala	Ravi at Sidhnai	Sutlej at Islam
January	28,076	31,153	2,768	4,687
February	22,428	39,263	3,185	1,281
March	53,157	60,236	3,818	990
April	157,634	75,038	5,078	4,765
May	178,468	87,923	4,168	7,965
June	168,945	128,862	3,374	22,506
July	162,509	292,324	24,044	15,062
August	144,006	300,466	73,407	220,009
September	80,733	169,261	44,728	1,281,205
October	39,259	48,111	13,454	31,233
November	23,395	24,432	1,638	2,371
December	26,667	22,586	1,752	1,670

Table 8

River discharge (cusecs)

River	Site of discharge	Date	Maximum	Date	Minimum
Indus	Attock	12-7-1942	1,000,000		18,000
	Kalabagh	12-7-42	917,015	17-12-36	17,304
	Ghazighat	7-8-50	827,998	5-2-41	15,836

River	Site of discharge	Date	Maxi-mum	Date	Mini-mum
Jhelum	Mangla (above)	29-8-28	760,000	9-1-17	3,943
Chenab	Marala (above)	29-8-29	718,000	25-1-39	3,618
Ravi	Madhopur (above)	5-10-55	650,000	-	1,300
Sutlej	Ferozepur (above)	15-8-25	353,960	23-3-32	2,651

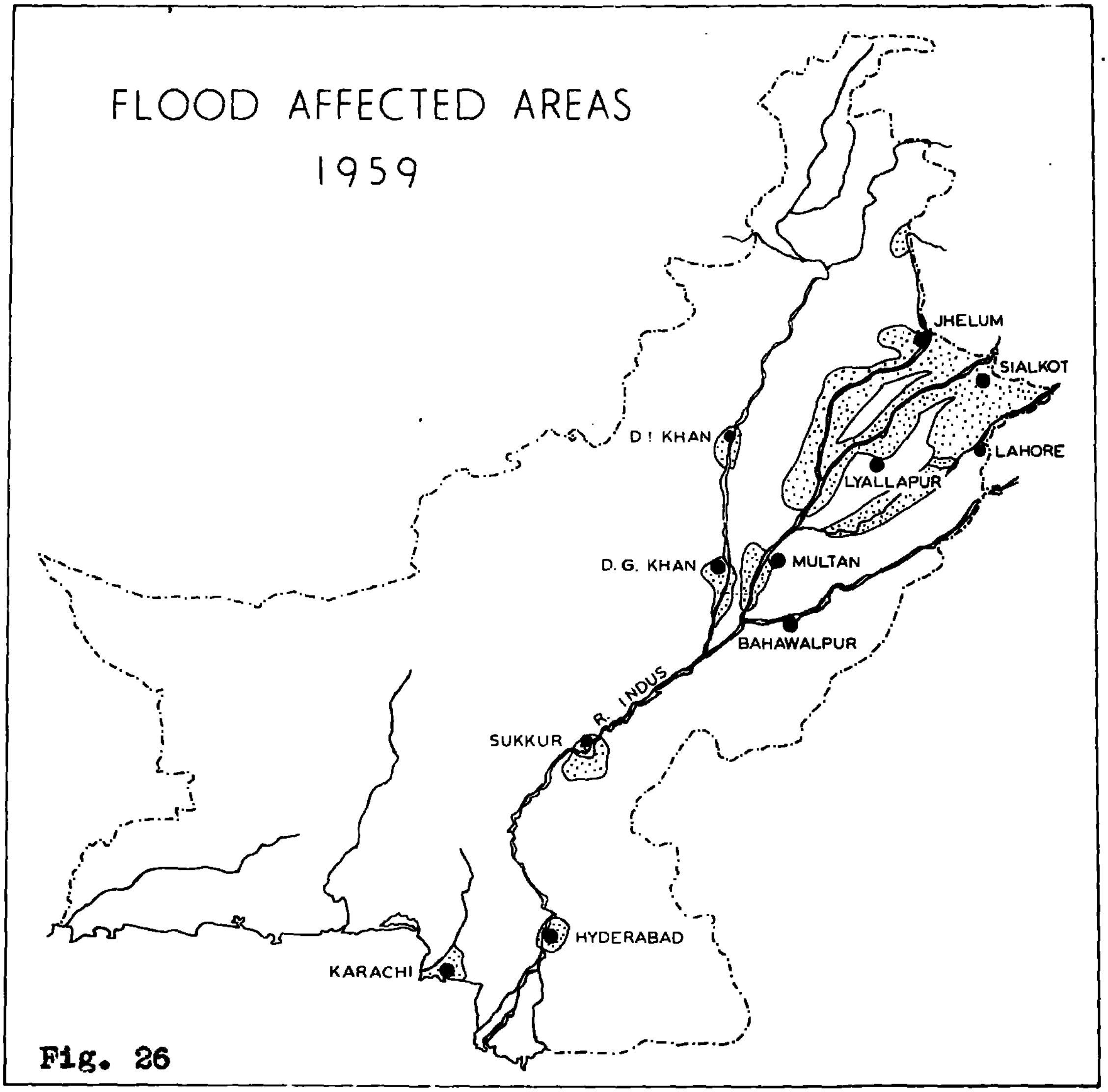
In general the summer discharges in all the rivers are about 20 times more than the winter; the lean period is from January to February.

The total average annual flow of the Indus jointly with its tributaries is about 168 million acre feet, a very high annual run-off. The determination of suitable storage sites may prove a means to diminish the run-off and to store some fraction of it. These dams must be built in such a way as to avoid the constant danger of dam choking by silt. Such controls of a very heavy run off bring grave problems of construction expenditure. Such long term schemes will not solve instantly the water problem nor capital will be returned soon, and in fact they may create an additional short term problem by displacing settled populations. A sum of Rs 247.0 million is expected to be paid as compensation for 68,000 acres of land which is submerged for the Mangla Dam. In addition to this, 2,200 urban and 17,000 rural houses will be affected, and nearly 200 villages in Azad Kashmir. A sum of Rs 80 million has already been paid. Eleven thousand acres of land have already been procured to resettle agricultural families.(2)

It is equally desirable to control and conserve the flow of flash streams and nullahs. Such small scale and short time schemes will suit many dispersed needs for water conservation and they are relatively economical as their outlay will be returned soon.

The colossal volume of run-off in the catchment basins and the amplitude of variations in river flow is of vast importance for irrigation, especially in the critical periods of drought and flood. If these variations in the river flow could possibly be predicted before hand it would be a great help in the regulation and distribution of the irrigation water. Moreover, the farmers could also plan out crop operations with efficient use of irrigation supplies.

As the river regimes depend on direct and indirect climatic factors, affecting the highlands, the agricultural programme of the plains, directly controlled by some climatic factors does not accord with this scheme. The Rabi crop (winter) and the Kharif crop (summer) are always short of water. On the other hand for 2-3 months each year rivers



FLOOD AFFECTED AREAS
1959
JHELUM
SIALKOT
LAHORE
LYALLAPUR
D I KHAN
D. G. KHAN
MULTAN
BAHAWALPUR
R. INDUS
SUKKUR
HYDERABAD
KARACHI

Fig. 26

carry large surpluses over and above the agricultural needs. Hence a considerable quantity is wasted, without being put to a beneficial use. Shortages and surpluses occur in startling proximity. Moreover the surplus water in the rainy season every year result in floods and renders widespread destruction in the productive areas.

<u>Floods</u>:-

The big rivers of West Pakistan undoubtedly are a gift of Allah, but they inflict ~~people~~ by yearly floods an incalculable damage to life, land, communication lines, agriculture and property. "The floods of 1950 were of such intensity that they were considered a freak. But floods recurred".(26)

"High intensity floods swept the West Pakistan plains in 1954, 1955, 1956 and again, though to a lesser extent, in 1957, and 1958. With each devastation spreading at times, over an area of nearly 30,000 square miles and resulting in damage to crops and property of over 10 crores of ruppes, the problem of flood control assumed a new importance".(26) (Fig. 26 and Plate 14).

The occurrence of flooding is in some ways a matter of recording of disaster. For statistical record the definition adopted by the old Indian Meteorological Department is used here, viz; years of flood or drought are equated with

Plate 14

those years in which specific deviation from mean devation is of the order of X 2 plus or minus respectively. In Figs. 27 A-B such data for the period 1875-1944 are plotted to show flood and drought frequency.(27) Their results show that the areas of greatest frequency of floods and droughts are those which receive the least amount of rainfall such as the Divisions of Quetta, Kalat, Hyderabad and Khairpur. The number of floods and droughts for West Pakistan are tabulated below:

	Division	No. of Floods	No. of Droughts
1.	Quetta - Kalat	12	12
2.	Khairpur and Hyderabad	11	7
3.	Peshawar and D.I. Khan	9	3
4.	Multan, Lahore Rawalpindi and Bahawalpur	8	3

This illustrates that the drier the area the more tendency of equalisation of floods and droughts as in case of Quetta, Kalat, Khairpur and Hyderabad.

Floods are the result of many combined factors. The immediate reason of course is the excessive and continuous seasonal rainfall which results in excessive run-off. The question,which remains is to what extent

FLOODS: FREQUENCY OF SPECIFIC ANNUAL DEVIATION 2x MEAN POSITIVE DEVIATION, RAINFALL 1875-1940

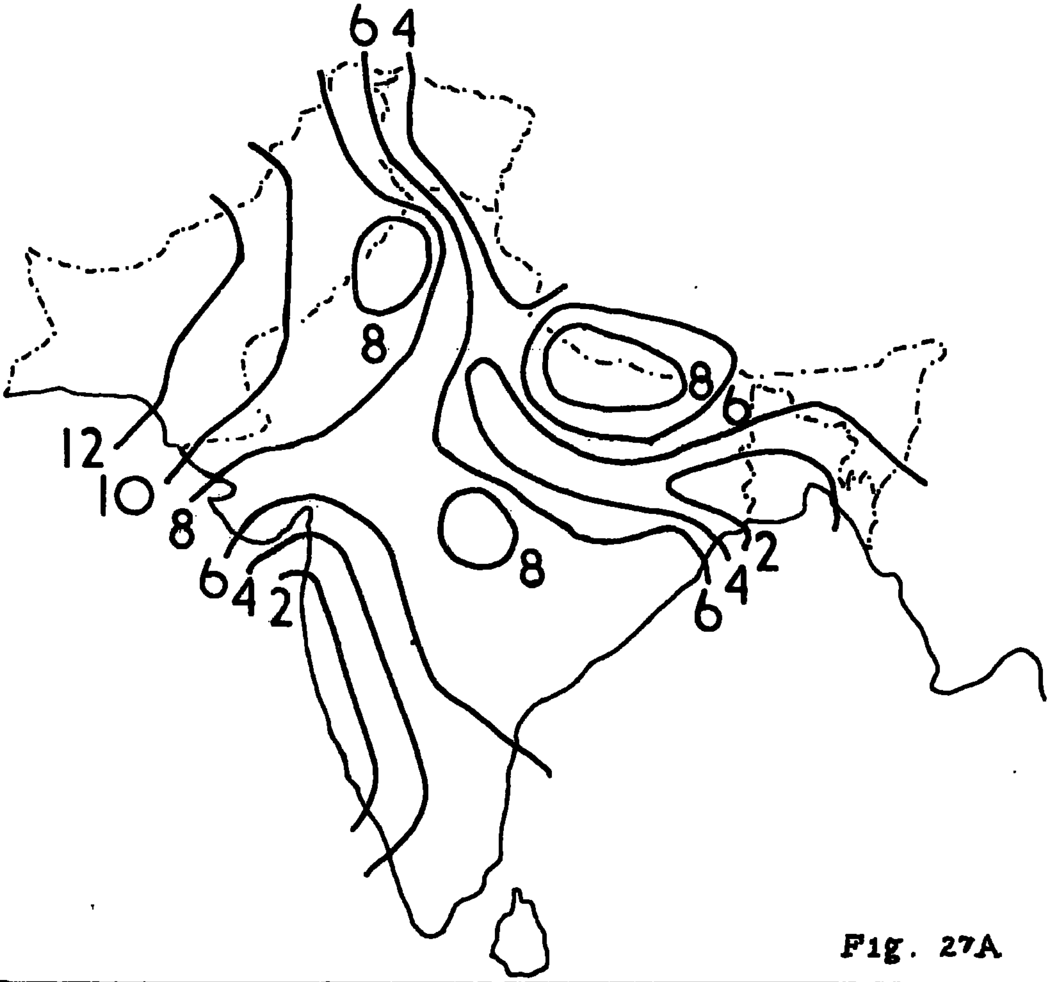


Fig. 27A

DROUGHTS: FREQUENCY OF SPECIFIC ANNUAL DEVIATION 2 x MEAN NEGATIVE DEVIATION, RAINFALL 1875-1940

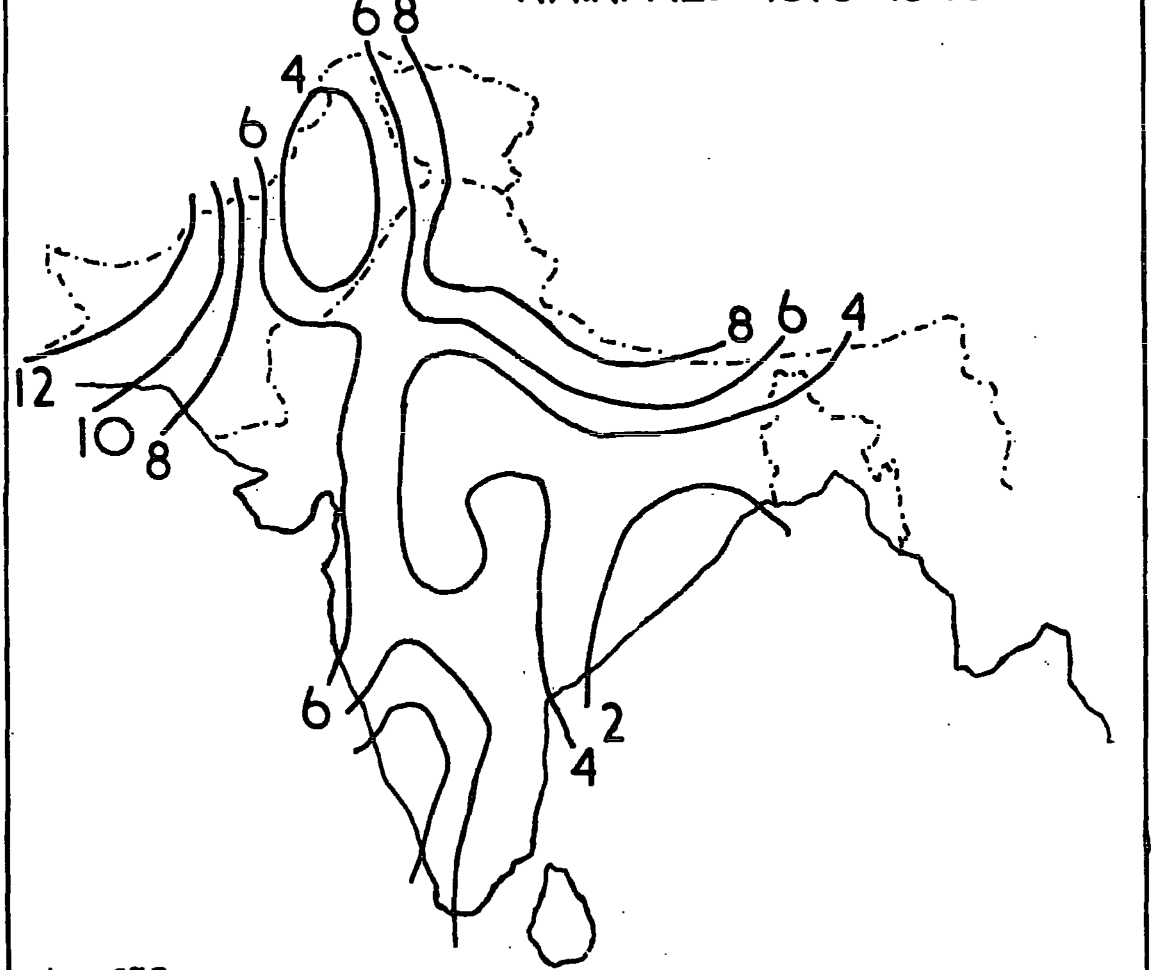


Fig. 27B.

run-off is increased by human interference with the ecological balance, particularly through the destruction of natural vegetation cover. (See Chapter 5). The seasonal regime of rainfall and snowmelt is not in itself solely responsible for the occurrence of floods. Floods are caused by torrential downpours falling on a rugged barren topography. The water volume is increased by the melting of snow which begins in March and continues into the monsoon rainy period. The Indus catchment and those of its eastern tributaries are characterised by monsoon rainfall maxima. The surface run off, which produces floods does not only depend on a rain of long duration but it depends on the heavy falls of short duration (discussed in the preceding chapter).

Conditions become conducive to the development of marked flood peaks when the catchment areas get saturated under continuous rainfall,or if owing to geological constitution rocks possess low capacity of absorbing water. The run-off proportion is also high when the surface of the catchment area is frozen or bare. On the other hand a thick vegetative cover retards the speed of runoff. Low temperatures and high humidity also enhance the run-off phenomena owing to the diminishing strength of evaporation.

The simultaneously heavy rainfall in all the catchment areas of the rivers of West Pakistan is the major factor in producing synchronised flood peaks from July to August in all the rivers.

Besides this, the frequency of the floods during the last 27 years has been contributed to by the ruthless deforestation of the catchment areas of the rivers.(28) (See Chapter 5, Soil). The raising of river beds with silt, further spreads the extent of floods as illustrated already. An immense quantity of silt is brought down by the rivers every year. It is estimated that Indus alone carries some 1,000,000 tons of suspended matter daily.(3) Structure and geology are also significant factors in the creation of floods. As noted above only the Indus and the Jhelum have their mountain section in West Pakistan territory. The mountainous course of the remaining rivers remain in Bharat. Downstream to Durband the Indus traverses hard sedimentary rocks. The area of Kalabagh and Warsak is made up of Siwalik beds which are readily erodable especially at present when they are barren and devoid of vegetation. The Jhelum flows over an area of hard rocks in the Hazara country and passes through some forest clad tracts. After Mangla it opens out in the country of weak rocks, vulnerable to erosion. The rest of the rivers flow over the alluvium of the upper Indus plain, where the rivers have cut braided channels and meanders particularly the Indus itself.

The study of silt data made by Nazir and associates showed that the amount of silt accumulation corresponds to the rate of discharge or run-off.(10) Silt is transported during July-October, but the heaviest discharges were recorded in July and August, as appears in the table below:

Table 9

Sediment and discharge data of Ravi at Shahdara 1956.

Months	Discharge in 10^3 A.ft.	Sediment in 10^3 A.ft.	Percentage
July	1,293	4.104	0.317
August	2,174	10.196	0.469
September	888	3.00	0.337
October	115	0.675	0.587

Under such circumstances not only floods are encouraged but the behaviour and physical conditions of the stream channels present special problem in taming the rivers and in dam erection. Simple barrages would only be suitable to store water during the period of low silt carriage, and during the months of high sediment bearing, the normal flow of the river must be kept. The silt accumulation is not only progressive in the plains but it is accelerating in the uplands also. "A curious thing has happened in Civil Lines in Tank. The silt has come down with the floods to such an extent that the surrounding country is now more than six feet higher than Civil Lines itself".(29)

The constriction of river channels consequent upon the construction of embankments as a means to prevent the floods is in itself dangerous. These embankments provide obstructions to the natural flow of river and silt deposition over the adjoining land. The river is forced more and more to deposit the silt in its channel. Extreme erosion of the upper reaches has increased the load on the river bed and its level has been raised. The river bed which was previously deeply sunk in a generally aggraded plain itself has become shallow and broad in the course of time with heavy silt deposits. In this way "All the larger rivers of the Punjab and Sind have been slowly but steadily building up their beds. Thus the lowest excavations at Mohenjo Daro in Sind show that 5,000 years ago that town was on ground 35 feet below the present ground level. It is estimated that the Indus bank levels have been rising since then at a rate exceeding 1 foot per 100 years".(4)

In addition to the above, the present floods are in part caused by human interference with the natural drainage of the lowland which has been upset by unscientific and haphazard canal constructions; modern roads and railways have further disturbed the drainage equilibrium.

The effects of floods:-

For the present work it is not possible for the candidate to calculate the number of possible combinations of flood causing factors. Whatever the flood producing factors, the yearly floods result in enormous physical losses, dislocation of the economy and continuing human misery. Every year an irreparable loss is produced and hardly has both Government and public meet the losses of one flood that it is followed by another of equal or higher intensity.

There are of course many areas, both in the lowland and uplands where agriculture is only made possible by the flood water. The flood water penetrates into such areas and spreads a layer of silt also, which contributes both to fertility of soil and high crop yield.

The most beneficial result of the floods is the washing away of salts from the salinity affected areas. Aside from this filth and refuse is rapidly washed away from the areas of ill-defined drainage. The floods produce a deep sheet of water over thousands of acres of thirsty land, minimise the effects of high temperatures on vegetative cover, and improve conditions for cultivated plants also.

On the other hand, the disadvantages particularly since population density has increased range so high, that the benefits fade into insignificance beside the disadvantages and irreparable losses, to agriculture, irrigation, industry, trade, transportation, communication, and many other human activities. The floods bring devastation to the maturing crops of food and fodder and almost all the irrigation devices from canals to tube wells are damaged in the flood affected colonies. Market facilities and commerce are disorganised, and the economy of both rural and urban sections collapses. The table below indicates the number of villages affected by the annual floods from 1948-1957.(30)

Flood years	Number of villages		
	Affected	Damaged	Destroyed
1948	5,000	3,456	122
1950	10,000	4,538	1,100
1954	3,747	2,000	600
1955	6,945	2,913	500
1956	11,609	4,000	400
1957	4,498	2,000	300
Total	41,799	18,907	3,022

It shows that the floods of only 6 years have damaged

18,907 villages, while 3,022 villages were destroyed completely. The damage rendered to private property excluding houses was estimated as Rs 17 million and the estimated total damage from 1948-1957 has been Rs 147 million, this in a country desperately short of capital.

An impression of cultivated area affected and values of crops destroyed may be gathered by the following statistics.

Years	Area Affected in acres	Area Destroyed in acres	Value of Crops destroyed m.Rs.
1948	1,000,000	754,000	75,000,000
1950	1,765,544	700,724	70,611,317
1954	1,587,177	308,810	30,000,000
1955	1,711,952	990,121	80,482,020
1956	2,180,489	798,956	79,290,108
1957	2,085,883	635,997	66,832,871
Total	10,331,045	4,188,608	402,216,316

Cotton was particularly adversely affected by the standing water, and sugarcane inspite of being a hydrophytic plant was also affected. The floods are very destructive of both private and government food grain reserves, the scale of loss stated below:-

Years	Food grains destroyed in maunds
1948	50,000
1950	1,425,253
1954	54,392
1955	1,428,496
1956	1,228,164
1957	242,556
Total	4,428,861

The value of the destroyed food grains was about Rs 2.9 million in 1957 and Rs 48.7 million since 1948-1957.

In the same way fodder for the livestock was washed away or completely destroyed. The value of such fodder was Rs 2.8 millions in 1957 and nearly Rs 25 million for 1948-1957:

Year	Fodder in Maunds
1948	1,000,000
1950	3,525,571
1954	1,500,000
1955	1,788,016
1956	1,074,284
1957	1,134,749
Total	10,022,620

Livestock was equally affected and for the protection of stock many difficulties crop up during such periods, the transportation of the animals from the low lying flooded areas to the safe high lying grounds, provision of scarce fodder, checking high death rates by provision of veterinary assistance and the disposal of dead beasts. During floods a number of temporary and emergency veterinary centres have to be opened to treat the animals; and a large number of cattle are lost even in the process of bringing them to these medical centres. The losses may be visualised from the data stated below.

Years	Cattle Head lost
1948	2,877
1950	41,662
1954	5,135
1955	36,985
1956	2,500
1957	4,050
Total	93,209

The calculated loss was Rs 9.3 millions, taking the average cost of animal as Rs 100 per head.

In 1957 alone about 5,337 wells and tube wells were damaged and the cost of their repairment was Rs 1.4 million. The value of damage done to canals in 1950 was Rs 7 millions.

The industrial towns located on the river banks are affected badly, Sialkot, Gujranmala, Shahdara, Badamibagh, remaining under water for several days, factories submerged, and electric and telephonic connections paralysed for a couple of weeks. The factories were not only affected in flooded areas, but in the areas out of flood reach were also affected indirectly for want of raw material in the circumstances of suspended traffic. Hence industry over a vast area is brought to a standstill which results in the fall of level of income and employment and the raising of production costs. The daily routine of labour is also affected as workers are displaced from their houses and evacuated to the safe areas, and industrial firms are forced to close for long periods even after the floods subside.

Along with this overall disorganization of human activities in vast areas, price structures are also disturbed seriously. The prices of all edible commodities are sharply raised in spite of controls:

Changes due to floods in wholesale prices Lahore 1950

Commodity	Percentage change
Grain	+ 1.2
Barley	+ 8.5
Rice Basmati	+ 18.3

Moong whole	+ 12.5
Chillies Dry	+ 12.4
Mash whole	+ 28.4
Onions	- 24.0
Potatoes	- 5.6
Gur Desi	+ 26.3
Salt Rock	+ 2.4
Firewood	+ 1.6
Cotton Desi (unginned)	+ 9.7
Toria	+ 1.4
Sarson Oil	+ 4.6
Cement	+ 31.4

As railway and road tracks were breached passenger and commodity traffic contracted, and as a consequence rail and road earnings and business and employment was curtailed. The number of the breaches in the railway track between Lahore and Multan was 100 within a distance of 200 miles. The cost of such damage was estimated as Rs 1 million in 1954 and Rs 6 million in 1957. Even so, the cost of measures adopted for flood protection was Rs 10 million. The table below relates the estimated value of all types of losses suffered during 1947-1957 in the whole of West Pakistan.

Flood year	Loss million Rupees
1947	100
1948	128
1950	212
1954	72
1955	185
1956	166
1957	121
Total	984

The colossal amount of loss presents a dismal picture of the Pakistan economy. The permanent prevention of flood would provide opportunities in saving a large fraction of this amount for the development of numerous aspects of the Pakistan economy. The floods have their repercussion on the development and implementation of not only the flood control schemes but each and every development scheme.

To sum up, floods have become a phenomena of permanent occurrence. Once called the granary of the sub-continent, the Punjab is now hard put to supply West Pakistan with its needs. Since 1953, Pakistan has been struggling hard to feed its population from its own food resources, without any seeming success. Among the host of reasons responsible for bringing about the near reversal of the once happy food position, floods of increasing regularity are one.

Large amounts of precious foreign exchange worth tens of millions of rupees have been spent every year on import of food stuff, which in its economic implications for Pakistan may be regarded largely as non-productive expenditure.

To provide for food requirements of a growing population and to alleviate the present food shortages in the country, additional agricultural production is essential. For this purpose further irrigation and power development which depends to a great extent on the storage of flood water now wasted, and on the carry over of these waters from one season to another for release in dry months is indispensible. In the United States of America, a good deal of success has been achieved in devising methods for delaying the flows by restoring what is known as water control through water shed management.(31) The effects of such control on water yields, flood control and soil conservation are tremendous. In Pakistan what little has already been achieved in this direction is outlined below.

To tackle all the problems associated with floods, salinity waterlogging, alkalinity and soil erosion, the Government of Pakistan has set up many departments, such as Department of Soil Conservation, Directorate of Land Reclamation and Wapda - The West Pakistan Water and Power

Development Authority. They are all working jointly since each problem is interconnected. All these departments have regional units in both wings (East and West Pakistan) as connecting links.

The purpose of river control fundamentally is to check the river from leaving its channel. To achieve all this apparently simple objective, the first step is to reduce the peak discharges which will reduce the flood-intensity. Secondly, to carry the floods at lower levels and finally, to bar floods completely.(32)

The techniques employed in lowering the flood peaks are many, for instance afforestation, contour bunding and terracing in the upper reaches, check dams, contour cultivation and detention reservoirs.

Afforestation is a significant control on the run-off as the tree roots and undergrowth litter absorb and detain the precipitated water. In West Pakistan re-afforestation and afforestation schemes are on their way in the shape of shelter belts, village plantations, national parks and plantations, made possible both by irrigation water and by rain water. Other devices such as contour bunding and terracing and the construction of check dams are examined in the following chapter on soil. The construction of detention reservoirs is relevant here.

Though detention reservoirs are considered to be the most effective and rapid method of diminishing floods, in the case of West Pakistan they are not always practicable. The biggest problem in the construction of collection dams is, as we have noted, the vast difference between the maximum and the minimum discharges of all the rivers. The normal summer discharges of the rivers may be 20 times the winter minimum.(3) Another estimate of great fluctuations in the discharges is "the maximum discharges being 50 to 100 times greater than their minimum".(26) (See Table 8). The second problem is the synchronised flood incidence in all the major rivers owing to the heavy monsoon spells in their catchment, in addition to the simultaneous melting of snow. Hence a similar basic hydrological regimes lead to a rapid and very large scale run-off. The enormous vastness of the Indus basin cannot easily completely be regulated according to the need of man. If the combined flow is regulated a reservoir with a capacity of more than a 100 million acre feet will be required!(32)

In West Pakistan the only rivers which can be utilised under national schemes for the regulation of floods are the Jhelum and the Indus and its western affluents. Under the management of WAPDA the Warsak Dam on Kabul river is completed and the Mangla Dam on the Jhelum is in its preliminary stage. A number of other sites have been chosen where the dam building schemes are under execution and others are planned. See Table 10.

Table 10.

Dams

	Dam	Salient features
1.	Warsak on the Kabul river-completed	Multipurpose hydro-electric project generating 240,000 Kw, for irrigation, 120,000 acres. holding capacity 62,000 a.f.
2.	Rawal on Kurang river, completed.	To irrigate 8,000 acres 16 million gallon, daily for domestic use for the new capital.
3.	Mangla on the river Jhelum, under construction.	Multipurpose, storage capacity c. 4.75 m.a.f. irrigate 3 million acres, 300 thousand K.w.
4.	Terbela on the Indus, under construction.	6 m.a.f. water will be available for irrigation.

The function of these reservoirs will be multipurpose, as flood control, generation of hydel power, provision of adequate water for cultivation and reclamation of saline and virgin lands.

The functions of artificial reservoirs held by dams deserve further study. First, the volume of water and the stream flow is regulated and extreme conditions are eliminated, in a way in which levees cannot. Secondly, the flow of the water is made more uniform thus permitting the use of water for many purposes throughout the year, and overcoming seasonal aridity. With erection of a few dams at suitable sites the whole controlling works can be centred on these points, and it is easier properly to maintain these structures than those which spread throughout the river course as bunds and levees. The account given of the river courses gives some idea of possible storage water points.

The floods may also be carried at lower levels in several ways. By shortening and straightening the river channels, one increases the velocity of the river at lower levels and discharges are carried with a greater speed. This process involves the removal of bends and meanders. In this connection various experts have suggested the erection of spurs at suitable sites which will help in deflecting the river flow. This approach if based on the new three-dimensional concept of meander formation (velocity, volume and turbulence) could at least maintain the courses of rivers and maintain an established equilibria.(33)

It appears desirable that the present channels of all the rivers should be deepened and desilted as a defensive measure against overflow, because the rivers overflow the surrounding country, "often to a distance of several miles on either side".(12) The silt which is removed from the river beds and canal beds will prove beneficial to crops as a fertiliser because of its high mineral content.

All these efforts are of no long-term value to West Pakistan as the rivers are aggrading their channels. These rivers need to be primarily controlled in their upper reaches and this includes the building of huge reservoirs to accommodate the flood water along with strict catchment basin management.

The techniques of lowland river channel control are not strictly relevant here, nevertheless in light of recent work some points should be made. Erosion and deposition occur in all streams and at all stages. The load capacity of the streams and the distance over which specific loads are carried, are a function not only of volume and velocity but also of turbulence.(33) Cut-offs may not necessarily improve the channel depth or prevent overflow, and channel levees built on the concepts of swinging lateral erosion are not sufficient. Geological and artificial means of providing 3 dimensional control of swinging can however maintain existing hydraulic equilibrium. The works involved have to be "set-back" confining channel movement to part of the flood plain rather than confining water flow to one channel. This gives rise to other problems.

Much of the land which in a sense would be abandoned to river action is now agriculturally used. Great seasonal variability means that works must be constructed to meet the peak and available demand, and this can best be achieved by reservoir control.

Several techniques have in fact been adapted to prevent floods. Under these methods flood waters are mechanically controlled by the erection of earthen dykes, bunds, and levees. The river channel is confined between these walls often 40 feet high, and a wider and deeper channel is temporarily created. The levees of this kind along the Mississippi river were primarily built for the improved navigation, and already their functioning has broken down.

These embankments are very important and simple traditional means of flood control and the people have a considerable experience in their maintainence. The Indus has in this way been controlled to some extent on both banks from Kashmor right to the sea. Another advantage of the bunds is that they can be built by the locally available cheap material and labour. Inspite of these merits,channel embankments are now strongly criticised. They produce obstructions in the natural flow of the river channel, and they deprive the land of the fertile silt transported by floods, while the protected land deteriorates with the rise of sub-soil salts, which could have been washed away by floods. They help in raising the river beds with silt which could have otherwise spread over a large area, and the high water level of the river is also raised.

This brief survey of the controlling methods indicate that every system has certain limitations, but reservoirs dams seem to be the best device among all the controlling measures. In addition to this, in the lowland the most feasible method would be the construction of open drains, spillways and diversion channels to carry the surplus water of one river to the other. Unluckily it happens that all rivers are in inundation simultaneously. Even so topographic depressions in the ancient river beds in the lowland may be utilised as diversion lakes or channels, into which the flood water may be led. Again surplus water during the rainy period could be directed to the desert areas now dependent on limited flood agriculture.

Finally, in the present circumstances the only remaining alternative is to divert the flood waters into a neutral storage area. In Iraq the topography of the Mesopotamian plain has enabled the use in this way of Habbaniya Depression, since the high floods of 1956. The waters of Euphrates are directed to this depression by means of intentional breaches.(34) In the Indus plain such diversion schemes are more difficult and will involve more construction. The formulation of flood control measures is a formidable task before Pakistan, but such schemes and their implementation have been very slow and inadequate. This is the result of many factors, including the lack of capital and experts, while the canal water dispute has remained the major impediment in this direction. Now after the final decision on river disputes in November 1960 these schemes can be finally undertaken.

It may be said that correct preventive measures can only be applied once the river courses, and river regimes have been studied fully, as in the Mississippi and the Tenessee valleys.

Uses of surface water:-

The above account shows that West Pakistan is an area of scanty, variable and seasonal rainfall, through which flows great rivers whose regimes are extremely seasonal; floods and droughts occur and recur. With such a background it is now proposed to consider how the surface water is being utilised, and what can be done to use a greater part of the potential.

The significance of conservation, control and utilisation of both rain water and large rivers have been realised since prehistory. Probably cultivation first started on the river fringes depending on natural flooding as man first sëttled on the river sides (Chapter 7). With the increase of population pressure, irrigation was extended further to the limit of the floodings. Beyond that limit water did not reach and the necessity of distribution of river water arose. The need of several means of artificial irrigation such as canals, wells, dams and reservoirs have been felt since remote ages, and as mentioned in the Vedas.(35) Throughout the historical period up till now great innovations and extensions in irrigation methods have been introduced as the demands and needs of people grew.

West Pakistan has vast resources of land and water; but the water is subject to aridity and a great waste of water in the form of run-off. It is estimated that "one third of the summer river discharges of the rivers of the former Punjab is utilised for irrigation".(3) If efficient storage schemes are implemented then much of the two thirds of water which is now being wasted could be utilised. In this former province of Punjab the canal heads have a total capacity of 96,000 cusecs and out of that 84,000 cusecs are being utilised. The author of this report opined that "It is possible that this latter figure applies to the water use of all irrigation works in West Pakistan. If the canals were continually running to full capacity and if there were no losses due to seepage and evaporation an average of 6.14 acre feet of water would be diverted per annum for each acre of the 13,000,000 acres at present under canal irrigation. This is probably more than three times the actual average water delivery".(3)

A rough estimate for the annual river flow in the whole Indus Basin averages 168 million acre feet.(36) According to the estimates of the World Bank in 1954, the total usable supplies of the Indus Basin is 119 million acre feet.(37) Out of that India "has appropriated about 12 m.a.f. as actual withdrawals and requirements for her prepartition projects. Pakistan appropriated another 96 m.a.f. as actual withdrawals and requirements for her prepartition projects". After these shares the balance remained only 11 m.a.f., where as Pakistan requires far more than this balance, about over 25 m.a.f., but no water is left to meet this extremely great requirement. Graaff has said that "there is too little or far too little irrigation water available for agriculture".(3)

According to the First Five Year Plan, an additional 2.5 million to 3 million acres feet water would be needed merely to maintain the existing standard of food and clothing for increasing population of the Indus Basin Region by 1960.(1) The water requirements for various purposes as domestic, commercial, and industry as assumed in the Plan is in the order of about 0.2 m.a.f. per million of the population, in the early years of the Plan period. The annual water requirement of the Indus Basin Region for agricultural uses alone is estimated roughly 72 million acre feet. These requirements are bound to increase with the progress of time, which may be estimated about 0.5 million acre feet by 1960.

The hydro-electric power stations do not consume water and are so planned that they do not interfere with supplies for other purposes. Thermal plants require water for cooling but return most of it to the river. The water requirements for thermal plants are included in the domestic, commercial and industrial uses. In addition to this, the combined water required for the purpose of navigation and control of sea water intrusion have been estimated at 17.2 million acre-feet below the Gulam Mohammed barrage at Kotri.

If we sum up these consumption data and compare it with the annual flow of the Indus river system and with the total usable supplies assumed by the World Bank, it comes to:-

The total flow of the Indus System*	=	168 MAF
The total usable flow	=	119 MAF
Share of India pre 1947	=	12 MAF
Share of Pakistan pre 1947	=	96 MAF
Remaining	=	11 MAF

The requirements assumed in the first Plan uptil 1960 were:-

Domestic + Commercial + Industrial	=	18.9 MAF
Navigation and Sea Control	=	17.2 MAF
Roughly estimated average annual agricultural uses	=	72 MAF
Total water required is	=	108.1 MAF

There is an unsurpassable deficit of 97.1 MAF, and shows an acute short supply of surface water. With the passage of time this shortage will grow more as more development schemes will be embarked upon. Thus the aridity is

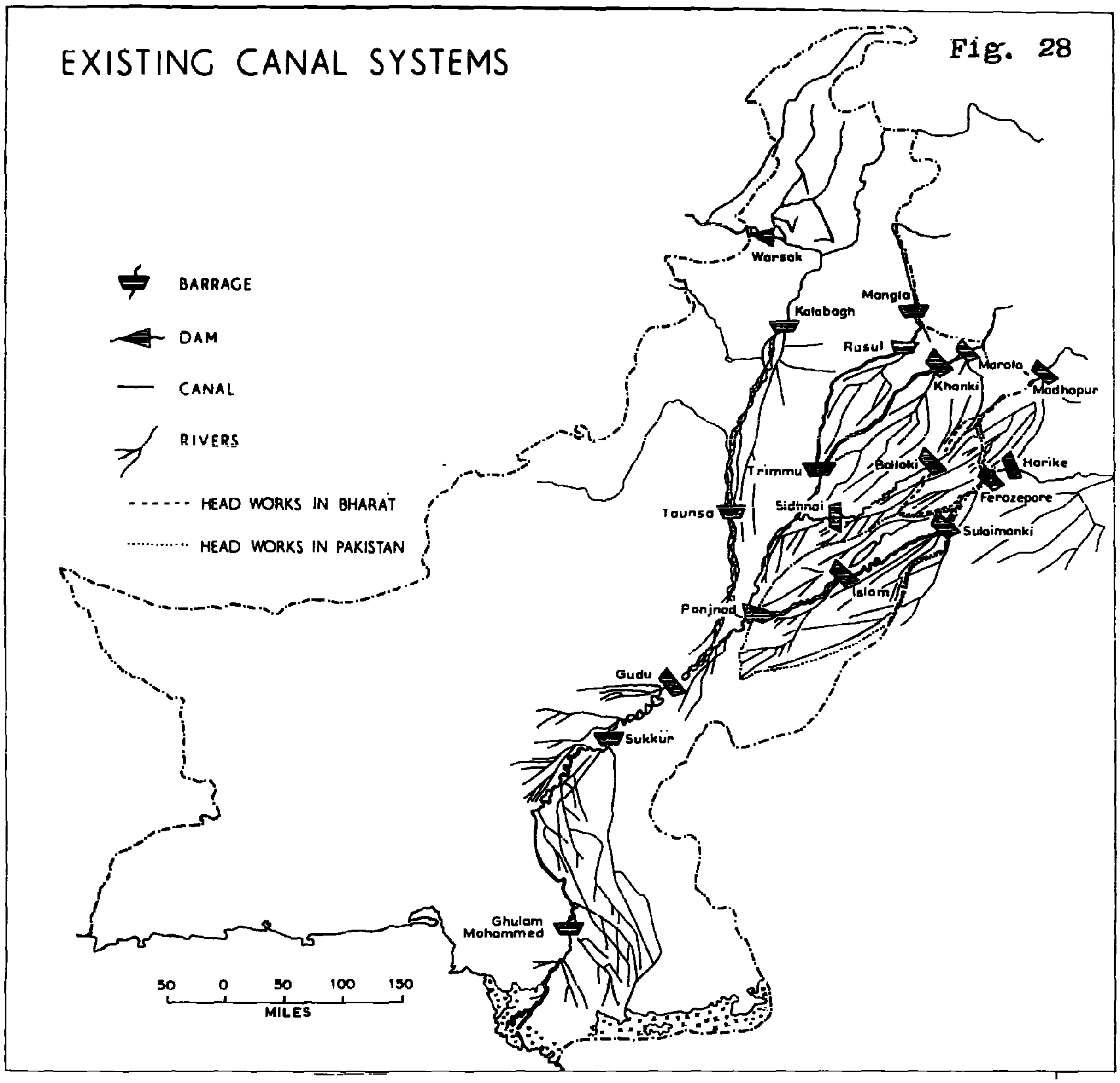
* including only the eastern tributaries. Reliable data for the western tributaries is lacking, but roughly their flow is 10 MAF.

enforced while the irrigation is imperative.

The only alternative for Pakistan is to control as much flood water as possible especially the hill torrents and seasonal nullahs flowing into the main river stems, or to induce rainfall in both winter and summer clouds.

The present supply of water for Pakistan is not at all dependable as Bharat is bent upon drawing further on the Ravi, Beas, and Sutlej. Bharat has withdrawn water temporarily from these rivers on many occasions, in 1948, 1952 and 1958, and Pakistan had to face grim situations.(37) Since independence, Bharat has stopped entirely the water in the Bahawalpur distributary and the green area served before such interference was turned into a "desert bowl"; thus is aridity invited and accentuated. The affect of deliberate obstruction of water by India is described by Dr. Harry who was the leader of United States Special Mission to Pakistan in May 1953. "In Bahawalpur we went out to inspect part of the wheat-growing area, and meet with 3 groups of cultivators around a hundred in each group. Their plight from lack of water was almost beyond description. We saw hundreds of acres of land on this trip of about 75 miles that had once been in production but were now covered with drifting sand. In the Punjab we covered 200 miles around the wheatland in 1 day alone. We saw sufficient good land which with enough water could turn a deficit area into a surplus area. Pakistan has good land but it needs water if the land is to produce. This year there just wasn't water".(37) This is a living example of aridity deliberately created by man in a few years only.

Space does not permit to trace out the history of the water dispute, nor does the candidate intend to examine the political conflict. Briefly, it is the result of the boundary demarcated by Radcliffe, by which India has the physical possession of the catchment areas and the upper reaches of the three eastern rivers, where lie the canal heads. Obviously the flow regulation of these canals is governed by India. The canals affected by demarcation are those flowing through the Central Bari Doab and Bahawalpur, viz., the branches of Upper Bari Doab flowing from the Madhupur Head works (India) and the canals of the Sutlej Valley Project. Though the three head-works belonging to this project lie in Pakistan they are under a constant threat of interference by Bharat as mentioned already and which has brought untold miseries to Pakistan. Fig. 28 discloses the actual state of affairs. The three Pakistani Head works are Sulimauki, Islam and Panjnad.


EXISTING CANAL SYSTEMS
Fig. 28
BARRAGE
DAM
CANAL
RIVERS
HEAD WORKS IN BHARAT
HEAD WORKS IN PAKISTAN
Warsak
Kalabagh
Mangla
Rasul
Marala
Khanki
Madhopur
Trimmu
Balloki
Harike
Ferozepore
Sidhnai
Taunsa
Sulaimanki
Islam
Panjnad
Gudu
Sukkur
Ghulam Mohammed
50 0 50 100 150
MILES

After the proposal of World Bank in 1954 the three western rivers namely the Indus, Jhelum, and Chenab would be reserved for Pakistan and the 3 eastern rivers namely the Ravi, Beas and Sutlej would be reserved for India, after the works to replace supplies from eastern rivers have been built by Pakistan in her territory with the funds provided by India.

"The World Bank proposal of 1954 was supplemented by the aide memoir of May 6, 1956; amounted to:-

(a) Reservation of Indus, Jhelum and Chenab - the western rivers - for Pakistan and allocation of the waters of the 3 eastern rivers - Ravi, Beas, and Sutlej - to India;

(b) Continued and "timely" supply of water from eastern rivers to Pakistan until arrangements for replacement of supplies diverted to India were completed and,

(c) Cost of construction of storage on western rivers and replacement works to be borne by India". An insignificant amount of Jhelum water will be utilised in Kashmir.(38)

India is insisting upon diverting the three eastern rivers to irrigate the Rajasthan desert. The need of irrigation in Pakistan is almost 4 times more than in India. Over 70% of the Indus Basin depends for its food on irrigation, while in India only 20% needs irrigation, the remaining receives an ample and flourishing rainfall, as India occupies a happy location geographically under the direct sway of the summer monsoons. The total usable supply of river water in India according to her own estimates is 450 m.a.f. of which only 19.8% will have been harnessed by the end of 1962, when the second Five Year Plan period is over. In addition to 450 m.a.f. India receives 12 m.a.f. from the Indus Basin; while Pakistan has a deficit of 97.1 m.a.f. India lets 80 percent of usable river water of her own to go to waste, but is obsessed by a "share" in water which is manifestly inadequate for Pakistan's own barest needs.(37) "The survey of Indian resources has shown that out of total annual flow through the rivers of India, only 5.6% is being used for irrigation, the rest is running to waste to the sea".(39)

Pakistan is very poor in respect of river water resources:

Indus Basin flow = 168 m.a.f.

Ganges and Jumna = 400 m.a.f.

Pakistan besides other uses has to irrigate with 156 m.a.f. as 12 m.a.f. is drawn by India. Pakistan possesses an unhappy geographical position as compared to the Gangetic plain in respect of rainfall, but the irrigated area of

India in the East Punjab is only 7 million acres while 3 times more is irrigated in the Indus plain, 21 million acres.(40) The East Punjab needs less water in particular because the interfluve zone between Jumna and Sutlej is much moister for the Kharif crop. The Indus irrigation system has been built up over a century and it supports a population of nearly 40 million people in Pakistan and some 10 million in India, approximately one-tenth of the combined population of the two countries. The irrigated area is about 30 million acres, the largest irrigation system in the world. Pakistan's existence now depends on irrigation from the Indus system. Hence, India might well have derived more water from Jumna and the Ganges to convert the Rajasthan desert into an agricultural land, and water now diverted by the Bhakra dam on Sutlej could have been used for Pakistan in Bahawalpur as it was earlier used.

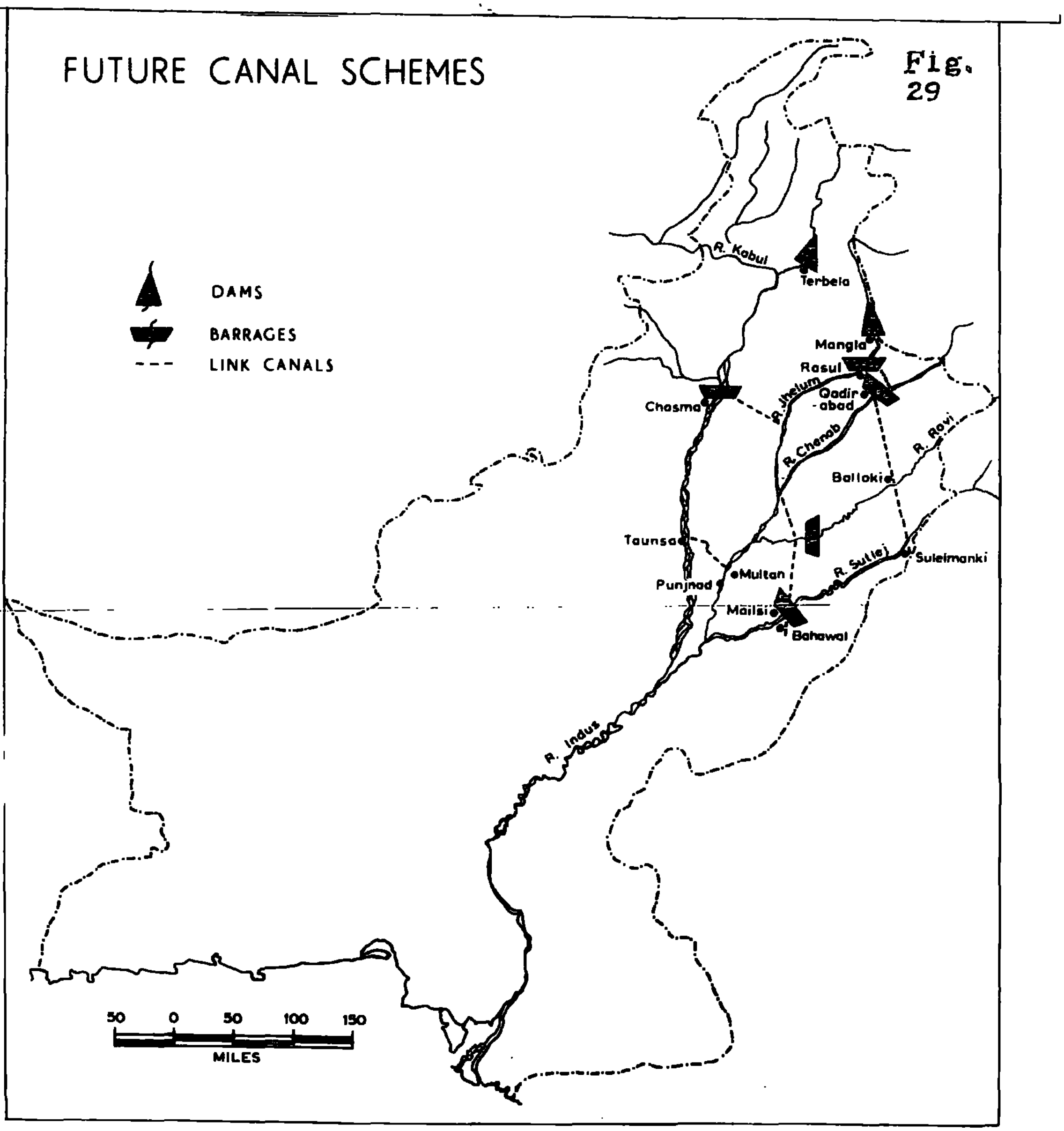
In Pakistan the supply of water for Rabi crops (from December to May) is usually insufficient, because of low winter rains and low river flow as noted above, particularly in areas lying at the tail of canals. The Bhakra Dam has now further deteriorated the situation. The Kashmir issue bears the greatest influence on the water balance of Pakistan. Had this dispute been settled amicably, reservoirs on Chenab and Jhelum would have been built at technically better points in Jammu and Kashmir, and effective forest protection and grazing control, could have combatted at source, soil erosion, silting and high floods. This is now not possible. In addition to this, there is a constant apprehension in Pakistan of further Indian diversion of water of Jhelum, Chenab and even of the Indus.

The more one studies the political geography of the situation in the vicinity of Pakistan, the more one becomes alarmed, as the head of our rivers lie in foreign lands. In the case of Indus and its tributaries coming from Tibet, China may one day interfere with their natural flow, and embark a development project on the Tibetan tributaries. What then will be the fate of Pakistan? With the development of nationalism, political and economic, one day a threat might come from Afghanistan for diversions of the Kabul and Kurram rivers, and the dams of Warsak and Kurram Garhi could be left like the empty "Gabar bands" of the Prehistoric times.

The acceptance of entirely ungeographical demarcation boundaries of both the Punjab and the Bengal by the early Muslim League leaders has been such a blunder, that Pakistan will always remain a "beheaded" lame and crippled country whose economy will always face an unstable situation. Even a cursory glance at Figs. 1 and 23 demonstrates that the Indus river system is naturally an integral part of West Pakistan and its development entirely depends on the sprawling rivers. The necessity of this water is succinctly noted by David, former head of the Tennessee valley Authority and Chairman of the United States Atomic Energy Commission: "without irrigation millions of acres would dry up in a week, tens of millions would starve".(37)

The Indus Waters Treaty was finally signed on 19th September 1960 and the following conditions have been accepted by both Pakistan and India. The treaty allocates the 3 Eastern Rivers - Ravi, Beas and Sutlej to India. The main condition is that during the Transition Period, during which Pakistan replaces the water of these rivers, India has to deliver the water to Pakistan for this transitional period which is tentatively fixed for 10 years.

The waters of the 3 Western Rivers - Indus, Jhelum and Chenab are allocated to Pakistan. Provision has been made for India to use some water of these rivers for irrigation and power generation. India is going to contribute to the dam construction costs some £62,000,000 to Pakistan. This final decision will bring great changes to the present net of irrigation, as explained in the



FUTURE CANAL SCHEMES
Fig. 29
DAMS
BARRAGES
LINK CANALS
R. Kabul
Terbela
Mangla
Rasul
Qadir-abad
Chasma
R. Jhelum
R. Chenab
R. Ravi
Ballokie
Taunsa
Suleimanki
R. Sutlej
Multan
Punjnad
Mailsi
Bahawal
R. Indus
50 0 50 100 150
MILES

account which follows, and with the exclusion of 3 Eastern rivers the total surface flow will remain as 135 million acre feet.

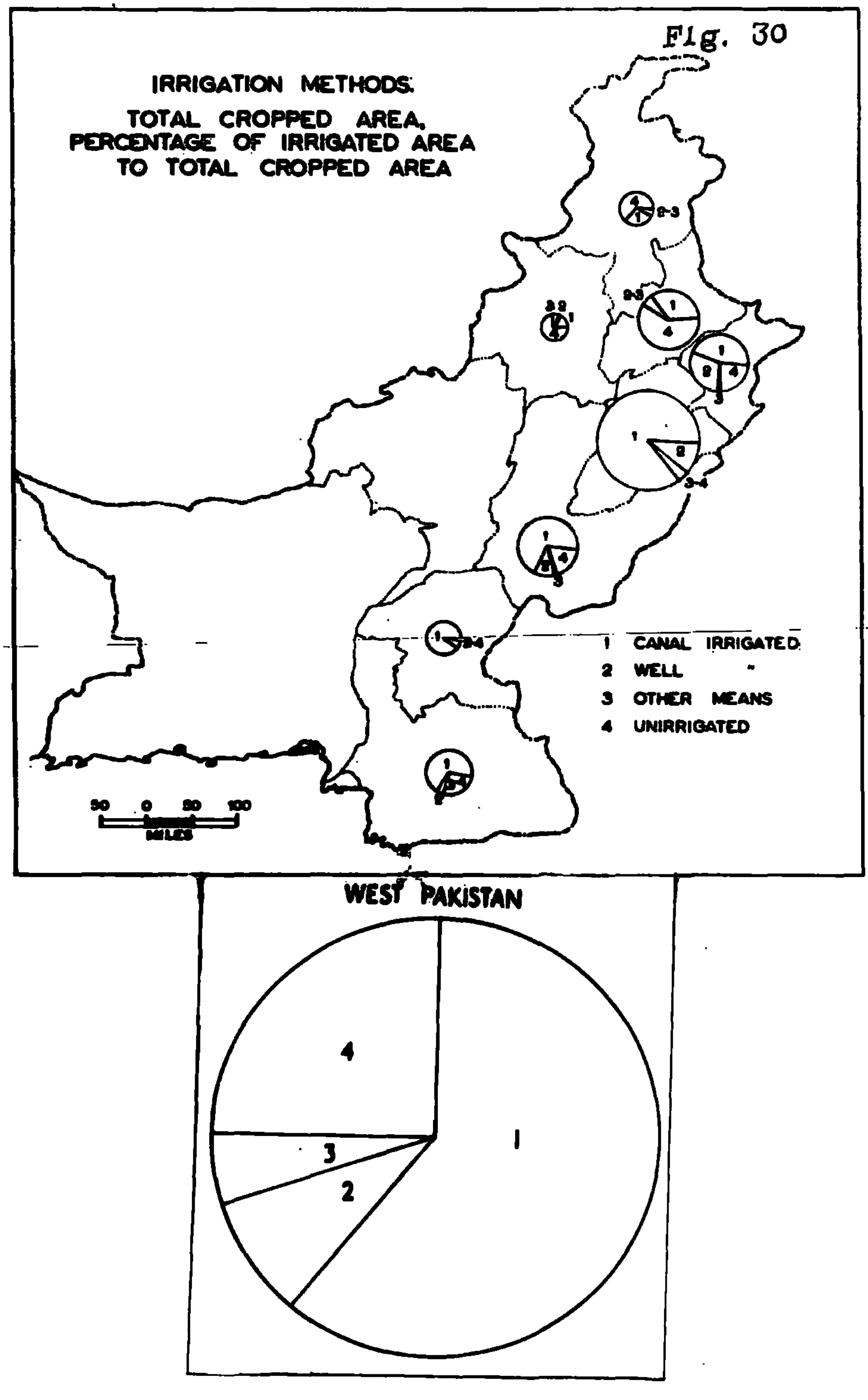
The water conservation by canals has been in vogue for long, but modern canals are the fruits of the 19th century. The restoration and prosperity of arid and semi arid regions depends on the canals of the present and future. For the security of the arid areas, many ambitious schemes for irrigation have been executed since 1947, Appendix 7 shows that following on measures started in 1859. Before the introduction of these canals the present canal colonies were no better than scorching bare sandy wasteland. Appendix 7 and Fig. 28 show all the completed works, and Fig. 29 shows the work contemplated with the effect of the final Indus Basin Treaty 1960.(41) The future irrigation Plan is based on a new type of approach for the attainment of the irrigation water. Until today irrigation was entirely developed from the river flow, and reservoirs were not constructed. In consequence water supplies were precarious to the extent that they were subject not only to the seasonal fluctuations but also to the annual fluctuations in the river flow. The creation of future dams carry manifold aims, to distribute the water equitably and economically, to provide work in dam construction, management of control of water both in quantity and quality, to check silting and finally to provide water for many purposes as irrigation, power generation, industries, navigation sports and pisciculture.

Irrigation

Climatically, most of West Pakistan lies in the arid and semi-arid zone. A territory of 200,000 square miles of the Indus Basin receives a rainfall less than 15", 60 percent of which obtains less than 10 inches and about 16 percent less than 5".(41) Thus in our region of inadequate rainfall the conservation and utilisation of the available flowing water is critical for the development of all resources of the country. The distribution of total available water in respect of river flow is subjected to extreme fluctuations at different periods. The maximum summer discharges in the river are 100 times the winter minimum discharges. The low flow generally lasts from the middle of September to middle of March, corresponding to the sowing and maturing periods. These variations bring in their wake frequent droughts and floods. Under these natural conditions of water supplies, irrigation becomes imperative.

In West Pakistan an organised type of irrigation began

Fig. 30


IRRIGATION METHODS:
TOTAL CROPPED AREA,
PERCENTAGE OF IRRIGATED AREA
TO TOTAL CROPPED AREA
1 CANAL IRRIGATED
2 WELL "
3 OTHER MEANS
4 UNIRRIGATED
MILES
WEST PAKISTAN

during the Mughal period, the first such work being the Hasli canal which irrigated mainly the Shalimar gardens.(41)

Through following centuries the population multiplied in a vast scale, particularly during the British regime when political stability reached to a high degree. The Government was forced to open new areas for the settlement of rapidly growing population. By means of barrages and weirs large diversions of water took place, the canal system in the Indus lowland becoming the biggest of its kind in the world. At present the net area commanded by the canals in West Pakistan is 23 million acres out of the total of 31 million acres of cultivated area. See Fig. 30.

The existing irrigation system was based on the construction of 15 barrages which head up river and divert their waters into canal networks. The relative size of this extensive irrigation system may be visualised thus: the total irrigated area in the Nile valley is a little above 6 million acres, and that in the United States some 7 million acres. The area irrigated alone by Sukkur barrage is over 7 million acres.(41) A visual impression can be acquired by Figs. 28 and 30 and Appendix 7 relate the intensity of canal irrigation in West Pakistan.

Canal irrigation is general except in the areas of low water table where it is replaced by wells. Along with the periodicity and variability of rainfall and increasing population, the other causes for rapid progress in irrigation result from suitable topography and great stretches of fertile soil.

The general types of existing canals are as follows:-

1. Inundation canals.
2. Perennial canals.
3. Non-perennial canals.
4. Link, Feeder or carrier canals.

Inundation canals:-

Most of these canals were built by the Muslim rulers, some of them later converted into perennial canals by the British. These are indigenous developments and their working is restricted to the rainy season. These canals are cut out parallel to the river in its flood plain, without the building of any structures at their heads. They depend for their water on river inundation ... other-wise remain dry. If the river swells they contain water from 5-8 feet. Normally, they start rising in the middle of March and start subsiding by September. Their minimum winter discharge may increase to over 20 times in summer. For the rest of the year they give way to lift irrigation.

They not only water the plants during the summer season, but they are also a means of flooding land intended for winter wheat, the subsequent watering of crop depends on well irrigation.(32) The largest number of inundation canals exist in the Divisions of Bahawalpur, Multan, Dera Ismail Khan and Peshawar. They form a special characteristic of the western three rivers, where they serve a loose sandy soil mantle. Irrigation by means of these canals is very important at the point immediately below the headworks of the main canals, especially on the right bank of the Indus and in Bahawalpur from the Sutlej. The number of distributaries is restricted away from the canal heads, but they are maximised at the point where all these rivers converge. Digging of more such simple canals and deepening of the former canals may prove a useful measure in the conservation of run-off. Their short-coming is their seasonal use.

The Perennial Canals:-

These are constructed by erecting a weir across the river and derive water from the river by artificial deflection of river flow. The water from these irrigation canals is destined for irrigation purposes only and it is conveyed to the fields through a network of smaller canals. Thus, every canal system consists of a main canal from which branches take off and distributaries and minors deliver the water to the irrigation plots. These canals promise a regular supply of water. The cost of irrigation water depends upon the nature of crop for which the water is used and it is higher for a cash crop like sugarcane and cotton, than for the crops which give low returns.

Non-Perennial Canals:-

The inundation canals are uncontrolled non-perennial, while these are controlled non-perennial. The water is allowed to run in these canals during the monsoon season and they are closed in winter when there is a shortage of water in the rivers. The newly accomplished Tanusa Barrage feeds these non-perennial canals.

Link Canals:-

These are perennial canals and their function is to transport the water from one river to another river. They supply water to Kharif lands to make up the deficiency in Sutlej valley canals, which water is often held up by India.

The salient features of the present canal irrigation have been charted in chronological order. Appendix 7.

The first steps were taken in the direction of controlling aridity in the period 1860-1932. During this period elaborate irrigation schemes were completed in the more tractable areas. After 1947 strenuous efforts have been made to build more canals in the more difficult desert areas. The cultivated area at the time of independence was 45 million acres and it has been increased with the establishment of more irrigation projects to 48.45 million acres. The yield of major crops has been increased from 19.4 million tons in 1947-48 to 20 million tons in 1956.(42)

Fig. 30 and Appendix 8 show that in West Pakistan 60.80% of the cultivated area is served by canals, the highest percentage of canal irrigation is in Khairpur Division, 91.64%. Canal irrigation in Bahawalpur, Multan, Hyderabad and Lahore Divisions is 69.46%, 86.20%, 71.22% and 44.97% of the total respectively. The canal irrigation dwindles towards the north west, and the percentage of unirrigated cultivation dominates, as the division of Peshawar, Rawalpindi and Dera-Ismail Khan the % of unirrigated cultivation are 64.17%, 57.57% and 88.37% respectively. The further analysis of the data shows that of all the irrigated area in the Indus basin 81% is fed by the Government and private canals.

Semi-arid zone irrigation pattern:-

Here perennial canals form the basis for schemes of varying complexity. Appendix 7.

The Upper Bari Doab:-

This system is a simple perennial irrigation and is a reconstruction and extension of the old canal initiated by the Moghals. Its headworks fell to Indian territory. (Fig. 28). It irrigates some parts of the Lahore district. As the Ravi commands relatively a small catchment Basin with a limited glacier mileage, and has summer maximum rainfall, thus its flow is the most unreliable during the lean period. It is pointed out that "The Upper Bari Doab, as its prehistory implies, served an already settled countryside, a fact reflected in its settlement and field patterns and the aspect of the village".(3) The existence of Upper Bari dates back to prehistory.

The Lower Chenab:-

Serves the Rechna Doab, the former wasteland known as Nilibar. It was first initiated as an inundation canal and it was converted into a perennial canal in 1889.(3)

Upper and Lower Swat Canals:-

A western tributary of the Indus, the Swat river has been canalised to carry water to the Mardan district. Similarly the Kabul river canal irrigates the Peshawar district.

More complex types involve carrier-cum-irrigation canals. The Upper Jhelum canal and the Upper Chenab canal, passing through the Doabs of Chaj and Rechna and the lower Bari Doab perennial canal serving the arid district of Multan and the semi-arid district of Montgomery. The purpose of this project was to meet the shortages of the Lower Bari Doab because the Ravi has a relatively small supply of water. Therefore, the water from Jhelum was transferred through the Upper Jhelum canal into the Chenab at Khanki. The upper water of Chenab was thus available freely to be branched off in the Upper Chenab Canal at Marala. After serving an area of 1,533,852 acres in the Rechna Doab, it discharges its water into Ravi at Balloki, the point where Lower Bari Doab takes off. This forms a crowd of five canals namely Upper and Lower Jhelum canals, the Upper and Lower Chenab canals, and Lower Bari Doab. These canals are also affected by the seasonal regime of the rivers, which fluctuations are unpredictable hence the situation becomes complicated. They irrigate a large area of Kharif crops.

The semi-arid area acquired the irrigation schemes just mentioned within a period of 90 years. An account of the major schemes completed or are in their phases of completion since 1947 now follows. (Appendix 7).

1. Balloki-Sulaimanki link. The aim contemplated was to

supply water to Kharif lands and to make up the deficiency in the Sutlej valley canals during Kharif season by designing a 54 mile link between Ravi and Sutlej.

Accordingly such link canals have been completed between Bambanwali and Bedian in 1956 and the Marala-Ravi link between Ravi and Chenab completed in 1958. In the former case the water is being conveyed to the Dipalpur Canal during its lean period, while in the latter instance the intention is to feed the Balloki-Sulaimanki Link at Balloki, by transferring the water from the Chenab to Ravi.

The purpose envisaged is being successfully fulfilled by these canals since their completion and the nation is benefited by an increase of 21,000 tons of food annually by the Balloki-Sulaimanki Link alone. This shows how the link canals are double purpose canals, they not only communicate water from one river into another, but they also irrigate the land on their way.

2. Kurram Garhi Multipurpose Dam Project is under construction. The objective is to impound 89,000 acre feet of Monsoon water supply to provide irrigation to new areas on the right bank of the Kurram river and use the run off. The food production will rise to 50,000 tons. Besides this the project will generate hydro electric power

of 4,000 Kw, by constructing a permanent diversion weir across the Kurram river.

3. Warsak high level canals. This was completed by the end of 1960, and it involved the erection of a dam on the Kabul river immediately it opens into the Pakistan territory. It is a multipurpose project in its character, the power obtained from this project being utilised among other things for the marble quarries at Mullegori. Agriculture is being extended in the tribal nomadic areas as well as in Peshawar District. An increase of 60,000 tons of food is expected, and the wastage of run off is put to beneficial use.

4. Pehur flow Irrigation. A canal with a capacity of 250 cusecs has been taken off from the right bank of the Indus near Pehur village in the Swabi Tehsil of Mardan District. With the completion of this canal a new area of 48,000 acres have been brought under cultivation and 12,000 acres of existing cultivated land has been stabilised; about 15,000 tons of additional food is obtained.

5. Gomal Zam flood Control and Irrigation Scheme. The river Gomal Zam an affluent of the river Gomal is being harnessed by a formation of a masonry dam across it. This will collect the monsoon water which will be utilised for cultivation during winter, besides which 74,00 kw will be

generated from it, and there will be created effective means of flood control. The annual increase in food grains is expected to be about 25,000 tons.

<u>Arid Zone Irrigation</u>

There are at present four group-types of irrigation canal systems which exist or are in course of construction in this zone. Some are relatively simple gravity flow canals as the case of the Sidhnai Canal which, leading off the lower Ravi, irrigates the Multan District. A second, longer, system, the Haveli group has recently been constructed, involving the building of a large barrage immediately downstream of the junction of the Jhelum and Chenab. From the west bank a main irrigation canal leads off, which from the east a feeder canal leads to the Sidhnai Canal in order to supplement the latters variable flow. At the same time the Rangpur Canal was led off from the Jhelum.

In the case of the Sutlej, a basic valley irrigation project of a relatively simple but extensive type has become involved in the political consequences of partition. Indian control of the Sutlej and the mutual distrust felt by Pakistan and India has resulted in a pattern of canal building based on separate approaches to the problem rather than joint development of regional water resources, in spite of the fact that the four-dam project can only work efficiently through cooperation.

The largest canal scheme of a relatively straightforward kind ranks among the largest in the world, the Sukkur Barrage project. Greatly improving the irrigation of the area between Sukkur and Hyderabad cities, by utilising Indus water, the whole scheme serves seven main irrigation canals on both sides of the river.

Of a different order is the Thal Development Project. The Thal desert covers some 50,000,000 acres, and forms a triangle based on the Salt Range Escarpment and its apex at the convergence of the Six Rivers in the Bahawalpur Division.

As noted earlier, it is probable that a proto-Indus once flowed through the Thal, east of its present bed. On the Sind Sagar Doab, and along its course the river deposited silt and alluvium. Following the westward shift of the Indus Channel, the old alluvial flats became desiccated, and gradually in large part covered by wind moved sand. The surviving underlying alluvium has for long attracted the attention of developers.

The Thal project has a long history.(43) It was first contemplated in 1870, and in 1873, was known as the

Andrews Plan. It was deferred until 1915, when with the completion of a proper survey it was formulated as Middleton's Project, but this was discarded on the basis of being insufficiently comprehensive. In 1919 it was advocated in a comprehensive form as Wood's Project, but this time it was shelved owing to the priority given to the Sukkur Barrage. The Sukkur Barrage gained priority because there were already developed a number of canal schemes in the former province of Punjab, but none existed in the former province of Sind, where the Sukkur scheme was projected. Moreover the Sukkur region offered more immediate returns for less effort because of more developed means of transport.

On several occasions the Thal project was recommended but owing to various reasons it was postponed, until, finally developed, by the Pakistan Government under the Thal Development Authority, the colonization of this area was sanctioned and pushed forward in 1949. The timing was forced by the need for the rehabilitation of the great influx of refugees from India, and to augment food supplies accordingly. The opening of new lands became inevitable to remove the pressure from already thickly populated areas.

The Thal Development Authority is a body which is responsible for the entire development of an area comprising 834,500 acres. In addition to this 638,000 acres will be developed through private enterprise with assistance extended by the T.D.A. The scheme aims at the establishment of new towns and villages and balanced by the setting up of industries based mostly on locally grown raw materials such as sugar, cotton, woollen and flour mills as well as a cement factory.

The purpose of this project is complete economic as well as ecological development by irrigation and by the colonization of the area.

The project embraces four major elements namely (i) Irrigation, (ii) Road building, (iii) Forestry and (iv) Colonization. The resulting increase in the irrigated cropped land may be seen in Fig. 31 and in the table below:

Year	Irrigated cropped area in Acres
1948-49	72,750
1949-50	115,304
1950-51	153,764
1951-52	226,327
1952-53	314,391
1953-54	365,642
1954-55	395,261
1955-56	458,221

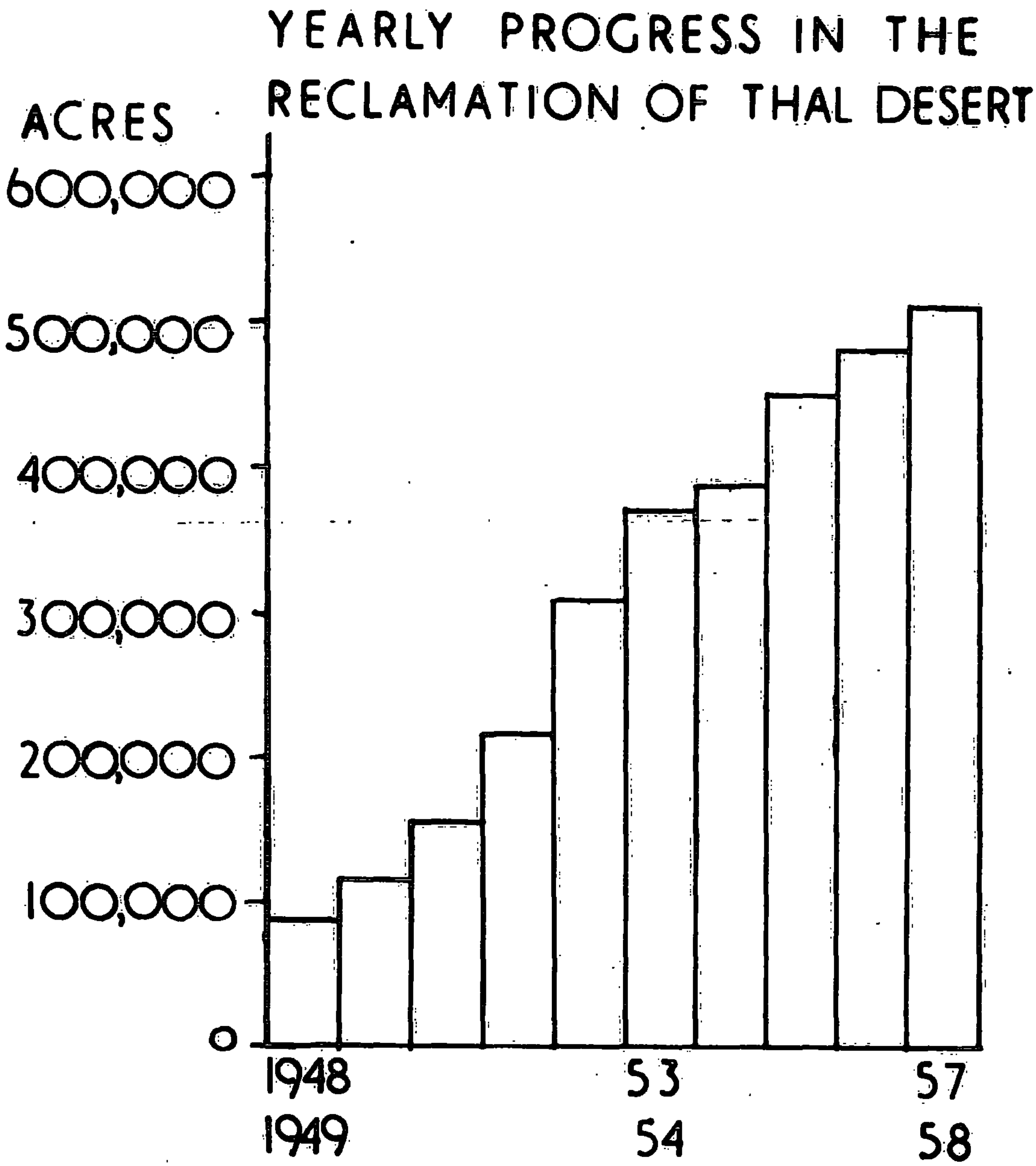

YEARLY PROGRESS IN THE
RECLAMATION OF THAL DESERT
ACRES
600,000
500,000
400,000
300,000
200,000
100,000
0
1948
1949
53
54
57
58

Fig. 31

1956-57	491,007
1957-58	524,404

Every year the increase is striking.

During the period of 10 years, 14,236 refugee families have been reestablished on an allotted area of 275,000 acres. The normal allocation unit is 15 acres per family. This project marks an important stage in the control of aridity and in the building up of the nation.

A second and only relatively smaller reclamation project is that of the Abbasia canal. It is a major developmental programme completed in 1956, with the objective of reclaiming waste Crownland in the former state of Bahawalpur. Desert land of 260,000 acres has been served by this canal. This canal is one of the first to be lined to save absorption losses, which were very heavy in the area of Panjnad.

The third main type is that of controlled non-perennial canals, built in order to link existing inundation canals. Their purpose is, to regularise flow as between different peak river supplies of water, and to diminish the importance of the twin menaces of waterlogging, and increasing salinity which so often follow over-heavy seasonal irrigation and flooding. The Taunsa Barrage is pre-eminent in this respect.

The Taunsa project consists of a barrage across the Indus, 65 miles down stream from Dera Ismail Khan, carrying a road and a railway line. The rail connects the Drapin Pach to the Shikarpur Kashmore-Taunsa line and the road bridge connects the Muzaffargarh district with Dera Ghazikhan. Three main canals take off on either side of the Barrage to link up the existing inundation canals, and to water the virgin lands of Muzaffargarh and Dera-Ghazi Khan districts. Owing to the limited available supplies in the Indus, it has not been yet possible to provide non-perennial supplies to more than 1.56 lac acres of new area. During the summer months the supplies are sufficient for another area of 2 lac acres in Dera Ghazikhan. If the result of these experiments will be encouraging the scheme will be extended to yet another 2 lac acres.

The Gulam Mohammad Barrage is an example of a scheme designed to improve the efficiency of irrigation previously carried out by inundation canals and associated with afforestion policies. Situated south of the famous Sukkur Barrage, at Kotri, it has been framed to supply irrigation facilities to the Hyderabad Division. This irrigation scheme is regarded as the biggest undertaking since 1947 in Pakistan. It has 3 main canals on the left bank and one main canal on the right bank. The rural economy of the Hyderabad Division now holds better prospects from assured supplies of water. Previously the Division depended on inundation canals, from which only a portion of the Division received irregular and unsatisfactory irrigation. Apart from irrigation facilities the new construction will control the Indus floods. An area of 73,000 acres will be watered for afforestation.

It may be stated here, and as is pointed out in Fig. 28, that, in the former province of Sind the Indus has been more generously canalised on its left bank than on its right, owing to softer soil and easy terrain on the left, than on the right. This is noticeable in all the barrages built on the Indus river but very pointed in Gulam Mohammad Barrage. Its expansion is limited by Laki hills on the right bank.

The Gudu Barrage is yet another example of new construction in an area of inundation irrigation, and the technical supplanting of simple inundation canals by the building of integrated water storage and distribution systems more suitable for the permanent improvement of agriculture. The site is very close to the boundary of Quetta Division and is only 90 miles north of Sukkur.

The scheme envisages a complete conversion of present inundation canals like the Desert, Unhar, Begari, and Sind-Wah on the right bank of the Indus and, Sehar, Dahar, Mahi, and Konai on the left bank. In spite of heavy flood flow of the Indus the volume of the inundation canals has lowered by heavier withdrawals in upper riparian area. With the completion of the Barrages, this position will be improved. Even so the new canals will run from 15th April-15th of October only, as adequate water is not left over during the winter, after meeting the needs of the areas earlier served by barrages.

The irrigated land will be put down to orchards and market Gardens in the Sibi area. The entire area benefited by this ambitious project is 25,000,000 acres and the extra food production is estimated to be about 666,000 tons. Now the entire area of the Divisions of Hyderabad and Khaipur falls within the reach of Indus will be commanded by the 3 Barrages, Gudu, Sukkur and Gulam Mohammad. The rest of the areas are either deltaic swamp or stony ground of the Sind Kohistan.

Lastly, may be mentioned some special, and, although only relatively so, minor projects.

The Makhi-Dhand Reclamation is a minor scheme for the levelling up the sand dunes, constructing irrigation courses and draining an area of 150,000 acres of waterlogged land in the riverine jungle of the lower Indus Basin.

The Nari Bolan Irrigation Scheme has been sponsored to trap the monsoon flow of Bolan river by, in the first phase, the erecting of an earth dam to irrigate an area of 34,000 acres in the Division of Quetta. The second phase includes the diversion of water of the Nari river into the Bolan reservoir through a cut.

Anambar Weir Project and Narachi Irrigation Projects in the Division of Quetta were designed to irrigate 60,000 acres, but the results were not achieved according to plan. Only 8,200 acres were irrigated for settlement of nomads.

Irrigation Schemes for the Future:-

With the effect of the Indus Basin Settlement Plan the existing Irrigation System has been greatly altered. Future irrigation works consist of two reservoirs, 7 link canals and 5 barrages supplemented with tubewells and drainage. The salient features may be noted in Fig. 29.(41)

The first reservoir dam will be erected on the Jhelum river near the village of Mangla 20 miles away from the Jhelum town. It's maximum height will be 370 feet and length about 2 miles at its crest. The main dam will be supplemented by 4 smaller dams of various size from 30 to 245 feet high. Their function will be to close gaps along the southern rim of the reservoir. These 4 small dams cover an area of nearly 5 miles in length. After its completion, the Mangla dam will be one of the largest earth-fill dams in the world, with a total fill of over 80 million cubic yards. The dam will command a reservoir 36 miles in length, with a storage capacity of 5.4 million acre feet. The dam will lead to a very big problem of submergence of 68,000 acres of agricultural land and dislocation of 85,000 people residing in 145 villages. In addition to its function of water storage, 340,000 kilowatts of hydel power will be generated. It's present capacity of storage and electricity will be enlarged in time.

The second such dam will be constructed on the Indus in the proximity of Terbela village 15 miles from the town of Haripur. This dam will be one of the largest rock fill dams in the world, with a total fill of 100 million cubic yards. The length of the reservoir will be 25 miles and its storage capacity will be 5.1 million acre feet. No provision has been contemplated for power plant at present, though there is large power potential.

The problems of land submergence and dislocation of population will be less serious with the creation of Tarbela dam. The land affected by this dam will be

34,000 acres and 40,000 people will be dislodged in 66 villages.

The Plan envisages the construction of seven major new link canals. They will be an addition to the 3 already existing link canals, namely, the Marala-Ravi link the B.R.B.D. link and the Balloki-Sulaimanki link. These links have been seriously damaged by the annual floods.

The seven new link canals are 1. Chasma-Jhelum Link, 2. Taunsa-Panjnad Link, 3. Rasul-Quadirabad Link, 4. Quadirabad-Balloki Link, 5. Trimmu-Sidhnai Link, 6. Sidhnai-Mailsi-Bahawal Link, 7. Balloki-Sulaimanki Link No. 2. These new link canals will be 388 miles in length, with capacities aggregating to about 100,000 cusecs. Their function will be to transfer water from the western rivers to the area irrigated formerly by the eastern rivers. The construction of these canals will involve the excavation of an area of 348 million cubic yards, which is almost double the volume of both Mangla and Tarbela dams. The whole landscape of these canals will be consisted of 19 regulators and falls, 150 aqueducts, siphons, inlets, and outlets; 14 railway bridges and 158 bridges of other categories. They comprise a colossal undertaking even on a global scale.

There is also provision of construction of 5 new barrages (Fig. 29). (1) at Chasma on the Indus, (2) at

Rasul on the Jhelum, (3) near Qadirabad on the Chenab, (4) above the present Sidhnai head works on the Ravi and (5) on the Sutlej near Mailsi. These barrages have a total length of 3½ miles. The barrages will have waterways designed to pass maximum floods aggregating to about 4 million cusecs.

This is a tremendous programme and its rapid implementation since need is urgent will bring manifold problems. The whole country will be affected by a scarcity of labour, construction material, transportation, and other development needs, and other activities will be seriously curtailed. WAPDA intends to complete in the first 6 years, 4 link canals and 3 barrages and the whole programme is as stated in the plan has to be finished within a decade.

The above review shows, that arid and semi-arid zones are now being served in every possible way by using the river water of the Indus System. The completion of all the irrigation and flood control schemes will be a big step forward in the development of arid and semi-arid sectors of West Pakistan. The Government is examining as never before the necessity of water to the nation. Irrigation has been promoted to top priority, yet though the irrigation projects completed or envisaged are extensive, they are not enough even for the present requirements.

The rivers have been harnessed at so many points that there seems to be little more scope for irrigation water take off. Therefore it has become a dire necessity for Pakistan to utilise the present water with utmost ingenuity and save wastage by all means. It has been repeatedly expressed by various authorities who are especially concerned with the water distribution that "we have tapped practically the entire utilizable flow supplies of our rivers to bring under cultivation millions of acres of barren and desolate lands. Our water resources are, however, limited and the Indian threat to cut off even our historic supplies from three eastern rivers looms large on the horizon. We have thus to plan our remaining resources with the greatest care".(44)

With the completion of Guddu the natural flow of Indus is completely utilised.

Water Saving devices:-

Aside from the new schemes attention may be directed to loss of water in the process of canalisation and distribution. Immediate steps should be taken to reduce losses of water to non-beneficial uses.

In the arid and semi arid regions water is lost particularly as a result of active evaporation. These losses can be reduced by using cetyl alcohol and related compounds.(45) They form a thin film on the surface of the water and evaporation is thus inactivitized. In Australia and Kenya this method has been very successful, 50% reduction in Victoria, Australia. Along with high evaporation run off is very heavy. The run off recovery is not difficult, in that water can be dammed i.e. stored up in the soil where it can contribute to the recharge of underground water. The run off may be recovered at headslopes where volume is small but waterflow dispersed, or it may be collected at a suitable concentration point downstream. The latter will generally be more profitable because water is then collected in the area of good soil and can easily be spread over the nearby ground. Furthermore vegetation, and grass both check run off and evaporation, and replenish the aquifers.

It is also desirable to check the growth of weeds in the canals, as it augments both seepages losses and transpiration. The seepage loss from the main canals, minors, distributaries and water courses is very heavy, as the top layer of the soil is pervious and sand is of common occurence often to great depths, and the water percolates readily through. This process becomes rapid when the canals are not lined. In his report Professor Zuur suggested, that at certain places seepage is more than

50% of the water carried.(46) To reduce the seepage loss and to kill the weeds, weedkiller oils have been investigated in the U.S.A.(45)

To cope with the water shortages re-use and even repeated re-use of water has been suggested by experts, and it is being practised in the U.S.A.

Professor Zuur has also recommended the use of pumped water from the water logged areas provided it "has a sufficiently low salt content".(46)

The use of saline water is in the experimental stage all over the world. In Pakistan a number of such experiments at different places have been undertaken by the Directorate of Land Reclamation. These experiments reveal that saline water is not harmful under special irrigation and farming practices. In this connection, an example of farmers of Thal area is quoted by Asghar.(47) These farmers use primitive ploughs for their cultivation procedure, and they irrigate their fields with Persian wheel wells. Some of these wells yield saline water but they do not retard their cultivation. The secret lies in their system of ploughing; they plough the land in such a way that the surface soil is disturbed only to the smallest depth, and it is watered very frequently but in small quantity. "To maintain proper spreading of water from low heads very small plots usually of the size of 10' x 15' are made. Thus the salts which are usually present at 3' to 4' depths are not contacted and they do not move upward and consequently are not accummulated in top surface soil on the root zone".(47)

Saline waters can be used for successful cultivation for salt resistant plants. Experiments have also been performed in Pakistan in this direction, with tomato crops, and growing of local paddy. The paddy crop proved a great success, but the cultivation of other crops is still in an experimental stage. Researches are being conducted actively to create the salt and drought resistant crops. The distinction between salinity and alkalinity is here of great importance. The most toxic mineral substances i.e. magnesium sulphate etc. are only found in high concentration under some geological conditions. Use of saline and alkaline water must vary with regional differences in chemical content of the water, movement of the water table etc.

Again experts are trying to discover the means of producing maximum crops with minimum water use. In Israel attention is concentrated on the de-salting of sea water for all uses, water differences, and similar researches are going on in the U.S.A.

The possibilities in the progress of water resources and economic uses of water are not exhausted in the arid and semi-arid ceded countries, but many of them are handicapped by want of capital; cheap methods will be of particular use.

Besides, all these means of water conservation which involve high expense, every individual should be persuaded by law to put every drop of water to an economic use. The farmers should be made to realise that application of excessive water by individuals is a luxury which is beyond the capacity of national water resources. The most important fundamental need is for more comprehensive hydrological and meteorological studies based on factual data, in order to compute and forecast waterflow and the probability of floods. It will provide a firm basis for conserving water. Such studies should be extended to the snow fields, to find out the yield of water from snow for irrigational operation. The forecasting of floods will automatically lead to the study of rate of run-off. Finally, such progress will help the farmer to plan his crop calendar and his harvests will be saved from the sufferings of floods and meteoric storms.

<u>Effects of canal construction</u>:-

The immediate effect of the canal system as noted below is the increase in the total irrigated cropped acreage. This is the great contemperary result of past work on water conservation and water use. The table below indicates an increase in the irrigated area in the former provinces of Punjab and Sind as decimal averages in million acres.(48)

	1901-11,	1911-21,	1921-31,	1931-41,	1941-51
Cultivated	25.6	26.7	27.2	30.5	35.6
Irrigated	7.1	9.1	11.0	13.3	16.4

It shows an increase from decade to decade in both types of cultivated acreages. The acreages are markedly high in the latter decades. The second effect is the development of underdeveloped areas by opening new colonies. All the new barrages have been designed in such a way to fulfil essential diverse needs of economic life such as communication and transportation facilities by construction of roads, railways, setting up new industries to combat unemployment and providing them with uniform and secure water supplies. Thus new vistas are opened for the empty zones of the country. Manifold purposes are being served by these projects, besides strengthening our food position and ensuring security from food shortages.

The irrigation benefits accruing to Pakistan do not end with riparian progress, but are augmented by the many potentialities particularly in the form of hydroelectricity on which depends present and future industries and the rural electrification. Irrigation is a fundamental part of the reclamation progress, through which virgin wastelands are being made efficient to produce food. Thus it is a means of using land and human resources to the optimum. The motive forces for such developments are the increasing population ——→ food requirements ——→ and employment ——→ power needs and ——→ domestic and industrial water supplies. The vital importance of irrigation is to combat droughts, and to rehabilitate the inundated areas. It is even considered by the National Meteorologist that irrigation has modified the climate of the dry region on a large scale.(49)

Along with incalculable bleesings, irrigation has also brought havoc to the fertile agricultural lands, by creating the twin problems of waterlogging and salinity, locally known as "Sem" and "Thur" respectively. These two evils are threatening seriously the agricultural lands which produce good irrigated crops on which the structure of Pakistan economy is built.

<u>Water logging</u>:-

The causes of water logging had been generally examined by 1917, but with the birth of Pakistan particular attention is being turned to the causes and remedies of waterlogging. Proper scientific studies of the problem was initiated in 1938, based on the belief that the rise of water table is the combined affect of rainfall, intensity of irrigation and improper construction of canals and ill-defined drainage. Since 1950, teams of foreign experts sponsored by F.A.O. have been visiting Pakistan and several reports pertaining to waterlogging have been submitted by them. Besides these a large volume of scientific work has been put forward by the national experts recently.

The phenomena of waterlogging takes place when "the sub-soil water table has reached such a height; that it exists within a zone, where due to the capillary action, evapo-transpiration becomes operative, and any further rise of water-table decreases comparatively, as the additions of water due to which the subsoil water rises are completely disposed of by the evaporatranspiration. When such conditions are reached, any further rise of sub-soil water level ceases and the land is termed "water-logged".(50)

Causes of Waterlogging:-

Waterlogging in West Pakistan has as a long history as the present perennial canal system has. The areas to which canals were applied early had an early start of waterlogging and the areas which came under irrigation, in later years developed the signs of waterlogging subsequently. A rough estimate of the area affected by waterlogging was 500,000 acres in 1956.(42)

The prevailing version of water-logging in Pakistan is that with the introduction of canals the level of the sub-soil water-table is constantly and considerably rising. This rising water table has been examined by many national and foreign scientists. There are many causes suggested by different authorities, but very recently the following causes have been suggested as the creation of this evil.(51)

1. Canal seepage,
2. Rainfall increase (within irrigated area),
3. Drainage destruction by roads and railways,
4. Spills from hill torrents and rivers, and sheet flow.
5. Cultivation of "high delta" crops such as rice and sugarcane,
6. Absorption from the fields.

Waterlogging was first noted in 1880 in the Bari Doab and in 1900 in Lower Chenab canal colony. To examine this phenomenon wells were dug out in the area served by new canals, and the level of their water was recorded twice a year namely in June, the month preceded by drought weather and in October, the month preceded by wet weather. Simultaneously river gauge stations were initiated to record the daily discharges of the rivers and canals.

The collection of systematic data on ground water levels for the Punjab was started in 1926 and for the former Khairpur state in 1932, for the purpose of noting the "trends and depicting the areas where ground water in each year stands at average depths beneath the surface of 0-5 feet, 5-10 feet, and 10-15 feet".(52) The study of these records disclosed that the porous sands and soils of the perennially irrigated lands were becoming steadily saturated. The extent of areas of varying water-table in the Doabs of Rechna and Chaj may be noted in the table following.

Doabs	Depth of Water-Table	Areas in Acres
Rechna	0- 5'	184,320
	5-10'	2,048,000
	10-15'	2,242,560
Chaj	0- 5'	291,841
	5-10'	1,469,440
	10-15'	919,040

The data illustrates that situation is very grave in Rechna Doab.

In the opinion of the Director of Land Reclamation the waterlogging at present "is not of a very high order yet the rate of rise of water table is high, and the problem is more serious than it appears to be".(50) The same author recently calculated the variations in the water table in the Doabs of Chaj and Rechna, and from the observations he has tabulated the volumes of water-table for the years stated in the Appendix 9.(53)

The water table level in the doabs is for analysis, regarded, as falling within the following categories of depth below ground level: 0-5 ft, 5-10 ft, 10-15 ft and lower than 15 feet.

Of the 2 doabs 7% of the area has a watertable stabilised since 1935 at between 0-5 feet. The areas where the watertable lies below 10 feet are decreasing in size. The area in which it lies between 5-10 feet are steadily increasing, amounting to 30% of the Rechna Doab, and 50% in Chaj Doab. Obviously, while the area at present periodically liable to waterlogging is fairly small, the area in which waterlogging is going to occur in the future unless preventive action is taken is frighteningly large.

Referring to the present Division of Khairpur and Hyderabad, William stated that "Although abandoned areas are not as extensive, ... degrees of deterioration are no less acute".

At present a grave situation has been realised in the newly reclaimed virgin land of the Thal. As has been reported by Zuur the depressions in the land have been filled with water at Harnoli.(46) Ahmad has recently reported that the total rise of water table in the Thal Canal area since 1935 is 7.13 feet.(54)

The problem of waterlogging is commonly found in the arid and semi-arid region, where rainfall is ill-distributed and highly variable in its seasonal incidences, and the countries which have a perennial supply of surface water and have exploited their water resources to the full capacity for irrigation. These countries are, Pakistan, Egypt, Iraq, Western U.S.A., South Africa, Australia and India.(53) The nature of the problem is similar in these countries because of the [illegible] poorly developed sub-surface drainage.

In the West Pakistan lowland, land is level and without construction of artificially deep drainage channels the water percolation from the canals finds no way out. In consequence water table rises near the soil surfaces, when evaporation sets in operation and water is abstracted.

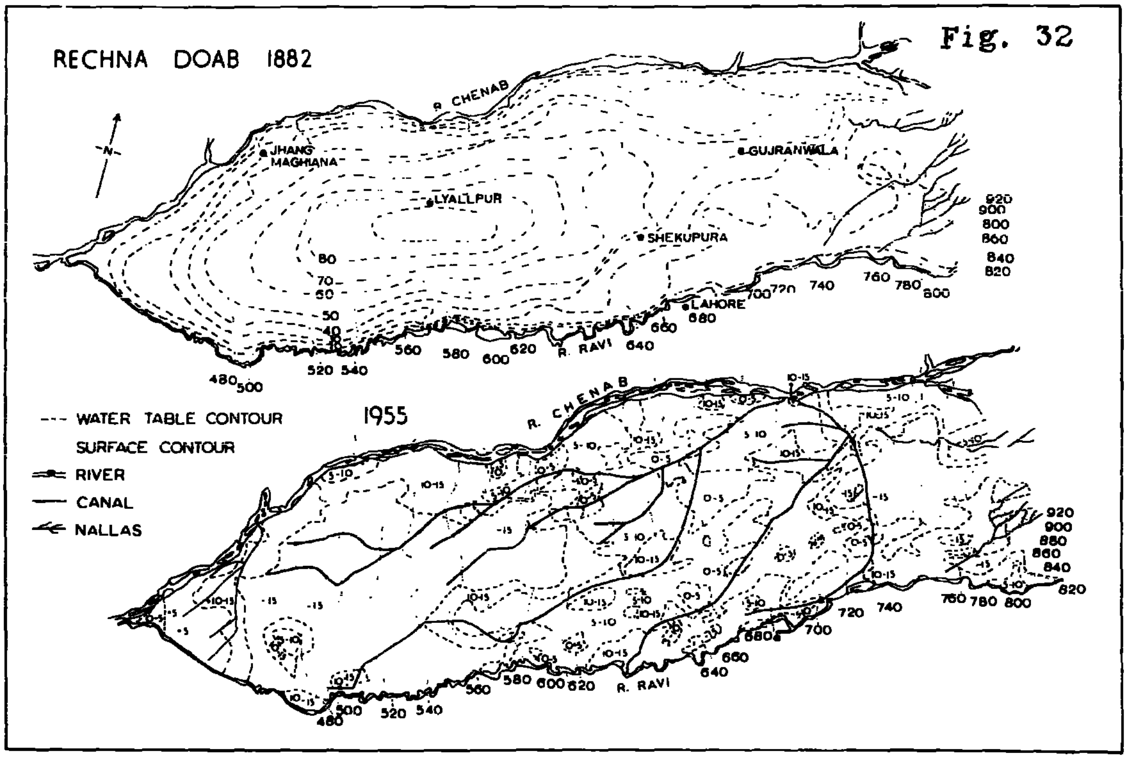
In the paragraphs which follow an assessment of the causes have been made.

As it has been explained in the Chapter 1, the slope of the lowland is very gentle but the gradient is very great in the foot hills which abruptly descends into the lowland. It has also been explained that the rainfall decreases in amount from North East to South West and south, corresponding with the grain of the country. Hence, the excessive percolation of rainwater and seepage from the skirting hills in the sub mountainous zone of north east is inevitable.

As an example, we may consider the Rechna Doab between the Chenab and Ravi, for which, 1882 data is available, i.e. for the period before the modern development of a highly concentrated network of canals. (Fig. 32).

In the northern part of the doab, the watertable is generally high but because of the relative impermeability of the alluvium, the water seepage from the hills is areally irregular and the watertable contours show an irregular pattern of groundwater lodging. South of the latitude of Lahore a symmetrical water table contour pattern indicates the presence of a water table depression between the channels of the Ravi and Chenab. Further study of the map illustrates a region of deep water table south of Lyallpur, having a steepest gradient in the north and steep to the west. With a water level from 50-90 feet, obviously evaporation is non operative. This low water table remained because of the great distances from the river. Carlstan's views on the depression were, that "a very porous aquifer, perhaps consisting of gravel beds of a Pleistocene river,

Fig. 32


RECHNA DOAB 1882
R. CHENAB
JHANG MAGHIANA
GUJRANWALA
LYALLPUR
SHEKUPURA
LAHORE
R. RAVI
1955
R. CHENAB
R. RAVI
--- WATER TABLE CONTOUR
SURFACE CONTOUR
RIVER
CANAL
NALLAS

exists at depth and also runs" according to grain of the area from North east to south west, "draining the centre of the Doab".(3) It is also thought, that, the water supply in both rivers has never been adequate to replenish the depression. Since 1882 many more canals have been constructed and more and more water distributed over the surface of the doab, with the result that the water table level has risen. In 1955 the regularity of water table contours is broken and replaced varying levels and local water tables. The geologic and topographic balance has thus been disturbed.

The rise in the Rechna Doab was commonly attributed in the first place, to the presence of a sub-surface ridge running from Shahpur to Delhi. It was thought that the flow of subsoil water was obstructed by this ridge and high water table resulted upstream. This theory has been discounted, as "The sub-soil water-table contours fail to show any abrupt change while crossing over the ridge, and are quite regular both upstream and down-stream",(53) with local variations.

It was suggested by Hamid that the soil above the rock ridge may be much more compact thus damming the sub-surface flow of water. Carlston rejected this view, as he considers that many million of years are needed in the production of compact soil, and the Indus valley deposits are too recent.(3)

The rise of water table is observed by some earlier writers and recently studied by Nazir and associates, as also caused by the breaking up of surface drainage by construction of roads, railways, canals and embankments, without provision of syphons.(51)

The rise in the water table observable at some places during the last eighty years could theoretically be attributable to an increase in rainfall. This has been advanced by various authorities, the most recent study being that by Ahmad who has analysed the rainfall data for the following canal regions, and periods:-(54)

1. Thal canal from 1935-1955.
2. Upper Jhelum canal, 1916-1955.
3. Lower Jhelum canal, 1902-1955.
4. Upper Chenab canal, 1907-1954.
5. Lower Chenab Canal, Upper region, 1905-1955.
6. Lower Chenab canal, Lower region, 1905-1955.
7. Lower Bari Doab canal, 1920-1955.

A fundamental difficulty arises in the advancing of any hypothesis concerning recently changes in rainfall. As may be noted from the graphs fluctuations from year to year are very large. (Fig. 33) It would therefore be statistically incorrect to try and plot any system of running means.

The candidate has selected four case studies, to show the relationship between rainfall, rise of water table and average fluctuations in the water table from June to October:

1. Upper Chenab canal.
2. Thal canal.
3. Upper Jhelum canal.
4. Lower Bari Doab.

It is clear and, as has already been pointed out by Ahmad that in all cases the long term trend of the water table height is upward. There is no direct ratio between rainfall and the general water table height. On the graphs, Fig. 33 the present writer has also plotted the details of annual fluctuations of the water table. Here a direct relationship is observable. In all cases heavy rains produce immediate rises in the water table and vice-versa. The question remains, (a) Are there observable any trends in rainfall amounts and consequently water table movements, (b) Are such movements significant?

In the region of Upper Chenab canal the water table distinctly and rapidly rises from 1907 to 1925. In post 1925 period the water table does not show a steep rise,

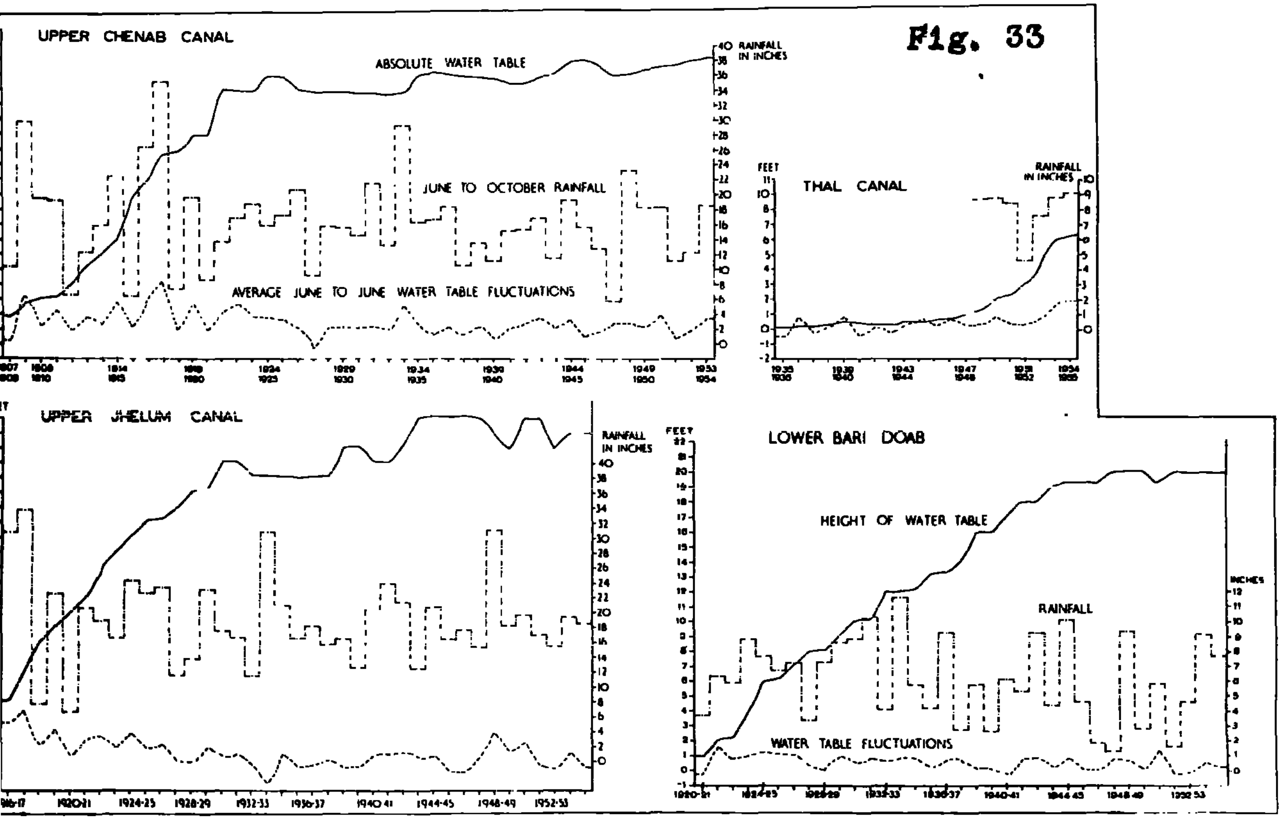

UPPER CHENAB CANAL
ABSOLUTE WATER TABLE
RAINFALL IN INCHES
JUNE TO OCTOBER RAINFALL
AVERAGE JUNE TO JUNE WATER TABLE FLUCTUATIONS
THAL CANAL
FEET
RAINFALL IN INCHES
UPPER JHELUM CANAL
RAINFALL IN INCHES
LOWER BARI DOAB
FEET
HEIGHT OF WATER TABLE
INCHES
RAINFALL
WATER TABLE FLUCTUATIONS

Fig. 33

but is stabilised, swinging between 17-20 feet. The annual fluctuations in water table are positive but for a few years caused by low rainfall. The rainfall peaks and the peaks formed by the water table fluctuations are corresponding.

The fluctuations of rainfall and water table indicate that rainfall does not tend to increase, nor it shows the regularity in its amount. Throughout the period of 1907-8 to 1953-54 the rainfall has been greatly variable in its amount. This indicates that irrigation has not clearly influenced the rate of precipitation, but it has raised the water table to an almost fixed level as between 17-20 feet.

In the case of Thal canal, there is a short period of rain recording, but in recent years 1949-1951, rainfall of order of 8" paralls a rise in water table. Low rainfall in 1951-52 paralls a drop. 1952-55 had increasing amounts of precipitation and rising water table. A hypothetic relationship is thus established, and on the basis of back projection one might assume a period of increasing rainfall since at least 1939. What we do not yet know, is the irrigation supply, which over a short period might coincide with a pattern of increased rainfall and might even be mainly responsible for the water table rise. Thus, we see the necessity for not only noting time-relationship but also measuring the significance of each element. The rise in the actual water-table is rapid since 1948 when first irrigation was applied to this area.

The conditions in the case of upper Jhelum canal are similar to the one noted for the Upper Chenab canal. The fluctuations in the rainfall parallel the fluctuations in the water table. Whenever the rainfall tends to steady water table also tends to be steady. The actual water table is very regular after 1930. Fig. 33 also reveals that water table rise has directly increased with the application of irrigation, but it does not indicate the increase in rainfall. The years of negative fluctuations are the consequence of low rainfall.

In the Lower Bari Doab area there has been a continuous and steep rise in the water table until 1937-38. Since then it is generally steady in rise. Except in 1940-41 and 1951-52 the annual fluctuations in the water table are mainly positive. The negative fluctuations correspond to the rainfall troughs. It shows direct relation of rainfall but no indication of increasing rainfall, or of the possibility over short periods of declining rainfall having any effect on water table.

An argument in the support of rainfall theory has been advocated by McLeod, which was neglected by previous research workers.(55) He pointed out that before the introduction of canal the ground was hard and untilled and there were no field embankments which could hold the rainwater so that the run-off was not obstructed. With the construction of canals the land is cultivated and every field is enclosed by an embankment,so,both the rainwater and the irrigation water are equally held up by these impediments, and favourable conditions are created for permeation.

McLeod has calculated the relative importance of the two sources of percolation, the rainfall and irrigation. He assumed a rainfall of one foot indicating that rainwater amounted to four thirds (4/3) of the total amount of irrigation water per unit of area, of which the normal intensity is 25%. He also pointed out the uselessness of rainwater which falls on the fallow land and is retained by embankments, this water percolates and raises the ground water table instead of supplementing irrigation.

The blockage of surface drainage of runoff is probably not the major cause, in the rise of water table, but is one of the causes which contribute more water to the ground water table locally, than before the advent of irrigation.

Carlston's investigations on the Rechna Doab rising water level revealed,that,the pattern of underground water level has been considerably changed between 1920-1950; owing to the canal system. Infilling flow from the north east has been rapid. The areas receiving no irrigation are maintaining a low water table, while the water has been completely stabilised with a water table at 5 ft. from the surface, with only seasonal fluctuations.(3)

Lately, Nazir and co-workers have explained the high water table as owing to the existence of clay lenses at certain places, which locally block the sub-surface water flow, thus the non uniformity of sub-surface strata is responsible for retarding the sub-surface flow.(51) This view is also expressed by Rahman for the cause of water-logging in Khairpur Division.(56)

Rainfall is hypothetically important but far more important is irrigation. This has led to an increased surface air-humidity, but as appears from the Figures the secular variations appear so large that there is no observational proof of this having any effect. Ultimately waterlogging is within the sphere of human action and power.

Canal Seepage:-

It is generally thought that the seepage from the canals is responsible for the accumulation of ground water. This aspect has been ascertained by measuring the seepage losses in the unit lengths of canals along with the records of water levels in the areas adjacent to canals.(54) It reveals that seepage loss is of high rate in specific areas particularly in the upper reaches of canals where they have been dug down deeply and water flows in the more sandy sub-soil. Most canals pass through non-homogenous soil, and within short distances there are pockets of pervious and impervious clay, the pervious soil encouraging seepage. In one case over the distance of 72 miles, 40 miles were in the sandy soil and 32 miles silt and clay. Thus the water seeps through the sandy portions and infiltrates into clay.

Permeability tests have been performed by the Irrigation Department for various canals. The following statement shows the order of seepage in the Upper Gugera Canal.

	Seepage in cusecs.	Length of Canal in miles.	Seepage per mile.
Pervious reaches	96	18.2	5 cs
Semi-pervious reaches	105	26.6	4 cs
Lower Permeability reaches	17	11.6	1.5 cs.

It may be said here that seepage loss should not be of much importance at present, as it must have been diminished considerably by the vast accumulation of silts and other sediments carried in the water and deposited in the canal bed. Again it is possible when considering the older canals, that, they must have been choked up with sediments, since they overflow with only a slight increase of water. Along with this it may be possible that a seepage may have stopped owing to the substantial rise in water table. Variations in time may thus be important. All these speculations need investigation.

The rising of water table was attributed by Asghar to the monsoon rainfall and only secondarily to seepage.(57) His point of view is based on the investigations for the years 1935-36 to 1942-43. He found the total water losses for the four main canal systems namely, Lower Chenab canal, Upper Chenab canal, Lower Jhelum canal and the Upper Jhelum canal was 3,421 cusecs, of a total main discharge at the heads of the canals of 23,521 cusecs. These losses include the evaporation losses also which he estimated as 10%, while only 4.4% he calculated as seepage loss.

Influence of crops on the water table:-

The lysimeter experiments conducted by the Director of Land Reclamation, show that, cotton, wheat, grain, maize are exhausting crops in respect of moisture, hence they extract from the under ground water table at a greater rate than normal increment from rainfall and irrigation.

On the other hand rice and sugarcane when irrigated allow an addition to the underground water. It has been observed that 60" of total surface application including rainfall is given to rice, out of which, 25% or 15" goes to the ground water. This means that growing of water exhausting crops like wheat, cotton and grain may prove a remedy to lower down the water table in the waterlogged areas.

Zuur does not agree with the idea of high water delta crops, he stated that more water is being applied to the experimental crops than the average for the whole of ex-Punjab.

At the same time evidence of waterlogging or high water table is largely confined to the rice growing districts. There are many contrasting pictures. If it is thought that water is rising owing to more crops of high delta, then there would have not been the prevailing salinity, which largely leads from water being more lightly applied than it is desirable. Hence, the relative influences of irrigation water through high delta crops on the water table is not clear. The high delta crops are the best way of leaching the salts and a decrease in their cultivation may prove harmful. A change in crop rotation may prove more beneficial.

According to Asghar a soil which contains at least 15%

clay, a pH-value of not less than 8.5 and a salt content below 0.5% would prevent the rise of water table.(58) In one of his papers Asghar explains the constitution of a typical ex-Punjab soil profile, containing 10-15% of clay and being of 10-15 ft thickness. Again the situation is paradoxical, in that from the candidates studies it appears that no simple relationship between soil type and water-logging exists. There is no single cause such as seepage, increases in rainfall, obstructions of natural drainage, torrents, cultivation of high delta crops, and absorption from the fields.(59)

In the case of the Rechna Doab (Fig. 32) we may say that the free return flow to the rivers from, canals, and drains is checked, by less porosity of the soil which has become saturated, and great distance to the river. It is improbable that the flow is retarded by any sub-terranean obstruction. There is an addition of water to the sub soil by the monsoon, but the run off is retarded by desired cultural features as roads and railways which add to the subsoil water. The percolation through irrigation is not considerable, but seepage losses are of high magnitude; hence the appearance of the waterlogged area primarily results from seepage. The other elements are secondary or third rate causes, which nevertheless are part of an integrated geographical whole.

Remedies for waterlogging:-

The prevention lies with any method which helps de-watering of the present watered area. There are several methods for such an approach. The main intention is to prevent the major contributing factor, the seepage from the canals, by lining the canal channels. The other steps in this direction are constructing open drains, tile drains, and dewatering of area by tube well pumping.

Lining canals:- All those canals constructed before 1939 are unlined and several of the post 1939 canals are lined.(59) The present unlined canals are creating havoc for heavy seepage through them, and it has made the installation of drainage an uphill task.

The reduction in seepage with lining may be offset to some extent,by the addition of increased irrigation supplies to the ground water to promote leaching.(51) Owing to economic conditions lining would necessarily be confined to the portion of heavy seepage losses. This will reduce the seepage but will not eliminate it altogether. Again it is not practicable and economical to line the rivers and all distributaries. Therefore,the lining is of limited value as an approach to lowering the water table. In Pakistan various types of lining have been tried for instance bricks incorporated with a layer of thin concrete, and bituminous sand. The bituminous sand proved to be satisfactory where the sides and bottom of the canals are strong.

The lining problem is aggravated when the ground water table rises above the canal bottom. Moreover closing of canals temporarily means a setback to agriculture. Thus all the experts jointly agree that lining of existing canals is impossible. Lining will in some cases retard the seepage process which replenishes the good quality potable ground water. The authorities conclude,that,a thorough lining of large portions of canal,which are in permanent use would only be feasible, if it is proved that there is no other remedy for rising water.

The candidate has read the recent unpublished reports of the experts and it is clear,that,every method carries physical advantages and disadvantages. With respect to lining each channel and water course, this is a financial impossibility. The lining does diminish the seepage water but no lining type will eliminate the seepage losses entirely. Therefore,the little water which seeps down through lining, in the course of time will still create a waterlogging condition. Therefore,it is desirable that lining should not be considered as a final approach to a cure for waterlogging. Again, lining canals,means a great reduction in ground water resources and an increase in the wastage of water. The water which runs off to sea is lost for ever, but if it is sucked down to the aquifers it can be utilised through pumping. This could keep the water table low, the water being saved in the sub-soil region where evaporation is nil. (See below).

Before proceeding to artificial drainage techniques it is suggested, that, an immediate step should be directed in the rapid disposal of surface water. As it has been explained in Chapter 3 that rainfall comes in torrents which does not profit considerably the crop growth, but runs off to the low lying areas, and finally to the sea. Such intermediate stops are very common in the low land owing to its flatness and this stagnant water contributes to the general rise of water table, and invites malaria and increasing the risk of flood damage. Such surface water should be quickly discharged to the rivers or canals.

Artificial Drainage:- To mitigate the rising of water tables some effective measures have been taken by Pakistan Government.(53)

1. Closing of canals.
2. Reduction in water allowance.
3. Providing flow surface drainage.
4. Installing pump drainage.

There are 5 methods of draining the surplus water from the land: 1. open drains, 2. tile drains, 3. Mole drains, 4. sunken drains and 5. the draining of water by tube wells.

<u>Open drains</u>:- Open drains are practised as a remedy for waterlogged areas in Australia, Egypt, United States and the Union of South Africa. Open drains are also used in the humid countries like U.K. and the Netherlands; though there is a greater use of tile drainage owing to the high value of land.

Although, open drains have been used in many territories, their construction presents certain problems.

First, heavy machinery is necessary for their excavation and much labour is required. Secondly, equipment and labour is needed for maintenance such as cleaning of weeds, silt removal and bank falling unless they are tiled. When completed, they obstruct the mobility of man and machinery and lastly, they take good land out of use. Their advantage is that, they are relatively cheap, easy and simple to install and prove effective. The cost in other words is absolutely high but relatively low. All the objections lose weight when the same system is used for disposal of both surface and underground waters. In this way they serve two purposes. Besides these, the drain water can be used for irrigation after treatment.

Some experts think that land lost to open ditches is not important for Pakistan. Land is the most important asset of Pakistan, it should not be wasted deliberately as Pakistan is an agricultural country and to raise the standard of agriculture and to expand this industry, good land is the foremost need. Since land is lost by salinity and water logging the remaining land should be valued much more. Land extravagance and the improvement of farming attitudes do not go well together. Besides this, the competitive uses of land are increasing every day with a demand for building of dams, settlements, industries, amenities, military, roads, railways, Public buildings, etc. as the country is making strides in all spheres every day. The land problem is essentially one of balancing future returns against present and short-term needs.

Tile drains:- These drains have an advantage over the open drains as they do not take valuable land.

As expressed by Eaton "In view of the general low content of clay in the soils ..... it would seem that tile drains should work remarkably well",(60) maintaining that the soils in general have a clay element of 5-15%, and only occasionally up to 35%.

According to this author's estimation the areas irrigated by canals have a water-table within 15 feet of the surface and this needs drainage. He assumed that if the present water was applied to 30-40% of the land for a continuous cultivation, there would have been no reduction in gross agricultural produce if productivity was increased to the maximum. This would necessitate the installation of tile drains on only about 35% of the 9,000,000 acres.

The tile drains are in vogue only in some parts of Australia and less commonly in Egypt. Tile drains are extensively used in the Corn Belt of the United States owing to high cost of land.(31) Tile drains are very common in U.K., but more extensive throughout Holland.

In Pakistan tile drains have been only tried in the Chakanwali Reclamation Farm where the water table was between 1-4 feet; out of 3,645 acres, an area of 1,765 acres has been entirely reclaimed by drains, the process of reclamation continuing. High yields are obtained from the reclaimed land as given below.(53)(61)

Crop Yields (maunds)

Year	Wheat	Grain	Paddy	Cotton	Sugarcane
1951	5.54	-	14.5	5.9	142.9
1952	3.3	4.9	14.6	2.8	90.0
1953	5.49	5.89	31.0	2.26	123.2

Though the data show fluctuations in yields, they tend to be high for Pakistan. Besides these arable crops, the experiments on fruit trees as Mulberry, grapes, guava and banana etc have proved successful.

The tile drainage system is expensive, and involves a very high degree of sub-surface investigation. As far as the making of tiles are concerned they would have to be prepared locally from the available raw material. Their baking will involve fuel which will have to be imported along with the machinery, unless the provision of gas made possible. Gas fuel can be employed because it is being provided to the districts of Multan, Lyallpur and Lahore. No problem will arise in the availability of labour which is local and cheap.

It is pointed out, that open drainage requires much labour. This should not be regarded as a drawback, as labour is not scarce in Pakistan. In fact excavation of open ditches will employ some of the present million of unemployed population, both temporarily and permanently for the maintenance of the drains. As in the case of much Italian development, in order to conserve scarce capital resources and to ameliorate social conditions, it is often necessary deliberately to use labour intensive projects.

If experiments in open drainage do not prove encouraging, there is a possibility of these being abandoned. The surface drains tried so far have inadequate outfalls and insufficient gradients. To cause proper gravity flow in drains, installation of pumping plants at the outfalls as in Egypt and Holland will be necessitated, such drains are relatively cheap and can serve three fold purposes as stated above. The expenditure for construction and maintenance for open drains is stated as averaging $ 7 (Rs 33) per acre. Williams however, recommended that open drains and ditches should only be installed when draining by pumping and tile drainage system prove uneconomical and less effective.(52)

In the view of the present writer open ditches are not practicable owing to the physical constitution of our soils, which contains higher amount of sand and low gradient. They are liable to the same defects as are unlined canals.

It is because of the high cost of construction, that Eaton has emphasised, that the expenses will be justified only in areas which with increased water-supply will promise a considerably high yields. However, while every expert has mentioned the high cost tile drains involve, they have not given any estimates in figures.

Thus, the tile drainage system sounds more suitable, but both seepage drains, and tile drains have proved less effective, where there are heavy surface soils. Shallow tube wells have proved better measures for extracting excessive sub-soil water and this is supported by Nazir and co-workers.(51) In fact, since all types of drains work efficiently only on good gradients, they are not everywhere efficient.

Mole drains and sunken drains were also experimented in Chakanwali Farm. Mole drains discharged good amount of water but collapsed quickly. The sunken drains could not be continued for their high cost.

Pakistan should in no way hesitate to use the available plenty of gas reserves for the working of tube wells and baking of tiles for the drains. The combination of these two devices will derive the waterlogging efficiently.

Tube wells:-

In Pakistan tube-wells are used for a variety of purposes. The Central Tube-well Project for example, is concerned in the Rechna Doab with lowering the water table and using some of the water obtained by well-pumping to leach out surface salts.

The tube well installations in the sub mountain region is to tap underground water reserves for local irrigation in the riverain areas, such as in the Dera Ismail Khan and in the environs of Rawalpindi.

Thus, the tube well schemes at present undertaken serve many fold purposes as:

1. To make up canal losses.
2. To lower the ground water table.
3. To remove the harmful salts.
4. To reclaim cultivable area.
5. To increase the water supply for irrigation and reclamation of saline soil by pumping ground water.
6. To tap the new underground water reserves, (this has been dealt with under underground water resources).

In the old Punjab of 1945 a total installation of 1860 tube wells was envisaged; out of that, 1,100 were installed to drain the excessive water from the land. The majority of these wells were laid down close to the main canals. In that, much of the water in the tube wells was part of the volume in vertical circulation through the canals, no appreciable land reclamation was possible. These wells were located without there being any full inventory of underground conditions and hydraulic characteristics for individual wells. The wells were spaced arbitrarily as close as 500 feet apart and from 25-600 feet from main irrigation canals. Eaton has reported, that, in pre 1947 era the canal irrigation was usually supplemented by installing wells at a distance of 1,000 feet apart from the canal.

In post 1947 a decision was made to bore wells close to canal, as an attempt to diminish the seepage by breaking up the connection between the canals and the ground water level. "Some 790 wells from 200-280 feet deep, designed for 2.5 cusecs of water delivery were therefore put down at 60 feet from the canals, lateral erosion of canal banks has in places reduced the distance to the wells from the canals. It was later computed, that 78% of the water from these wells was coming from the canal itself".(3) This was a result of sheer absence of investigation in the fields of hydraulics, soils, and underground water level. Such are very expensive lessons for Pakistan.

The failure was only partial in that, part of the purpose of installation was to remove sub-surface water, but the closeness of the wells to the canals was too great, and by producing narrow zones of low water table immediately next to canal beds increased seepage. Since, moreover the general cost of tube well water for irrigation averages Rs 32 per acre as compared with Rs 10 for canal water, any failure in even one of the multipurposes of tube-well installation is critical from the economic point of view.

Quality of Tube well water:-

Eaton reported, that, there is no considerable difference in the ground water quality between different areas.(60)

It was also expressed by both Eaton and Asghar, that water in some wells turned saline in the course of time, which in the view of Eaton is a common feature.

Asghar however estimated, that, nearly 50% of the wells situated away from the canals yield a water of bad quality, while 95% of wells located near the canals yield good quality water. It has been assumed that, the top 50 feet of water is commonly saline in areas situated away from canals, usable water generally lying at the depth of 200 feet.

The sample studies of the tube wells' water analyses made by Eaton are tabulated below. These samples represented the wells close to the canals, hence they contained up to 80% of recirculated water. Two thirds of the samples contained more than 1,000 p.p.m. (part per million) of salts.

<u>Part per million of dissolved solids by classes</u>

Class:	0 to 250	251 to 500	501 to 750	751 to 1000	1001 to 1500	1501 to 3000	3001 to 5000	5000 and higher	Total
Number	1	20	21	19	36	42	13	24	176

Another set of samples from Lyallpur has been considered. Of the samples taken at greatest depth, only half contained over 500 p.p.m. of salt, "and using this criterion alone, much of the water would appear to be of good quality". The majority of the samples show that the upper samples were more saline than the water at lower depths (as mentioned already). Almost all the samples contained residual sodium carbonate i.e., there was more bicarbonate than calcium plus magnesium. Practically, all of these waters would ultimately cause the soils to become alkaline and rather impermeable, so that gypsum would be required for their maintenance.

On the basis of Eaton's work in the case of 7 samples having less than 1,200 p.p.m. of total salt, their drainage requirements ranged from 3-24%, and those for gypsum varied from 678 lbs to 7,020 lbs per acre feet; and average being 22,880 lbs. According to the recent standard for drinking water for human beings in the arid areas, salinity of 3,000 parts by weight of NaCl per million of water can be drunk regularly. The limit set for horses and dairy cattle is 3,000 part and 15,600 for sheep. The limits for crop production has been ascertained as 100-200 parts per million. Tamrisk and palm grow with 6,000 parts of NaCl.(62)

Considering the economic feasibility of using gypsum, Eaton assumed, that, the gypsum can be supplied to the land for Rs 30 per ton and that 4 acre feet of water are used per year. The total cost of gypsum for amelioration of one acre per year is over Rs 166. If his estimates are true then economical treatment is only possible where the sweetest water is used. The economic possibilities of frequent pumping,as a means for expanding the agricultural area would appear limited.

If the above estimations and experiments are accepted, there is no chance to obtain a considerable amount of water by tapping ground reservoirs. In this way river water will remain the only source of good water in the low-land.

The utilization of sub-surface water is,however,made more feasible if its introduction can also serve to drain critical areas. In his report Zuur expressed,that the combination of pumping and drainage would prove the best solution for dewatering, provided,the subsoil is permeable and the water quality is satisfactory.(46)

It is highly advisable,that,before undertaking any measures for draining the areas, an adequate knowledge of the subsoil surface and ground water status should be built up. Acquision of systematic data on boring and its full investigations should be given top priority. Only when, the true nature of the ground water balance is known can the mistakes made in 1950 be avoided.

In his report, Zuur stated,that most of the national experts are in the favour of pumping by open and tube-wells as a measure to prevent the appearance of high water-level in the lowland, by pumping out the surplus of water. This decision is arrived at,because low surface gradients make gravity drainage often difficult. In such circumstances, it is assumed water will have to be pumped and re-pumped on its way to the river system. The Central Lowland is located inland far from the sea, which requires an efficient system of wastage disposal. Lower Indus basin drains to the sea naturally. Hence the chief problem remains with the ex-Punjab.

In his report Eaton proposed a solution to get rid of the unwanted drainage effluent.(60) He recommended that a portion of land should be allotted for the drainage discharge. From this depression,the collected water will be evaporated leaving the salts on the surface. He estimated,that land required for such "evaporation flats" would not be more than 10% of the irrigated area. This solution has remedial merits but no economic gain is likely to result. It is a good and the cheapest suggestion as far as the use of poor land is concerned. The waste lies in the formation of salts, for which Pakistan has already a surplus even for commercial and industrial uses.

Many proposals and suggestions for the implication of several draining methods have been discussed above. No one method seems to be advantageous fully in its application. Every method is still passing through experimental stages, because of the geographical complexity of the area. The application of each method is related fully to the local geographical circumstances.

The literature which has been produced by the national as well as the foreign experts shows that, there has been no satisfactory comparison yet made in the advantages and disadvantages of dewatering the land by pumping and gravity drainage. It is advisable to evaluate the merits and demerits of each method from the financial as well as from permanancy points of view. Asghar's estimation of tube wells permanancy in the former Punjab is only 10 years;(57) in spite of heavy outlays they do not work even for a generation. According to the Australian experts, the life of Tube-well is far too short. Tube wells are in an experimental stage in Australia also.

Asghar has given the estimated time required for dewatering specified areas by tube-wells, but we cannot lay down generally valid conditions. In Sheikupura district, experiments revealed, that, the water table close to the well could fall by upto 6 feet and by 30" at a distance of 5,000 feet away, furnished within 22 days of working of the well, pumping 4 cusecs.(53)

Another test in the Rechna Doab near the Upper Gugera canal with a single well, pumping 20.0 cusecs and located 60 feet from the canal, the water receded 4 feet close to the well and 3 feet at 3,000 ft on both sides of the canal. (No time lapse been stated for this case), but Asghar has stated that, at the same site 9 wells were installed in 3 groups which affected the water table from 10-3 feet in the observational area of 10,000 by 5,000 feet in 3-4 months.

Contrary to this, at Chuharkana Reclamation Project 24 wells were bored which pumped 1,700 acres feet per month in 1953, but no effect was produced in lowering the water-table. Daily pumping for 5-6 hours seems not enough to produce benefit to the land. A five hours daily pumping operation in Khairpur Division failed to be an effective measure.(63) Continuous pumping with large pumps will probably produce a material affect over a large area. The slow progress in dewatering the area in above cases directly points to insufficient investigations of the areas in respect of geology of area, depth of water table, direction of flow, and the physical conditions of soil. The points of high leakage should have been chosen for well installation, moreover estimation of removal rate and quantities removed should be established before hand. These preliminary steps would be involved in the preparation of such inventory. The modifications in the Tube siting and delivery arrangement may bring better results.

In the whole of West Pakistan the following areas have been put in the schedule to be reclaimed from water-logging by different methods.

Table A

Location	Waterlogged area to be reclaimed	Methods	Cost	Completion
Peshawar district	7,796 Acres	Construction of new drains, remodelling of existing (no mention of whether open, tile or mole probably tile as gradient is suitable).	Rs 8.14 lacs	1960
Chaj and Rechna Doabs	592,024	200 Tube wells of 2.5 cusecs capacity.	68 million	1961
Khairpur and Shikarpura	Gravity Drainage	N.D. (no data)	N.D.	N.D.

The gravity drainage devices are adopted for Peshawar and Khairpur as these areas have steep gradient especially in Peshawar. In these localities the subsoil is rather sandy and permeable, in which case drainage is a cheap measure.

The selection of tube well pumping in the central low lands results from its location in the foot of the hills. In the first place, much storm-water comes downhill especially of the Salt Range, which gives rise to the high water table in this area. This means that, there is an extra need of drainage there. In the second place much clay has been washed down from the Salt Range and adjoining north east Siwalik hills, so that, the soils at the foot are rather clayey and for that reason rather impermeable which mean a more intensive drainage system is needed and drains are more expensive. These soils will rapidly respond to the proposed operation. As stated above the water becomes sweeter at lower depths, to obtain this water tube-well is the best alternative.

The situation in the Indus Basin is so grave that, other methods of maintaining a correct water-balance need consideration. Afforestation of selected areas particularly by water-loving species such as the willow, might help, because along with water extraction, local need of wood might partly be satisfied. As is already happening in Turkey, this might prove more positively useful than merely creating evaporation areas.

Besides this, both in the Upper Indus Basin and in the Lower Indus Basin, canal system should be remoulded by reducing the network of canal density in the heavily concentrated areas; especially in Rechna and Chaj Doabs. These doabs are most thickly populated, most heavily irrigated and in the greatest danger of waterlogging. The future dam-cum-link irrigation system may prove an effective measure in the eradication of twin diseases of waterlogging and salinity when the water availability will be more balanced and assured.

In the reclamation programme priority is given to the doabs of Rechna and Chaj, as these two doabs before deterioration maintained a high level of productivity, and were the heart of agricultural West Pakistan. The quality of ground water is quite satisfactory. Moreover this area has been recently investigated geologically, and these two project areas are contiguous and combined to form a block of a desirable size. This area is affected badly by malaria breeding grounds of mosquitoes created by waterlogging.

Finally, it is desirable to do away with the waterlogging by a combination of many methods, which will render a quick solution. Drainage of both irrigated and rainfed areas is as important as the irrigation itself. The main discussion is on the efficiency and economic aspects of the different methods but greater emphasis should be laid on the former.

Drainage of the Makran Coast

The whole area is drained by several intermittent streams which empty themselves into the Arabian Sea, originating from the highlands of Central Brahui and Central Makran Ranges which form a divide between the Makran Coast and Quetta region.

The common characteristics of these rivers is that their flow is seasonal owing to scanty and periodical rainfall, the physical make up of the area they flow through, and the general vegetational barrenness of the country. These rivers become raging torrents whenever there is any rain otherwise being mere strings of small pools. On the mainly limestone rock the streams are of intermitten surface flow. Every stream commands a net of ramifications which again reflect the nature of rock strata.

Porali river, in some ways is the most important, irrigates the triangular plain of the Las Bela and flows to the sea at Miani Hor after a journey of 175 miles.(64) As a result of silting up of the main channel of Porali, it forms a distributary on its left side, which drains into Lake Siranda during its inundation. During the time of flood the water of lake rises from 2 to 3 times more than its usual depth. Normally it maintains a depth of 3-5 feet, which increases to 10-12 feet in flood time.

The floods in the Lower Porali Basin are frequent, as the area receives a measurable rain both in winter and summer. The basin is rather flat with an insignificant gradient, thus, the river over flows the whole lower valley and silt is deposited which increases the productivity of the area.

Owing to the non-existence of data on river discharges, a pattern of the Makran rivers' annual flow cannot be analysed here. It is estimated that all these coastal streams and desert streams, in a year of good rains discharge 5 m.a.f. of water.

This part of West Pakistan needs utmost attention paid to the conservation of its available water, since water is the most scarce resource in this region, for which reason it is an almost empty and negative area. All activities, agricultural and pastoral and population concentrations are centred around the water spots. Activity is limited by water shortage which is a mounting problem.

The salient features of the water supply are:-(65)(66)

1. Normal flash flow of rivers.
2. Flood water.
3. Underground flow of the streams and
4. Occasionally torrential and always meagre rain.

The flood water is an important source of water supply for agricultural purposes. Flood water is detained by the earth embankments by the sides of rivers. A number of diversion dams are erected before the flood season starts, these dams being built of boulders, ash wood and clay. The water,thus obtained is directed to the fields. These embankments are often washed away by intensive floods, and then no water is conserved and the fields are left waterless. The retention of flood water by bunds round the fields is nedessary so that the soil cover may be renewed by the flood water, moisture content of soil increased and eventually the fertile soil may yield good summer crop. The general size of these embankments is 5-6 feet wide and 4-5 feet high. The flood water is also available accumulated in shallow pools in the upper reaches of the streams. Such pools may be expanded to accommodate more flood water. This system of water conservation has been in vogue since time immorial, the huge Gabar bands stand a witness for such practices. These bunds or devices of water detention often get damaged by the on rush of water and also suffer from a considerable leakage. Moreover these dams quickly get silted up. Therefore special types of conservation dams are highly desired. A modern dam has been contemplated on the Hab river to irrigate

85,000 acres.

Though flood water is conserved by unscientific and primitive methods, yet much water is still lost to the sea by run off as in the case of the Indus Basin. The problem here too confronting man is to conserve this run off. The conservation of flood at present is difficult because of paucity of data on the run off characteristics, and evaporation losses which are considerable. The evaporation losses worked out at the Geophysical Institute at Quetta show an average of some 70 inches per year reduced to an open water surface.(66)

The run off in the Porali valley is said to be 65-70%, owing to denuded hills and the treelessness of the Las Bela plain.(65)

Fortunately,the topographic configuration is such, that at many points water can be arrested by using new techniques and by improving the old methods, the latter being on the whole more advisable. These points are "Tangis", (gorges), confluences and the intermediary space between the coast and high ground. (Figure 1) Furthermore vegetation cover improvement or range development should prove effective in controlling the run off and soil erosion. Development work would be essentially similar to that considered below for the inland drainage region.

It is desirable to pay particular attention to the Dasht valley, as it has excellent soil, and climate other than precipitation, is suitable to a variety of crops such as wheat, cotton, indigo, sugarcane and rice, viz.(67) both high delta crops and low delta crops. If a regular water supply is made available, good yields are likely to be achieved by maintaining scientific rotation. The run off in Dasht valley is heavy owing to its shaley nature which inhibits percolation.

Las Bela is receiving more attention and a number of schemes for construction of diversion and sub-surface weirs will be completed in the Divisions of Quetta and Kalat. The first phase of these irrigation plans has been commenced. Under the plan more than 800,000 acres of land will be brought under cultivation. The entire plan will take about five years. It has provisions for the reclamation of 400,000 acres of land under flood water irrigation and another 400,000 under perennial irrigation.(68)

Lack of water is a draw back of great magnitude not only of the coastal Makran area but of the whole of the former province of Baluchistan. Other obstacles to development of this region are inadequate communications and sparse population, which are in turn direct results of water shortage. Therefore, to obtain economic results from this negative area government have introduced small schemes within the populated areas. The first attempt is to restore the existing indigenous irrigation methods.

Available water and actual need:-

According to Unesco news letter June 1959, the yearly stream flow for the ex-Province of Baluchistan has been roughly estimated as 4 and 5 millions acre feet and $2\frac{1}{2}$ million acre-feet of ground water. The total available supply is $7\frac{1}{2}$ m.a.f. The water needed for the proper development of range lands, agriculture and fruit crops is estimated at about 25 million acre feet. Out of this total, 17 million acre feet is allotted for the requirements of food crops and 8 million acre feet for range and fodder crop development. The deficiency of water is about 17 million acre feet. This deficiency may be made up by water conservation, in that present stream flow and ground water account for only a small fraction of total precipitation.(66)

It is estimated, that in the ex-province of Baluchistan the area now irrigated by different sources is:-(69)

1. By perennial surface flow - 30,000 acres.
2. By surface flood water - 80,000 acres.
3. By ground water from Karez, and open well - 30,000 acres. Total irrigation acreage 140,000 acres.

It was further estimated that these irrigated areas annually utilise about 438,000 acre feet of 1/7 of a potential 3,212,000 acre feet of surface and underground run off.

Inland Drainage Basin

This inland basin is a vast area stretching from the north of Dasht Basin, to west to the Hingol Basin; upto the Afghan border in the north and to the Iranian border in the west.

The area includes the Kharan basin of 35,000 square miles, and the Pishin-Lora basin of 15,000 square miles on which depends the prosperity of Quetta. The significant rivers are Pishin-Lora, Baddo with many lakes in its course and Rakhshan. The Pishin-Lora crosses the boundary into Afghanistan for a distance of about 50 miles and then reënters West Pakistan. The Pishin-Lora plain forms the desert basin of an inland drainage, which extends westwards into Afghanistan. The Mashkel salt flats lie at the height of about 1,600 feet above sea level on the Pakistan-Iran border, forming the bottom of the drainage basin. Innumerable streams flow from both countries into the swampy depression.

The rainfall in this region as already explained, is almost nil and water courses are extremely undeveloped.

Whenever there is rainfall the hills, being barren owing to aridity, are gullied deeply by torrent flushes, thus a large portion of the run off escapes unused into the desert sink. These ephemeral streams carry small amounts of water to the interior playa-lakes called "Hamuns". These hamuns are converted into lakes and marshes when it rains. Still smaller ephemeral lakes are called Nawars. Some of these contain a permanent storage of water such as Zangi Nawar, Zahro Nawar and Barkho Nawar. The former two are situated between Nushki and Chagai with a length of 2 miles, and depth of 50 feet with a water of splendid quality. These nawars can easily be deepened to hold more water for the promotion of agriculture as many large pockets of fertile soils are available.

The floods in the ephemeral torrents are so destructive that they even occasionally wash away the railway lines. In 1902 a large bund was built by the government at the cost of Rs 3,910 for the fertile Dak lands of the Lora river. It was partially washed away in January 1903 and again repaired for Rs 4,700 but was again damaged.(70) Dams in such country are very difficult to maintain to arrest water. In that, flood water cannot escape to the sea but must either percolate to sub-terranean aquifers or collect in hamuns, and nawars, the water is hypothetically at least reclaimable. Moreover, much unleached chemically fertile silt is deposited in places and could with underground water be cultivated. Control of flood water could lessen the destructive effects of flood and improve possibilities of cultivation.

In this survey of the interlocking of many elements in the water balance appears the value of the geographical approach. The main climatic controls are established, along with the main elements of topography and geology. On the human side we must accept a growing population, shortage of capital and a need for expanding agricultural production. No simple economic or technical solution can be preferred, but there must be fundamental investigation of the various combinations in which these elements appear in the different regions. Human beings can control some of the physical factors involved but only by developing flexible policies based on integrated knowledge. Aridity in West Pakistan is not a simple matter of climate-all physical and human elements are involved.

Underground Water

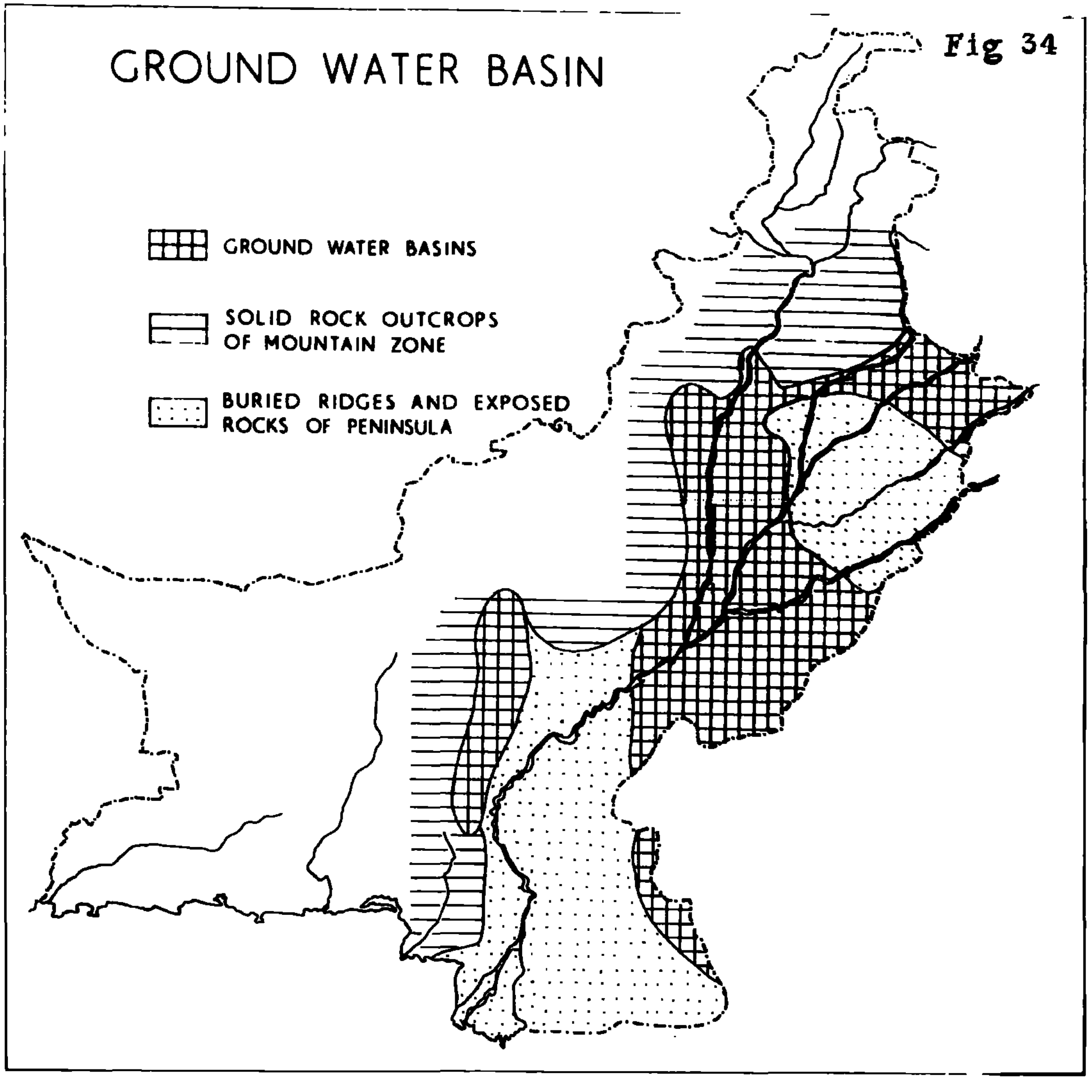
Of the rain that falls in West Pakistan, much is carried away speedily by the surface flow to the sea, the remainder is absorbed by vegetation or percolates into the unconsolidated material, or returns to the atmosphere by the process of evaporation which is very active because of heat and barrenness of surface.(71)

In view of the rapid run off, only a fraction of water is allowed to sink underneath the ground. As explained in the preceding chapter, the rapid run off results from the nature of monsoon rainfall which is concentrated in few months and falls in bulk. The intensity of run off is less in the lowland because of its almost level surface. The run off is very high in the adjoining Sulaiman Ranges because of their barren steep slopes, (raimfall is higher only in the north east and north) and typical topography is that of badlands. The run off in the Divisions of Quetta and Kalat is extremely great because of rugged topography and absence of vegetation. The little amount which is absorbed by the porous rocks circulates through the permeable strata and when these layers are fully saturated or attained the level of saturation, water emerges to the ground surface in the shape of springs and seepages. Springs frequently exist in the hilly zone between the permeable and impermeable rock strata, where they are folded, or the springs issue at joints, fissures or faults. Cathrow made a point that the numerous springs in the Peshawar Division owe their origin to the outcropping of limestone stratum.(72)

The largest reservoir of stored up water is found in the Indus alluvium which contains a considerable amount of sweet water at various depths. The annual rainfall is low over the whole country averaging less than 20". As a consequence of this the underground water reservoir is not rapidly replenished.

In Pakistan studies in underground water are comparatively recent,therefore at this stage it is not possible to give a correct amount of water recoverable from the ground reserves. It is surmised,that about 10 million acre feet may be available from the underground water reserves in the Indus Basin alone. The available groundwater in the former province of Baluchistan is 2½ million acre feet.(66)

Underground water exploitation is an expensive undertaking, therefore it is desirable to ensure that an optimum use has first been made of surface water. In this direction the basic problems are those of location of subsurface water in economic quantity and of the testing of quality and suitability for agricultural and human uses. In the Regions III-IV, the methods of investigations being applied are seismic reflection and refraction. There is, then a need of power supply to extract the water. Thus a large scale and economical development of underground water


GROUND WATER BASIN
Fig 34
GROUND WATER BASINS
SOLID ROCK OUTCROPS OF MOUNTAIN ZONE
BURIED RIDGES AND EXPOSED ROCKS OF PENINSULA

is a doubtful feasibility.

In 1936 the Geodetic Survey of India published a map of north west India locating the Ground Water Basins.(73) The candidate has used this as a base for Fig. 34.

Three main points emerge. First, in the Indus basin sand and alluvium exists a large ground water basin, which includes the upper Indus doabs and parts of the Tharparker desert and Sibi plain. Secondly, this basin extends westwards to the mountain zone of water accumulation in the considerable stretches of limestone and talus. Thirdly, the internal continuity of the ground water basin is broken up by the upswelling and emergence of Pre Cambrian rocks of the platform which underlies the Indus plain infill. In the north-east exposed ridges predominate, while in the lower Indus the upswellings are concealed in the alluvium.

Present knowledge concerning the nature of the underground water resources is summarised below. In the submountain Region, certain localities have been studied by Coulson which are based on his observations of deep boring records at the Isa Khel Masit, Mardan, Kohat and Peshawar.(74)

At Masit Isakhel, deep water exists under artesian conditions, developed by the presence of a thick layer of consolidated clay. These artesian reservoirs are fed by the water percolation from the Indus, but the requisite "hydrostatic head of sweet water will be provided by percolation of rain water from the valley between the Marwat and Khasor region" south of Kurram, an affluent of the Indus. Coulson's studies on salinity point out that salinity decreases with depth at Isakhel and Mianwali as:-

Analysis of water from deep bore at Masit in the Isakhel Tahsil

Depth in feet	Total Solids	Carbonate Na_2CO_3	Bicarbonates $NaHCO_3$	Chloride NaCl	Sulphates Na_2SO_4
12	879.8	Nil	140	529.5	212.8
60	926.7	"	58.8	625.0	237.4
113	216.9	"	18.84	144.5	45.5
176	250.0	"	27.7	158.0	47.0
282	49.0	3.2	28.6	13.5	5.1
309	73.9	"	35.30	33.34	5.90
327	55.4	"	28.56	17.55	9.0

Calcium Ca	Residue	Loss	Classification
"	29.5		Unfit for irrigation and drinking
"	22.0		" "
"	210.0	6.9	" "
"	239.8	10.2	Suitable for drinking and irrigation
"	34.4	10.6	Usable
8.10	60.8	13.1	"
6.48	44.8	10.6	

Details of borings in or near Peshawar

Location	Islama College	Locomotive Sheds	Robert's lines No. 1	Robert's lines No. 2
Depth of boring in feet	295	207	500	415
Size of bore in inches	8	?	18/14	22/6
Level at which water was meet in feet	1073	1014	1095 x 837	1066 800 1052 1046 1031½ 848
Residual level to which water rose in feet	1087	1070½	1123	?

Regarding Mardan and Peshawar Coulson noted, that water quality tended to stabilise with an increase in depth. The sweeter water at deeper levels suggests, that the parent rocks of the area are not saline. The water obtained from the intermediate depths proved to be the best for domestic uses being free from contamination because of its considerable depth. Coulson pointed out, that the depth of extraction should not exceed 800 feet, which is the drainage level at Attock. When the depth of water exceeds this level, there is a great possibility of the quality becoming poor.

At Peshawar Coulson failed in 4 trial borings to reach the main aquifers, but did reach signs of a deep lying water body. The water here lies in the lower lacustrine not alluvial material on top of the underlying impervious rock. (See Table for Peshawar).

At Charsadda and Nowshera Coulson found water at 100-120 feet. He also recommended more wells for Risalpur in bed of Kalpani river. The table shows the water tested in 6 wells in the Kalapani and their per hour flow.

	1	2	3	4	5	6
Water gallon per hour	453	6618	503	732	471	9660
Reduced spring level feet	937	937	939	937	939	939

The total capacity of these wells was 18,437 gallons per hour.

Kohat has interbeded deposits of clay lying on a succession of Cretaceous limestone and sandstone beds. Here is a profusion of springs of good water. The sub-terranean water tends to become saline away from the stream channels, because of intensive evaporation and the extension of the effects of Salt Range materials. Coulson recommended the tapping of "the sub-surface flow of these streams by large diameter shallow wells augmented if necessary by an adequate number of dry stone galleries, following upstream or across, underneath their beds". Tube-well opportunities are limited by the salinity of the lower lying water.

In the Potwar zone the underground water is lying at the lowest levels of recent alluvial deposits. The low rainfall of the area, only slightly replenishing the supply of the underground water, makes utilisation of limited value.(75) The inhabitants of the area face adverse conditions also, because the water is often saline or alkaline again affected by the Salt Range. The Siwalik mudstones and sandstones are well supplied by relatively heavy hill precipitation, but the islands of loess and alluvium have poor and small quantities of sub-surface water.

In the valleys of Quetta and Kalat Division, sands and gravels exist under the clays at certain depths. After examining the geological conditions Auden has recommended trial wells in some parts to ascertain the sand and gravel beds.(76) His opinion is that the exploitation of ground water has scarcely been started in the Quetta valley, and much development needed, in order to obtain an increase in the safe yields, is possible. Besides well boring, infiltration galleries with a series of deep wells have been recommended in many parts of both Divisions. Recently a fresh water aquifer have been located in the coastal tract from Clifton to Sonmiani beach. It is believed, that both fresh and sweet water exist further inland and attempts are being made to differentiate and locate them.

Lifting of ground water

1. Open wells:-

Wells are indigenous and an economical method of water raising where the water table is high and the water suitable for use.(77) The wells are mere vertical holes in the ground below the line of saturation, touching the more pervious strata, where water accumulates by percolation or drainage. Wells aid the independent and small scale development irrigation, and farmers can use the water at any time according to their needs, hence their short term efficiency and practicability needs no emphasis. Another advantage of wells is that they are family property and fit very well in the agricultural routine, and consequent normal self-sufficiency. The most frequent use of wells is made in Divisions of Lahore and Multan. Wells are also in use in the sub-montane regions of Peshawar, Dera Ismail Khan and Rawalpindi while the use of wells is least in the Khairpur Division. (See(Fig. 30), and Appendix 8). By comparing Fig. 30 of irrigation and Fig. 34 showing the ground water Basin we can see,that,the areas of well irrigation coincide with the ground water Basin, where the water table is high and soft rocks provide facilities for the construction of wells. The main disadvantage of single well development also derives from the possibility of separate, independent farmer use. As in Malta in the case of wind pumps, unplanned well sinking may rapidly lower water tables and in a short period produced large scale danger.(78)

A more effective and extensive use of wells can be made in association with flow irrigation. The present irrigation capacity could be further extended by tapping the lower strata through tubes. Figs. 35A and B show the distribution of springs, wells and Karez and the recommended sites for tube wells as a mean of water-supply in the Quetta-Kalat Region. (Note the devices installed in the gravel fans. Fig. 66A).

2. Tube wells:-

The first pre-requisite for tube wells is the location of water-bearing strata and second is the availability of cheap power.(25) An area of 300-350 acres can be irrigated annually by the average small tube well power-unit and it is cheaper than the bullock-power used for open wells.

Recent extension in the distribution of electricity provided an incentive for the installation of tube-wells. With the probable addition of natural gas to water power for electricity generation, this development may proceed even further. These wells offer a possibility of irrigating those areas where canal irrigation is not feasible since the tube wells can be installed both for high water table at c.25 feet or even to as deep as 200-400 feet.

There is a newly completed scheme of tube-wells in the area of Dera Ismail Khan and under this scheme 10 tube-wells of 2 cusecs discharge, irrigate 45,000 acres of riverine area on the right bank of river Indus. Nomadic tribal people are being settled on the irrigated lands. Both diesel and electric power units are being used for pumping purpose.(42)

In the alluvial tract the simple method for drawing water from the depths of 200-400 ft, is by tube-wells.(20) This water is often of good quality to meet domestic, industrial and general needs. Their capacity again depends on the water bearing rocks. As the tube-wells water is drawn from great depths it is freer from bacteria and organic impurities, than common open wells worked by draught animals. This water however contains greater proportion of dissolved chemical salts.(65) Tube wells are considered to be useful even in the Divisions of Quetta and Kalat as sources of water-supply.

In September 1960, Leonard assessed the value and benefits of tubb wells in terms of an average holding of 12½ acres in the Upper Indus Plain.(41) At present the average farmer irrigates nearly 3rd of his land in Kharif crops and about ½ of the land in Rabi with canal water application, and he maintains a crop intensity of approximately 85%. Under the current canal water supplies, the delta maintained for Kharif crop is about 2 feet, and a little more than 1 foot for Rabi crops. He requires additional water for three purposes (a) to increase the acreage in each season, (b) to apply greater depths of irrigation water and (c) to remove the salts from the root zone. The farmer could have utilised more than four times his present water supply for the optimum use of his land. If his present water supply is made double,his land can yield more than double, his present crop production of improved quality, remove salts from his soil. By achieving this type of balance annual income and the value of land increase automatically.

Leonard is certain that with the installation of an average of two tube wells to supplement water for each hundred land holdings, the requirements of reclamation and increased productivity can be successfully achieved. He stated that a sum of less than Rs 1,700 is required as the capital investment per land holding. "The long range overall average cost of operating a tube-well supplemented water system is about Rs 250 per year for each land holding". This amount covers (a) amortisation of the invested capital, (b) interest on the invested capital, (c) establishment of sinking fund for repair and replacement of tube-wells and (d) the cost of power consumed in operating the tube-wells.

The economics of tube well water application obviously depends on a comparison of the net present income of a farmer to that which he will earn under the tube well water supply system. At present the average land holding of 12½ acres produces a net annual income of about Rs 450, in addition to the value of, in wages, of the work done by farmer and his family in crop raising. In the absence of reclamation devices land is deteriorating gradually and crops tend to reduce in quantity and deteriorate in quality and the farmers annual income also drops. The benefits of reduced waterlogging and salinity by the tube wells will appear within 3 to 5 years of their operation. The average crop production should more than double the present production in the first 20 years of this reclamation programme. As "the cost of raising a crop does not increase in the same ratio as the increase in production, a two fold increase in crop production will result in more than a five-fold increase in annual net income. Thus each agricultural family in a tube-well reclamation area will be doing their share of eliminating the present food shortage and simultaneously, will be increasing their net income". This is how the tube wells are appreciated by one expert.

Artesian Wells:-

The promise of artesian conditions in various localities have been attracting the attention of research workers since 1890.(79)

Originally, the term artesian was applied to wells where as a result of underground pressure water flows freely to the surface and need of pumping does not arise.(80) Commonly, now the artesian term is applied to any drilled well from which water flows or in which the water level rises so near the surface as to require little pumping. In West Pakistan notable artesian Karez structure is found in the gravel slopes of Divisions of Kalat and Quetta; (Fig. 36) and also in alluvial parts of Rawalpindi where pockets of loose gravel or coarse sands lie in the alluvium. The introduction of more and more artesian wells or Karezes will be of immense utility as these areas suffer from precarious and untimely rainfall. The investigation of alluvium and gravel fans in arid and semi-arid zones of

West Pakistan is now being intensified, and more experimentation being made.

The alluvium of the Indus plain has always been considered suitable for the formation of artesian structures, but their scope remained a debateable proposition.(81) Medlicot after performing experiments concluded, that the upper Indus region is favourable where continuous zones of gravel and sand layers intervene between clay deposits in the alluvium. In the Division of Quetta the impervious cover of loess has served as "cap-rock" for artesian wells. Moreover there are a number of water bearing gravel fans underlying the impervious layer and overlying the limestone bed-rocks.

It has to be confessed that irrigation by artesian means is not likely to be of great importance, when considering the great extent of the area which will remain barren for want of water, but as advocated by Vrendenburg, the use of artesian water is of great importance where cultivation is dependent only on this source.(82) He has drawn attention to the Karez prospects of Quetta-Kalat Divisions, where this is the most suitable means of irrigation. Recently, it has been emphasised, that in the ex-province of Baluchistan, "In the majority of the territory ..... recovery of ground water will be more fruitful than damming of surface water".(66) This judgement must be balanced against the fact that replenishment is slow and the greatest loss of potentially available water occurs on the surface.

The former province of Baluchistan is the most important zone for ground water, where remarkable ancient method of irrigation "Karez", has long been used. Karez are shafts sunk in the gravel fans hemming the hills, shafts are connected with galleries to form tunnel, which penetrate the water-table and brings water down the channels by gravity.(77) They are basically similar to the Iranian "Qanat". Some of the Karezes yield considerable water, and have flowed since antiquity. Fig. 35A shows both existing and old Karezes. Their expansion and concentration illustrates their favourability and geological feasibility.

Figs. 35 A-B show 4 methods of lifting underground water in Quetta, springs, Karezes, wells and tube-wells for future application. At present tube wells are worked in Quetta only at some railway stations.(65) In the Divisions of Quetta and Kalat there are 1,800 springs and 600 Karezes which irrigate 300,000 acres. 7,000 acres are irrigated by wells, 100,000 acres are watered by spreading of surface flow and the rest, some 400,000 acres, are cultivated by rain water.(66)

It may be concluded, with Medlicot, that researches and trials up to recently were performed on the basis of local needs than on a regional or national basis. The optimum use of underground water involves comprehensive research on a national scale.

Reviewing the hydrographic situation it is desirable to summarise the whole account briefly. The chief hydrographic regions may be listed thus:

1. The region of regular irrigation.
2. The region subjected to regular floods.
3. Land lying outside flood reach but watered by spreading flood water.
4. The areas of underground water.
5. Entirely rainfed areas.

Speaking broadly the problem of water in West Pakistan has two aspects namely (a) the utilisation of surface water and (b) utilisation of ground water. It has been pointed out, that, the rainfall in West Pakistan is periodical in incidence and meagre amount generally. This circumstance makes it compulsory to make an optimum use of the available water supply. To achieve this purpose, canals, wells and tanks have been in vogue since early ages. Several projects of great and small magnitude are still in excecution.

The problems confronting Pakistan which arise from dense canal systems is (a) percolation and absorption and (b) loss of water by evaporation and (c) waterlogging. The methods for the prevention of evaporation loss are still in an experimental stage everywhere in the world. No significant work is directed towards this in Pakistan or has there been designed any standardised method for measuring the evaporation losses. Contrary to this, considerable scientific investigations have been carried out by national research workers in the control of percolation and absorption from canals, particularly in connection with the problem of water-logging in the area of irrigation concentration.

The problem of preventing these water losses is the same all over the world particularly in the arid countries. Any solution would equally be applicable in West Pakistan but the economic feasibility of specific works is of great importance to a country which is short of capital.

Great strides have been made in percolation theory, but an insignificant work has been done on preventive methods. The work done on lining the canals, shows that chemical methods are more useful than others and have the advantage of cheapness. Several methods are of lining the canals each economically feasible under different conditions. There is no single device claiming universal superiority.

The maximum utilization of the surface water is imperative before undertaking any project for underground water exploitation,as the latter is at the moment uneconomic. Nevertheless in some regions underground water exploitation is desirable.

After ascertaining and recognition of ground water reserves, exploitation by different means is possible. Wells, - open wells, tube-wells, and artesian wells are the means of extraction, the first and the last the most frequently used. The construction of tube wells is becoming common in the canal colonies, but techniques of use are still not in an advanced stage.

It is obviously of the utmost importance that sub-soil water level may be stabilised by means of encouraging percolation up to a critical point, constructing tanks or reservoirs by constructing small dams across tangis (glens, ravines) to entrap the run off. These dams made of simple local material may render a vastly valuable service in the conservation of water, underground and surface flow, without which largely costly projects of high technique for daming rivers may prove ineffective over long periods. The renovation of old wells and reservoirs may improve the yield of wells.

Attention should be directed to an effective control in time and quantity, efficient use and diligent conservation of whatever supply is available are necessary to the nation.

The amount of both surface and ground water could be altered, if the distribution of meteoric water could be controlled and modified by stimulating artificial rainfall from the rain-inducing clouds. Such steps might solve the problems of water supply to some extent or might be insignificant. Aridity only in a limited sense in any case has to do with a shortage of meteoric water. In a broader sense it concerns the effective availability and use of such water by man and other organisms.

This is not the place for a comparative study of arid regions of the world, but some notice may be taken of the main recent developments in other countries. From the advances made by the other arid countries in the development of water resources West Pakistan must learn.

In Somalia, recently Macfadyen developed techniques for water investigation with the help of aerial photographs.(83) These photographs defined very well watersheds and the limits of catchment areas, and the direction of flow and water channels are also well marked. Thus, in order to get the true impression of water resources aerial survey is badly needed using vegetation patterns to indicate the presence of water. This is borne out also by Iraqi experience.

The South African Government is aware of the water problem. The investigation of underground water has become an integral part of the geological survey like the search for other minerals. Geophysical methods are being applied in the search of water on the regional basis.(84)

In Aman the problem of water is similar to West Pakistan in general and particular to the Division of Kalat.(85) The Wadis are clad by palms, woods and bushes, after showers of forceful rain. The water table at places is hardly a foot below the surface which is often brackish. The wadis are surrounded by villages and small gardens which utilise the water of rivulets. The people have dug underground channels known as Aflaj similar to Karez; which supply a good domestic and irrigated water. The wadis in Kalat could be developed in the same way for water supply.

In Russia 20 million acres of Asiatic desert area has been brought under irrigation, now supporting forests and agriculture. The sub-soil water of the Kara-Kum desert have been investigated, and attempts made to deflect underground water to the surface. Along with this salinity and seepage have also been studied.(66)(62)

U.S.A. is the leading country in respect of regional planning under the National Resources Planning Board, and a thorough study has been done of every region and sub region to locate underground water resources and solve the water problem of western states, a problem now becoming acute.(86)

Almost everywhere a vigorous campaign has taken place to fight the aridity. The best example is the neighbouring country India. The Bakhra Dam is a magnificent achievement in the direction of controlling aridity. Above all, better utilisation of water and reduction in the wastage of water is now everywhere being recognised. Every drop should be put to a maximum use. The wastage of water by seepage, evaporation, and transpiration can be minimised by canal lining, closed conduits and by irrigating the fields by sub surface methods or by sprinkling. Crop sequences must be designed so that moisture applied to each crop can benefit the succeeding crop. In all areas of the fight against aridity it is being increasingly recognised, that, the process is complicated and far-reaching, affecting every part of human life and the natural environment.

Chapter 5

Soils

We have considered the climatic forms of aridity, and the elements of hydrography,which firstly,are important because of climatic aridity and secondly,are functions of that same climate operating in the terrain and on the structures earlier described. The consequences and implications of the forces making for aridity become less and less meterological and more geographical as the inter-weave of factors becomes more complicated. Aridity in the last resort is ecological, and edaphic as well as atmospheric. In this and the following chapter some of the edaphic and ecological elements are considered from two main points of view. First,these elements have characteristics derived from their position in the complex of total forces. Secondly, insofar as we can isolate soils and plants from the complex, man can only regard or utilise them so far as the other links in the chain will let him. Thus the rice-plant can be considered to have a very small natural ecological niche in West Pakistan - here it is part of the complex. Paddy-rice grown by man has been made more adaptable, while man attempts to expand the area of suitable environment. As soon as such interference starts then the total environment - from catchment basins in the Himalayas, to rainfall regimes, to water-table stability, to soil alkalinity and many more - has to establish a new equilibrium. Because, climatic aridity is so dominant then all elements have to be referred to it, and all man's actions, have particularly in connection with soils have swift and far-reaching consequences.

The majority of people in Pakistan derive their livelihood from agriculture. Soils are a factor of vital importance in agricultural production and rural advancement. Therefore, "The first principle of agriculture is an understanding of soils and how to distinguish those of good quality from those of poor quality".(1)

In West Pakistan we are concerned with the soils which are developed under dry tropical and sub-tropical climatic conditions. They are collectively designated as steppe soils and desert soils. These soils, generally are of grey colour, and possess organic matter and nitrogen content too low for an optimum yield.

The early Russian soil experts were the first who recognised the "soils as an independent body with a definite morphological organisation reflected in the profile".(2)

They were also the pioneers who established the modern inter-connection between climate, soil, vegetation and geology. They further regarded soil as "a dynamic and not a static body, a living organism allied in the plane of development to biological bodies". The soil from the surface to the solid rock is now regarded, as a natural body made up of various layers developed under the perpetual influence of the environment. The dynamic character of the soil appears out of the study of soil profiles; which study gives information of the past evolutionary imprints and future potentialities as well.

We may sum up as follows; the soil is a dynamic substance of variable thickness which supports all life and is composed of organic and inorganic matter. Soil is the outcome of multiple factors of disintegration, integration and decomposition which are discussed below. The soil is constantly affected by variable pedogenic factors such as geology, climate, hydrography, vegetation, fauna, time, man and organic matter.

The Geological Element:-

The pedology of Pakistan has never been studied along modern scientific lines. In the 1930's an outline study of the influence of geology on soils of the sub-continent was

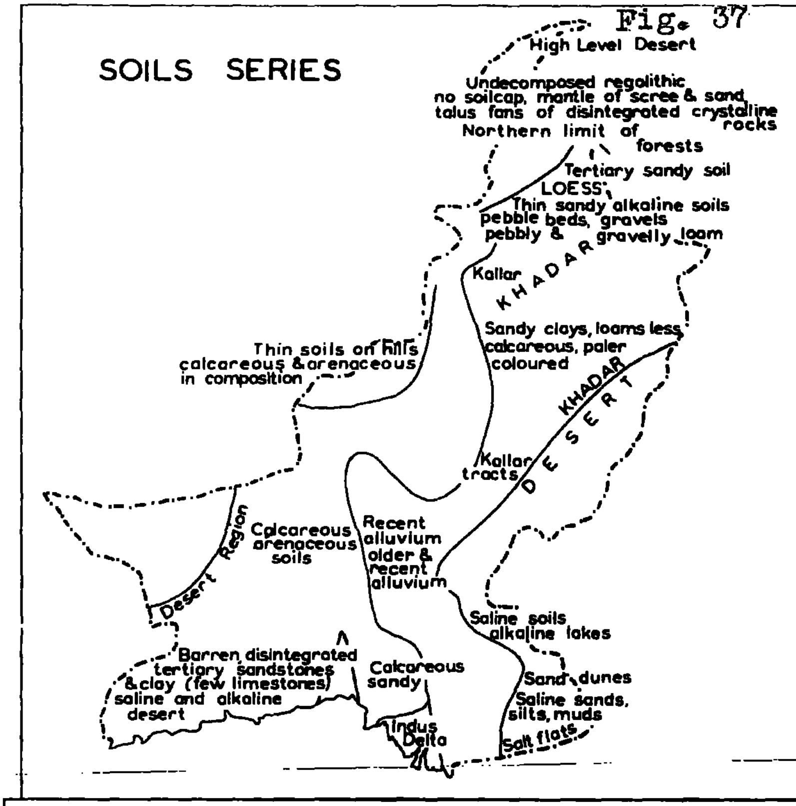
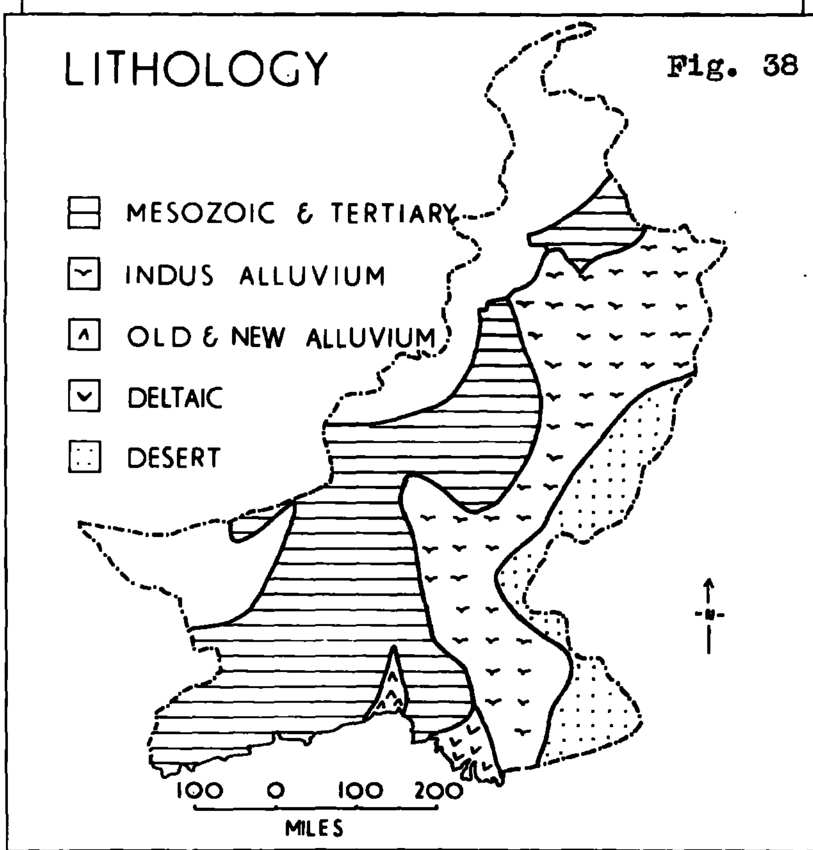


Fig. 37
SOILS SERIES
High Level Desert
Undecomposed regolithic
no soilcap, mantle of scree & sand
talus fans of disintegrated crystalline rocks
Northern limit of forests
Tertiary sandy soil
LOESS
Thin sandy alkaline soils
pebble beds, gravels
pebbly & gravelly loam
Kallar
KHADAR
Sandy clays, loams less calcareous, paler coloured
Thin soils on hills
calcareous & arenaceous
in composition
KHADAR
DESERT
Kallar tracts
Desert Region
Calcareous arenaceous soils
Recent alluvium older & recent alluvium
Saline soils
alkaline lakes
Barren disintegrated
tertiary sandstones
& clay (few limestones)
saline and alkaline
desert
Calcareous sandy
Sand dunes
Saline sands, silts, muds
Indus Delta
Salt flats


LITHOLOGY
Fig. 38
MESOZOIC & TERTIARY
INDUS ALLUVIUM
OLD & NEW ALLUVIUM
DELTAIC
DESERT
N
100 0 100 200
MILES

presented by Wadia and collaborators.(3) This study indicated ,that limestone and sandstone tend to produce sandy soils, which are generally sterile. Shales have given rise to clay soils, which are sticky and fertile; and found in our regions III and IV.(4) In the same regions at some places volcanic rocks have given rise to small parcels of fertile soils. In Figure 37 are mapped the recently derived soils from the regolith (here unconsolidated debris or drift deposits).

Each soil derives many characteristics from its parent rock under arid conditions. Even after the soil is affected by climatic, biotic and hydrographic factors, it retains the same total constituent elements as had the parent rock. The process of soil formation in the first instance is a process of rock decay. The soils of arid and semi-arid West Pakistan are now being developed from material under conditions of a low moisture and are therefore slowly developed. Hence, they have maintained their dominant mineral characteristics, with relatively minor ingredients of organic matter. Based on geology, the soils of West Pakistan may be classed in two groups (Figs. 37 and 38), Residual Soils and Drift Soils.

Residual Soils

They are again classified as derivatives of (a) Ancient crystalline and metamorphic rocks, and (b) Tertiary and Mesozoic sedimentary rocks of the highlands. (Fig. 38).

(a) Ancient crystalline and metamorphic rocks occupy an insignificant area of Region I, the Kirana Hills in Region VI and in Tharparkar in Region VII. They are mainly of granites, gneiss and crystalline schist. These rocks have given origin to an undecomposed regolith with mantles of scree and sand, talus, fans of disintegrated crystalline rocks, and no true soil cap is formed. The soils are shallow and chemically poor, hence are useless for cultivation purposes, but support a little grazing. South of this zone lies the northern boundary of timber line.

(b) Tertiary and Mesozoic sedimentary rocks:- Many pockets of these soils are found in the plateau of Potwar and Quetta-Kalat. These soils fall into two groups. The older soils, which are calcareous and arenaceous are derived from the mesozoic rocks of regions II-IV. New soils are dominantly sandy and originated from the Tertiary sandstones of Region V. These soils occur on the uplands and are thin and severely eroded. These soils are not of constant character, belonging to the arid and semi-arid belts of West Pakistan, where rock desquamation is active owing to the vast range of temperature. Soil formation is not active due to insufficient moisture and slow humus formation. These soils are highly porous and at places contain injurious chemical salts and alkaline soils. These soils include pockets of clay, loams, pebbles, and gravels, products of soil wash and deposition. On steep gradients these soils are particularly vulnerable to gully and ravine erosion.

The productivity of these soils can only be maintained by reducing run off, controlled grazing and an application of fertilisers. This type of development in that it implies the encouragement of sedentary agriculture in arid regions III-IV will greatly affect the nomadic population. Irrigation in these areas is not generally feasible because of the broken topography, and arable farming is possible only in the valleys. Again sandy and coarse soil is an obstacle in the way of irrigation. If run-off is controlled, these areas could be turned into flourishing grazing grounds, as the water is the chief limitation especially in regions III-IV.

Bordering these residual sedimentary soils in the foot hills, is a zone of transition with the drift, where under unstable conditions immature soils partly residual and partly derived from a deposited regolith of gravels and boulders are being formed. The soils described above are formed in situ, derived chiefly from limestones and sandstones.

Drift Soils

The major portion of the Indus Plain has a mantle of drift soils formed by alluvial and aeolian deposits. These deposits contain the most important soils of West Pakistan, on which depends the agricultural prosperity of the country and where the major concentration of population as well as irrigation is found. These soils are entirely different in origin from those mentioned above, in that they are not formed by locally decomposed rocks. These deposits fall into the following categories. (Figs. 37-38).

(a) Alluvial
- i Older Alluvial.
- ii Newer Alluvial.
- iii Deltaic Alluvial.

(b) Aeolian Material.

(a) Alluvial:- The chief content of the soil is silt, deposited by the Indus river system. The newer alluvial 'Khadar' is predominant in the eastern portion of Indus plain. This light coloured alluvium is mainly composed of fine grained material. The older alluvium or Bhangar is sporadically distributed and its surface appearances are mostly confined to the north west of Region VII. The Bhangar is of darker colour and is more stony and less uniform in texture than the newer alluvium.

The alluvial soils range from sand through loam and fine silt to stiff clays. They are regularly visited by furious floods. These soils are irrigable and can be responsive but are often unsatisfactory owing to high inherent salt content and poor natural drainage. Therefore, there is always a danger of waterlogging and salinity which phenomena are presently spreading. Permanently wet and salty tracts already exist. Alluvial soils are most agriculturally productive near the river valleys, provided drainage be supplied to counter water logging which follows irrigation.

Deltaic Alluvium, is the seaward extension of the recent alluvium of the river Indus. These soils are continually renewed with a new covering of silt, and can be very fertile. There are many marshy tracts of peaty soils containing high proportions of organic matter.

Desert deposits of Aeolian soils are found in two main tracts. First, there is the latitudinal belt consisting of the Cholistan and Tharparkar deserts in Region VII 3a and b, and secondly, the stony desert of Region IV. The former has a mantle of blown sand, the raw material for which has been transported from the coastal region and the Indus plain by winds. The whole of this desert belt is scattered with sand dunes.

The latter desert is a dreary region consisting of stones, caused by the rock disintegration under large diurnal and periodical range of temperature. The limited amount of moisture prevents soil formation. Both these desert areas are useless for agriculture.

Loess, a wind deposited sandy loam is found in Regions V 2 a and III-IV. Deep and highly absorbent, loess is naturally well drained and for this reason rather than chemical richness is agriculturally very productive. Loess is very vulnerable to gully erosion.

From this introductory sketch it might be concluded, that the residual soils are poorer from the farmers point of view than are the non-desertic drift soils. Although, we must qualify this statement by an examination below of other elements in the complex, we can use the geological approach as a base for assessing the usefulness of the soils of major regions. (Fig. 38).

Climate

In addition to this geologic origin, soil is influenced by the climate. Climate exerts its influence on soil to such an extent that geological differences may be obliterated. In an extreme climate like that of West Pakistan, one general type of soil is produced whose characteristics transcend in importance to man,the differences already considered.

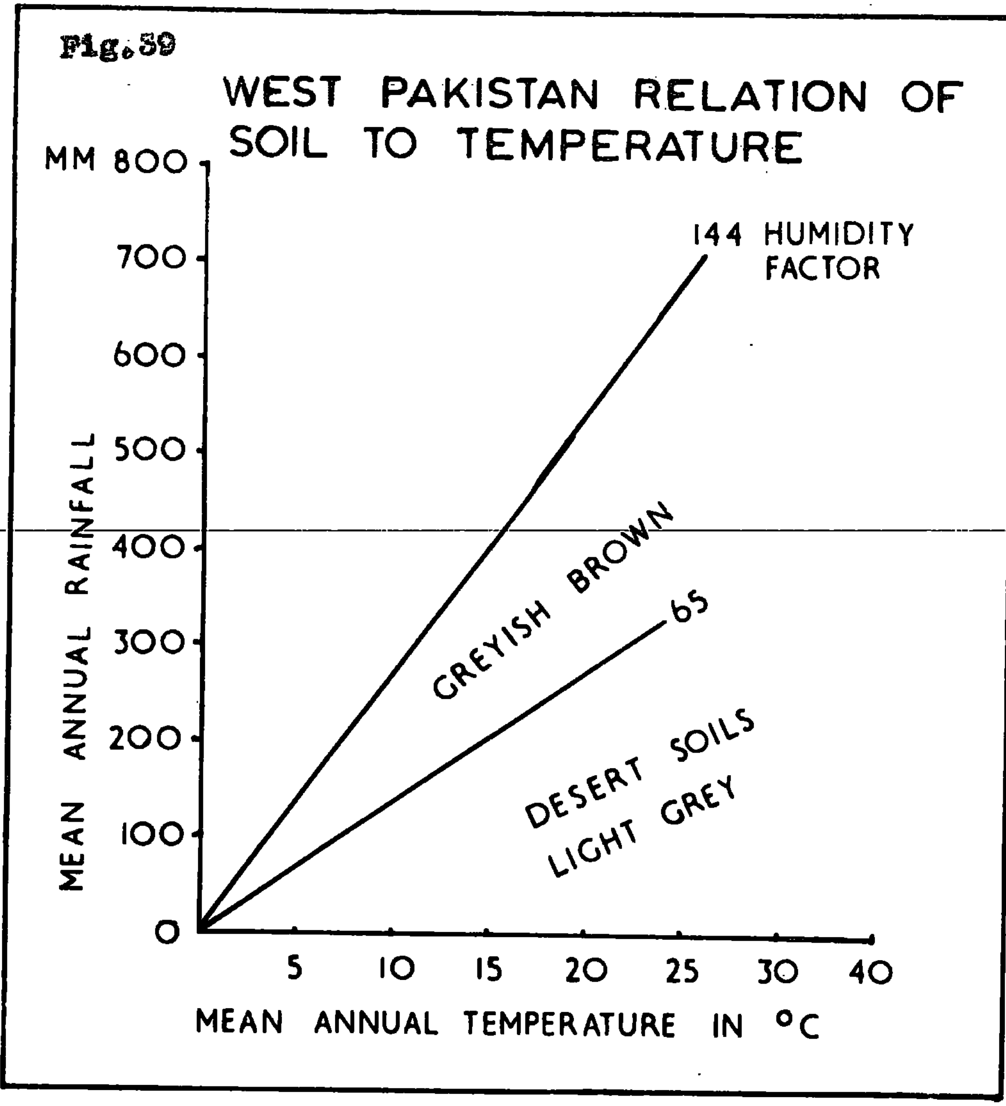
If we compare the soil map with the geological map little correspondence appears. On the other hand the pattern of soil formation bears great agreement with the distribution of rainfall. For instance desert soils predominate when rain falls below 10 inches annually, whether the rain comes in winter or in summer or throughout the year. (Figs. 4,13,21B, 37 and 43). Again the productive soils approximate in their distribution to the zone between the 10-25 inches Isohyets. On the whole, the soil map shows that soil types approximate more to the climate map and less to geology. This correspondence between the climatic zones and the soil zones theoretically leads to the zonal adaptation of cropping, hence the farming types would be expected to be established on the bioclimatic basis of any area.

The soil is influenced by the local temperature, and meteoric water.(5) The climate on the whole regulates the amount of warmth and water penetrates into the soil. The temperature variation is the main factor decomposing the rocks. The soils of arid region, mainly because of low humus content are of light colour, have low specific heat absorption and respond quickly to the alterations of temperature. Contrary to this,the heavy soils retain moisture and are not as readily affected by heat and cold.

It has been noted earlier that effectiveness of rain does not depend on the total fall but the amount which is available for plant growth. In West Pakistan where evaporation and run off are very great, the efficiency of rainfall is diminished. In general the soil characteristics are related to temperature and rainfall. Under mean annual temperature of 30°C or higher, desert may occur even in the regions of rainfall as high as 1,200 mm annually. If the mean annual temperature is only 10°C the rainfall does not exceed 400 mm. When the rain factor is between 40 and 60 the soils are blended with iron oxide, as the yellow soils, red earth's and laterite soils. These soils are formed in the areas with a rainfall between 500 mm to over 1,000 mm. None of them exist in West Pakistan.(6)

The devices for reducing the daily range of temperature at soil level may be adopted in Pakistan as it has been undertaken in Malaya.(7) The daily range of temperature has been reduced by a coating of dried mulch but it did not reduce the mean soil temperature. The latter was best reduced, up to 3°F-4°F, by establishing a cover of low creeper on the soil surface. Using Meyer's "humidity factor",(8) the relation of soil to temperature and rainfall for the arid and semi-arid West Pakistan has been illustrated in Fig. 39. When the annual rainfall is 335 mm and

Fig. 39


WEST PAKISTAN RELATION OF SOIL TO TEMPERATURE
MM 800
700
600
500
400
300
200
100
0
MEAN ANNUAL RAINFALL
144 HUMIDITY FACTOR
65
GREYISH BROWN
DESERT SOILS
LIGHT GREY
5
10
15
20
25
30
40
MEAN ANNUAL TEMPERATURE IN °C

temperature is 24°C, and the humidity factor is 65, the soils are highly sandy and deserts occur. The colour is light grey. The arid part of West Pakistan abounds with these soils.

In the semi-arid section of West Pakistan the rainfall approximates to 710 mm and temperature is 26°C and humidity factor is 144. Under such conditions the soils developed are greyish brown and pinkish grey. The process of leaching may also be used as a criteria for soil classification.

Classification of Climate in Relation to Soil Formation (9)

1.	High leaching.......... (leaching factor about 70 cm).	podsol Brown Forest soils. Red and yellow soils. Ferruginous laterites.	with increase of temperature.
2.	Transitional........... (leaching factor considerably less than 70 cm. Rainfall greater than 70 cm.).	Prairie Soils.	
3.	Low leaching........... (leaching factor and rainfall both less than 70 cm.)	Techernosan Chestnut coloured soils. Brown semi-desert soils. Grey desert soils.	with decrease of rainfall.

The above classification gives three categories of soils based on the degree of leaching; 1, high leaching soils. 2, Transitional, when the leaching is neither high nor low, and 3, low leaching soils. High leaching and Transitional soils of this type are not found in West Pakistan.

Low leaching soils are predominant when the temperature is high, rainfall and leaching factors both are lower than 70 cm. These factors give origin to soils such as chernozems, chestnut coloured soils, brown semi-desert soils, grey desert soils. The soils of West Pakistan belong to this group. Where leaching is low and rainfall is the deciding factor, these soils are rich in mineral content.

Both Lang and Crowther, arrived at the same conclusion. According to Lang, a mean temperature of 30°C may result in the formation of deserts even with rainfall of 1,200 mm; and according to Crowther, desert soils are produced under similar conditions of high temperature, low rainfall and low leaching. Thus both experts considered temperature as the chief or dominating factor in the development of soils of sub-tropical regions. In West Pakistan low fertility of soils suggests common causative factors viz, rainfall which can fall below 5", temperature which can rise above 115°F and evaporation which always exceeds the precipitation. As a consequence the ground water moves upward by capillary action, and salts are accumulated on the surface.

In the United States of America Jenny has shown, that there is a constant decrease in the nitrogen content with the rise of mean annual temperature. (10) The general average decrease in nitrogen is twice to thrice for every rise of $10^{o}C$. Arid climate works against the formation of nitrogen in the soil. The antiforces can be controlled by adding the organic material to keep the balance in the rate of decrease of nitrogen and by keeping the soil temperature low so as to encourage the humus formation. The maintenance of a suitable vegetative cover will also lead to the formation of nitrogen.

Hydrography

The whole of West Pakistan is still affected by the consequences of Tertiary orogenesis. In the highlands erosion is very actively removing the weathered rock mantle as quickly as ecological conditions allow. Under such conditions, particularly on sedimentary rocks, soil accummulation and the formation of mature soils is hindered. Lowland Pakistan is affected by the continued infilling of the old structural depression, by the incoming stream loads. Stability of soil formation here, ultimately depends on the speed of detrital deposition and on the type of material laid down. As noted in Chapter 4, hydrography, human action has, both in the highland and lowland critically accelerated these processes and soils have rarely been allowed to develop fully mature structures.

The rivers deposit the coarser material in their higher and middle reaches and carry down the finer material to the lower courses where stream velocity decreases. In the last stage soil material is built up by rivers but in the early and middle stages river deposition is only one agent in the formation of the solum which is also produced by meteoric agents.(6) The soil on the hillsides is shallow and immature.

In the plain, topographic conditions allow not only water movement along stream courses but also stagnation. Under such conditions absorption as well as evaporation start functioning. The absorption rate depends both on local soil and parent rock. These circumstances lead to the formation of alkaline and saline soils.

In the preceding pages, three genetic factors of soil, namely Geology, Climate and Hydrography have been noted. These are mainly external characteristics of soil formation. The internal characteristics of soil mainly are affected by vegetation and organic matter.

Vegetation (11)

Soil is essentially influenced by vegetation, which exerts its influence upon the soil in the form of living vegetation, dead vegetation and variations in plant species.

Living vegetation affects the soil surface as well as below. In the first instant, the vegetation provides a covering of varied thickness, which renders protection to the soil from sun, winds, and cold, and drought. The thicker the vegetative covering the weaker is the evaporation and smaller the temperature range. Thus generally, the soil underneath such covering loses less moisture by evaporation and transpiration than the bare surface loses by evaporation alone. The deeper the roots of a living vegetation, the lower the depth to which water will be extracted from the soil. This is governed by the type of vegetation. In West Pakistan there is a dearth of naturing living vegetation, such covering being created only during the short period of rainy season. In other seasons evapotranspiration is almost nil, replaced by evaporation.

The problem of balance of gain and loss through evaporation and evapotranspiration is still not completely solved. In recent years experiments conducted by Zingg(12) and Hide,(13) indicate that evaporation rate is enhanced by tree cover, since this serves as wind breaks, limits the air circulation and increases the ground temperature. Another argument advocated is that, plant litter helps to conserve the heat rather than moisture in the soil, which augments the rate of evaporation, "affects soil formation chiefly by modifying the moisture, and heat conditions to suit its peculiar character, thereby practically transforming the soil climate."(14) Further scientific research is needed to form usable conclusions, since generalisations are at the moment dangerous, especially for Pakistan, where every work is in its experimental stage. A great number of local experiments would be highly desirable in this direction.

In the second instance, living vegetation influences the soil aeration below the surface. In a soil in which there is a high retention of air, carbon dioxide increases, pH is lowered and availability of nutrients increased. This phenomenon is common in sandy and gravelly soils and is of special value in calcareous soils. Furthermore, the lower levels of the soil are loosened by root action. It is true, that the bulk of soil is composed of mineral material, but soil becomes different from the regolith only, when it is mingled with organic matter of dead vegetation. In all the humus soils the organic content changes first, when the organic matter is increased by fresh formation, secondly, when the organic matter is decreased under the persistent oxidation and leaching. When these two processes are equalised a state of equilibrium takes place, or vice versa.

The degree of development of humus content in a soil is determined by climatic influence. In West Pakistan, on account of extreme temperatures and aridity, the humus content of the soil is low. In the desert region it is almost absent as there is a lack of vegetation.

Effects of type of plant formation

The plants have so much influence on the formation of soil, that soils have often been referred to by the characteristics of vegetation. Thus, reference is made to 'beech soil', which abounds in humus and belongs to the humid climate. In the same way oak soil is confined to the tropical and sub-tropical regions. The steppe soil is formed in the semi-arid regions by the thick mosaic of grass roots in the surface horizon. These terms call attention to the connection between soil and vegetation.

In the former province of the Punjab(15) a soil survey was carried out, based on the indigenous natural vegetation, which inhabited the area before the introduction of irrigation cultivation. The land covered with Jand scrub (Prosopis Specigera) is regarded as suitable for irrigational crops. The soil has low pH and salt content. Wan (Salvadora Oleoides) covered an area which has 8.5 pH value, which was considered to be suitable for a successful cultivation of American cotton. Okan (Tamarix articulata) is a salt tolerant plant and such areas are not fit for irrigation. The soil carrying the growth of Karai shows very high pH value in the upper layers and a high salt content in the lower layers; and the crops yield is poor. The area supporting the natural growth of Harmal (peganum harmala) is an area of better soil. Ak (Calotropis procera) indicates a soil of sandy substratum. Sarkand (Sachharum munja) inhabits the sandy areas along the canal and river banks, and it might also be found with high water table. The area would be highly alkaline and saline, where the Lani (Sueda fruticosa) plant grows, and the soil reaches the last stage of deterioration. Bui (Kochia indica) shows extremely sandy conditions of the soil. The thriving Dhak (Butea frondosa) occurs on the heavy clay soils and shows that their deterioration by salt and pH increase is in an advanced stage, of Rakkar soil refers to the hard impervious soil devoid of vegetation.

FAUNA

Soil fauna and micro-organisms are active and plentiful only under suitable conditions of humidity and temperature.(16) When conditions do not favour the formation of humus and the accumulation of organic matter, then soil fauna as in West Pakistan, have only limited beneficial effects on soil character.

The animals include both wild and domestic animals. The Wild animals grub the vegetation and humus cover, and the grazing animals or domestic animals help to increase aeration of forest soil. The balance is however delicate. Over grazing leads to the depletion of soil on a large scale. At the same time the metabolism or fertility of the soil may be furthered by the exêrements left by the graziers. Animals, thus exercise both constructive and destructive influences on the soil. Pasturing can be proved beneficial if controlled grazing is adopted.

TIME

All the above mentioned factors involved in soil formation require time to produce the soil. Hence, time itself becomes a factor. The pedologist regards time as the "stage of development".(11) Zonal soils are well developed and the azonal soils are still undeveloped. The fresh, alluvial soils and sandy soils have been considered as the underdeveloped soils by the scientists. Time is not a constant factor as the same span of time is not required for all factors to produce a soil. Therefore, the pedologists are not able to establish a definite time, which a soil takes to form.

MAN

Man exploits and influences the soil in his pursuit of types of agriculture namely, pastoralism and sedentary cultivation.

Primitive people mainly live by hunting, fishing and grazing. In West Pakistan this primitive use of soil riches is still pursued by nomadic pastoralists. Extensive agriculture implies in this case,the exploitation of some resources for short-term returns. Cultivation is carried out without any intensive application of capital labour, and land resources are not treated as permanent assets. Yields per acre and per capita are low and the general tendency is for the few cultivators to concern themselves more with the area used than with land productivity.

Forests may be destroyed in order to put the land under the plough. After deforestation crops provide less foliage cover and the soil is exposed to direct insolation particularly during fallow. The soil temperature is increased and humus content is destroyed, hence the plant nutrients are depleted rapidly and the structure physically and chemically deteriorates radically. The natural organic cycle is then often left to destruction.(6)

Even when capital and techniques are restricted, factors such as population pressure may turn cultivators attention to raising crop yields,since the alternative of extending the area under cultivation is not present. This means,that the crop nutrients are rapidly consumed by a succession of crops and restoration of soil fertility becomes crucial. Under such circumstances a wise crop rotation will be valuable to maintain the soil fertility.

The factors of soil formation described above may be summarised in the equation formulated by Docuchaiev which "expresses that soil is the function of various factors.(6)

P = f (K, O, G, V). P means product (soil).

K climate.

O organism.

G parent rock geology.

V age of the soil.

f shows the P (soil) is the function of these agencies".

Thus "the evolutionary(2) character of soil formation makes it possible to explain soil differences as expressions of different conditions governing evolutionary process". On this concept has been based the system of contemporary soil classification, which has been studied through the medium of soil profiles.

From the point of view of agricultural utility, both the physical and the chemical suitability of soil play vital roles.

Here, we first, examine the physical characteristics, viz. texture, structure, porosity and colour. In the following table a textural classification by soil particle size as established by the International Society of Soil Science is cited. The table also states the mechanical analysis of three typical samples.(5)

Table 11

	Separate	Diameter mm	Sandy loam Shropshire%	Loam Anglesey%	Heavy Clay Czecho.%
1.	Coarse Sand	2.00-0.20	66.6	27.1	0.9
2.	Fine Sand	0.20-0.02	17.8	30.3	7.1
3.	Silt	0.02-0.002	5.6	20.2	21.4
4.	Clay	below-0.002	8.5	19.3	65.8

The mechanical analysis of the surface soil of valleys in Region I of West Pakistan as determined by Asghar(17) is tabulated below.

Table 12

Sample	Clay %	Fine Silt %	Silt %	Sand %
1	18	23	12	48
2	12	19	13	56

Asghar's groups of soil particles by size do not, unfortunately, correspond with the international size scale.

The textural status of the surface soil of the former province of Sind is shown in Table 13.(18)

Table 13

Separates	Surface Soil at Kohistan %	Surface Soil at Central Alluvial Plain %	Surface Soil at Tharparkar %
Clay	10.59	24.19	5.97
Silt	2.60	56.11	2.33
Fine Sand	35.15	19.52	30.41
Coarse Sand	51.66	0.18	61.29

Tables 12-13 clearly reveal that soils of West Pakistan on the whole are dominantly sandy, and silt dominates the alluvial areas.

From the above analyses the separates may be distinguished as the coarse and fine separates. The course separates, include stone, gravel and sand.

The size of gravel ranges from 2 mm up to 3 inches; and the size of stone is more than 3 inches. These particles are not influenced by change in moisture unless they are coated by silt or clay. They are of porous nature and water percolates through them rapidly. Agriculturally, these soils are good if water and organic matter is supplied to them. There is no danger of bad drainage, salinity or waterlogging. The sandy soils contain up to 70% or more of the sand material. Such soils are poor in moisture retentiveness, which is typical of arid region. In such areas the water drains down and accumulates as a subterranean water body if geological conditions permit.

The fine separates are clay, silt and loam. A soil has a fine texture when both silt and clay are present, and when drainage and aeration is impeded. This type of soil is sticky when moistened and forms hard clods when dried. Generally the clayey and silty soils possess a high degree of water holding capacity. They are liable to waterlogging and salinity increases in dry climates. Both clay and silt are heavy soils and difficult to work.

Loam:- A true loam is "a mixture of sand, silt and clay particles, such as to exhibit light and heavy properties in about equal proportions. Roughly,it is a half and half mixture on the basis of properties".(5) These soils are best for agriculture as they are neither too absorbent nor too compact hence,they are easy to work.

A soil is termed loamy sand when its constitution of separates is approximately 85% of sand, 10% of silt and 5% of clay, clay is inconsiderable in amount. This soil is of frequent occurrence in West Pakistan.

Sandyloam is composed 65% of sand, 25% of silt, and 10% of clay. When there is a little difference in the amount of sand and silt the soil is assigned as loam.

When a soil consists of 60% of silt and an equal proportion of clay and sand it is called silt loam.

A silty clay loam constitutes 55% of silt, 30% clay and only 15% sand.

When there is an insignificant difference in the amount of silt and clay the soil formed is clay loam. Clay, highly absorbent, expands and becomes plastic when wet while desiccation brings shrinkage and hardness. When the clay fraction exceeds 35% then soils have dominantly clayey characteristics.

Silt soils are a mixture of clay, sand and humus in which non-rounded micro sand particles are dominant. Such material has less absorption power but great non-plastic cohesive strength than clay.

The above summary shows that soil is a component of many separates of varying nature. The soil texture signifies the inorganic constituents in the soil.

Structure:- All the significant physical properties of soil are not conveyed by textural character. Had this been the case, fine-grained soil would have been always impermeable which is not true. Instead, pedologists have been able to find out that many fine textural soils have an arrangement of particles,which permit water movement, allows aeration and keeps the soil light. This arrangement or building up of particles is designated as soil structure(19). It may be interpreted that soil structure refers to the grouping of individual particles or of each separate into larger pieces.

Soil is regarded as structureless when composed of separated grains of loose sand, this soil is known as 'single grained'. When the grains bind together in an irregular mass the soil is called as "massive".

The following structural types have been commonly recognised in the soil profile. (a) platy, (b) columnar, (c) prismatic, (d) blocky, (also known as angular), (e) nutlike (also known as nuciform or sub-angular blocky), (f) granular and crumb.

Platy soils are built up of thin horizontally arranged plates. This arrangement derives from the character of the regolith. More frequently found in arid and semi-arid areas are the columnar structures. Nuciform to block structures are generally confined to the subsoil, under conditions of free aeration. Crumb structures have smaller aggregates, generally under half an inch in diameter. Degree of granularity varies but such soils are always open and friable and give good conditions for plant root development of the various structures. This is the most agriculturally valuable and when found naturally must be carefully maintained by physical and chemical means. Thus for instance correct tillage and crops like rye-grass are physically beneficial while the legumes are most beneficial chemically.

The aggregates of the above mentioned structure types may vary considerably in hardness and size.(20) In the same way soil has one or more horizons containing different structure, and at the same time a soil may show the above mentioned various types of structure at different horizons. The possible permutations are of course limited by the close relationships between the horizons. If the structure is distinctly visible, and clearly marked, that type of structure is exceptionally well-developed.

Briefly, structure is the arrangement of soil contents, both organic and inorganic matter and these are arranged into various types of aggregates. It regulates and controls the water entry, its movement, aeration and root penetration.

Porosity:- Soil porosity has been "defined as that percentage of the soil value which is not occupied by solid particles. In a soil containing no mixture, the total pore space will be filled with air. The pores of a moist soil are filled with both air and water".(20)

The pore space(21) of a soil depends on both texture and structure of a soil. In general two types of pore space occur in soil, "macro and micro".(5) The macro pore spaces as the name implies are wider spaces, through which water and air move readily. In contrast to this the micro spaces impede the passage of both air and water, but through which water passes under the capillary action. Macro spaces are dominant features in the sandy soils.

The pore(11) space usually decreases downward, and it reaches the minimum in the compact illuvial horizon; "on soils of the same type those in arable cultivation and unmanured have the smallest amount of pore space and those under old meadow soils the largest the range may be from 40-60% or more".(19)

The pore spaces are of vital importance to the soil habitat for plants, as they draw all water, air and light through them. Therefore, it has been advocated, that "It is useful to think of the soil as an assemblage of spaces rather than an assemblage of solid particles, as the growth of plants is primarily dependent on water which passes through or is retained within the larger pores".(22) The grades of porosity are usually classed as:

"O = no visible pores.

L = Low porosity.

M = Medium porosity.

H = High porosity.

X = Exceptional porosity with conspicuous cavities".

As recognised by Baver "The ideal soil should have the pore space about equally divided between large and small pores. Such a soil would have sufficient aeration, permeability and water-holding properties".(20)

Experiments in the United States have shown, that pore space surface is demoted under cropping, as is clear in the data tabulated below.(5)

Soil Type	Cropped Soil Years Cropped	Pore Space %	Uncropped soil Pore Space %
1. Hagerstoner loam (penus)	58	50.0	57.2
2. Marshall silt loam (Iowa)	50+	56.2	62.7
3. Nappanee Silt loam	40	50.5	60.3
4. Ave. 19. Georgia Soils	45-150	45.1	57.1

The study of the table reveals the following results:-

1. That the pore space is not readily affected by the crops, it is a process of long duration.

2. That the pore space in loam and silt loam is diminished in 40-50 years.

No studies of this kind have yet been carried out in Pakistan. Since, in Pakistan there are large tracts of these soils, which elsewhere have been shown to be proved to deterioration in porosity, and many of these have been cultivated for long periods, such an approach would be valuable.

Besides pore spaces, a soil is liable to develop clay pans, crust and hardpans.(21) Clay pan is the compact layer at various depths in the soil horizon which restricts water flow. These form either from a high concentration of clay in the "sub-soil", or from the concentrating movement of clay particles. They are usually widespread in the flat plain areas. In the lowland of West Pakistan, clay has been concentrated and accumulated at many localities owing to bad natural drainage of the area. Had there been a free movement of particles such conditions would never have been created. Thus the difficulties occasioned, are generally, due to poor permeability and unfavourable arid climatic conditions. Their formation is spectacularly exhibited in solonetz formed in the lowland. Because of their compact nature, the clay pans as a rule are inhibitive to plant growth.

Hard pans are similar to clay pans in obstructing the movement of air and water, but dissimilar in containing a smaller proportion of clay. These layers are impenetrable and interfere with root penetration and water passage, hence, these also are unfavourable for a beneficial use of soil. They are of common occurence in areas where an overlay of loam over clay, loam over sand, or loam over gravel is deposited. In West Pakistan there are many areas of such accumulation in Potwar, Salt Range and Quetta, Kalat Region.

The clay pans and hard pans are factors in the creation of salinity and waterlogging on a vast scale. The accompanying Fig. 40, illustrates the depth of the solum of an experimental reclamation farm at Bhalewala in Montgomery district.(23) The thickness of the solum varies from less than 6 to more than 10. It shows very well how conditions vary strikingly at short distances and how compactness and depth are not uniform.

Soil Water:- In the arid areas plant growth is limited by the limited amount of water available for plants. In West Pakistan the natural availability of water is periodical; either there is a drought or a flood. Under such abnormal conditions, cultivated plant growth depends upon irrigation and drainage, as well as rain, and they lose water by drainage, evaporation and transpiration. Conservation of water for agriculture becomes a necessity. Water retained by a soil varies according to its capacity. "The amount of water retained in soil which has drained for about two days (while covered to prevent evaporation) is known as the field capacity."(24) This definition is widely adopted for the water storage capacity of a soil. It provides the "approximate upper limit to the amount stored

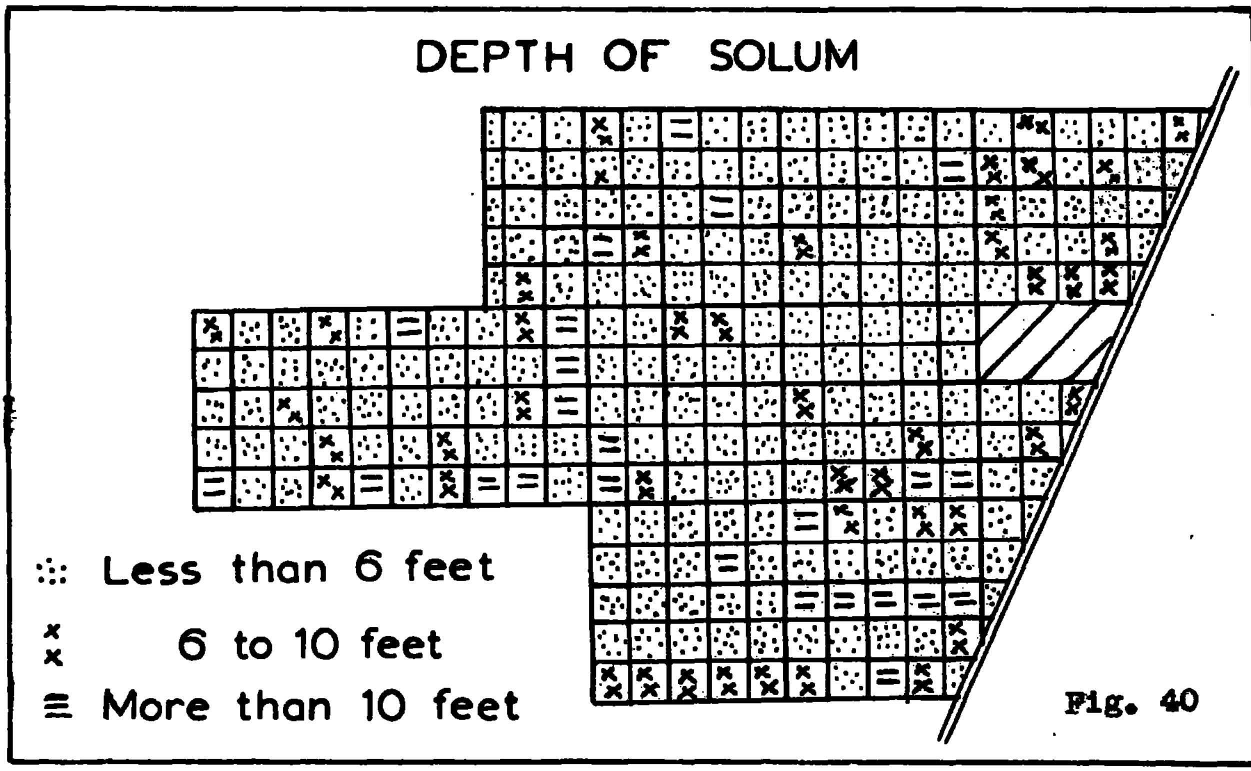


Fig. 40

for subsequent use by plants. The lower limit is the permanent wilting point and the difference is the range of available water for plant growth". The concept of field capacity basis is very helpful in irrigation practices to avoid the wastage of water and to ascertain the time of recharge. A high field capacity is possessed by the soils of high texture and colloidity and organic matter. The soils in West Pakistan in respect of these qualities are poor, as has been illustrated in the previous pages. "In agriculture the water content at field capacity is significant as representing the amount of water which stays long enough in a particular horizon to be of possible use to plants subsequently".

The main concern in West Pakistan is, how to conserve the soil water which is lost by evaporation and drainage, in order that field capacity may be maintained above plant wilting point. The water lost by evaporation can be reduced by various methods. The most widely used method advocated (24) for annual crop farming, is the removal of vegetative cover between crops and the maintenance of a loose surface tilth. "Loosening of the soil surface can reduce liquid flow to the surface and so create a dry barrier which reduces evaporation". Generally the surface of the soil dries out quickly and it provides protection in the dry season without loosening the soil. Moreover, it is noted by Marshall, that the water lost from a bare soil by evaporation is nearly of the same rate, as it is evaporated from an open water surface, as long as the soil surface remains wet. Evaporation decreases markedly, when it exceeds the rate of moisture supply from below. In his laboratory after experiments on fallow soil(25) Penman realised that, when a wet soil is subjected to the conditions which dry it at a quick rate, the total water lost during that period would be less than that lost under less severe drying conditions, and that a protective mulch is rapidly formed under rapidly drying conditions. He suggested that cultivation in spring may prove effective in reducing the water loss from the bare ground. In the same context Gardener and Fireman(26) are of the opinion, that rate of loss by evaporation depends on the rate of supply of water from the sub-surface, which is again conditioned by precipitation. In his studies on anti-evaporation devices, Lemon has referred to the use of wetting agents by Russians to check the water loss from the soil.(27) The field work carried on evaporation loss at Lyallpur shows that evaporation virtually ceases as the

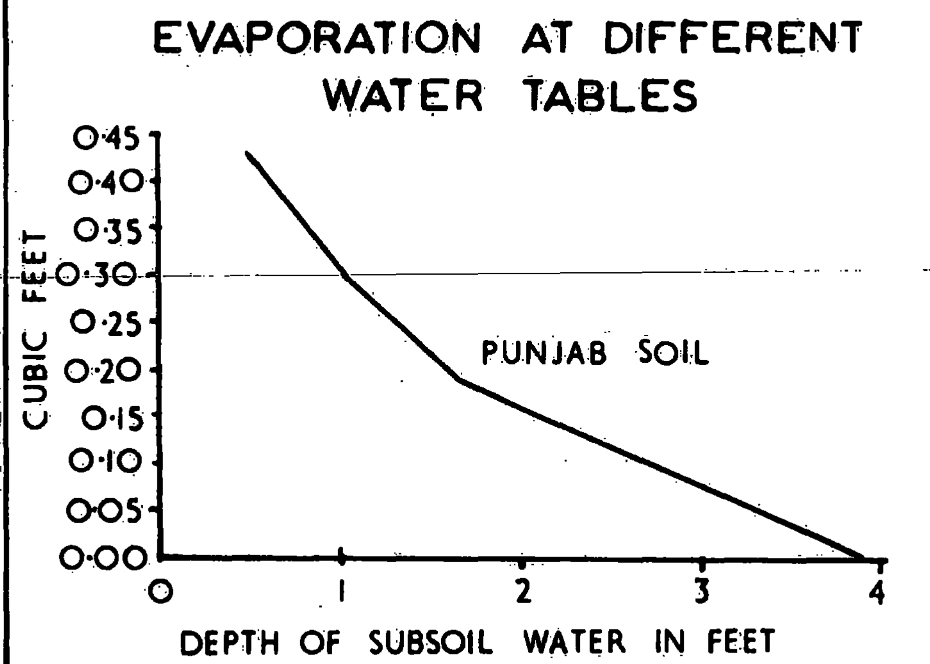

EVAPORATION AT DIFFERENT WATER TABLES
CUBIC FEET
0·45
0·40
0·35
0·30
0·25
0·20
0·15
0·10
0·05
0·00
PUNJAB SOIL
0
1
2
3
4
DEPTH OF SUBSOIL WATER IN FEET

Fig. 41.

water table falls to a depth of 4 ft. Fig. 41.* Other evaporation prevention measures include stubble mulching and soil covering, where economical, by metal foil, plastic sheeting etc.

Water loss by drainage:- It has already been noted under Hydrography that excessive ground water must be removed by artificial drainage and there are many types of drainage for the disposal of extra water. These types are selected according to the local environments, soil, crop, climate and above all economic limitations. The purpose of the drainage is to dispose of excessive water from the soil to maintain aeration. This will lead to the removal of dissolved salts and their movement towards the surface will be restricted, while at the same time surface evaporation will be reduced. Drainage is one of the chief needs of the irrigated areas in arid regions and is an effective protection against salinity and alkalinity. The need for drainage may be ascertained from the water-table records and from surface appearances referred to in the previous chapter.

Water Retention in Soil:-(24) The retentiveness of a soil depends on its texture, structure and the humus content.

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* Contrary to this, lysimeter tests at Lahore have shown that "high summer evaporation rates can attract water from a depth of 13' below the soil surface". Murphy, P.H. "The Agricultural Development of the Thal Desert". 1957, p.43.

Sandy soils will give better response for plant growth than will clays after minimum water supply because surface-tension holding of water is less strong. Equally, if sandy and clay soils are in proximity the former will lose water to the latter, such water becoming not available to plants until the clay's capacity of retention has been satisfied. The distribution of water in soil is not equal, it keeps on changing. The water falling as rain or applied by irrigation, is at first distributed equally. This process slows down with decreasing supply, and water is then lost to drainage, evaporation and transpiration.

Water available for Plants:-(24) The permanent wilting point is the water content of a soil at which plants wilt and do not recover turgidity when placed in a humid atmosphere overnight". The stage at which wilting occurs depends on the type of plants and their behaviour. The water availability and irrigation programme involves the study of plants, soil and atmospheric conditions. Hagan(24) has studied these factors and summarised the probable conditions as tabulated below.

	Relatively Frequent Irrigation Desirable	Relatively Infrequent Irrigation Possible
Plant	Shallow, sparse, slow-growing roots, Fresh weight yield of vegetative organ desired.	Deep, dense, fast-growing roots. Dry weight yields of reproductive organ desired.

	Quality dependent upon size of vegetative organ.	Harvest for content of sugar, oil etc.
Soil	Shallow soil, poor structure impeding root growth.	Deep soil: good structure.
	Slow infiltration and internal drainage; poor aeration.	Good infiltration, internal drainage, aeration.
	Small fraction of available water held at low soil moisture stress levels.	Large fraction of available water held at low soil moisture stress levels.
	Saline soils or water.	Non-saline.
	Fertility level high; nutrients concentrated in topsoil.	Fertility level low; nutrients distributed in profile.
	Root disease, nematodes present.	Constant water table in reach of roots.
Weather	Planted at beginning of hot dry season.	Plant well ahead of hot dry season.
	Major growth period during hot dry season.	Major growth period before hot dry season.
	High evaporation rates.	Low evaporation rates.

In the light of above we may say that the soils which need frequent irrigation are of most common occurrence in West Pakistan.

Colour:- The colour of soil demonstrates clearly the complex phenomena of soil formation. Though the soil colour conveys the best impression of the climate and topographic features, still colour is an indicator of both physical and chemical properties of a soil.(11)

These physical properties are the inherent qualities of soil, which are the "product of geographical environment which determines the process of formation".(2)

Chemical Properties:- The bulk of soil constituents are mineral, but it is also said that "the essential difference between a productive surface soil and a mere mass of rock fragments, however, fine, lies in the organic content of the former".(5) Puhr and Olson concluded, that organic matter exerts its influence on the following physical properties of soil, weight, cohesion, structure, absorption, porosity, colour, temperature and tilth.(28) Organic matter is an important index of fertility and physical conditions of the soil.

The importance of organic matter and its relations to soil structure have been studied by various experts.(29) Their studies reveal, that organic matter promotes soil aggregation and improves the soil structure. Though cultivation practices and root system also affect the soil structure, it largely depends on type and amount of organic matter present. Sigmond states, that chemical changes in the accompaniment of biological phenomena "give the soil its permanent character".(6)

The chemical properties explained here under two heads:-

1. The mineral chemical composition of the soils, and
2. The chemical character of soil organic matter.

The mineral chemical composition:-(30)

These may be considered as acid soils, alkaline soils, and saline soils. Acid soils are of common occurrence in the humid regions, but in arid areas acid surface layers only occur where rainfall is about 20 inches.(5) Owing to absence of leaching, in arid areas, the base status is increased, hence calcium carbonate accumulation becomes greater than in the parent rock, and there carbonates draw nearer to the surface. In consequence such soils have alkaline subsoils and alkaline or neutral surface layers. Only a slight acidity may develop in the surface horizon. In West Pakistan acid surface layers of this kind occur in small patches in the areas of saline and alkaline soils.

Saline and Alkaline soils are collectively named sodium soils.(6) Sigmond has classified the sodium soils into five groups, considering their genetic, dynamic and chemical characteristics:-

1. Saline soils, 2. Salty alkaline soils, 3. Leached alkali soils, 4. Degraded alkali soils (soloti soils), and 5. Regraded salty alkali soils. Sigmond regards this group

as composed of artificial soils, as they are developed by the mishandling of man.

In West Pakistan an investigation of such deteriorated soils has been carried out but did not produce useful results, hence no logical classification of deteriorated soil yet exists. As research work in this direction was seriously hindered owing to political dislocation and absence of experts, in 1944 a classification of 'thur' deteriorated soils was devised by the Irrigation Branch of the Revenue Ministry.(15) This classification is based on the cultivation capacity of the soil. "Thur" land is so termed, when salts are visible on the soil surface. If the whole of the field was visibly affected by thur to the extent of 20% or more it was also recorded as 'thur'.

During the last decade salty soils have been tentatively classified into three types. In American literature the salt deteriorated soils are defined by the severity of conditions, interfering with plant growth - they are saline soils, saline alkaline soils and non-saline alkaline soils.(5) Jackson maintains "perhaps the most important chemical property of soils as a medium for plant growth is its pH value".(31) Generally speaking the lower the pH value the better will be plant growth under subtropical conditions in sandy soils. These deteriorated soils are always surrounded

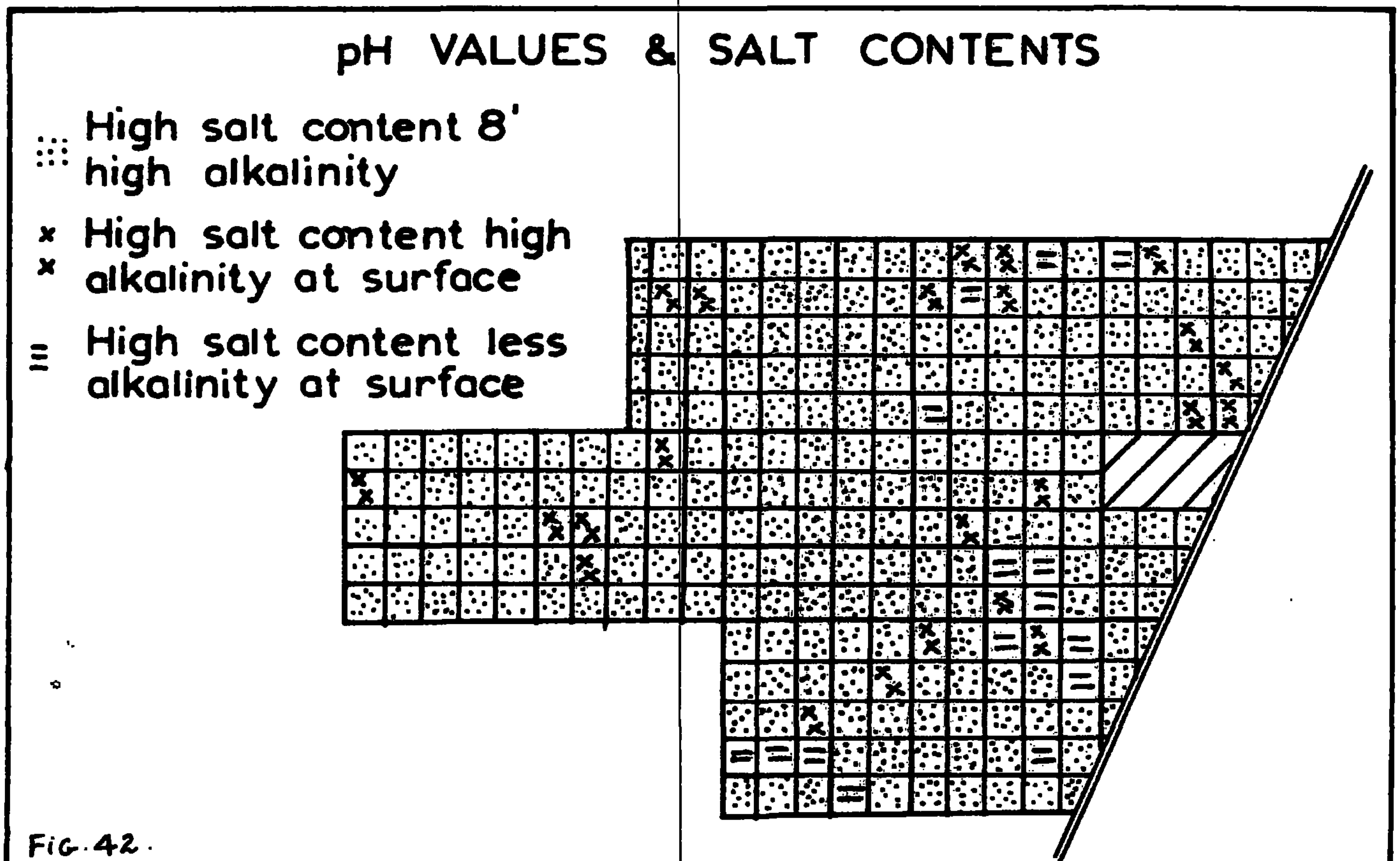

pH VALUES & SALT CONTENTS
High salt content 8' high alkalinity
High salt content high alkalinity at surface
High salt content less alkalinity at surface

FIG. 42.

by more fertile soils.

Figure 42, illustrates the process of chemical deterioration of an experimental farm at Bhalewala Reclamation Station, West Pakistan.

Organic Matter:-(21)

The organic matter of humus in a soil is predominantly a production of micro-biological decomposition of plant and animal residues. The status of organic matter is higher under grass than under trees because finer roots of grass readily decompose and "tend to concentrate in the top 9-12 inches of soil".(19)

Organic matter supplies some particular chemical elements carbon, nitrogen, hydrogen, oxygen, sulphur acid phosphorus, carbon and nitrogen being the most decisive elements.(30) These elements give origin to the three substances or compounds, as 1. Carbohydrates, 2. Lignin, 3. Protein.

Carbohydrates are composed of carbon hydrogen and oxygen, and while predominant in amount are easily decomposible.

Lignin is attacked very slowly owing to different molecular structures of carbon, hydrogen and oxygen and it is lesser in amount.

Protein consists of carbon, hydrogen, oxygen and nitrogen, and it decomposes readily. Compared with carbohydrates and lignin, plant tissues contain little protein.

The original raw material for these finished elements have come from the atmosphere as carbon dioxide, nitrogen and water vapour and, "by the continual process of life, death and decay, they become embodied in living tissues and finally return whence they came". Thus the formation of organic matter is a cyclical process. The break up of these products in addition to the dead soil organism, fungus and plant residues, make up the "true soil organic matter",(19) generally ascertained as humus, which is "black structureless, and amorphous, in the form of very minute particles or a jelly coating the sand, silt and clay particles". The chief properties of the humus are strongly colloidal "swells on wetting, shrinks on drying, has some power of absorbing ions, it can also hold and exchange bases".

In West Pakistan there is a scanty cover of vegetation, hence poor humus formation and almost no information exists on the humus status of these soils. The table below is the only available chemical analysis of samples of soil at Sakrand in the Hyderabad Division.(32)

Total Nitrogen %	Total P_2O_5 %	Total K_2O %
0.043	0.11	0.19

The desert portion consists of rolling sand dunes alternating with valleys. The soils are sandy and deep. They are very poor in organic matter and normal in fertility ingredients, but owing to the sandy nature of the soil, most of the ingredients drain away even with little rain. The above is probably a typical analysis of the surface layer. The inducement of humus in these soils is only feasible, if there is an adequate water supply. The most suitable approach for retaining the humus content in the soil is ley farming and green manuring which again needs water. The importance of humus formation arises from the fact that structure, chemical fertility, mechanical stability are all maintained at a high level only in the presence of humus stability.

Soil Survey in West Pakistan:-

The scientific study of soil is of modern origin a product of the last 50 years.

For an arid country like West Pakistan the first pre-requisites for soil studies and surveys are data on climate and water resources.(33) As these factors are the basis for the planning of agricultural development, hence a geographical knowledge of the location, extent and nature of various soils is earnestly needed.

The soil types may be graded, first by the study of underlying rocks, to determine whether the underlying rock is actually the parent rock of the overlying soils. In the study of salinity this principle will be of great value, as the deep underlying strata of the soil in the plains are often said to be saline series and a main causative factor of the prevailing salinity. Secondly, only by the examination of the local orographic conditions, by the study of the characteristics of the natural flora supported by the soil, and the evaluation of local meteorological records, can extreme climatic conditions be studied. Integrated bioclimatic studies will then be possible. Moreover the climatic records will also denote the deviation from the normal and their effect on the biotic conditions. The causes of deviation involve further investigations.

Soils are often classified on the basis of their fertility, assessing their nutrient (nitrogen, phosphate and potassium) status, the lime content and mechanical composition of surface and sub-surface soils. The necessity of this type of soil survey was advocated by Ibn-al-Aman even in the 12th Century as noted earlier. This type of survey has an immediate agronomic value and needs a great number of sample studies. Such studies will save the wastage of irrigating irresponsive soils. Such surveys prepared on the basis of nutrient status, though useful for agricultural purposes, are not sufficient to denote the physical composition of the soil. The nutrient status of a soil is transient affected by external factors, and this status can be promoted by the provision of the required amount of nitrogen, potassium and phosphate. Studies based on this aspect do not prove permanently valid, whereas knowledge built up on the profiles study or the physical character which is intrinsic will have a lasting validity.

In the light of these views we shall now see what type of soil surveys have been undertaken in West Pakistan. It has already been mentioned that soil surveys in Pakistan have never been embarked methodically and scientifically. The information existing at present is both empirical and deficient; and cover a very small area. This information may be grouped into the following phases.

1. Surveys before 1947.
2. Surveys after 1947.

Surveys before 1947 consist of: i land settlement records of 19th Century. ii District Gazetteers 1907-1910. iii Royal Commission on Agriculture 1928. iv Z.J. Schokalskaya 1932 and v soil survey from the point of view of geology 1935 (explained already under the pedogenic factors). These surveys do not contain much information about the area now comprising West Pakistan.

Since 1947 only reconnaissance soil surveys of some parts of West Pakistan have been carried out by various bodies such as F.A.O., Colombo Plan Canadian Surveyors, and Pakistan Land Reclamation Department. Most of the area which fell to the destiny of West Pakistan had never attracted the attention of soil surveyor before 1948, owing to its inhospitable terrain and hostile climate.

The present writer has endeavoured to collate the existing informations and to explain the ideas, and lines along which these soil surveys and soil classifications were assessed.

Land settlement records, supply the earliest information about the soils. These records of old settlements noted soil productivity and physical conditions as assessed through farming experience. Soil assessment was determined by the factors of colour, texture, availability of water, level of land and crops yield. The only crude classification was that of loamy and sandy soils. This type of classification does not provide adequate information for optimum use of land, and the productive capacity of the soil as it is based on traditional experience rather than scientific process studies. Nevertheless, these records contain useful information for further research especially in noting the physical conditions of the soil at the surface. It further illustrates that the value of indigenous farmer evaluation which must never be ignored even if superseded at a later date by fuller knowledge.(34)

District Gazetters contain scattered informations on the traditional classes of soils as loam, loamy sand, and silt are met with. Some idea of both physical suitability and fertility are thus given.

The geological soil survey as explained earlier was a collaborative effort made by the various experts of the Geological Survey of India. The survey has contributed much knowledge about the soil as it is based on the lithology of the sub-continent, and was presented in map form. In that,other elements and processes are of great importance, this approach by itself is inadequate.

The only comprehensive study of soils produced has been that of the Russian pedologist Schokalskaya, who attempted to describe the natural conditions of soil formation in India from meagre and scattered data.

The Report of the Royal Commission on Agriculture, 1928 is an account of soil classification, prepared on the traditional methods and nomenclature and using groups such as loamy and sandy soils.

Since 1947, soil study has become to the forefront. As Pakistan's mainstay is her agriculture therefore the study of soil has become of vital importance. In addition to this, soil problems of salinity, alkalinity, waterlogging, drainage and others have given soil studies considerable impetus. A campaign has been launched by the Land Reclamation Department and a new soil survey is being conducted on a scientific basis.

In 1950, the Director of Soil Reclamation carried out a generalised tentative soil survey report.(17) The soils of the former provinces of Pakistan have been analysed from the point of view of deterioration of soil by salinity and alkalinity, and physical conditions. This is the first study of its kind, which has been based on the study of soil profile of each soil type. Asghar has shown, that various types of soils are the product of topographic anomalies, inefficient drainage and subsoil water table. Though it is a very generalised study, yet it conveys a picture of soil types as well as their condition. Not yet considered are the differences in soil manurial and irrigation responses. Moreover the number of samples are too small for a big country like Pakistan.

Besides this, some soil studies have been conducted by F.A.O. experts during 1953 and 1955.(35) They have described the soils, in particular, in terms of physical conditions as porosity and drainage and also of their capabilities of production. These studies have not been based on full analysis of soil profile but rather on their upper horizon characteristics.

A reconnaissance soil and land use survey of the Indus Valley has been conducted by the Canadian Surveyors under the Colombo Plan during 1954-1956.(36) This soil survey has manifold aspects. The chief bases of soil classification are land forms, and the landscape map shows 20 "distinct features," some of which have not been introduced in the literature of geomorphology as yet. This study also does not rely on profile study, because of the indistinct profile development under the arid and semi-arid climate. The other factors considered for the classification of soils were texture, water and the current land use. Finally, the land use classification has been tentatively established after the World Land Use Survey of the International Geographical Union. This work has not been released to the public as yet. After its publication and availability this work will prove of an overwhelming help and a pre-requisite to the further studies of soil.

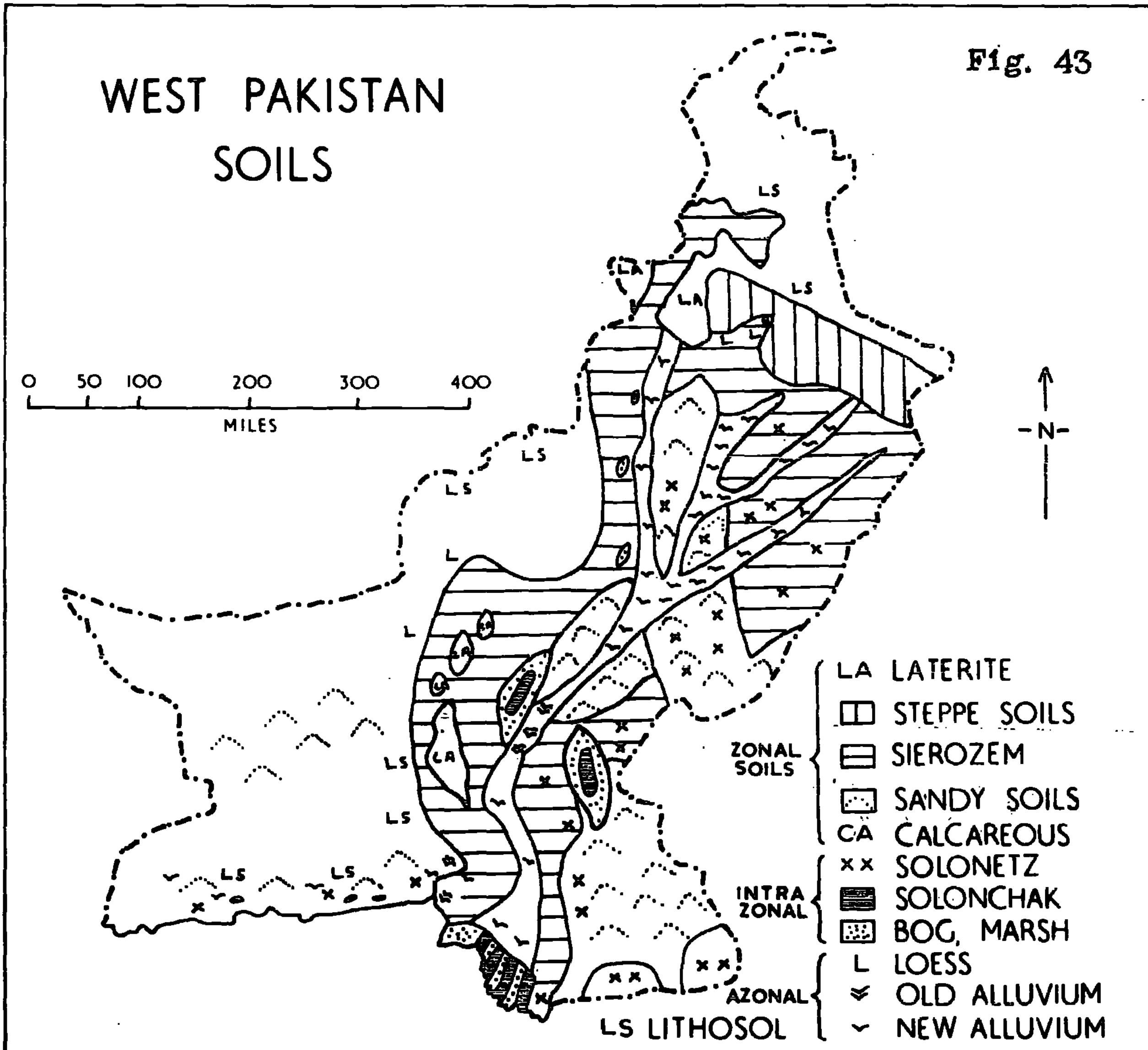
In addition to this, a soil survey was carried out by Rafique in 1956 on the Nari Bolan area of the Kalat Division, which is not yet published. The same author has prepared a report about the soils of Northern Uplands of West Pakistan in 1957.(37) His approach of soil study is based on the profile study of both organic and inorganic matter, from the point of view of erosion control.

The present writer has made an attempt to classify the soils of West Pakistan after the American soil system. Under the American soil system the soils are grouped into Orders, many sub-orders and they are then broken into Great Soil Groups. These types are grouped together into successive larger classes based on the general characteristics of similarities. The soils of West Pakistan are tabulated in Table B, their characters and agricultural utility is explained here. (Fig. 43).

Table B

West Pakistan Soils Classified

Order	Sub-order	Great Soil Groups	Locality
Zonal	1. Soils of forested warm temperate and tropical retions.	Laterite	Patch work in Region I of 1-3.
	2. Semi-arid Steppes.	Dry steppes on older alluvium.	Parts of Lahore, Rawalpindi and Peshawar Divisions.
	3. Light coloured soils of arid regions.	Sierozems and sandy soils.	Divisions of Multan, Bahawalpur, Hyderabad, and Quetta.
Intra zonal soils.	1. Hydromorphic soils of marshes swamps, flats and seepage areas.	Bog, soils.	Canal colonies, patches at foot of Sulaiman range, and the deltaic region.


WEST PAKISTAN
SOILS
Fig. 43
0
50
100
200
300
400
MILES
N
LS
LA
L
LS LITHOSOL
ZONAL SOILS
LA LATERITE
STEPPE SOILS
SIEROZEM
SANDY SOILS
CA CALCAREOUS
INTRA ZONAL
SOLONETZ
SOLONCHAK
BOG, MARSH
AZONAL
L LOESS
OLD ALLUVIUM
NEW ALLUVIUM

	2. Halomorphic soil of the poor drainage.	Solochak (saline soils) solonetz alkaline soils. soloth soils.	Canal colonies, deltaic region and littoral areas.
Azonal Soils.	No sub-area.	Lithosol.	The uplands of Peshawar, Quetta and Kalat Divisions.
		Alluvial	Indus Plain.

1. Zonal soils are developed primarily by climatic influences. The influence of other genetic process as geology, vegetation, time etc. are subordinate in their assertion. These soils are of vast extent, and spread in the areas of 30 inches and less rainfall.(5)

2. Intra-zonal soils are those, which are influenced by climatic but dominantly affected by the local conditions as poor drainage, and salt concentration. They give rise to saline and/or alkaline soils and marshes.

3. Azonal soils, their chief distinction is that they are without any profile. Their characteristics are conditioned by the parent material. They are found in all types of climate. They are immature soils, hence less duration of time is the dominant factor of genetic. In West Pakistan they are incompletely developed alluvial soils, and are not confined to a particular zone, and hence, they are azonal.

Laterite soils:-

A few patches of this soil occurs in Region I to IV. These soils are termed as latosol in the region of forested warm temperate and tropical regions of relatively abundant rainfall and high temperature.(5) Hence heat, moisture and vegetation are the soil forming factors. These soils have a high content of oxides of iron and alluminium. In the former province of Baluchistan a fossil laterite in the nummulitic series has been suggested by Wadia(38); the presence of this soil in the area which is arid today, is an inference of past humid climate. Its colour varies from red to yellow while uneroded laterite is often brown or grey. When the bed rock is basalt, its surface is red and yellow. Erosion also helps to expose its red and yellow sub-soil. Another salient feature of laterite is its granular aspect, which in the upper levels of the solum gives excellent conditions for drainage, but this soil may often have lower hardpan surfaces and is always low in organic matter. Hence agriculturally, it is not valuable except where water is plentiful. As these soils are well drained naturally under semi-arid conditions they offer an opportunity for the grazing grounds, and can carry full scrubland. They may be improved by addition of lime. Their present main economic use is for brick making.

Steppe Soils:-

These soils are found in the area with annual rainfall of between 15" and 20". Dry steppe type of vegetation predominates here, and the cover of short deep rooted grasses supplies organic matter slowly and in small quantities. Rich in calcium carbonate, these soils are greyish, pinkish and brown. Gypsum is often found in sub-stratum concentrations. These soils are usually used for cereal production and provide the best agricultural land in West Pakistan particularly when irrigated. Tillage of these soils has encouraged wind erosion as the stable natural structure is weakened by the more rapid chemical cycle associated with cultivation of crop plants. Sierozem soils are now being developed under scanty rainfall of 5-10". These soils occupy a larger area, from the Kabul valley in the north to the Indus Delta in the south. Their extent is interrupted by the periodic occurrence of solonetz, solonchak, alluvium, loess and bogs. (Fig. 43) Sandy soils containing clay elements of less than 10% and heavier soils are both found in this group. Schokalskaya has considered them as saline serozem.(34) These soils at places are fairly rich in organic matter and the assumption is that, many areas were covered with a luxuriant forest in the near past - in this sense many of them are fossil soils.

Desert Soils:-

Their formation is due mainly to the physical decaying of the rocks since rainfall is only an occasional phenomena. In West Pakistan annual floods and the big rivers traversing the desert tracks provide abundant seasonal water, and the effect of water is very spectacular. As the desert is devoid of vegetation cover, flood water flows into broad valleys and detritus is spread over vast areas.

As vegetation is confined to the seasonal water courses and that is composed only of xerophytic desert shrubs, the soil receives little organic matter and is very poor in humus. The plant characteristics of these soils are conditioned by the predominance of fine and coarse sand with low colloidal capacity which is not absorbent. Water flows readily through the wide pore spaces of these dry soils. Soluble matter is quickly lost if water is applied and such soils may only be made useful by the addition of clay or compost, thus increasing their colloidal capacity. These soils are still very obscure and have not been sufficiently studied, therefore they are often distinguished as a group of "ill-defined" soils.(11)

Swamps or Hydromorphic soils:-

As clear by their name, they are soils of excessive moisture. Drainage is poor, often because of formation of hardpans which have blocked the filtration passage of water. These soils are formed in low lying flat areas. As noted in Fig. 43, these soils are found in the Indus south of Sibi re-entrent, in the central Nara, and few patches on the stream fans flanking the Sulaiman Range. Such soils may be utilised for growing of perennial water loving plants or hydrophytes or used for annual hydrophytes such as rice. No information is available in general about their present uses in West Pakistan.

Halomorphic soils:-

The Halomorphic soils group includes solonchak (saline soils) Solonetz (alkaline soils) soils. These soils crop up in the zonal soils of steppes, Sierozems and desert soils. Their occurrence is conditioned by the local causes such as imperfect natural drainage in the arid and semi-arid areas. Their salient feature is the concentration of salts in the upper horizons. In Pakistan the terms "Thur" and "Seem" are used for efflorescence salts on the land surface, which hamper vegetation growth.

In West Pakistan like the rest of the arid and semi-arid world,salinity problem is becoming acute owing to the introduction of irrigation. A second causative factor is salt bearing parent material derived from recently deposited marine sediments. On the coast there are saline tracts resulting from sea flooding. At places there have been formed salt pans by a combination of water accumulation and excessive evaporation. Thus we may say the Halomorphic soils are formed by natural phenomena and by cultural devices like irrigation.

Natural Saline Soils:-

The factors accounted for the formation of such soils may be recapitulated from preceding chapters. The aridity of West Pakistan is combined with 1. the great depth of lowland alluvial soils washed down from the uplands, 2. Sub-soil saline water, 3. Impenetrable sub-soil or clay pans and 4. the soil bearing parent rock. The first combination occurs in the areas of flat topography having heavy textured soil. Salts concentrate in the lower horizons, both A and B horizons become highly sodised, and compact. The second case exists in the foothill zone where the soils are accumulated in the deep lying soils and concentrated into compact layers. The third instance is found mainly in the uplands and sub-montane region, where sub-soil saline water is very near the surface. The fourth case usually occurs in the saline soils exclusive of slope, and is common in the central doabs.

The rapidly deteriorated halomorphic soils in West

Pakistan were first noted in the lower Bari Doab, in 1918. A typical description of these soils may be reproduced here. "Bara land is highly arid, cracks, hexagonal shaped clods of porous structure and highly charged with alkali salts, while riding across the bara land gives a metallic sound. In sunlight from a distance, it looks like a mirage. The surface of the soil is generally covered with a sort of "papri" or thin cake like material, which contains about 80% clay, and is impervious to water. The profile is deep, soil crust thick, salt content is high and the pH values are usually above normal".(15)

The formative causes, have been studied by many pedologists. In Pakistan Asghar has adduced an explanation of alkaline soils taking into consideration the physico-chemical nature of the alluvial deposits, which vary from place to place under the dry climatic conditions in West Pakistan, and with a water table ranging from 0.0 to 10' from the natural surface.(39) After a close study of the affected soils, he has described the alkaline process as follows:- "The presence of the sodium salts in the soil profile brings about further chemical reaction in the soil complex. A higher alkalinity is developed and soil is rendered unfit for crop production. In areas, where the water table is high in addition to high alkalinity, the soil profile exhibits a bed of calcium carbonate nodules beneath the surface layers. Sometimes the high alkalinity is due to free sodium carbonate, and the soil is infested with dark coloured patches, formed as a result of dissolution of humus. Such soils are known as black alkali soils".(40)

Hilgard quoted by Sigmond, made a distinction in alkali soils based on the absence and presence of soda. If the soils contain neutral salts, they are known as white soils, while if they contain humus and soda they are known as black soils.(6)

Some of the other exponents of the soil science have also offered explanation of the formation of alkaline soils. Baron Berthollet noted solid sodium carbonate existed on the banks of Nile.(41) He assigned the appearance of this phenomenon to the floods in the Nile. He believed, that, the formation of sodium carbonate took place owing to inter-action of sodium chloride brought by the floods and calcium carbonate existing already in the soil. His theory was supported by Hilgard and his co-workers in the United States of America.

The definitions of alkaline soils may be summed up as follows:- soils with a pH value of 10.8, and deficient in calcium salts but rich in sodium salts. They are inhibi-tive to crop production, as they are deficient in nitrogen and organic matter is practically absent, and they are highly impermeable.

The chief characteristics of those alkaline soils examined by Dhar and Mukherjee were:-(41)

1. Their pH was as high as 10.8.
2. The amount of calcium compound was less in alkaline soils than in normal ones.
3. Their nitrogen content is small and in several samples the total nitrogen was varying from 0.008 to 0.02%.
4. These soils were highly impermeable to water.
5. The soil particles do not settle readily when shaken with water.

Average pH values

Scotland	5.64	Denmark	6.69
Finland	5.61	Sweden	6.74
Japan	4.5-6.9	Egypt	7.9

Pakistan 7-10.8

The recent extension of alkaline soils is associated with the combined effects of irrigation, high water table, evaporation and the character of the parent rock.

In 1938-39 observations on the water table were recorded.(42 For this purpose sites of variable water table were selected, where the depth of water table varied from 9-40' from the surface. The profiles were drawn down to the water table both in good and deteriorated lands. The results of the

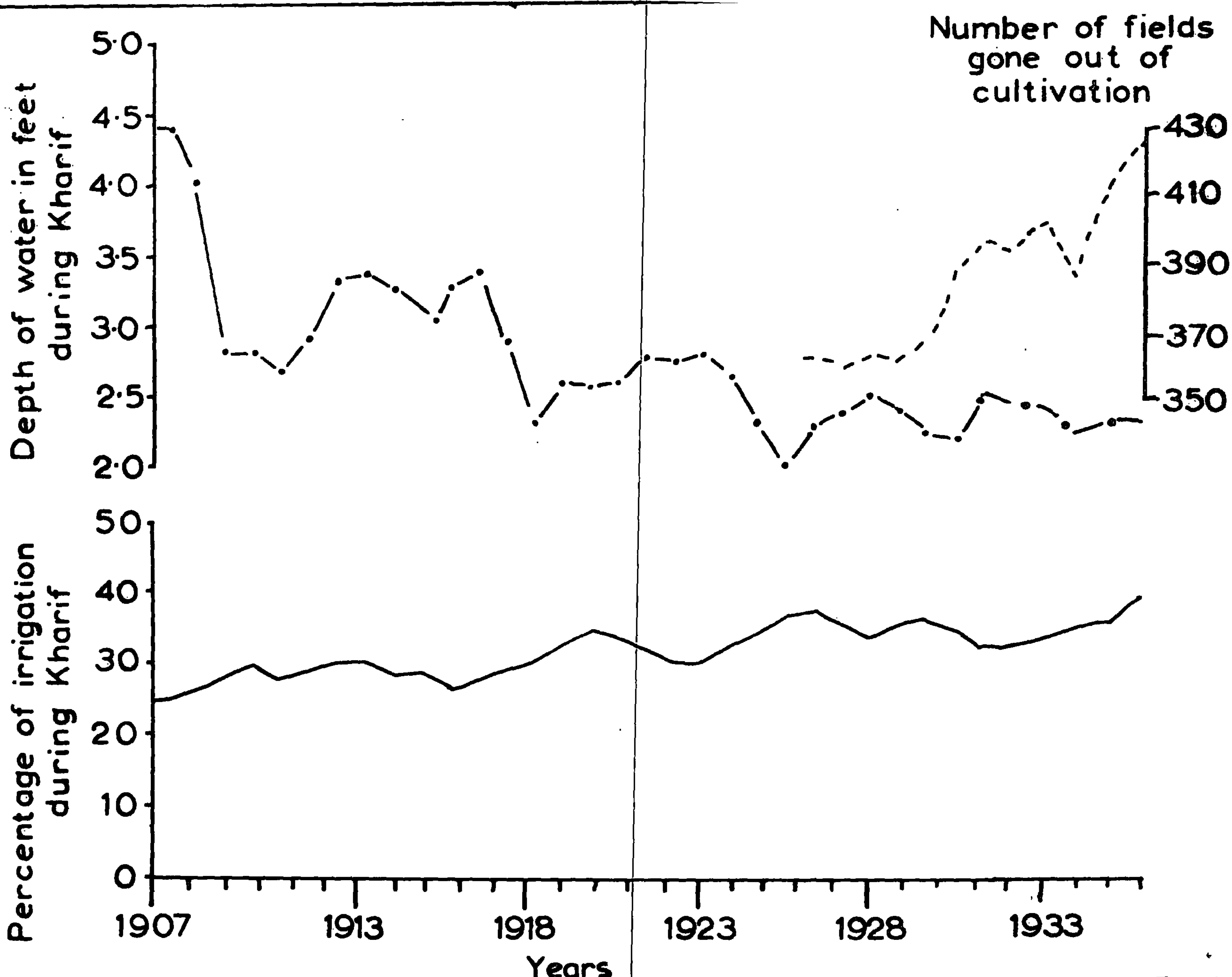

Number of fields gone out of cultivation
430
410
390
370
350
Depth of water in feet during Kharif
5·0
4·5
4·0
3·5
3·0
2·5
2·0
Percentage of irrigation during Kharif
50
40
30
20
10
0
1907
1913
1918
1923
1928
1933
Years

FIG. 44

analysis indicated that in the derelict soil the salt was present 2' below the soil surface, and in the good soil the salt lay deeper but at varying depths. No simple relation between salinity/alkalinity and height of water tables was established.

For the same purpose, observations on the rate of evaporation have also been conducted by lysimeters.(43) These results show,that with 10.5' subsoil water table the average annual rate of surface evaporation over a period of 5 years was 1.5 feet per year. The present accumulation of salts is much greater than would be expected from this rate of evaporation alone. Carlston has also reported that the prevailing salinity could not be caused solely by evaporation of added water as the quality of irrigation water was excellent.(44) He saw the major cause as the application of small quantities of water for irrigation, thus producing a concentration of salts originally present in the soil root zone. Such salts were washed out when irrigation water was applied at heavier rates. Fig. 44 is evidence of the effect of a low water delta. It illustrates how from 1907-1936, 430 fields have gone out of cultivation owing to salt accumulation.(15)

Along most of the northern courses of the rivers in the Central Plain as well as along the lower courses, the water table is within the top 10 feet of the soil, and these areas are considerably saline. Furthermore the soil is not continuous, but is broken by patches of sand which help to cause the high water table. It may be said, that, these variations are governed by differences in local geography. The rising water table and subsequent waterlogging is one of the salt producing causes. In this way the soils also become too wet to allow sufficient respiration for the plant roots.

Nevertheless, as already emphasised in the chapter on hydrography that there is no necessary relationship between saline soils and soils of high water table, as large tracts of saline soils lie in the areas of relatively low water table. Hence it would seem, that the original salt content and inadequate application of irrigation water remains one of the major causes of salinity.

From the studies emerged one general concept. i.e. that, the whole of the soil profile contains soluble salts and that, when any water from rain or precipitation enters, some of these salts are concentrated in certain zones within the soil. The basic premises are certainly correct, soil contains soluble material, and soil-water must be a solution containing some of these salts. Nevertheless, at some places, irrigation has been practised for long periods without producing a dangerous concentration of strong solutions rich in mineral salts.(45)

Since in many cases the irrigation water has been judged to be of excellent quality then one tendency has been to blame the soil content. In Baluchistan certainly parent-rock salinity is often responsible. In the Nari Bolan area irrigation which does not even completely penetrate the root zone has produced surface salinity.(35)

The only way in which the various approaches can be reconciled is to regard salinity/alkalinity in irrigated areas not as a function of salt rich water but as a function of the rate of application of water. If for mistaken reasons of water economy the maximum area is irrigated with the minimum of water,then in all conditions of water-table height, and natural salt content of soil and water, then salinity in the plant root zone will increase to the point of danger. Other factors may control the speed of this happening but are not the prime causes. Therefore,as we have seen in Chapter 4 the problems of rising water table must be tackled by drainage in order to lower it; in the case of salinity produced by incorrect watering rates,then remedial and maintenance measures involve leaching and drainage. Thus,while,plant needs of water may be supplied by one scale of irrigation, the maintenance of productive soils necessitates an additional supply of water. These areas which require irrigation, which are necessarily deficient in water, are precisely there where overall water demands are greatest, and where drainage essential.

In the opinion of one expert the present rapid expansion of the deteriorated soils is accounted for the political tension after 1946. The land suffered by the negligence as in some cases tenants and in other cases land owners emigrating from India were not cultivators. The land was mishandled and the canals were silted.up.

The rate of soil deterioration:-

Soil deterioration by Thur and Seem is spreading at some 200 acres every day. If this is not brought under control, the whole agricultural land will become a mere waste of salt within 40 years as declared by the Director of Land Reclamation, Pakistan.(40) The progress in the rate of soil deterioration may be visualised from the following estimates taken from an unpublished report. Appendix 10.(44) These estimates are based on taxation surveys, the land which has deteriorated and declined in yields not being taxed any longer. The criteria used are visual and these estimates do not make it clear, whether the lost areas are always included in the total area under canal irrigation or whether they, having gone out of cultivation, are not counted any more. Probably, categories 4 and 5, represent a proportion of category

3, category 3 being on the increase, as many new irrigation projects have been opened. In that classification in these cases was visual rather than by scientific measurement of the soil, the estimates cannot be very precise and their validity is not of first significance in a treatment of the whole country. Nevertheless, the data brings out the fact, that the major part of West Pakistan is far from possessing perpetual suitability for agriculture which is very alarming for an agricultural country.

It has been explained in the Chapter on geology that the whole of West Pakistan has been created of marine sediments overlain by later river deposits. The salt was left in the soil as the sea receded. Metha has reported, that many of the desert soils at some places were saline and alkaline even before the advent of irrigation.(15) He states that, even at present there are large tracks of saline waste land that have never been irrigated nor have been cultivated up to this moment. However, true this may be in human history, the soil survey of these waste lands does indicate that almost the entire area is laced with salt both at the surface and in the profile. The examination of profiles of un-irrigated soils has shown that sodium sulphate is distributed throughout. Metha has also suggested a possible explanation for the present large amount of sodium sulphate in the alluvium by pointing out that sodium sulphate is deposited from a solution of mixed salts at a temperature of 3°C, which he thought might have occurred under the last glacial age, known to have existed in the Punjab.

William M.B. has reported that most of the salts in the Kallar lands are sodium sulphate and sodium chloride which are soluble in water, and which should not raise many difficulties in leaching.(46) It is also pointed out by him that such soils have a high content of calcium carbonate which can supply the soil again with available calcium.

The status of alkalinity and salinity in soil has been rated by Asghar,(17). The table listed below is an analysis of a typically highly alkaline clayey soil.

Table 14

Depth from Natural Surface in feet	pH	Total Salt %	Clay %	Coarse Silt %	Fine Sand %	Coarse Sand %
1	9.02	.20	25	35	28	9
2	9.10	.13	35	41	17	4
3	8.78	.13	32	38	22	4
4	9.00	.15	33	36	23	4
5	9.02	.15	49	34	13	5
6	9.21	.18	23	38	21	9
7	9.37	.14	15	35	38	7
8	9.33	.13	14	35	42	7

The table indicates that alkalinity tends to increase as the depth increases. The salt tends to increase in the opposite direction to pH. The clay content in this sample is smaller in the lower layers, thus, the upper 6 feet have become compact. Coarse silt is more or less equally distributed from 1-8' downward, and there is no marked difference in the grades of coarse sand from top to bottom. The percentage of the fine sand is smallest at 5 feet, at 8 feet its content is highest 42%. The high percentage of fine sand is also responsible for blocking the natural drainage.

Another typical sample analysis of the clayey soil of high percentage of salt as well as alkalinity is shown below.

Table 15

Depth in feet	Total Salt %	Clay %	pH
1	.94	21	10.00
2	1.10	21	10.11
3	.54	21	10.28
4	.60	25	10.11
5	.59	21	10.10
6	.54	25	10.20
7	.64	24	10.09
8	2.10	18	9.00
9	N-A	N-A	N-A
10	.27	22	10.25

This sample shows that both salts and lime are richest in the upper layers. This profile is strongly salty at 8 feet with a percentage of 2.10 salt and strongly alkalinised at 3 feet with value of 10.28 pH. The % of clay is almost equally present at all depths. The clay is fairly uniform in its distribution.

The following table 16 is an analysis of a sandy loam, containing salts and pH at variable depths from the natural surface.

Table 16

Depth in feet	pH	Total Salt %	Clay %	Silt %	Fine Sand %	Coarse Sand %
0	8.40	0.41	7	16	41	37
1	8.20	1.65	6	19	46	31
2	8.30	1.95	7	23	39	29
3	8.24	2.50	4	30	50	13
4	8.10	1.4	4	26	59	10
5	8.20	.85	4	23	67	7
6	8.34	.65	6	11	57	19
7	8.60	.29	4	8	20	17
8	8.77	.13	3	9	30	57
9	8.80	.08	2	1	35	60
10	8.50	.25	4	7	27	63

This sample shows that in the sandy loam pH values are never more than 8.80, whereas in the clay soil pH went up to 10.28 at the depth of 3 feet in table 15. pH is also high in table 14, showing the high alkalinity. In respect of total salt content, sandy loams are richer than the two clayey samples; in tables 14 - 15 the pH value is fairly uniform throughout the profile, but salt tends to be higher in the upper layers. Clay content is higher in the upper layers, and silt tends to be higher in the middle layers, and it is lowest at 9 feet, 1%. The percentage of fine sand tends to be higher also more in the middle layers, and tends to decrease after the depth of 7 feet. The percentage of coarse sand is higher at the lower layers while lowest in the middle layers, and medium in the top layers.

The Table 17 contains the results of a sandy soil.

Table 17

Depth from Natural Surface in Feet	pH	Total Salt %	Clay %	Silt %	Fine Sand %	Coarse Sand %
0	9.12	.08	3	2	38	58
1	9.12	.05	4	2	40	56
2	9.10	.04	3	1	43	54
3	9.4	.03	3	2	39	59

4	9.14	.03	2	2	38	60
5	9.14	.04	2	0	37	61
6	9.10	.03	3	1	39	40
7	9.20	.03	5	3	54	41
8	9.4	.03	5	3	52	41
9	9.20	.03	4	2	26	71

These results indicate that the pH value in a sandy soil is higher than the sandy loam at all depths; and the case is reverse in respect of salt contents, it is lower at all depths. It shows that the sandy soils tend more towards alkalinization than towards the salinization.

These results give us four types of West Pakistan soils,

1. Clayey soils - highly alkalinised.
2. Clayey soils - highly alkalinised as well as saline soils.
3. Sandy loam more saline than alkaline.
4. Pure sandy soils - more alkaline.

The chief characteristics of the strongly alkaline soils(17) in Region VI are; that they have a laminated superficial horizon overlying a deep strata of columnar of prismatic structure. The columns and rounded tops, are often covered with a layer of white salts. Besides this, a highly developed alkaline soil depicts 3 striking layers resting on sand strata as follows:-

1. The upper layer which is highly alkaline, compact and impermeable.

2. It is a layer of medium alkaline content, consisting of calcium carbonate nodules or kankar.

3. It shows the lowest alkalinity, and is naturally more permeable than the former layers.

The soils in the first layer are called black alkaline or 'termed' in the 2nd layer as transitional alkaline and in the lowest as white alkaline.

Black alkali contains Na_2Co_3 and it is among the most intractable soils. The principal ingredients of white alkali are sodium chloride (Nac_1) other common salts and sodium sulphate (Na_2No_4) or Glauber salt.(47)

Effect on crops:-

Saline and alkaline soils are detrimental to plant growth as their soluble salts content is very high. Only those plants grow which are highly tolerant, the crops varying in their power of tolerance to alkali and salty soils. It is considered possible, that the continually growing of the same suitable crops may even gradually remove the alkalinity of the soil in the long run by absorbing the salts. Generally, the plants stop growing in soils, when the salt content exceeds the following percentage:-(47)

Sodium Carbonate	0.10%
Sodium Chloride	0.25%
Sodium Sulphate	0.50%

The Appendix 11 . . . indicates the crops which can survive in the soils containing varied amount of salts and alkali.

The crops in the power of their resistence are listed below:

Table 18

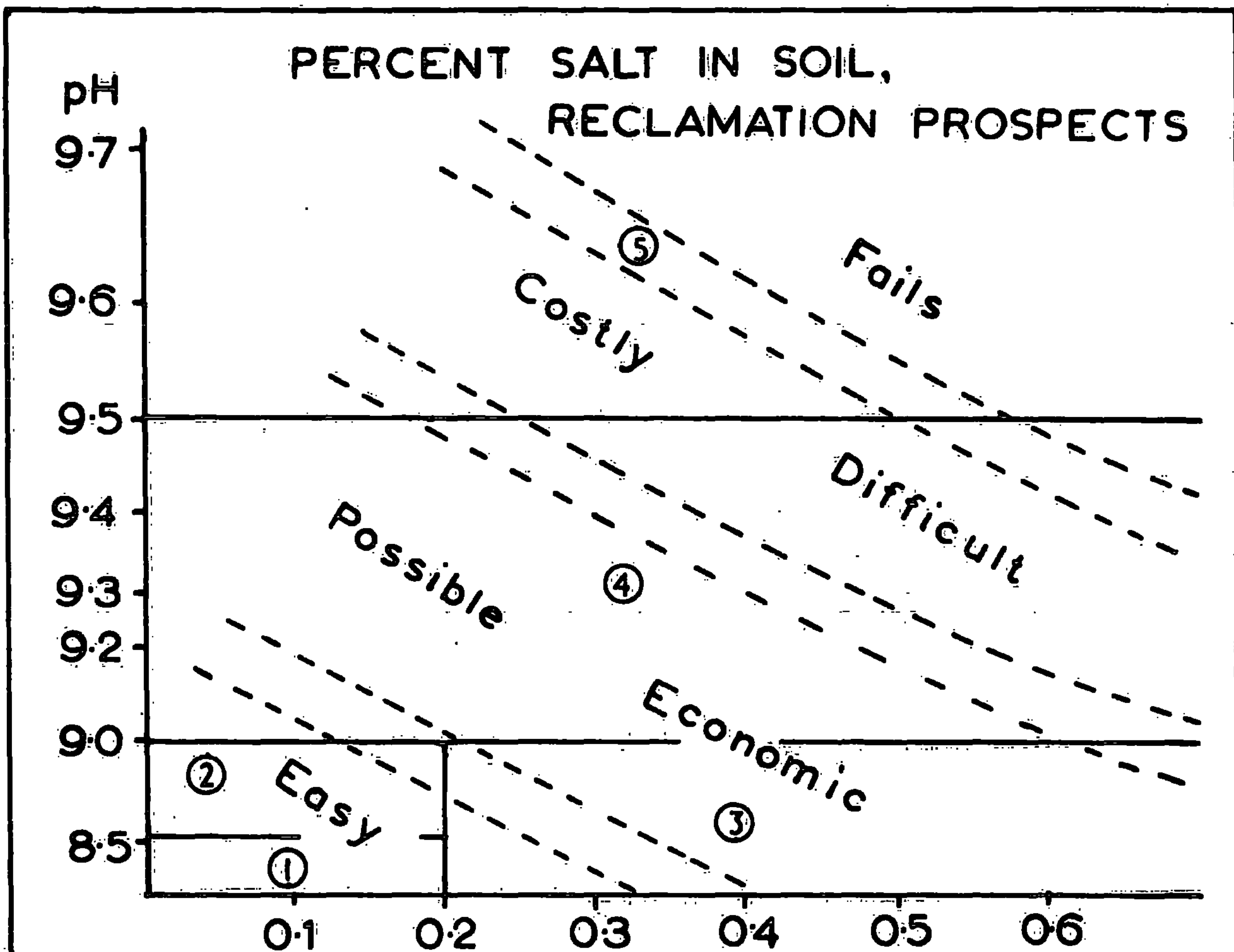
1. Salt bushes like those that grow in the marshes near sea-coast.
2. Portulaceae
3. Berseem
4. Lucerne
5. Beets
6. Lucerne
7. Barley
8. Beans
9. Vines
10. Wheat
11. Oats
12. Lucerne
13. Potatoes
14. Onions
15. Peaches
16. Apples
17. Apricots
18. Citrus fruits.

It has been experimentally shown that most crop yields fall when the 0.2% of salts concentrate with the root zone, and fail when the salt percentage reaches to 0.5. Fig. 45 illustrates the degree of intensity of salinity which is curable.(42) This illustration brings out the characteristics of soils containing the variable amount of salts and pH. The soils which contain 0.1% of salts and 8.5 pH is good land. The other marked as 2, contains 0.1-0.2% of salts and pH 8.5-9.0, is claimed to be land of easy reclamation. The land marked as 3, consists of 0.2-0.4% of salts content and pH value from 9.0-9.4 and here reclamation is an economic possibility. When the salt content reaches to 0.4-0.5% and pH 9.3-9.4, the land restoration will take a period of 2 years. When the salt quantity reaches 0.5%-0.6% and pH to 9.5-9.6, the restoration is costly and difficult and when the deterioration crosses these limits the reclamation fails.

If we examine the analytical schemes of the soils presented in tables 14-17, in the light of fig. 45, all such soils are difficult to reclaim and for some reclamation is not economically feasible.

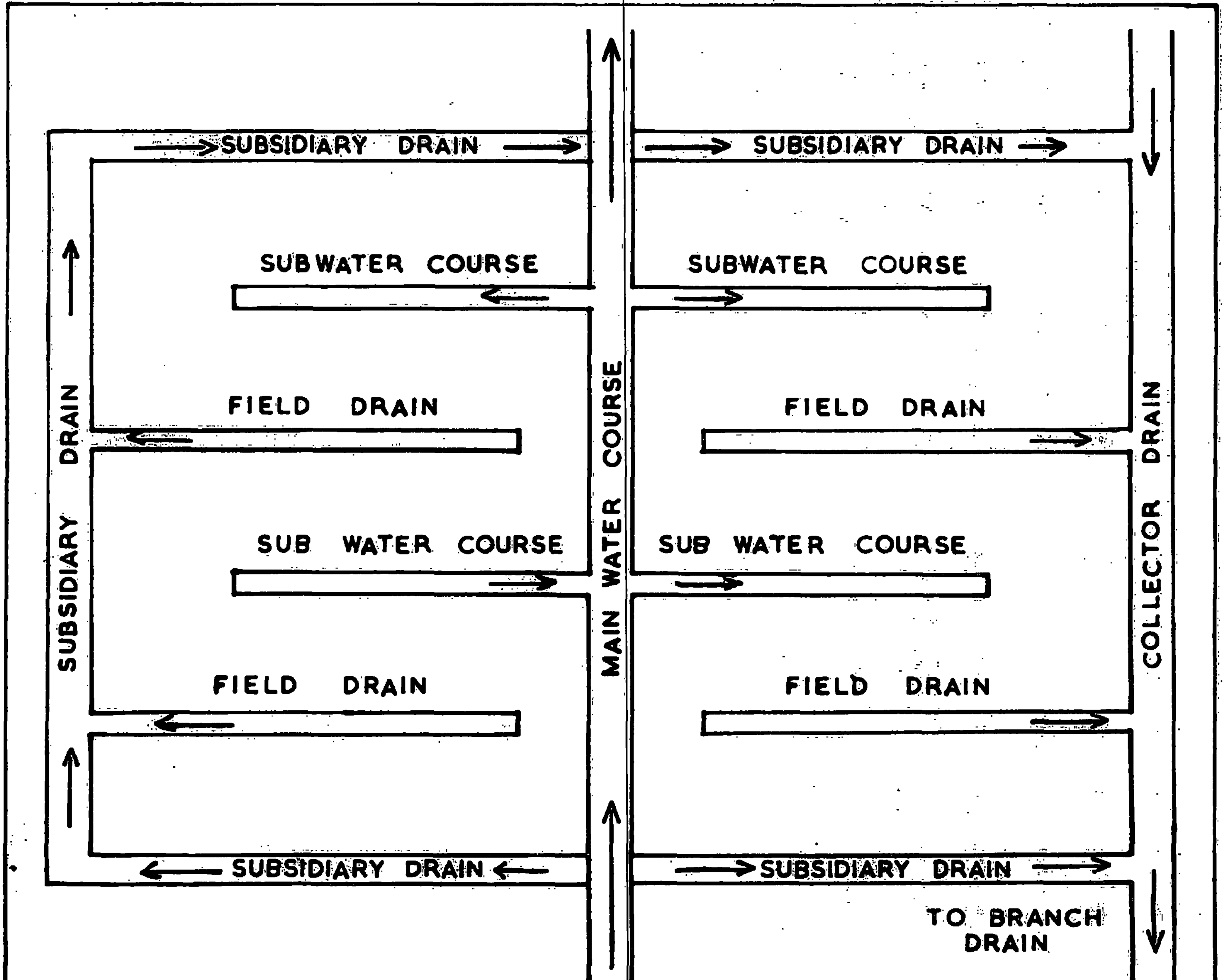
Reclamation:-

Before the establishment of Pakistan the term 'land reclamation' was applied strictly to the reclamation of irrigable land which had gone out of cultivation owing to


PERCENT SALT IN SOIL,
RECLAMATION PROSPECTS
pH
9·7
9·6
9·5
9·4
9·3
9·2
9·0
8·5
0·1
0·2
0·3
0·4
0·5
0·6
Fails
Costly
Difficult
Possible
Economic
Easy
①
②
③
④
⑤
Fig. 45

the twin menaces of waterlogging and salinity.(48) The amount of land going out of cultivation at present in this way is about 30,000 to 40,000 acres a year. The first golden rule is that prevention is better than cure, that precautionary measures to nip the salinity and alkalinity in the bud are easier and more effective than total reclamation. The measures are as follows.

If irrigation water is used in the economical way, then evaporation loss can easily be avoided. Areas, which may be waterlogged should be given with a comprehensive drainage system, which would also lead the water charged with injurious salts away to the natural drains. Precautions should be taken in using the irrigation water containing salts. If its use becomes unavoidable then very large amounts of water should be applied so that the concentration of harmful salts would not take place, and the salts will be leached away. This measure will be possible on a loamy soil. This type of prevention will not work on a non-porous clay soil, when water containing even a small quantity of sodium carbonate should not in general be applied. However, the use of such water is safe only, if the soil contains a large amount of flocculating salts so that sodium carbonate will not concentrate to form a hard pan. Finally,impounded,water in depressions should be drained.



SUBSIDIARY DRAIN
SUBSIDIARY DRAIN
SUBWATER COURSE
SUBWATER COURSE
FIELD DRAIN
FIELD DRAIN
SUB WATER COURSE
SUB WATER COURSE
FIELD DRAIN
FIELD DRAIN
SUBSIDIARY DRAIN
SUBSIDIARY DRAIN
SUBSIDIARY DRAIN
MAIN WATER COURSE
COLLECTOR DRAIN
TO BRANCH DRAIN

FIG. 4.6

Preventive measures can stop deterioration of good land, deterioration which is the result of an unscientific and thoughtless irrigation. Reclamation of alkaline and saline land is a costly enterprise. Many investigations are being done in advanced countries in respect of saline and alkaline soils. All these methods are in an experimental state in Pakistan. Speaking broadly, there are three methods practised for the reclamation of these soils:-(5)

1. Technical methods or eradication.
2. Chemical methods or conversion.
3. Agronomical method - control.

Technical methods:-

The first step in this respect is the provision of efficient drainage system in the irrigation areas. The area to be restored is divided into beds, which are left fully flooded for a long time; the salts are dissolved by the impounded water, and the water is then allowed to drain off into the surface drains. Fig. 46 shows that distance between successive field drains varies according to the soil type.(15) If the soil is light then field drains are constructed approximately 200 feet apart. If however, soil is relatively heavy then they should be placed at 110-120 feet distance. A repitition of this process will finally restore the soil. This method is effective, when the salts are not dissolved by natural flooding. Sometimes both flooding and impounding are employed to obtain quick results. This method is employed also for de-watering of waterlogged areas.

The other technical approach in this direction is leaching or under-drainage system. This process needs an abundance of water to percolate through the soil and remove the salts from the root zone. If the land is not drained naturally a number of artificial drains are necessary. It is also possible to divide the land into plots, for leaching purposes not more than ½ acre, which should be flooded heavily and frequently. Precautions should be taken, not to allow the soil to get dry during the interval times between two floodings, otherwise salts will again appear on the surface under capillary action. It is also simultaneously possible to grow crops like wheat. In America technical methods used, include the scraping of white alkali incrustation off the soil surface. This method alone is not sufficient as a considerable amount of salts still remain in the soil. It may be combined with leaching for quick and better results.

Chemical methods become obligatory when technical methods are not feasible. Under this method, chemicals as gypsum, sulphate of amonia separate or mixed, especially with soil, ameliorating devices like molasses, sulphur and press mud. An application of gypsum (calcium sulphate) ameliorates the soil by producing calcium carbonate and sodium sulphate. Calcium carbonate is not harmful as it is practically insoluble. Sodium sulphate is injurious but not to the extent of sodium carbonate, and the former can be removed by surface drainage. Many tons of gypsum is required for an acre, the soil must be kept wet, and the land should not be cultivated. In America emphasis is laid on the use of chemicals during reclamation time and also to the use of fertilisers after reclamation.

Agronomical Methods:-

In Pakistan economic pressures favour methods which also involve crop production, for instance salt tolerant crops such as paddy rice could be sown during summer, when plentiful water is available. Along with this a suitable crop rotation will be highly effective. In Holland the amount of salts need to be eradicated from new polderland, is of a very high order, therefore the reclaimed land is left to the growth of natural weeds and vegetation for the first few years.(49) This stage is followed by pasture grass, which is ultimately connected to the normal crop production after a liberal use of fertilisers. The agronomic process in semi-arid conditions has to prevent the evaporation losses from the soil. To achieve this,it is advisable to use soil mulch intensively.

Reclamation of Saline Land:-

The rate of soil reclamation depends on the quantity of water available for this purpose, and also on the geographic conditions of the soils such as, 1. thickness, 2. Clay content, 3. Initial degree of alkalization, 4. Initial total solids content, 5. Delta of water applied during the reclamation operation-leaching, 6. The organic matter content of the soil - green manuring, 7. Continuity of cropping, cultivation and fallowing.

Water quantity is the chief handicap in the process of leaching, since in sandy soils the leaching is rapid and easy. Leaching is also influenced by the crop rotation practised. The water need for reclamation has been estimated at about 7-3 acre-feet per acre for 3 years, six times more than the normal allowance for irrigation. This is equivalent to an estimated reclamation allowance of 100 acre-inches, per acre during six summer months. Owing to seepage losses particularly, during canal closure 70-75 acre-inches was considered a more correct average delta of water applied. This water is applied in 20-25 irrigations of 3-4 inches depth. In Egypt a similar method is practised for leaching the salt by flooding the area with Nile's water.(49)

According to Pakistan standards the soil is declared reclaimed, when the soluble salts are washed down below the depth of 10' with less than 0.2% concentration, and alkalinity reduced to pH 8.5 or less. It is estimated that in a cycle of 3 years 100,000 acres are being reclaimed annually. About 263,800 acres were rehabilitated before 1953-54; and to this 28,000 acres were added in 1954-55 . At the same time 40,000 acres are going out of cultivation every year. In his report Zuur,(50) after crossing the country, said when one makes excursions through Punjab, the deterioration of the area at many places is very clear. Whole plains can be seen which were once under cultivation and now, abandoned, are covered with a glittering crust of salt. In other areas the situation is not yet so bad, but even there one sees fields which have been partly attacked and which are obviously in decline. He also stated that "irrigation authorities were fighting a losing battle, because about 70,000 acres, as an average of the last decade, were added to the area of 3,000,000 acres with salts visible on 20% or more of the surface". In the view of such appalling deterioration, at present only partially affected soils can be considered for restoration. Moreover the area once reclaimed is likely to develop salinity again, if a low crop delta is applied.

In the reclaiming process it is required for the cultivator to level the fields, and construct dykes to hold the water in quarter acre plots. The water is applied after every 7 days in summer. He has to sow crops like paddy (rice) or legumes such as Jantar (sesbania aculeata) during summer and a suitable winter legume such as Berseem or Gram. These ameliorate the soil and a rotation of rice-berseem follows.(43)(49)

The process of reclamation is begun on the first of April, and from the upper 2 feet the preliminary washing down of the salts is done by weekly irrigation for 2½ months. By the middle of June the rice is transplanted in the standing water, plants prepared on good nursery land. This crop is prepared with weekly irrigation till the end of September, when it is mature and harvested in the next month. The delta of standing water required for the rice crop is some 5 feet. As a result harmful salts are removed from the soil profile, but it removes some of the food nutrients also. The reason for emphasis on rotation of soil-exhausting and soil-building crops is obvious.

The water duty may be raised to 60 acres per cusecs in the event of non-availability of field drainage. It is self-evident that leaching is possible and thorough only when the drainage system is effective. Besides this leachate percolates to the adjoining areas of low level and low water table.

In the reclaiming process in 1945, Asghar and associates advocated flooding of the land as much as possible in a single treatment followed by frequent irrigation, so that no chance is given to the soil to get dried. The reclamation experiments at present show that, this system of high flooding and repeated irrigation is useful for soils of excessive soluble salts, of good permeability.(51) In the U.S.A. this method has proved beneficial for the soil structure and permeability.

In his experiments on nitrogen deficiency, Metha in 1951 investigated three crops that will counterbalance this deficiency in winter when the available water is less on the whole. These three crops have different demands on water.(15) He has recommended Berseem when the water available is sufficient; Senji (Melilotus parviflora) can be grown when there is no availability of water in winter, grain will grow with the residual water of rice crops. From the point of view of the experts, rice generates carbon dioxide from its root system, which counteracts the process of alkalinity, and helps washing down of the salts by increasing rate of percolation, as the rivers in the canal colonies contain the residues of bicarbonate which have adverse effects on the leaching. This influence may be strong when evaporation is high. Therefore, the growing of suitable plants will be beneficial on the sodic soils, as the physical action of plant roots improves the action of soil permeability and leaching.

Reclamation of Kallar areas is of vital importance and it has received great attention in West Pakistan. The aim is to convert the sodium clay to a calcium one. A considerable amount of research has been going on in restoring the alkaline lands. In this direction, the pioneer work was done by Hilgard and his colleagues in California.(41) They reclaimed alkali soils by an application of calcium sulphate (gypsum), followed by flooding. The amount of gypsum per acre used was 12 tons. By the application of gypsum, sodium sulphate was produced, which was later washed away by flooding, and consequently sodium soil was converted into calcium. The alkali rich soils were also treated in Russia, with an application of gypsum according to the recommendations of Gedroiz and his associates.

In Hungary, alkali soils have been treated by Sigmond, by reducing the rate of evaporation from the surface by growing lucerne, which requires large quantities of moisture and dries up the soil, and the upward movement of the sodium salts were decreased. The other reclaimants used were press lime, gypsum, farm yard manure etc. in reducing sodium carbonates.

In the United Province of India, press-mud and molasses are used in the reclamation process. It was noted, that, as molasses contain acids, carbohydrates, soluble calcium salts, phosphates, and potash etc. it can readily remove the alkali menace. Press-mud is a bye-product of sugarcane factories, can be made available for the reclamation process. It contains calcium compounds, carbohydrates and nitrogen, and it proved an excellent reclaimant. Further agents of reclamation such as oil cakes, oils, cellulose material have been tried since they contain nitrogen compounds.

In West Pakistan the first attempt in the reclamation of Kallar soils was made in 1932 at Lyallpur, Kala Kaku, Montgomery and Bara Farms, by an application of a mixture of gypsum and calcium chloride. The pH value of these soils was 9, it was reduced to 8.2 after treatment.(41) It was reported, that the soil permeability was increased appreciably after 4 years, which was the period of reclamation process. The same period was required under the treatment of gypsum and powdered sulphur.

In Pakistan in the recent communication and experiments, the chief emphasis is placed on the agronomic methods to erradicate the alkali from the soils. It is referred to already,that leaching is not an agent of remedy for the alkali soils, as the soils become highly impervious due to high clay content and dispersed colloidal matter. Therefore, two types of methods have been advocated to reclaim the sick lands, first,by growing suitable crops, second,by an application of chemical along with deep ploughing.

The salt tolerant crops,which can absorb the alkaline salts to the greatest extent are the salt bushes as indicated in Table 18 , but these plants have no utility value. Slightly saltish plants can be utilised as a fodder and certain varieties of portulaçeae can be grown as vegetables. Berseem comes third,in the order of salt resistant capacity, it has a market value, and is used as a fodder crop for cattle and buffaloes. Lucerne also is effective and a good fodder. Rice is a beneficial crop for a less alkaline soil, and cures the heavy saltish soils. The sample studies in the following pages indicate that the best results have been obtained when berseem is alternated with guara. (vetch). Berseem is an excellent kallar removing crop. It eases the soil within 2-3 years, depending on the intensity of alkalinity. The agronomic methods, cannot ease the highly impregnated soils and the need of surface drainage remains.

Asghar has also examined green manuring which helps to demote the pH value of the sick soils to a "permissible range". He also suggested,that green manuring should preferably be done by Kharif leguminous crops and the superiority of Jantar over other crops as a green manure was indicated.(40) It also appears that alkali soils can be successfully cured, if leaching is followed by a Jantar crop. (Sesbania aculeata), and a treatment of gypsum, but this method is not adopted in Pakistan because of its high costs.

Metha has also explained the advantages of Jantar. He reported,that there was some evidence of the formation of H_2S by decomposition of Jantar stalks and leaves, which has proved a natural active agent of demoting the pH in the soil.(15 Metha has not stated the proportion in which the leaves and water were mixed, nor did he make clear the pH value of water released. However, it has been accepted,that green manure is a remedial agent for the maintenance of favourable pH value in soil. Repeated emphasis has been laid on Jantar because of its manifold advantages. It grows in all types of soils and it is tolerant to both waterlogging and drough conditions. It also has economic values like that of Jute and can be used as a fibre for the making of ropes, sacks, mats, linoleum and webbing etc.

The comparative restorative capacity as examined by

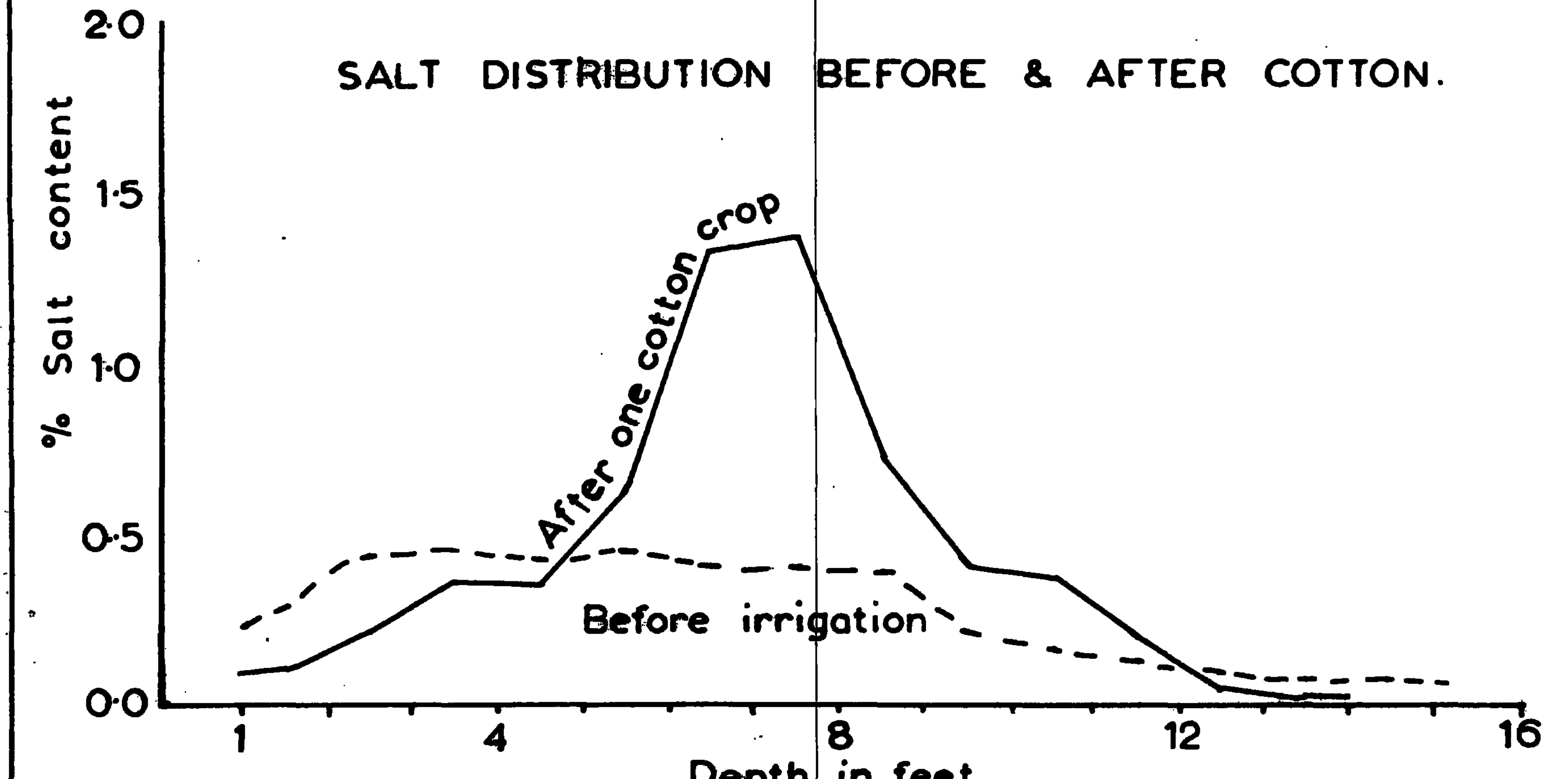

SALT DISTRIBUTION BEFORE & AFTER COTTON.
% Salt content
2·0
1·5
1·0
0·5
0·0
After one cotton crop
Before irrigation
1
4
8
12
16
Depth in feet

FIG.47

Asghar is presented in the following chart.(52) He divided the portion of the farm into 3 blocks, A, B and C, and the variety of crops grown as in Appendix 12.

Average yields of cotton obtained after gram and berseem

			Yield of cotton in Mounds per acre	
Crop	Years	Block	Gram	Berseem
Kharif	1945	A	6.50	6.72
	1946	B	14.42	12.87
	1947	C	10.13	8.97
	1948	A	5.10	4.72
	1949	B	4.85	4.65
		Total:	41.00	37.93
		Average yield per acre:	8.20	7.58

This experiment shows that cotton yields are higher after grams than after berseem. Figure 47 (15) illustrates the behaviour of salts before and after the cotton crop. Figure 48 shows that under heavy irrigation for rice crop the salts have been almost completely removed from the soil, and no zone of accumulation left. The rotation followed was rice and fallow.

Yield of wheat obtained after the quara green manuring was as under:

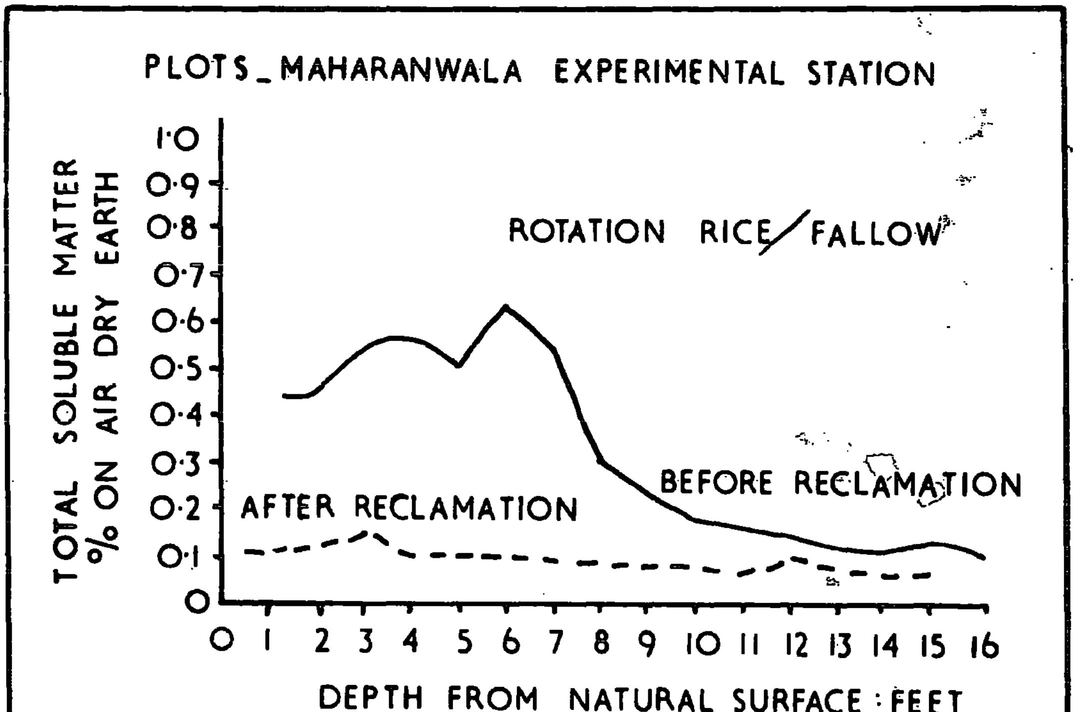

PLOTS_MAHARANWALA EXPERIMENTAL STATION
TOTAL SOLUBLE MATTER
% ON AIR DRY EARTH
1·0
0·9
0·8
0·7
0·6
0·5
0·4
0·3
0·2
0·1
0
ROTATION RICE/FALLOW
BEFORE RECLAMATION
AFTER RECLAMATION
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
DEPTH FROM NATURAL SURFACE : FEET

Fig. 48

Year	Yields of wheat in Mound per acre after: Gram	Berseem
1946-47	28.47	25.25
47-48	22.52	22.22
48-49	15.45	15.90
Average yield per acre	22.14	21.12

The above results of wheat are for the period when green manuring was introduced in the rotation. The differences in yields after gram and berseem respectively were not considerable. It is clear from the samples quoted, that both gram and berseem are equally competent as restorative crops but their adoption in the crop rotation entirely depends on the availability of water-supply. Where winter water-supply is scanty, gram should be preferred and berseem otherwise. Data for yields on lands partially and completely reclaimed are only available for single years at Moharanwala Experimental Farm and are inconclusive in that cultivation conditions were not strictly comparable. Thus, the quoted figures which indicate higher yields of cotton and wheat during reclamation than those obtained after completion, only really indicate the delicate balance of factors involved. Saline soils are not necessarily harmful to crops, if the highly salinised or sodiumised elements are maintained compactly low in the solum. This necessitates leaching and then proper crop rotation. About 2.3 million acres of the Central Canal region are saline but owing to insufficiency of water, improvement cannot be carried out on a large enough scale. All finally depends on water, the most precious commodity in arid and semi-arid regions. Alkaline soils can be treated chemically but agronomic methods seem generally suitable. Here again all depends on water for the growing of suitable plants and for leaching, and on the prevention of water table rise by reclamation and applications of water. Fig. 485 A-B indicate the scale of recent reclamation work on saline and alkaline lands and the water supply sanctioned. Appendix 13.

Soil Erosion

In addition to the increase in acreage of damaged soils, as a result of incorrect water application, soil fertility is damaged by erosion in the un-irrigated land as in the undulating country of the Potwar region, which traditionally is a region with a wheat surplus. The agriculture here is barani (rain-watered).(48) In good years of rain these lands produce bumper crops which contribute even to world supplies. Here soil erosion is acute and is typical of all such regions.

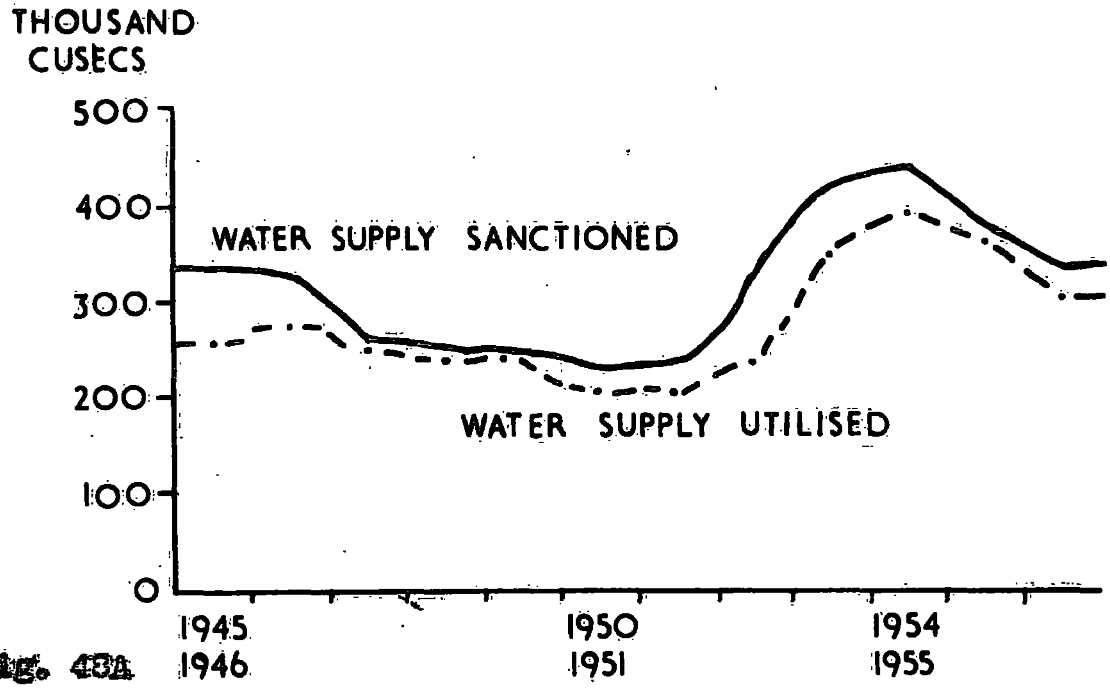
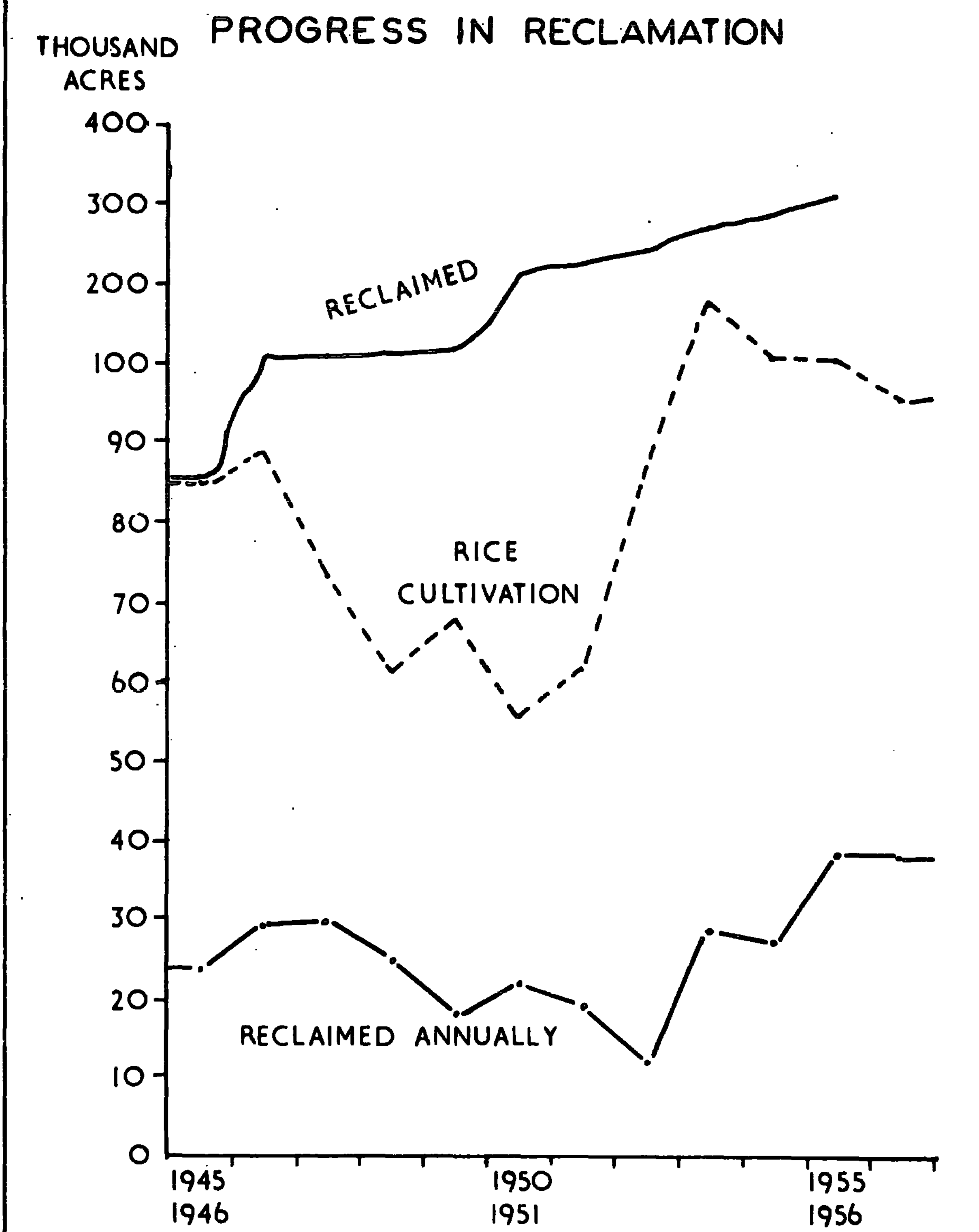

THOUSAND CUSECS
500
400
300
200
100
0
WATER SUPPLY SANCTIONED
WATER SUPPLY UTILISED
1945
1946
1950
1951
1954
1955

Fig. 43A


PROGRESS IN RECLAMATION
THOUSAND ACRES
400
300
200
100
90
80
70
60
50
40
30
20
10
0
RECLAIMED
RICE CULTIVATION
RECLAIMED ANNUALLY
1945 1946
1950 1951
1955 1956
Fig. 48B

Soil erosion is described as "the theft of soil by the elements, and is the removal of soil particles either singly or in mass. It may be due to wind and water action".(53) Soil is whirled up from flat grounds and accumulates into dunes. The soil is seldom cut deep by wind action, but water moves down the soil createsa fretwork of gullies both in the sub soil and underlying strata.

Like salinity,erosion is also a world wide epidemic, The area scoured by erosion in the United States is enormous. Nearly two-thirds of its total land area has been damaged as estimated by Lowdermilk in 1935.(54) Two-fifths of the total area suffers from erosion in Newzealand. In Pakistan reliable data are lacking, the estimates made are varied. Menon estimated, "that about 77% of the total land area is affected by erosion. Most of which has been deprived of its top soil,either partially or wholly by sheet, wind or gully erosion".(55) In his recent communication Gorrie stated, "out of 40 million acres of West Punjab, 14 million are irrigated, including Bahawalpur, and the Mianwali Thal. The unirrigated cultivation is about 8½ million, and out of this 2½ million is badly in need of terracing. Then, apart from the existing cultivation, there are two million acres of ravined land, much of which could be turned into a real national asset if it were broken down into terraces".(48)

This is the state of affairs in Upper Indus plain only. For the rest of West Pakistan the conditions are even more alarming. As he states, "there is the rest of West Pakistan with another 160 million acres, but out of this, one can only make a guess that there are at least four million acres of ravined land". On the same context, the U.N. expert reported,"Baluchistan is the hardest hit region in the whole of Pakistan, which is losing soil at the rate of 3,000 tons per day per square mile".(56) He stated, that, "This is a horrifying rate and if it is continued unchecked it would turn the whole of Quetta and Kalat Division into dry desert in a comparatively short period". He has also given a fearful estimate for the Upper Indus Plain, as is losing soil at the rate of 2,500 tons per square mile each year.

It is said, that upon soil, depends all life, so soil forms the most precious natural resources, especially for Pakistan as she is an agricultural country. It is now believed, that the remote civilisation of Harappa and Mohenjo Daro vanished owing to the loss of soil fertility. The same may be true of the other great civilizations of Babylonia, Iran and Egyptian. Hence the dictum that civilizations decline and fail when soil fails to produce", bears an ample truth.(56)

Civilization and the very survival of Pakistan depends on her soil resources and her industries depend in turn on the primary produce.

In West Pakistan, like the rest of the arid world, climatic conditions vary with moderate to low but torrential and uncertain rainfall, while at some localities conditions of perpetual drought prevail; these are the main causes of both wind and water erosion. Combined with that, physical, social and economic causes have created a colossal amount of destruction to the soil. Thus present erosion is the result of human acceleration of the natural processes, yet such interference with natural process is basically necessary for any use of land. In West Pakistan and in all the tropical and sub-tropical lands, the normal pattern of rainfall is one of concentrated and heavy falls. This type of torrential rainfall has a forceful impact on the soil and is very conducive to a rapid erosion. Visher concludes, that the rainfall intensity is a great handicap in the development of tropical lands.(57) Local rainfall in West Pakistan sometimes reaches to the intensity of 20" in a day. The rain comes with greater intensity than the rate of absorption. Erosion results not from rainfall intensity only, in fact the damage "depends upon the size and velocity of each rain-drop, the intensity of the fall and the strength and direction of the wind".(53) The absorptive rate of soils in Pakistan has not been calculated. As the soils in West Pakistan are mostly sandy, they soak up the water quickly and then release it quickly afterwards. In the northern extremities of West Pakistan where climate tends to be humid an erosion of "linear torrent" resulted. It causes local run off which has repurcussions on the low lying areas at the foot of the mountains.

In the sub-montainous and semi-arid regions, particularly, the districts of Peshawar, Rawalpindi, Attock, Jhelum and Gujrat, are the most affected areas by water erosion. The fertile land here has been ruined so much that its economic reclamation is not possible. With inadequate water and mismanagement of the soil wind erosion is converting the vast area into a desert. (See Chapter 3).

In the arid region, wind primarily, and secondly, ephemeral water are degrading the land rapidly, which has been worsened by over grazing by goats and sheep. The desolate appearance of the hill areas is due mainly to deforestation and over-grazing.

Wind erosion is active in the sandy desert tracks of the lowland. These are used as the seasonal grazing grounds whenever the rain falls; and cultivation is pursued only on some fragmentary patches of land privileged with fertile soil whenever there is a timely rain. The land lies exposed to the weathering otherwise and the soil is blown away.

Nature provided a blanket of vegetation as an anti-erosion protection for the soil. A forest canopy is considered to be the "most perfect" protection against both wind and rain action. There is an ample archaeological evidence, that the Pak-Hind sub-continent was once generally covered with a thick forest. (See Climate and Pre-history). Historical records depict that Alexander's army and elephants escaped in a 'sal' forest near Lahore, while the Sal tree is not now found within a radius of hundreds of miles of Lahore.(34) Another example, furnishes the presence of a thick jungle is the discovery of remains of elephants at Taxilla. With the gradual destruction of forest vegetation, calamity has fallen on this area resulting in erosion and loss of fertility of the soil. At present Pakistan is badly affected not so much by losing soil fertility as by losing the whole top soil cover.

The implications of deforestation not only appear in erosion. Deforestation intensified the floods, and reduced the winter discharges of the rivers. In consequence, the sub-soil water supply has been threatened and ultimately the whole agricultural structure has been shaken by the resulting diminishing output.

Generally, forests serve twofold ecological purposes. In the first place, forest retains a large amount of water, both rain and flood, so the impact of the heaviest rain is not destructive. The undergrowth and the litter carpet in a forested area, soaks the water and releases it steadily to the underlying soil.(58) When this cover is removed, erosion sets in instantly. In the second instance, which is rather of vital importance, the forest serves as a cover to the catchment basins in the highland. The soil under such a protective covering has a great water-holding capacity and it ensures a regular flow to the streams further down. As the soils are destroyed by ruthless forest-cutting the flow of rivers is rendered irregular, and floods of immense destruction are experienced frequently in the rainy season, while the rivers become tiny streams in the dry season. The amount of soil lost by subsequent run-off depends on the slope of the land; the type of vegetation and the soil exposure. The remedy lies in the regulation of river supplies which can only be attained by reafforestation and afforestation schemes in the catchment basins. It has been recognised widely, that the importance of keeping water-shed areas under vegetation cover as is the most effective means to ensure, regulate and control the water supply throughout the year. Plates 3, and 15-16 show the rills formed by occasional rain on the mountain slopes in the north west highlands. Plates 15-16 show that under thick cover the surface is protected while it is damaged under scattered bushes.

Defective systems of agriculture are also responsible for the present extent of soil erosion. The most destructive system is over-grazing. Over grazing and deforestation follow one another. Sheep and cattle weaken the soil mantle by grazing the undergrowth, and when they finish with the undergrowth goats even climb up the trees and finally bring death to the whole vegetative life. West Pakistan highlands and sub-montane regions have long been under a particularly destructive impact of grazing. The eroded conditions of these areas has been portrayed thus, "For thousands of years (man's) flocks of goats and sheep have been busy eradicating every trace of vegetation on the uncultivated tracts, until now there is not remaining a vestige of the original herbage except grass. The depredations of goats and sheep are visible up to about 7,000 ft. in the Safed Koh, below which they have trodden away all the soil and eaten out every species of tree and shrub; vegetation in that range commences only at a point beyond which goats cannot reach in a day's

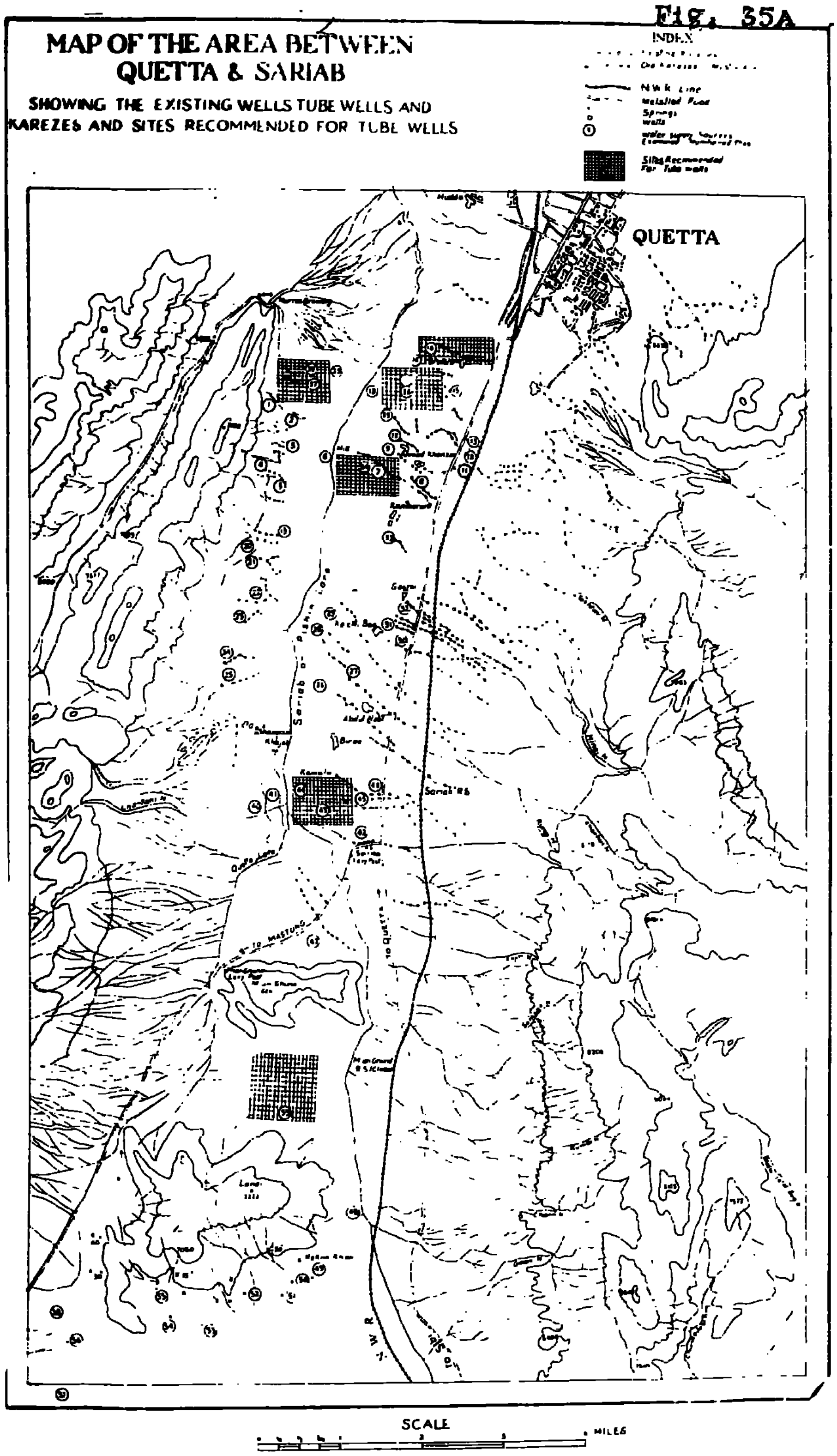
Plate 15

Plate 16

Plate 17

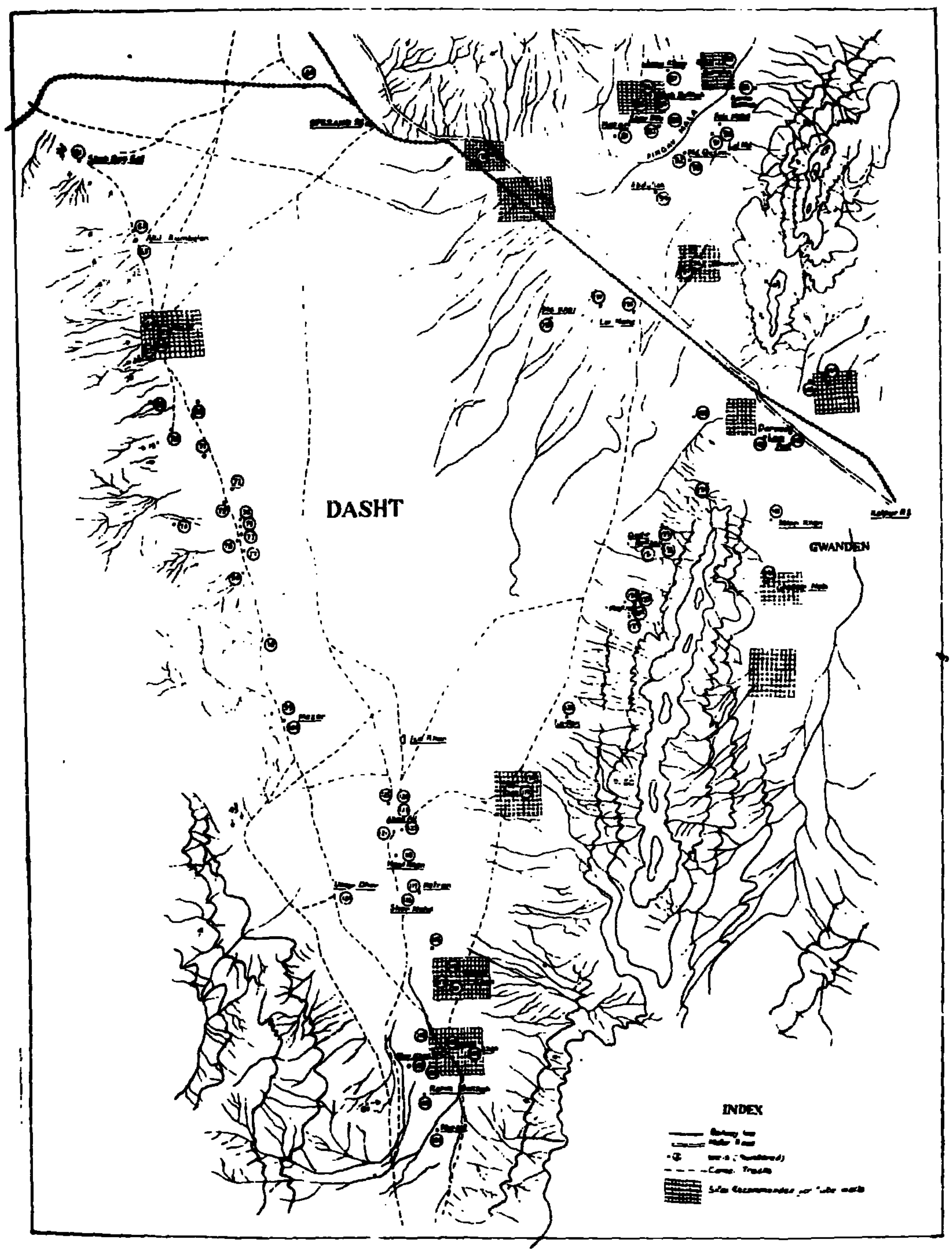
Plate 18

Fig. 35A


MAP OF THE AREA BETWEEN
QUETTA & SARIAB
SHOWING THE EXISTING WELLS TUBE WELLS AND
KAREZES AND SITES RECOMMENDED FOR TUBE WELLS
INDEX
QUETTA
SCALE
MILES

SHOWING THE EXISTING WELLS AND SITES RECOMMENDED FOR TUBE WELLS

Fig. 35B



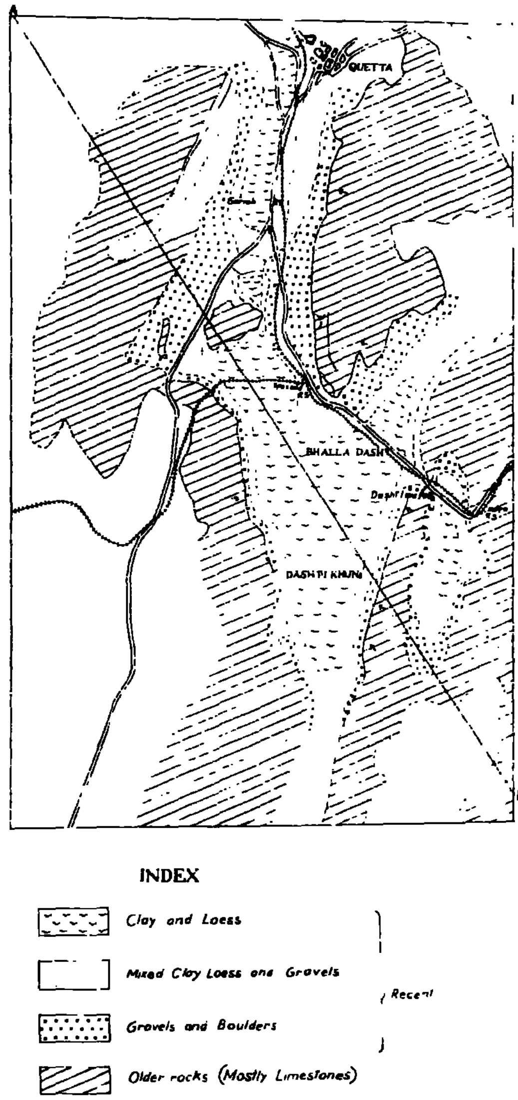
SCALE

MILES

FROM SHEET Nos 34J, 34N

Fig. 36

MAP SHOWING THE DISTRIBUTION OF VARIOUS RECENT WATER BEARING STRATA BETWEEN QUETTA AND KOLPUR.



SCALE MILES

journey from the villages below. In the comparatively dry countries of Asia where the soil throughout the year is not moist, and where the roots of growing grasses do not bind it together, goats and sheep have either killed or are fast killing the mountain slopes and rendering them as the barren islands in the Red Sea".(59)

Plate 17 is a spectacular picture of how cattle have almost finished the undergrowth and they have stunted the trees too. The area shown is in the uplands, Region V. In this connection the ravines of Potwar noted in Plate 7 Chapter 1, are the result of reckless wood cutting. The present writer has seen in the north west highlands, Regions I-II how soil erosion is widespread mainly due to goat grazing and cattle. As the timber line is very high, out of reach of both man and beast, it is the highlands below 8,000 feet which are chiefly destroyed by grazing. Over grazing is also attributed to the arid and variable climate especially to variable rainfall. The grazier is always expecting a serious drought in the arid and semi-arid climate of West Pakistan and he tends to stock the grazing ground to their limit and tends to cut green fodder very heavily during the wet season. Consequently, pastures are overstocked and vegetation destroyed.

A balanced animal husbandry and arable agriculture could be visualised if a choice is made between sheep and goat on the one hand and cattle on the other hand. Italy Greece, Spain and Turkey have chosen sheep and goat and suffered serious erosion and agricultural deterioration. In Switzerland, circumstances have encouraged reliance on cattle, and their agriculture flourished.(18) In Pakistan, grazing grounds should be organised on the basis of a mixed farming of cattle rearing and arable, both based on the tube-well, wells and rain irrigation in the areas of desert fringe, submontanes and highland. Laws of controlling grazing should be framed and practised strictly.

The growing technical tendency to integrate many conservation techniques into a general 'Range Management' approach, shows, how with soil erosion, mechanical and biological balances have to be maintained. Fundamentally, of course such balances depend on the character of the human societies and on pressure on land resources.

Land has been exposed to great pressure of both human and livestock population particularly since 1947. This, under present conditions has lead to the destruction of the remaining vegetative cover and to widespread erosion. The nomads and Powidah are also destroying the land (Plate 41, Chapter 8). The following table indicates the density of cattle per square mile and the number per 100 persons in

West Pakistan and other countries.

Country	Cattle Population in 000	Animals per square mile	Animals per 100 persons
1. Argentina	33,101	31	259
2. Australia	13,078	4	191
3. Austria	2,596	80	38
4. Canada	8,511	2	77
5. Denmark	3,239	195	86
6. England & Wales	6,849	117	17
7. France	15,622	73	37
8. Germany	19,911	110	29
9. New Zealand	4,506	44	281
10. U.S.A.	66,821	22	52
11. West Pakistan	28,821	90	85

This density does not include the migratory stock of Powindah.

The seriousness of the erosion problem is barely yet realised in Pakistan. The foremost step in erosion control is to "hold the soil in place. If the soil remains, its other qualities can be improved".(60) There are many devices for the control of soil erosion but the best are associated with the intelligent positive use of land.

Having realised the gravity of the situation and urgency of the more food requirements, the Ministry of Agriculture set up a body - Central Soil Conservation Organization - in 1951 and it was made responsible, (i) to advise the Government about soil conservation, (ii) to undertake a reconnaissance soil survey to measure the vastness of eroded areas in East and West Pakistan, (iii) to establish research work on the methods of erosion control and soil conservation, (iv) to give instructions to the Divisions on matters, related to soil conservation and preparing plans and schemes for pilot projects and demonstration, (v) to produce trained personnel for the organisation of Central and Divisional organisations, and (vi) to give demonstration to the farmers on the soil conservation practices.(61)

Under these conditions the first step undertaken by this Organisation to conduct a detailed reconnaissance soil survey in 1952, in order to elicit the degree and type of deterioration and present land use. After its completion, the areas needing immediate control will be located, and their proper use will be determined and applied, which in turn will indicate the promising food producing areas. After establishing these aspects, studies in the biotic approaches will be essential to find suitable crops, their rotation, handling and fertiliser needs.

The soil survey was first started in the valley of Nari Bolan and extended to Quetta-Pishin plain; uptil 1959 an area of 8.8 million acres was surveyed. In the Indus Plain such survey was completed with the collaboration of Canada.

In West Pakistan steps have been taken in the control of erosion at several places, which are still in the experimental stage; but their results are encouraging. The problems involved, are rainfall variability, lack of water and shortage of capital. The methods employed in Pakistan are primarily agronomic rather than mechanical.

The land reclamation was first attempted by the growing of drought resistant forage plants of various species in the proximity of Quetta, an area accessible for frequent observations.(37) The experiment was conducted by sowing of seeds of a large variety of nutritious grasses, legumes and forage shrubs imported from foreign countries. Out of a wide range of grasses the most promising were Boutelona curtipendula, Boutelona gracilis, Eragrostis curvula, Eragrostis trichodes, Eragrostis Lahmanniana, while Elymus giganteus, Lolium multiflorum, Sorghum almum, Panicum antidotale were the most useful of the fodder shrubs, etc. and the most successful legume species were several strains of rambling alfalfas. This procedure has been tried in the Agricultural Farm at Kot-Diji in the

Khairpur Division. In the vicinity of Karachi near the Hab river some 76 exotic and indigenous varieties of grasses have been experimented.

Experiments have been conducted,to utilise the surplus winter rain water in the Quetta/Kalat region, since this water is at present wasted during the severely cold winter. The water was detained by land bunding, and was used for the growth of such crops, grasses and trees which do not require a second application of water. The wheat crop produced in this way,was normal. This water may also help in raising the firewood and fodder as there is a derth of these commodities.

In the greater part of Quetta-Kalat Divisions, cultivated land belonging to each tribe is divided into four divisions, owing to limited available water and only one portion is cultivated in any year with wheat as the main crop. After this crop,this part is left in fallow for 3 years and is exposed to erosion.(37) For a profitable use of this fallow land during the idle years and for the improvement of existing crop sequence, it was first attempted in 1954, to grow drought resistant strains of Lucerne along with the winter wheat at Mastung. After the wheat harvest lucerne was left in the fields which served twofold purposes, the protection of soil and the provision of fodder. No subsequent irrigation was provided for it and it subsisted with the occasional rains. Promising results were obtained by this performance.

The stabilisation of sand dunes has also been experimented with, in the Mastung Valley. This fertile valley has been ruined by wind erosion and rendered sterile. The approach is again agronomic and Nar (Arunda donax), Phog (Collegnnuma polygonide), Surkanda (Sacrum celiara), Tamarix and Kochia scoparla provided a vegetative cover on the sand dunes. These plants have now been deeply rooted and are maintaining their growth. Such experiments are being extended and other grasses are also included, and this approach of wind erosion control has become very popular among the farmers. The reclamation of sand dune is carried on in Thal and Tharparkar deserts also, where shelter belts are also being established.

Erosion has been also controlled by the introduction of new crop rotations in the Division of Rawalpindi. The general crop system previously pursued by the farmers, was wheat-millet-fallow-fallow-wheat; only two crops were obtained in five years and the land remained vacant for the rest of the period. Experiments on the increased intensity of cropping by cutting the fallow period, and thereby, reducing the chance of erosion are under way.(37)

Steps are being taken to check erosion by growing shelter belts, by both irrigation and rain water, in the irrigated lands, and on the hills. In almost every part of the country some type of preventive measures are going on. In this respect, the Agriculture Ministry has asked for the foreign assistance. In its response the International Co-operation Administration of the U.S. of America offered $ 259,000 for soil conservation work in the Division of Rawalpindi and for Range management in Quetta-Kalat Divisions. The most important measures now being applied for erosion control are contour bund, management of grassland, use of dry farming, afforestation, reafforestation and shelter belts.

In addition to the above programme, before 1947, erosion control was undertaken by Gorrie in the region of Salt Range. The methods employed were mainly torrent control by bunds, and by plantations. The soil was preserved by terrace and trenches. Plate 18.

The uplands in particular, are largely affected by soil erosion. These areas if properly utilised may be turned into profitable range country and will return higher and better quality of meat, milk, butter, hide, skins and wool than it yields at present. The land is misused by communal grazing on an extensive scale. The immediate remedies are the localisation of the new water points, rotational grazing according to the carrying capacity of the specified areas. This may be combined with the growing of improved forage strains, and well organised transport and marketing will promote the productive capacity of the vast acres of misused, unused and unproductive land. For full effect, remedial and developmental measures, thus based on an ecological approach, must involve social and economic changes. The human element usually proves more intractable than the ecological factors.

The productivity of soil is necessarily relevant to the present study. In the foregoing account, we have considered the physical and chemical properties of the soils of West Pakistan; these form the background to the general pattern of soil fertility. The dominant characteristics of the soil, as stated above, are, the lack of organic matter, and low nitrogen content, on which depend potential crop production.

It is generally considered, that the soil of tropical and sub-tropical regions are poor in their production potential. This statement is truly confirmed by the experiments conducted by Hall. He drew a comparison of temperate and tropical regions by taking crops commonly grown, like potatoes and wheat for the temperate and rice as tropical crop. (61a)

These studies do not imply, that the low yields are due mainly, to the inherent infertility of the soils. Many causative factors are involved for the present low yields. Among these factors, the natural factors as climate, and soil types have been sketched already. The remaining factors are cultural such as farm management i.e., cultivation systems and methods, irrigation feasibility, fertiliser and seeds, tradition, illiteracy and poverty of the peasants.

The soils in Pakistan are generally chemically fertile, their major draw back is their general dessication. It is said ..... "you have only to scratch the soil and add a little water, and you can grow what you please".(62) "The valley soils are very deep and fertile". Inadequacy of water "has restricted cultivation to 1% of the total area" in the Divisions of Quetta-Kalat.(37) Thus the implications of the undoubtedly limited water supply are social, cultural and practical, which altogether need applications of capital, time and effort on a nation wide scale. Thus the final problem is one of human response to the soil.

The fertility Status in Pakistan Soils:-

The soils have already been classified according to their parent material. The influence of climate over-rides the geological influence. Taking all the factors into account, the soils of West Pakistan from the point of human value may be briefly and finally considered as follows.

Alluvial soils are derived from the inland deposits brought down by the Indus and its tributaries in the Indus Plain, which were developed in situ. In the remaining portions of West Pakistan alluvium is transported by seasonal streams, and some small rivers in Regions I-IV.

The Indus Valley alluvia stretch in a continuous belt of varying width from Lahore to Karachi. They form a broad belt in the Upper Indus plain which is the most productive region of the country. Their sequence is first, narrowed towards the south and is interrupted by desert on its peripheries on the east and west. In the middle also, their continuity is broken by the intrusions of saline and alkaline soils, owing to impeded drainage, and these wheat and cotton producing soils are losing their fertility rapidly. In the lower Indus Plain they spread over an area in the shape of a triangle between, desert on the east and the limestone ridges on the west. In the highland and in the sub-montane, the distribution of the alluvium is limited by topography. The major portion of these alluvia are derived from the sedimentary rocks. These soils are rejuvenated by annual floods and their fertility is increased by a fresh soil cover.

Limestone soils, are largely located in the areas formed by the outcrops of limestone, rising suddenly from the gird- ling plains. These soils are rich in lime only, therefore, they are not as fertile as the alluvium. The soils derived from the igneous rocks are restricted to the Chagai hills section. Though these soils are fertile their use is hampered by shortage of water. The steep slopes do not support a usable cover of soil, hence, hold no agricultural value. The above survey conveys the evidence of poor and fragile and fertile soils and how, the chemical changes demoting the soil fertility.

With the human response, the immediate problems are the poverty and ignorance of the peasantry, and its primitive and unscientific cultivation methods. In this age of every day scientific advancement and discoveries, it is not difficult technically to overcome the prevailing infertility of the soil, which is chiefly owing to poor human responses.

As we have already considered, physical deterioration of soil sets in with human interference with the vegetative covering. The nutrient content is depleted. The soil which was once under the blanket of vegetation starts losing its fertility by cropping, especially when little or no fertilisers are applied. The successive cropping of cereals, ultimately deprive the soil of its nutrient. This disappearing fertility may be retained, if the soil is worked under good management, to which in particular, means suitable and flexible crop rotations, green manuring, practice of mixed farming and intercropping, and direct application of fertilisers, farmyard manure and synthetic.

If the land is properly managed it can yield great wealth. The human factor in this reference has been emphasised by the famous writer Karl Brandt, (63) "It is not often realised that land is really only an opportunity to apply capital, management and labour in varying degrees and that without these or with too little of them even the most fertile soil will yield only weeds". These directions have been ~~totally~~ largely ignored by Pakistan for centuries. In the U.K. the amount of stress on agricultural advancement is laid may be noted in a speech made by the Parliamentary Under Secretary to the Board of Education: (64) "While Tariffs, subsidies and marketing boards were important, let us not forget that the basis of true Agricultural Reconstruction was the intelligent human being and the maintenance of a rural culture which made a prosperous agriculture so valuable in the country as a whole". The countries which are industrially advanced are also making tremendous progress in the uplift of rural life and agricultural conditions. In all these countries, community centres are opened throughout their agricultural areas. There are many institutions which confer agricultural education on its all spheres, Farm and Home Bureaux, Farmer Unions, Clubs and several such activities. Besides this, generous subsidies and loans for sheep, cattle, fertilisers, tractors and ploughing of virgin land have kept the standard of agriculture very high. If crops fail even then some subsidies are extended to the farmer to make up the loss, inspite of mixed husbandry by which a farmer does make money from some part of his pursuits.

In Pakistan, such activities are in their preliminary application under the village uplift organisation, which is termed "village aid", first started in 1953.(65) As the name village aid connotes the Village Agricultural and Industrial Development programme, it has manifold aims. Under this scheme programmes are designed to solve the problems of the rural population by helping them to help themselves. It's aim is to mobilize the national resources for the reconstruction of rural areas. The programme co-ordinates both the people and the Government. This scheme is proving very effective throughout the country even in remote corners like Chagai-Kharan.

In order to confer nationwide benefit through this programme the whole country is split up into V. Aid regions,

(1) Peshawar, (2) Lahore, (3) Bahawalpur, (4) Quetta and (5) Hyderabad. These regions are served by 6 training institutes, opened at (1) Peshawar, (2) Lala Musa, (3) Rahim Yar Khan, (4) Layallpur, (5) Quetta and (6) Tandojam. In turn, these 6 training centres serve 71 Development areas. The objectives pertaining the V. Aid programme are several. First, to increase land productivity and the income of the villagers, with the application of modern farming implements, co-operative cottage industries and sanitation. Secondly, emphasis is laid on the multiplication of community services available in villages, as schools, dispensaries, health centres, hospitals and sources of clean water. Thirdly, to engrave a spirit of self help and leadership, and co-operation among the villagers, which lead to economic progress, and fourthly, to provide recreational opportunities for both sexes. Lastly, to improve co-ordination of the working of various government Departments and to extend their assistance to the villagers, with the provision of extended service to the whole country and to give a welfare bias to the entire administrative structure of the government.

These objectives are meeting with a great response from the people. Up till December 1959 over 1,905 persons were trained in the 6 institutions. Among these 179 are women. These trained hands are then sent to every corner of the country.

As far as, the land is concerned certain practices and techniques have to be adopted by village cultivators. Bearing in mind the general soil background, we turn to a brief consideration of these.

Artificial Manures:-

By continuous cropping soil becomes degenerated by the removal of nutrients by plants. Unless these nutrients are replaced, the soil becomes impoverished. Under these circumstances use of fertilisers becomes indispensible. Appendix 14 shows the soil nutrients removed by different crops.

In Pakistan, the use of chemical or artificial fertilisers is not in vogue. (61) The primary factor again is the under developed economy of Pakistan. She cannot afford a policy of import of fertilisers, and because of the general poverty of the peasants, it is beyond their means to buy expensive imported fertilisers.

In Pakistan the use of commercial manures was almost unknown before 1952, and their import was absent. Since 1952, their use is spreading gradually and the table below shows the amount of imported fertilisers in different seasons. They were chiefly imported from U.S.A.

Synthetic Fertilizer imported into West Pakistan

Season	Tons
Winter 1952-53	10,925
Spring 1953	75,000
Winter 1953-54	49,400
Spring 1954	15,700
Winter 1954-55	nil
Summer 1955	nil
Winter 1955-56	37,349
Summer 1956	17,200
Winter 1956-57	80,870
Summer 1957	10,114
Total	296,558

The shortage of food during 1952 proved an incentive for their use. The Agricultural Department in various provinces set up a campaign to popularise and teach the use of these fertilisers. Above all, to make their use common, government gave a generous subsidy. The table below shows the extent of subsidy:

Season	Subsidy basis
Winter 1952-53	60% on cost and freight value
Spring 1953	66% on price at distribution centres
Winter 1953-54	50% " "

Spring 1954	50% on price at distribution centres
Winter 1954-55	50% " "
Spring 1955*	70% (for cotton only) on Price at distribution centres
Winter 1955-56	66% on price at distribution centres
Spring 1956	58% " "
Winter 1956-57	58% " "
Spring 1957	58% " "

* During this season the subsidy was 50% but for cotton and rice it was increased to 70%.

The Government has revised the subsidy policy as it was not possible to continue the high subsidy. The expenditure incurred on the imported fertilisers was, Rs 874,085 as a charge for handling and Rs 23,175,000 on the subsidy. Under such circumstances, a fertilizer factory was established at Daud Khel. Its annual output of Ammonium sulphate is 50,000 tons and in this way a basic supply is assured.

The Government of Pakistan with the assistance of F.A.O. has now been able to asses the scale of potential fertilisers requirements for the main crops:

Fertiliser requirements in West Pakistan in 000 tons

Fertiliser used on % area under crops	Wheat	Rice	Sugarcane	Cotton	Total
Percent					
20	77.0	10.5	13.5	34.8	135.8
100	385.4	52.6	67.3	174.2	579.5

It indicates,that if fertilisers are used only for 1/5th of the area under above crops total requirements will be 135.8 thousand tons. On the other hand,if fertilisers are applied on the whole of the area,the total need will be 479.5 thousand tons. Besides,these fertilisers are required for the use of market gardens, orchards and pastures. The standard of fertilisers used in Pakistan may be compared with other countries in the following table:

Use of Fertilizers in Selected Countries

Countries	Nitrogen	Phosphorus	Potash	Total
		Lbs per acre		
Netherlands	134.6	91.4	134.6	360.6
Japan	67.7	46.6	31.2	145.5
United Kingdom	30.2	46.2	29.3	105.7
Egypt	40.8	4.5	0.7	46.0
Peru	19.5	13.9	1.4	34.8
Italy	11.4	19.6	2.2	33.2

Australia	1.2	27.3	1.1	29.6
U.S.A.	6.8	8.2	6.6	21.6
Ceylon	9.0	1 .5	5.9	16.4
Canada	0.9	2.6	1.6	5.1
Mexico	2.1	1.6	0.45	4.2
Brazil	0.6	1.5	0.7	2.8
India	0.57	0.1	0.04	0.7
Pakistan	0.44	0.009	..	0.45

Source:- F.A.O. Year Book of Food and Agriculture Statistics, Vol. VIII. Part I.

The use of commercial fertilisers made in Pakistan is the lowest in the world except in case of India. The level of their consumption is the highest in Netherland; then in Japan, and Britain ranks 3rd in the total consumption of nitrogen, phosphorus and Potash.

Organic Manure:-

The application of organic manure is a known method to all peasants. The soils are naturally low in organic matter. In Pakistan farmyard manure mostly serves as domestic fuel. With the provision of substitute fuel the farmyard manure will be put to beneficial uses. The proposed extension of gas to the cities of Lahore, Multan, Layallpur and Rawalpindi will cut down this misuse of farmyard manure.

Green Manuring:-

This method consists of legume growing, to plough into the land as a measure of enrichment of the soil. This method, though it sounds easy and cheap is not easily adapted, because many small farmers cannot sacrifice the harvests of food or cash crops.

Mixed cropping:-

This is another remedial measure for an exhausted soil. Under this method various type of crops are grown on the same field simultaneously. These plants are different in their demand for nutrients and in a suitable combination, can supply each other to some extent, during their process towards maturity which varies in each case. As a method of the simultaneous growing of soil-building and soil exhausting crops, and of diversifying the demands of plants upon the soil this practice has much to recommend it, but much depends on water availability and the cycle of plant growth and the soil products. These practices are common in many advanced countries. It may for instance be used for cereals grown with legumes or with vegetables.

Mixed Farming:-

It forms the basis of the farming in the United Kingdom. Originally it aimed at arable farming, manured by the farmer's own livestock. The land under this system is used for multiple pursuits of farming and involves rotational and ecologically based husbandry. To establish such diversity, the first pre-requisite, is the maintenance of ley pastures, good soil management together with suitable economic and market conditions. Extreme climatic conditions are injurious to grasses and ley farming is not easily developed in West Pakistan. Fast growing legumes may prove suitable for forage and fodder. Moreover climatic extremes affect the health of livestock also. Further, mixed farming has finally developed in Western Europe, as a synthesis of use of organic and synthetic substances for a variety of rich commercial markets. In much of West Pakistan, the commercial advantages are smaller than the less powerful, but more important needs of ecological stability and balanced diet.

It can now be pictured, that the rural development and a rise in the standard of living of the people have to be weighed and assessed, first, against environmental problems of a Herculean nature, viz; the shortages of water, the low organic level of soil content and the rapid increase in population. The development of agriculture has first to be accorded with the predominantly adverse environmental conditions. Since the start of the development projects the people are passing through a transitional stage. The pastoral people are becoming sedentary agriculturalists in the

Regions II-IV and herding and cultivation are combined. Village cultivators half-see new opportunities with and without irrigation. The soil wealth can be maintained and made to give improved returns. There are some areas already in existence which serve as examples,where high crop yields have been maintained under good soil management,even under adverse conditions of shortages of both water and manure supplies. A year to year increase may be noted in the table below. The level of wheat yields now remains almost constant in the District of Montgomery. In the district of Tharparkar the yields of both wheat and cotton are high in the beginning,but tended to decrease in the subsequent years. The reason is obviously falling water supplies and increasing manurial needs. It seems as if a thorough geographical revolution can take place,if the people are supplied with the required needs for the development.

From soil in general,to the maintenance of soil fertility and improved husbandry in particular, all progress finally involves particular village societies in specific areas. Only by taking integrated region views can the problems be finally understood. This is the justification for geographical investigation in general,and for this thesis a geographical appreciation of the complex implications of the terms 'arid and semi-arid'.

Moving Average of Yield per Acre of Wheat and Cotton on a Few Selected Farms.

Year	Montgomery Cotton	District Wheat	Multan Cotton	District Wheat	Tharparkar Cotton	District Wheat
			maunds per acre			
1923	-	-	13.0	-		
1924	6.6	16.5	13.2	18.4		
1925	7.2	17.6	12.1	19.1		
1926	7.1	18.9	10.6	19.7		
1927	7.5	19.6	9.8	20.1		
1928	7.6	20.5	10.2	19.8		
1929	7.6	20.3	10.5	19.3		
1930	8.1	19.6	10.9	18.3		
1931	8.9	21.0	12.1	19.2		
1932	9.4	20.8	12.2	19.9		
1933	10.0	20.8	12.3	19.8		
1934	11.6	21.7	11.0	19.6		
1935	11.0	21.9	10.9	17.3	11.9	-
1936	9.7	21.2	9.7	16.7	12.0	31.7
1937	9.2	21.3	8.2	16.4	11.2	21.7
1938	9.4	21.9	9.3	15.8	11.4	11.8
1939	9.7	21.6	8.7	15.4	11.5	13.1
1940	10.8	21.9	10.3	18.2	11.7	13.3
1941	10.8	22.7	10.7	18.2	11.3	13.6
1942	10.5	22.4	11.0	17.4	11.6	14.1
1943	9.9	22.9	10.4	18.0	12.2	14.8
1944	9.4	22.7	11.1	18.4	11.8	14.6
1945	8.1	21.9	9.5	17.8	11.1	14.7
1946	7.6	20.4	10.5	17.2	10.8	13.7
1947	8.8	20.2	12.2	16.1	11.0	13.5
1948	9.2	20.7	12.2	18.2	10.2	13.6

1949	9.1	21.9	10.7	18.7	10.7	13.0
1950	10.1	23.1	10.9	19.1	11.1	13.5
1951	10.6	23.3	10.3	18.8	9.8	13.3
1952	11.3	24.6	10.4	19.5	9.5	13.3
1953	11.4	24.2	11.8	18.9	9.1	-

Source:- Ministry of Agriculture, Karachi.