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Land and Water Resources of Pakistan— A Critical Assessment

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1. RESOURCE AVAILABILITY

1.1. Land Resources

The country's geographical area is 79.61 million hectares (mha), excluding the Northern Areas of Pakistan. Out of this, only 72 percent area has been reported indicating a major limitation that 28 percent area is not yet surveyed for land use classification. The reported area is further classified into four major classes: (a) forest area of 4.02 mha; (b) area not available for cultivation of 22.88 mha; (c) culturable waste of 8.12 mha; and (d) cultivated area of 22.05 mha. *Out of the reported area, around 8.1 mha are available for future agriculture and other uses, if water is made available. If rest of the area (28 percent) is also surveyed then one can have better picture of country's land resources* (Table 1).

Table 1

Land Resources Classification of Pakistan

Type of Land Use	Area (mha)	Area (%)
Geographical Area	79.61	100.00
Total Reported Area	57.07	71.7
Forest Area	4.02	5.1
Area Not Available for Cultivation	22.88	28.7
Culturable Waste	8.12	10.2
Area Cultivated for Agriculture	22.05	27.7

Source: Pakistan (2006).

1.2. Water Resources

1.2.1. *Precipitation and Aridity*

Country's mean annual rainfall varies from <100 mm in parts of Balochistan and Sindh provinces to >1500 mm in foothills and northern mountains. In the Northern Areas at altitudes of above 5000 m, the snowfall exceeds 5000 mm and provides the largest

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resource of water in the glaciated zone. About 60 percent of rainfall in the moonsonal climates is received during July to September. Most summer rains are also not available for crop production or recharge to groundwater because of rapid runoff of torrential showers. Contribution of rainwater to crops in the Indus Basin Irrigation System (IBIS) is about 16.5 billion m^3, which is around 13 percent of the mean annual canal diversions in the post-Tarbela period [Ahmad (1993a, 1999a, 2005)].

There is seasonality in precipitation. Mean Rabi season rainfall (October to March) varies from <50 mm in parts of Sindh province to >500 mm in the NWFP. The mean Kharif season rainfall (April to September) varies from <50 mm in parts of Balochistan to >800 mm in the northern Punjab and NWFP. The extreme variability in seasonal rainfall has direct impacts on river flows which have rather larger variability during the Rabi and the Kharif seasons. Due to the higher aridity around 92 percent of country's area is classified as semi-arid to arid facing extreme shortage of water.

1.2.2. *Glaciers and Snow Deposits*

*The Northern Areas (NAs) of Pakistan contain the greatest area of perennial glaciers outside the polar regions (22,000 km^2) and estimates are that as much as 28 percent of the region is glaciated; the area of winter snow cover reaches up to 30-40 percent***.** There are more than 100 glaciers that are over 10 km in length and many go beyond 50 km. Many of them are very remote and have barely been studied. Hence glaciers and seasonal snow constitute a huge reservoir for freshwater in the area and contribute vastly to the flow of the Indus river [Ahmad and Joyia (2003)].

ICIMOD, *et al.* (2005) conducted a spatial inventory of glaciers in the NAs and NWFP. *The study revealed that all the ten selected basins contribute to total glaciated area of 15,041 km^2 which is 11.7 percent of the total area. The total ice reserve estimated is about 2,738 km^3 (billion m^3), which is around 16 times the average annual river flows.* Thus, it is the largest frozen water resource in the country. Altogether, around 83 percent of the ice reserves are contributed collectively by Shyok River (32 percent), Hunza (30 percent) and Shigar River basins (21 percent). The Chitral and Gilgit River basins contribute about 9 and 3 percent, respectively. However, the GIS based image processing results need field validation in selected sub-basins.

1.2.3. *Surface Water Resources*

Pre-storage Era

Glacier-melt, snow-melt, rainfall and runoff constitute the river flows. Inflow measurement facility has been established at the Rims of the Indus River tributaries and thus referred to as Rim Station inflows. The Rim Stations of the western rivers are located at Tarbela, Attock, Mangla and Marala for Indus, Kabul, Jhelum and Chenab rivers, respectively. The Rim Stations for the eastern rivers are located at Balloki and Sulaimanki for Ravi and Sutlej rivers, respectively.

River flows were limited in the *Rabi* season because of limited glacier- and snow-melt and low rainfall during the winter season. Western rivers have provided 173 billion m^3 of surface water in an average year during the pre-storage period of 1937-67. Bulk of the river flow was during the *Kharif* season, which was more than five times the flow in the *Rabi* season.

Variability in flows of the eastern rivers was even higher than the western rivers. Before the construction of Mangla and Tarbela storages, the eastern rivers have contributed about 26 billion m^3 of water to the Indus River system in an average year of which about 84 percent was in the *Kharif* season. Contribution of the eastern rivers to the mean annual flows of the Indus River system was around 13 percent, whereas it was 11 percent during the *Rabi* season, which was a significant contribution (Table 2).

Table 2

Variability of Rim-station Inflows to Indus River System (Pre-storage Period)

	Rim-station Inflows (billion m^3) for Pre-storage Period 1937-67						
	Western Rivers			Eastern Rivers			
Probability (%)	Kharif	Rabi	Annual	Kharif	Rabi	Annual	Total
Minimum	111.0	19.1	134.5	9.6	1.7	11.3	145.8
10	123.9	22.8	143.9	15.6	1.9	17.5	161.4
25	136.2	24.2	163.1	17.9	2.9	22.3	185.4
50	144.5	26.3	173.0	22.1	3.3	26.2	199.2
75	155.3	30.5	184.9	27.4	4.9	35.2	220.1
90	166.8	32.6	198.2	32.2	8.6	38.1	236.3
Maximum	192.7	40.7	231.7	39.3	18.1	44.5	276.2

Source: Water Resources Management Directorate, WAPDA.

Post-storage Era

Seasonal and annual river flows in the Indus river system are highly variable [Ahmad (1999a); Ahmad (1993a); Kijine, *et al.* (1992); Mohtadullah, *et al.* (1991); Warsi (1991)]. The analysis of the daily and monthly flows also indicated a similar trend [Bhatti (1999)]. This variability in river flows restricts the assessment of real contribution of storage in regulating flows of the Indus River System. However, data were analysed to evaluate the effect of key influences on the flows in western and eastern rivers.

River flows were limited in the *Rabi* season because of limited glacier- and snow-melt and low rainfall during the winter season. The western rivers have provided 168 billion m^3 of surface water in an average year during the post-storage period, which was around 2.9 percent less than the pre-storage period, indicating the impact of climate change—more severe droughts. Bulk of the river flow was during the *Kharif* season, which was around five times the flow in the *Rabi* season. Variability in flows of the eastern rivers was even higher than the western rivers. After the construction of Mangla and Tarbela storages, the eastern rivers contributed about 8.6 billion m^3 of water to the Indus River system in an average year of which about 80 percent was in the *Kharif* season. Contribution of the eastern rivers to the annual mean flows of the Indus River system was about 4.9 percent, whereas it was 5.0 percent during the *Rabi* season. This shows that contribution of eastern rivers reduced from 26.2 to 8.6 billion m^3 in the post-storage era uptil 2006-07. The total mean annual flows both from western and eastern river flows was 176.5 billion m^3 (Table 3).

Table 3

Variability of Rim-station Inflows to Indus River System (Post-storage Period)

	Rim-station Inflows (Billion m^3) for Pre-storage Period 1937-67						
	Western Rivers			Eastern Rivers			
Probability (%)	Kharif	Rabi	Annual	Kharif	Rabi	Annual	Total
Minimum	93.4	17.2	112.5	0.5	0.0	1.0	113.5
10	111.6	20.9	135.5	1.1	0.2	1.4	136.9
25	125.7	23.9	153.3	3.2	0.6	3.7	157.0
50	140.4	26.9	167.9	6.9	1.4	8.6	176.5
75	157.2	30.5	180.8	12.6	2.3	15.4	196.2
90	159.7	34.3	194.6	18.5	4.3	20.1	214.7
Maximum	192.6	40.7	231.6	20.4	7.8	24.1	255.7

Source: Water Resources Management Directorate, WAPDA.

Variability in river flows is a major limitation in the development of run-of-river type irrigated agriculture in the Indus Basin, especially to meet crop irrigation requirement during low-flow period of the Rabi and early and late Kharif seasons. The recent drought was so severe that the annual river flows of the western rivers during 2001-02 were 112.5 billion m^3, which were less than the historical minimum of 114.1 billion m^3 since 1937. During the same period the mean annual flows of eastern rivers were reduced to around 1.0 billion m^3. This has created a situation of water crises in the country and also deepens the inter-provinces water conflicts.

1.2.4. Flows to the Arabian Sea (Downstream of Kotri Barrage)

Annual variability of river flows downstream Kotri barrage has been very high (Figure 1). In the normal year (50 percent probability), the annual flow was reduced from 95.4 to 48.4 billion m^3 during the post-Tarbela period from that of the pre-Tarbela period. The percent reduction in annual flows in the dry years (10 percent probability) was higher than the normal years, where flows were reduced from 31.6 to 13.5 billion m^3 in the post-Tarbela period (the probability of dry year was one-out-of-five in the pre-Tarbela period). The percent reduction in annual flows in wet years (>50 percent probability) was relatively less than the normal and dry years [Ahmad (2000); WCD (2000), Table 4].

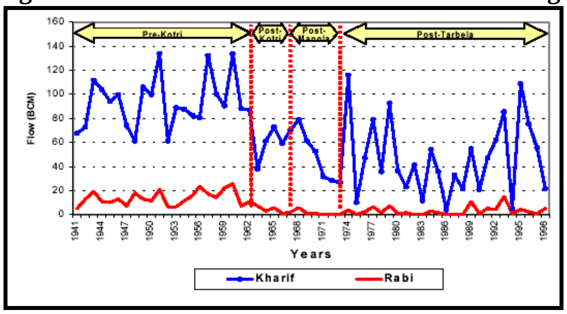
Table 4

Variability of Flows to Arabian Sea (Downstream Kotri Barrage) under Pre- and Post-Tarbela Periods

	Flow Downstream Kotri Barrage (Billion m^3)					
	Pre-Tarbela Period (1940-75)			Post-Tarbela Period (1975-98)		
Probability (%)	Kharif	Rabi	Annual	Kharif	Rabi	Annual
Minimum	10.0	0.0	10.0	11.6	0.05	11.9
10 percent	31.3	0.3	31.6	13.5	0.1	13.5
25 percent	61.3	2.7	62.3	23.1	0.5	33.2
50 percent	80.6	7.1	95.4	41.4	1.7	48.4
75 percent	99.3	13.0	112.5	55.2	4.5	65.3
90 percent	115.8	20.3	130.8	85.4	6.9	99.5
Maximum	133.8	25.5	159.0	108.9	15.2	113.4

Source: Water Resources Management Directorate, WAPDA.

Fig. 1. Seasonal Flows Downstream Kotri Barrage



Rabi season flows in the normal year (50 percent probability) were reduced from 7.1 to 1.7 billion m^3 in the post-Tarbela period from that of the pre-Tarbela period. The effect was more pronounced in the dry years, where seasonal flows were even less than 0.5 billion m^3 in one-out-of-four years. Reduction in seasonal flows was also observed during the wet years (>50 percent probability).

In conclusion, the construction of Kotri barrage reduced the seasonal and annual flows below Kotri due to the canal diversions. The seasonal and annual flows were further reduced during the post-Mangla and post-Tarbela periods due to further increases in the canal diversions at the Kotri barrage and at upstream commands. The canal diversions at Kotri barrage were increased from 5.42 to 10.8 billion m^3 (representing 100 percent increase) during the post-Tarbela period. The probability of dry years was doubled in the post-Tarbela period compared to the pre-Tarbela period, which is a serious concern for the downstream flows to maintain the delta eco-system.

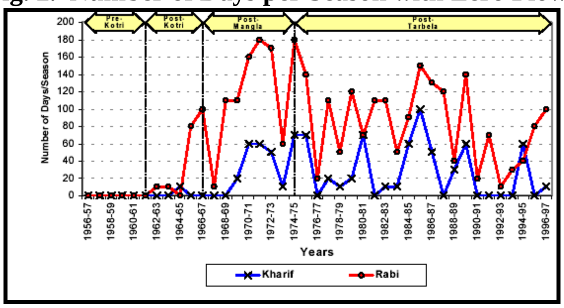
Recent drought was so severe that the annual river flows downstream Kotri Barrage during 2001-02 was less than the historical minimum flows of 10 billion m^3 since 1937.

Distribution of Days with Zero Flows per Season

A clearer picture emerges when looking at the extreme events when there was no flow below Kotri. Analysis was made of the number of days per season when flows downstream of Kotri barrage were zero (Figure 2). In the pre-Kotri period (1956-61), there was not a single day with a zero flow during both the Rabi and Kharif seasons. Zero flow days were observed during the post-Kotri period (1962-67). One year (20 percent) in the Kharif season and four years (80 percent) in the Rabi season were identified as having zero flows. Occurrence of zero flow days increased to six years (75 percent) in the Kharif season and eight years (100 percent) in the Rabi season in the post-Kotri and post-Mangla period (1967-75). Zero flow days were marginally reduced to 14 years (61 percent) in the Kharif season and 22 years (96 percent) in the Rabi season in the post-Tarbela period (1975-98). In the Rabi season it was effectively the same at 96 percent compared to 100 percent [Ahmad (2000) and WCD (2000)].

Thus occurrence of zero flow days progressively increased following the commissioning of the Kotri and Guddu barrages and the Mangla dam in the Rabi season (Figure 2). In fact, the frequency of zero flow days in the Rabi season has a direct impact on the downstream system. In the post-Kotri period (1961-67), the maximum number of days with zero flows in the Rabi season was 10. This increased to 180 days in the post-Kotri and post-Mangla period (1967-75). The highest number of zero flow days recorded post-Tarbela period was a slight reduction to 150 days, although even this represents 82 percent of the Rabi season. In the pre-Kotri period there were no days with zero flows. In the post Kotri/Mangla periods there were on average 33 days with zero flows in the Rabi season; and in the post-Tarbela period there were 81 days [Ahmad (2000); WCD (2000)].

Fig. 2. Number of Days per Season with Zero Flows



1.2.5. Per Capita Surface Water Availability and Storage

Pakistan is now classified as a water short/stress country, as the per capita water availability is around 1223 m^3/year, considering the mean annual Indus River flows and floodwater available outside the Indus basin as a criterion (Table 5). The country is going to be a water scarce country after 2017, when the per capita water availability is going to be < 1000 m^3/year.

Table 5

Population, Water and Storage Availability in Pakistan and Balochistan

Parameter	Pakistan
Population 1998 (millions)	132.35
Population 2007 (millions)	159.651[1]
River Flows (billion m^3)	181.4[2]
Floodwater Outside Indus Basin (billion m^3)[3]	27.10
Floodwater Outside Basin but Drained to Indus River System (billion m^3)[4]	–13.21
Total Available Water (billion m^3)	195.29
Geographical Area (million ha)	79.61
Water Availability per Capita (m^3/person/annum)	1223
Water Availability per ha (m^3/ha/annum)	2453
Total Designed Live Storage Capacity (billion m^3)	22.95[5]
Storage Availability per Capita (m^3/person)	144
Storage Availability per ha (m^3/ha)	288

Source: Pakistan (1998); IPD (2006a); Pakistan (2006a); Pakistan (2006b); World Bank (2005).

[1]Based on estimates made for Pakistan by the NIPS (2006).

[2]Considering 177.70 billion m^3 (144 MAF) of average annual river flows at rim stations and 3.7 billion m^3 (3 MAF) of water used by the Civil Canals at the upstream of the rim stations as indicated in the National Policy of 3 MAF.

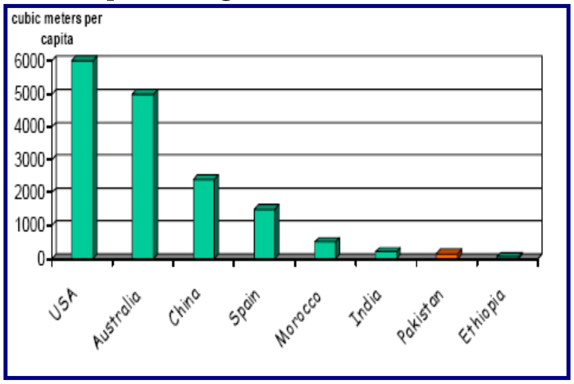
[3]Estimated using a runoff coefficient of 26 percent instead of 18 percent used by the NESPAK (1998).

[4]Estimated using the flows currently drained to the Indus basin using the current level of water use.

[5]Include 19.25 billion m^3 (15.6 MAF) from designed live capacity of Mangla and Tarbela and 3.7 billion m^3 (3.0 MAF) from raising of Mangla Dam.

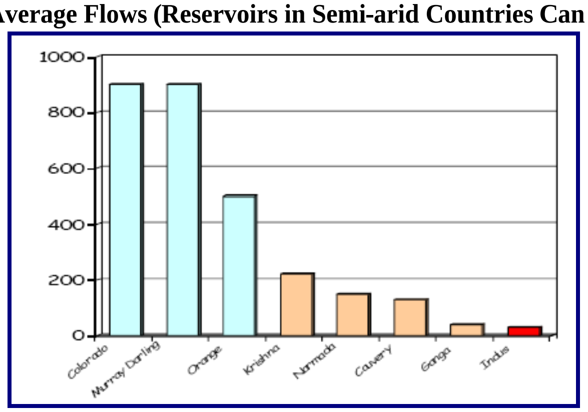
Pakistan is now one of the world's most water stressed country. The per capita designed live storage capacity available in Pakistan is around 144 m^3/person, which is higher than Ethiopia considering the arid regions of the world. The highest is in USA of around 6000 m^3/person followed by Australia and China (Figure 3). The storage available in Pakistan is sufficient for storing flows of 30 days compared to 900 days in the Colorado River of USA, which is almost sufficient to store 2.5 years flows of the Colorado River in the USA (Figure 4).

Fig. 3. Per Capita Storage in Different Semi-arid Countries



Source: World Bank Analysis of ICOLD data.

Fig. 4. Days of Average Flows (Reservoirs in Semi-arid Countries Can Store in Basins)



Source: World Bank Analysis of ICOLD and DRC data.

1.2.6. *Groundwater Resources*

Pre-storage Era

Indus Basin represents an extensive groundwater aquifer covering a gross command area of 16.7 mha. Water table was well below the surface and aquifer was in a state of hydrological equilibrium before the development of canal irrigation system. The recharge to aquifer from rivers and rainfall was balanced by outflow and crop evapotranspiration. When canal irrigation system was introduced, percolation to the aquifer was increased in irrigated areas of the Indus basin resulting in twin menace of waterlogging and salinity.

Although, there are disadvantages in having a high water table, it was used for irrigation by tubewells in fresh groundwater zone. Groundwater contribution for irrigation was around 11.3 billion m^3 during the pre-storage period, which was 10 percent of the total water available for agriculture [Ahmad, *et al.* (2001)].

Post-storage Era

Estimated annual recharge to the groundwater in the Indus Basin is 67.9 billion m^3, out of which 44 billion m^3 occurs in areas of usable groundwater [Zuberi and Sufi (1992)]. The additional conveyance losses in the IBIS due to Tarbela contributed 10 percent to the overall recharge of groundwater [Ahmad (1993a); Ahmad, *et al.* (2001)]. The 1979 basin-wide survey of WAPDA indicated that water table in 42 percent area of the Indus Basin was <3 m and classified as waterlogged, whereas water table in 22 percent area was <2 m. In the Sindh province, around 57 percent area was affected by waterlogging, where water table is <3 m (Table 6). The groundwater reservoir of freshwater in the Indus basin is around 2000 billion m^3 (i.e. considering gross command area of 16.7 million ha and depth of freshwater of 12 m), which is equivalent to 10 times the mean annual river flows. Therefore excessive pumping in few dry years is not going to have lasting negative impacts on the resource, rather it creates space for excessive recharge during wet years when flows are more than two-fold (225 percent higher) of the lowest flows and 43 percent higher than the mean annual flows.

Table 6

Indus Basin Province-wise Trends of Water Table Depths and Area Affected

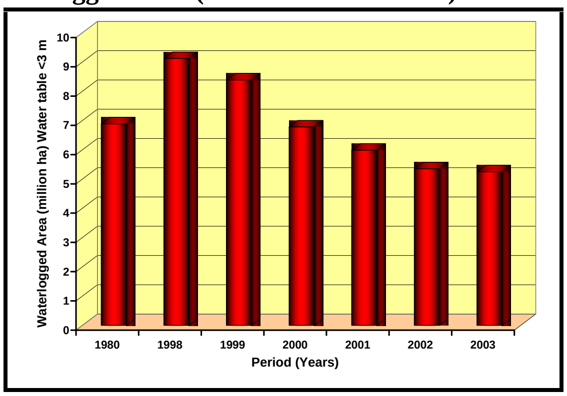
Province	Total Area (mha)	Percent Area under Water Table Depth in Meters					Total <3 m
		<1	1-2	2-3	>3	Misc.	
Punjab	10.17	7	11	17	63	2	35
Sindh	5.57	6	24	27	40	3	57
Balochistan	0.35	1	6	9	84	0	16
NWFP	0.62	6	12	6	66	10	24
Total	16.71	7	15	20	55	3	42

Source: WAPDA (1980).

The rise in water table in the post-Tarbela period is a good indicator of worsening situation but it cannot be taken as solely due to Tarbela or Mangla reservoirs. This increase in waterlogging, in case of increased water supplies from Mangla and Tarbela could be attributed to lack of appropriate drainage facilities and inadequate improvements in irrigation management. The major reason was the failure or transition of SCARP projects and 10 percent more recharge to the groundwater due to additional surface supplies from Tarbela.

Additional water supplies from Mangla and Tarbela storage dams diverted to the newly constructed canal commands also contributed to recharge of groundwater. One of the examples is the Chashma Right Bank Canal (CRBC) command area, where rise in water table has been observed creating a freshwater aquifer [Alurrade, *et al.* (1998)]. However, for sustainability purpose, sub-surface drainage has to be provided to control water table depth. In fact the rise in water table was faster than expected and required an additional loan to introduce drainage in the CRBC. The 1979 basin-wide surveys were actually conducted during 1976-78 and therefore represent early post-Tarbela conditions. Although, groundwater use has increased significantly in the post-Tarbela period, the waterlogging was on the increasing trend uptil 1998. The waterlogged area (water table <3 m) was reduced from 42 percent to 32 percent in 2003 due to the drought and increased abstraction of groundwater during this period. Although, data since 2003 are not available, but waterlogging is continuously on the declining trend due to drought. The significant reduction in waterlogged area to the tune of one-third with water table of <1.5 m was observed in 2003 (Figure 5).

Fig. 5. Waterlogged Area (Water Table of < 3 m) in the Indus Basin



(SCARPS Monitoring Organisation, WAPDA, Lahore).

2. WATER QUALITY

2.1. Surface Water Quality

Water of the Indus River and its tributaries is of excellent quality. TDS (total dissolved solids) range between 60-374 ppm (parts per million), which is safe for irrigated agriculture, domestic and industrial uses [Bhutta (1999); PWP (1999, 2000)]. TDS in the upper reaches at various Rim Stations range between 60 ppm during high-flow to about 200 ppm during low-flow. The water quality deteriorates downstream but remains well within permissible limits, with TDS in the lower reaches of Indus (at Kotri Barrage) ranging from 150 to 374 ppm. However, TDS of some tributaries such as Gomal River at Khajuri, Touchi River at Tangi Post and Zhob River at Sharik Weir range between 400 to 1250 ppm [IWASRI (1997)].

Indiscriminate and unplanned disposal of effluents (polluted with fertilisers, insecticides, pesticides and untreated sewage and industrial waste effluent loaded with heavy metals and poisonous materials), into rivers, canals and drains is causing deterioration of water quality in the downstream waterways and water bodies. According to an estimate, in 1995 some 9,000 mgd (million gallons per day) of untreated water being discharged into rivers, canals, drains and water bodies [Saleemi (1993)]. It was estimated that 350 and 250 mgd of sewage was produced in Karachi and Lahore metropolitans and most of it was discharged untreated into rivers, canals, drains and water bodies. The polluted water of rivers, canals and drains, which is also being used for drinking downstream, is responsible for numerous water borne diseases.

At the current rate of population growth, the population of Pakistan is estimated to increase from 160 millions in 2007 to 209 millions in the year 2025, an increase of nearly 31 percent [NIPS (2007)]. If no remedial measures are taken, the quantity of untreated sewage and industrial waste effluents, now being discharged into waterways and water bodies will increase by the same proportion; thus further seriously polluting the surface water so vitally required to meet the increasing demand of human beings, livestock and plants. There is, thus, an urgent need to control pollution of surface water and to improve quality.

2.1.1. *Groundwater Quality*

Total annual groundwater potential in Pakistan is estimated at 67.9 billion m^3. The annual groundwater pumpage has increased from 4 billion m^3 in 1959 to around 62 billion m^3 in 2000-01 and then it is stagnant till 2005-06. *About 79 percent area in Punjab and 28 percent area in Sindh have fresh groundwater suitable for agriculture* [Afzal (1999); Bhutta (1999)]. *Since most of the easily exploitable surface water resources have already been tapped, the future demand of water for agriculture, people and nature will have to be met largely through water conservation and further exploitation of already over mined groundwater resources.*

Quality of groundwater varies widely, ranging from <1000 ppm to >3000 ppm. Around 5.75 mha are underlain with groundwater having salinity <1000 ppm, 1.84 mha with salinity ranging from 1000 to 3000 ppm and 4.28 mha with salinity >3000 ppm. In addition to TDS, there are quality concerns in terms of sodium adsorption ratio (SAR) and residual sodium carbonate (RSC). The groundwater quality for agricultural uses is classified into: (a) saline waters having TDS >1500 ppm, SAR <15, RSC <2.5 milli-equivalent; (b) sodic waters having TDS <1000 ppm, SAR >15, RSC >2.5 milli-equivalent; and (c) saline-sodic waters having TDS >1000 ppm, SAR >15, RSC >2.5 milli-equivalent.

Although, investments in drainage have been significant in Pakistan during the last two decades, waterlogging still affects large tracts of land [World Bank (1994)]. Soil salinity and sodicity also constrain farmers and affect agricultural production. These problems are further exacerbated by the use of poor quality groundwater [Kijne and Kuper (1995)]. In fresh groundwater areas, excessive pumping by private tubewells leads to mining of the aquifer [NESPAK (1991)] and redistribution of the groundwater quality [Zuberi and Sufi (1992); WRRI, MONA, and IIMI (1999)].

Recharge to the freshwater zone due to the additional supplies from Tarbela has contributed significantly in maintaining groundwater quality. However, recharge to the brackish groundwater zone created serious quality concerns for the disposal of the saline effluents despite creating a top layer of potable water for the concerned population [Ahmad (1993a)]. This problem was mainly due to the approach followed for drainage of area under the SCARPs in brackish groundwater zone, where saline groundwater was pumped from deeper depths [Ahmad (1990)].

Mining of groundwater, which is presently occurring in many areas, will cause intrusion of saline groundwater into the fresh groundwater areas. In addition, seepage of water from farmland will add dissolved fertilisers, pesticides and insecticides to groundwater. This will further increase pollution of groundwater and deteriorate its quality. The use of polluted groundwater for drinking may cause serious health hazard and its use for irrigated agriculture may adversely affect production potential of irrigated lands due to aggravation of the problem of salinity, sodicity and specific ions effect on crops and plants. It is essential to minimise groundwater pollution to improve its quality as far as possible through regulation of groundwater extraction and/or increasing the recharge in areas where mining of groundwater is taking place.

3. LAND AND WATER USE

3.1. Land Use

Cultivated area is classified as canal command, tubewell command, Rod-Kohi and Barani (Table 7). Total cultivable area is around 33.74 mha, out of which around 8.12 mha are classified as culturable waste. This leaves around 25.62 mha as cultivated area, which is higher than reported by Agricultural Statistics, as Rod-Kohi, Barani and riverine areas are not fully documented. Around 4.02 mha are under forests [Pakistan 2006)]. *Thus, 37.76 mha are suitable for agriculture and forestry. The rest of 41.85 mha are not suitable for agriculture and forestry within existing framework and require systematic development of water resources.*

Table 7

Land Use Classification of Pakistan

Type of Land Use	Area (mha)	Area (%)
Irrigated Area	19.02	23.9
Canals Only	7.06	8.9
Canal and Tubewells	7.98	10.0
Tubewells and Wells	3.76	4.7
Others	0.22	0.3
Rod-Kohi (Hill Torrents)	2.00	2.5
Sailaba Riverine	1.25	1.6
Barani (Rainfed)	3.35	4.1
Total Cultivated Area	25.62	32.2
Culturable Waste Inside CCA	2.25	2.8
Culturable Waste Outside CCA	5.87	7.4
Total Culturable Waste	8.12	10.2
Total Cultivable Area	33.74	42.4
Forests	4.02	5.0
Total Area Suitable for Agriculture and Forestry	37.76	47.4
Total Geographical Area	79.61	100.0

Salinity is one of the major problems in irrigated areas. WAPDAs’ 1981 basin-wide surveys indicated that 26 and 39 percent area was affected by surface and profile salinity, respectively. There was a decrease in salinity due to installation of SCARP and private tubewells in fresh and marginal groundwater zones. However, use of groundwater in the brackish zone resulted in secondary salinisation and sodification. During the last 20 years, considerable amount of area affected by surface and profile salinity was reclaimed primarily through the use of amendments (gypsum and sulphuric acid) and canal water supplies.

Waterlogging is another problem affecting irrigated agriculture. Within 100 years of development of irrigation system, water table has risen from 40 m to within 3 m on about 42 percent area during 1980 (Table 6). The situation was worst in the Sindh province. High water table creates problem of oxygen deficiency, salt build-up in soil profile and poor soil workability. The recent drought resulted in considerable lowering of water table and reduction in area under waterlogging, where waterlogged area was reduced from 42 percent in 1980 to 32 percent in 2003, and continuously on decline in area having water table depth of <3 m [WAPDA (1986, 2006)].

3.2. Water Use

3.2.1. *Agricultural Water Use*

Water will remain a critical and a limiting resource for sustained economic development of the country. The IBIS network is the largest infrastructural enterprise accounting for about US$ 300 billion of investment (at current rates) and contributing around US$ 18 billion, or nearly 22 percent to the country's GDP during 2005-06. Irrigated agriculture provides 90 percent of wheat and small grains besides nearly 100 percent of sugarcane, rice, cotton, fruits and vegetables, whereas the Barani (rainfed) and Sailaba areas contribute only 10 percent of wheat and a portion of small grains and pulses. It also provides milk, meat and fuel wood in addition to crops. Majority of buffaloes are located in the Indus basin command area.

Surface Water

Indus Basin Canal Diversions. Canal diversions represent total amount of water diverted at all the barrages constructed on rivers of the IBIS. The water diverted to individual canals at their offtake from the barrages is a good indicator of the contribution and effect of the storage reservoirs (Mangla and Tarbela). Considerable increase in canal diversions of about 9 billion m^3 was observed during the post-Mangla period. Further increase of around 12 billion m^3 was observed during the post-Tarbela period. Out of this, the major increase of 9.6 billion m^3 per annum was in the Rabi season (Table 8).

Table 8

Historical Canal Diversions to the IBIS under Key Influences

Key Influences	Period	Canal Diversions (billion m^3)		
		Kharif	Rabi	Annual
Pre-Partition	1940-47	58.5	24.9	83.4
Partition	1947-48	57.0	27.6	84.6
Dispute	1948-60	63.4	30.4	93.8
Pre-Mangla	1960-67	74.2	34.0	108.2
Post-Mangla	1967-75	80.3	37.1	117.4
Post-Tarbela	1975-80	83.7	47.0	130.7
Post-Tarbela	1980-85	84.1	45.9	130.0
Post-Tarbela	1985-90	81.6	46.4	128.0
Post-Tarbela	1990-95	81.5	47.3	128.8
Post-Tarbela	1995-00	86.5	45.3	131.8
Post-Tarbela	2000-05	79.0	32.4	111.4
Post-Tarbela	2005-06	73.0	31.5	104.5
Post-Tarbela	1975-2005	82.7	44.1	126.8

Source: Water Resources Management Directorate, WAPDA.

Contribution of Tarbela to canal diversions during the *Rabi* season was almost 26 percent, which is significant, as most of the staple food grown in the country is produced during the *Rabi* season. However, the main objectives of Tarbela dam were to provide storage for replacing water of existing canal commands of 1.8 mha dependent on the eastern rivers flows; and improvement of supplies to the canals off-taking from the Indus main commanding 6.9 mha.

However, there was variability in the canal diversions in both the seasons. The variability between the highest and lowest post-Tarbela canal diversions was 24 percent (92.2 and 70.4 billion m^3) and 47 percent (50.3 and 26.5 billion m^3) during the *Kharif* and the *Rabi* seasons, respectively. The variability in annual canal diversions was around 28 percent (137.1 and 98.2 billion m^3). This shows that stochastic nature of the river flows has a pronounced effect on the canal diversions, instead of loss of storage capacity (Table 9). The loss of storage capacity has negative impacts on canal diversions especially during the average and dry years. This information along with shortages and surpluses can be used for planning of new irrigation projects in the country.

Table 9

Variability of Post-Tarbela Canal Diversions in the IBIS

Probability (%)	Canal Diversions (Billion m^3)		
	Kharif	*Rabi*	Annual
Minimum	70.4	26.5	98.2
10	72.2	30.3	103.9
25	75.6	38.4	115.5
50	79.6	43.1	122.2
75	84.1	46.2	127.3
90	89.7	47.4	135.1
Maximum	92.2	50.3	137.1

Source: Water Resources Management Directorate, WAPDA.

The recent drought was so severe that annual canal diversions during 2001-02 were less than the historical minimum diversions of 116.5 billion m^3 in the post-Tarbela period (1975-2001), which comes to 90.3 billion m^3. This reduction in canal diversions during the Rabi season 2001-02 has adversely affected the crops like wheat, rice, sugarcane, orchards and vegetables.

Irrigation System's Losses and Overall Irrigation Efficiency. Indus River flows through alluvial plains and thus the phenomenon of losses and gains assumes greater importance [Ahmad (1993b)]. In the Indus Rivers system losses generally occur in the rising stage during the period from April to July. During the falling flows, covering the periods from end of July to September and from October to March, the rivers usually gain water. Analysis of annual historic gains and losses was conducted using the data between the period from 1940-41 to 1997-98 for *Kharif* and *Rabi* seasons (Table 10).

Table 10

River Gains and Losses in the Indus River System

Period	River Gains and Losses (Billion m^3)		
	Kharif	*Rabi*	Total
Pre-Mangla 1940-67	–20.23	5.71	–14.52
Pre-Tarbela 1967-76	–10.80	3.64	–7.16
Post-Tarbela 1976-98	–14.36	1.02	–13.34
Average 1940-98	–16.54	3.61	–12.93

Source: Water Management Directorate, WAPDA.

Earlier studies revealed that conveyance losses in canals varied between 15-30 percent [Ahmad (1993b); Harza (1963); IACA (1966); LIP (1966)]. The Water Sector Investment Planning Study (WSIPS, 1990) provided a synthesis of the work done by WAPDA (1979) on canal conveyance losses for 24, 5 and 14 canal commands in the Punjab, NWFP and Sindh provinces, respectively. *The average canal losses computed were 23, 12 and 20 percent for the canal commands of the Punjab, NWFP and Sindh provinces, respectively. These losses were around 21 percent at the whole basin level.*

Systematic work on watercourse loss measurement was initiated jointly by the Colorado State University and WAPDA. Based on the two systematic studies of 40 and 61 watercourses, the actual watercourse losses were 47 and 45 percent, respectively. The field application losses were around 25 percent [Ashraf, *et al.* (1977); WAPDA (1979); Trout and Kemper (1980); PARC-FAO (1982)]. *Average losses of 21, 40 and 25 percent were used to compute losses from canals, watercourses and fields, respectively*, by Ahmad (1990, 1993a). As the President's Programme for Watercourse Improvement is being implemented in all the provinces and in the past watercourses have been improved leading to improvement of 76,403 watercourses out of 140,627 in 2005-06. Therefore, the watercourse losses of 30 percent were considered in this paper based on 40 percent losses in half of the un-improved watercourses and 20 percent in improved watercourses. *These losses provided canal, watercourse and field application efficiency of 79, 70 and 75 percent, respectively. Thus the overall irrigation efficiency at the basin level is around 41.5 percent.*

System losses corresponding to canal supplies in the IBIS were 75.5 billion m^3 during the year 2005-06, which represented around 58.5 percent of the water delivered to the IBIS (Table 11). In fresh groundwater areas, this induced recharge resulted in accelerated installation of tubewells to exploit the resource.

Table 11

Irrigation System Losses Corresponding to Canal Supplies to the IBIS

Description of Losses	Annual System Losses during 2005-06 (Billion m^3)
Canal Conveyance Losses	27.09
Watercourse Conveyance Losses	30.57
Field Application Losses	17.84
Total Losses	75.50
Total Canal Diversions	129.0
Overall Irrigation Efficiency (%)	41.5

- Annual canal diversions of 129 billion m^3 during 2005-06 were used for computation of losses using canal, watercourse and field application losses of 21, 30 and 25 percent, respectively.

Maximum Possible Efficiency in the Indus Basin Irrigation Systems. The maximum possible efficiency in the Indus basin irrigation system within the context of improved earthen canals and current level of watercourse improvement having around 15 percent lining (10 percent for freshwater zone and 20 percent in saline groundwater zone considering the hard core lining excluding the control structures) is given in Table 12. The overall irrigation losses would be 43.6 percent leading towards availability of 72.8 billion m^3 considering the current level of canal diversion, which might reduce due to situation of the current storage capacity.

Table 12

Irrigation System Losses Corresponding to Canal Supplies to the IBIS

Description of Losses	Efficiency (%)	Annual System Losses (Billion m^3)
Canal Conveyance	85	19.35
Watercourse Conveyance	83	18.64
Field Application	80	18.20
Overall Irrigation	56.4	56.19

*Annual canal diversions of 129 billion m^3 during 2005-06 were used for computation of losses using canal, watercourse and field application losses of 15, 17 and 20 percent, respectively.

Still the huge losses of 43.6 percent are an indicator that major changes in irrigation system would be required in future (beyond 2010), where lining of canal would be required with application of high efficiency irrigation systems at the farm level. With the introduction of fully lined and effectively managed irrigation system and introduction of high efficiency irrigation systems further savings of 24.8 percent losses (31.97 billion m^3) can be made (Table 13).

Table 13

Irrigation System Losses Corresponding to Canal Supplies to the IBIS

Description of Losses	Efficiency (%)	Annual System Losses (Billion m^3)
Canal Conveyance	95	6.45
Watercourse Conveyance	95	6.13
Field Application	90	11.64
Overall Irrigation	81.2	24.22

*Annual canal diversions of 129 billion m^3 during 2005-06 were used for computation of losses using canal, watercourse and field application losses of 5, 5 and 10 percent, respectively.

The overall saving of 51.28 billion m^3 would be possible at the cost of reduced recharge to the groundwater. The school of thought based on the view that efficiency in irrigation system would affect the recharge and thus canals should not be lined is true only if quality of groundwater and energy are not the limiting factors. As energy is a limiting factor and one can not retrieve the same quality of recharged water, the improvement in irrigation efficiency must be considered as potential intervention for sustaining the cost-effectivity of irrigated agriculture. *The situation of Punjab is already alarming where 50 percent of total water use in agriculture is now contributed by the groundwater and farmers are suffering due to high electric tariff and poor quality of power supply. The government has provided subsidy to the tune of 25 percent to all the tubewells in the three provinces excluding Balochistan, where there is 91 percent subsidy on electric tubewells.*

Groundwater

Resource Abstraction. In the last 30 years (1976-06), the groundwater contribution to irrigated agriculture has doubled from 31.6 to around 62 billion m^3 [Pakistan (2006)]. The country has made considerable progress in the development of innovative and indigenous tubewells technology. However, with the rise of the electricity tariff and diesel fuel prices, problem of secondary salinisation in marginal quality zones and closure of the SCARP tubewells, the groundwater pumpage is now stagnant since 1996-97 (Table 14). The groundwater now contributes around 48 percent of surface water available at the canal head.

Table 14

Pre- and Post-Tarbela Groundwater Contribution to Irrigation Water Supplies

Key Influences	Period	Groundwater Contribution (Billion m^3)	Increase in Groundwater Contribution (%)	Contribution as Percent of the Canal Diversions
Pre-Mangla	1965-66	11.3	–	10.0
Post-Mangla	1967-68	14.5	28.3	13.0
Post-Mangla	1970-71	21.6	91.2	20.8
Post-Tarbela	1975-76	31.6	179.6	26.6
Post-Tarbela	1980-81	40.2	255.8	31.2
Post-Tarbela	1985-86	48.3	327.4	41.8
Post-Tarbela	1990-91	54.3	380.5	41.1
Post-Tarbela	1995-96	61.0	439.8	49.7
	1996-97	62.1	449.6	46.6
Post-Tarbela	2000-01	62.4	452.2	62.4**
Post-Tarbela	2005-06	62.1	450.0	48.1

Source: Agricultural Statistics of Pakistan, Ministry of Food, Agriculture and Livestock, 2006.
* Base year of 1965-66 is used for computations.
** This was due to reduced canal diversions because of drought where mean annual river flows were reduced significantly.

Another contributing factor was transition of the public tubewells under SCARPs, where the community refused to take over the deep tubewells because of high O&M cost. The SCARP Transition Projects were aimed at reducing public involvement in the groundwater sector by closing down or transferring public tubewells to the water users [World Bank (1988)].

Recent drought forced the farmers to install tubewells to meet shortfall in canal supplies. The growth of private tubewells contributed to sustain the groundwater abstractions even after the closure of the SCARP tubewells.

Tubewell Development. Enhanced power generation from Mangla and Tarbela dams and the government policy of price incentives for electric power motivated farmers to install electric tubewells. There were 36921 tubewells in 1970-71, which were increased to 60386 during 1975-76 largely due to post-Mangla power generation. Consequently, with the commissioning of Tarbela dam, there was around two-fold increase in number of electric tubewells (113,635) during 1990-91. Afterwards, there was a slight increase in number of electric tubewells to 128823; representing 13.4 percent of total number of tubewells in 2005-06 and rest are being operated by diesel prime movers.

This rapid growth of diesel-operated tubewells since 1990-91 is largely due to the cost-effective development of tubewells technology, rise in electric tariff and flexibility in operation of diesel-operated tubewells, as farmers do not have any dependence on WAPDA (Table 15).

Table 15

Tubewells (Electric and Diesel) Development in Pakistan

Key Influences	Period	Number of Tubewells			Percent Increase		
		Electric	Diesel	Total	Electric	Diesel	Total
Post-Mangla	1970-71	36921	60301	97222	–	–	–
Post-Tarbela	1975-76	60386	100569	160955	63.6	66.8	65.6
Post-Tarbela	1980-81	83855	115818	199673	127.1	92.1	105.4
Post-Tarbela	1985-86	99224	158058	257309	168.7	162.1	164.7
Post-Tarbela	1990-91	113635	226205	339840	207.8	275.1	249.6
Post Tarbela	1995-96	114305	370745	485050	209.6	515.0	399.0
Post-Tarbela	2000-01	113733	545545	659278	208.1	805.0	578.0
Post -Tarbela	2005-06	128823	829093	957916	248.9	1275.0	885.0

Source: Agricultural Statistics of Pakistan, Ministry of Food, Agriculture and Livestock (2006).

Subsidy on Electric Tubewells. The federal and provincial governments are providing subsidy to the tune of Rs 7.0 billion per annum for 15,206 deep electric tubewells in Balochistan. Recently, in the federal budget of 2007-08, the federal government has provided subsidy to the tune of 25 percent reduction in electric tariff to electric tubewell farmers in other three provinces. The benefits of this subsidy are provided to only 13.4 percent tubewells in Pakistan, whereas the larger population of diesel-operated tubewells has been deprived. The subsidy on electric-tariff in Balochistan resulted in wasteful use of scarce resources of groundwater and energy.

Ahmad (2007) evaluated the current subsidy on electric tariff for agricultural tubewells in Balochistan and suggested sustainable options for helping farmers instead of providing subsidy on agricultural tubewells in other three provinces.

3.2.2. *Domestic Water Supply*

Water supply and sanitation sector is characterised by extremely low level of coverage particularly in rural area. Presently, only 80 percent of the urban population have access to piped water supply, whereas 11 percent of rural population is benefiting from this facility [PWP (1999, 2000)].

Water supply systems in the urban centres are based on either by the utilisation of surface water or groundwater abstraction through tubewells. The cities, which depend on surface water for their drinking water needs include among others Islamabad, Karachi and Hyderabad. The water supply of Lahore, Peshawar, Faisalabad, Abbotabad and Quetta is mostly dependent on groundwater.

Almost all the cities depending on surface supplies face moderate to acute shortage of water, whereas the situation in Lahore and Peshawar can be considered somewhat satisfactory due to the presence of a high yielding aquifer.

Rural areas depend on groundwater for domestic water supplies, wherever available, but in irrigated areas underlain with saline groundwater, canal waters are used to satisfy the domestic requirement. Outside the canal commands, where groundwater cannot be depended upon, rural water supply is dependent on the available stream flows in the upland areas or on rainfall collected in natural depressions, such as Tobas in the Cholistan desert. In such arid locations, the local populace is constrained to travel long distances to procure drinking water—a task, which is assigned to women.

It is estimated that present water demand for domestic and industrial uses is about 3,302 mgd, whereas the available water for the purpose is about 2,369 mgd [PWP (1999, 2000); NESPAK (1998)]. Therefore, there is a net deficiency of 22 percent of total domestic water requirement.

Recent drought was so severe that it has affected the availability of domestic water supply. For example, the availability of surface water supply in the Simly dam in Islamabad during 2001-02 has reduced to the extent of 40 percent of the requirement that the Capital Development Authority has started rationing of water on alternate day basis to the citizens of Islamabad.

Sanitation and Sewerage

Sanitation coverage is lower than the water supply coverage i.e. only 60 percent and 13.5 percent in urban and rural areas, respectively. In most of the cities, the wastewater from the municipal areas as well as the effluents from the industries is disposed of untreated to the natural water bodies.

In urban areas, sewerage consists of sewage collection and disposal system. In cities sewage is collected through RCC pipes and open drains. The collected sewerage is disposed to nearby water bodies through gravity or by inducting sewage pump stations in the system. In areas where sewage collection system is non-existing, sewage is discharged into groundwater through soakage wells, sometimes even without passing through septic tanks. In rural areas, the proper collection and disposal system is almost non-existing. The sewage is collected through open drains and disposed of in the fields, which usually forms huge ponds.

Presently, the treatment of effluents is almost non-existence on the municipal front. Only few cities have proper treatment facilities and most of these plants are not in operation.

3.2.3. *Industrial Water Use*

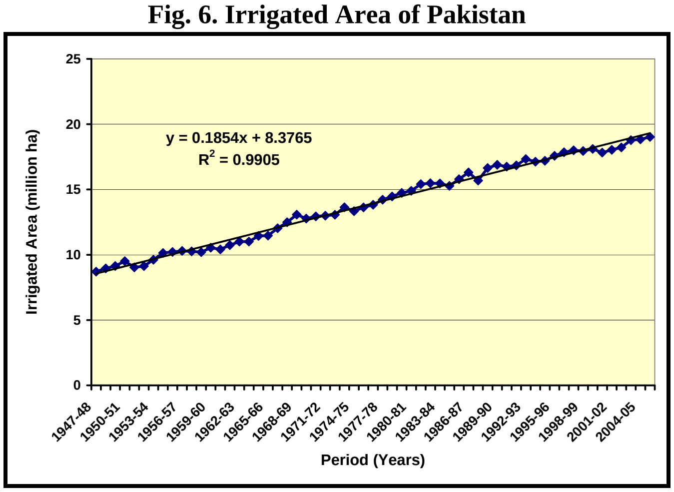
On the industrial front very limited units have proper treatment facilities. Generally the multinational or some factories involved in the export are forced to have treatment facilities. Major industrial estates are established in Lahore, Faisalabad, Karachi, Hyderabad, Peshawar, Hattar, Kasur and Sialkot. All these Industrial Estates are discharging their effluent, without any prior treatment into the nearby water body/stream, the ultimate fate of which is the river and sea. The untreated industrial effluents from isolated plants are allowed to be disposed in open fields or in nearby water body. Huge ponds can be seen in various industrial estates of the country.

4. IRRIGATED AGRICULTURE IN THE IBIS

4.1. Irrigated Area

Irrigated area in 1947-48 was around 8.71 mha and increased to 12.02 mha in 1966-67, representing the pre-storage period. This was increased to 13.63 mha in 1975-76 in the pre-Tarbela period and further increased to 19.02 mha during 2005-06. This doubling in irrigated area in 60 years was primarily due to increased water supply both from surface and groundwater sources (Figure 6).

Fig. 6. Irrigated Area of Pakistan



The analysis of increase in irrigated area was in-line with the predictions made in the Lieftinck Report (1968), where actual irrigated area during 1999-00 was around 18.1 mha, slightly higher from that of the predicted of 17.9 mha. Further growth in irrigated area was largely due to the increased abstractions of groundwater during 2000-07 because new storage dams were not constructed during this period.

4.2. Cropped Area

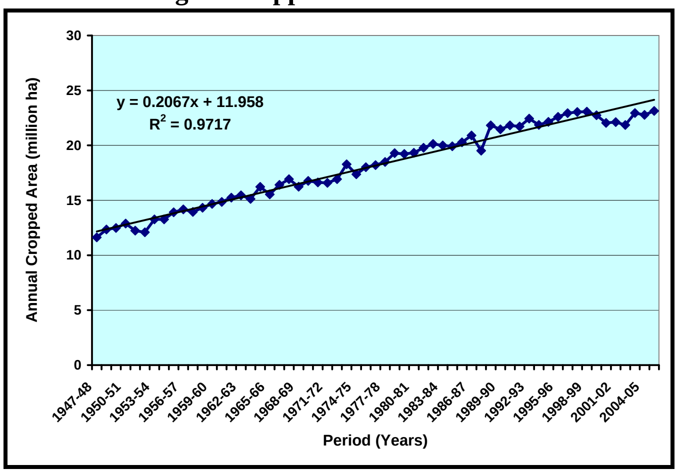
Cropped area was 11.63 mha in 1947-48 and it was increased to 16.41 mha in 1966-67. Although there was considerable increase in the cropped area but this was largely due to improvement in availability of canal water as a result of Indus Water

Treaty and development of groundwater. The cropped area in 1975-76 was 18.02 mha representing the post-Tarbela period. It was increased to 23.13 mha in 2005-06, which was largely due to availability of increased water supplies largely from groundwater resources (Figure 7).

Irrigation is essential for crop production because of an arid environment, where rainfall contributes 15 percent of crop water requirement. Increased number of tractors, availability of planting machinery, credit support helped to increase the cropped area. The increase in population was another reason, which influenced the increase in cropped area.

The major *Rabi* crops are wheat, fodder and horticultural crops. Sugarcane crop also needs irrigation during *Rabi* season and thus competes for water with other crops. Trend in area under *Rabi* crops shows considerable increase in area under wheat, fodder, sugarcane, and horticultural crops. Wheat is a leading food grain for human consumption, while its straw is used as a source of cheap roughage for livestock feed. Generally, farmers consider water as a key input, thus with the availability of sufficient water; they normally increase cropped area.

Fig. 7. Cropped Area in Pakistan



The increase in area under sugarcane is primarily due to availability of additional irrigation water from the storage reservoirs as it is a high water demanding crop. Other factors that contributed towards this increase were the development of sugarcane industry and the road infrastructure, which provided the necessary backward and forward linkages for growth.

4.3. Cropping Intensity

There is a wide variation in the cropping intensity of the Rabi and Kharif seasons of various canal commands. The annual cropping intensity data were used to categorise the canal commands into three categories representing low, medium and high cropping intensity. The comparative analysis indicated that cropping intensity varied both for the Rabi and Kharif seasons irrespective of the authorised canal water allowance. Thus non-water inputs and management of the available water and production practices also contributed to increased cropping intensity [Ahmad (2005)].

- The first category represents canal commands with lowest cropping intensity of <100 percent.
- The second category represents canal commands with medium cropping intensity of 100 to 150 percent.
- The third category represents canal commands with higher cropping intensity of >150 percent.

The authorised canal water allowance does not affect the cropping intensity in all the three categories, as it varied significantly within each category of canal commands. The variation is highest in the lowest cropping intensity category where it varied from as low as 200 to 1860 lps/1000 ha. This shows that the lowest and highest authorised canal water allowances are in this category. The variation in the second category was 244 to 1115 lps/1000 ha, whereas it varied from 357 to 993 lps/1000 ha for the third category.

5. NATIONAL AND PROVINCIAL POLICY CONTEXT

5.1. Draft National Water Policy

The First Comprehensive *Draft National Water Policy* was formulated to optimise the development of water resources (surface and groundwater resources) and to enhance productivity and sustainability of water in agriculture and efficiency in other sub-sectors of water use, which is yet to be approved by the federal government [Pakistan (2006b)].

Around 93 percent of annual available water is being used for the agriculture sector; therefore, emphasis of the *Draft National Water Policy* is to contribute to food security and poverty reduction by fostering sustainable increases in productivity of water through optimal supply and effective management at the basin level.

5.2. IWRM Policy Balochistan

The Balochistan's First Comprehensive Integrated Water Resources Management (IWRM) Policy was prepared by the Government of Balochistan with the assistance of Asian Development Bank while developing the Balochistan Resource Management Project, which was formulated as a Programme Loan for Balochistan. The consultative process was developed and used for formulating the IWRM Policy, where stakeholders from all the sub-sectors of water use participated. The IWRM Policy also addresses all sub-sectors of water use and all sources of water (surface and groundwater).

6. FUTURE WATER DEMAND AND AVAILABILITY

Future water needs were computed for the years 2007, 2010 and 2025 for two major sub-sectors of water use (irrigation and non-irrigation). The irrigation sub-sector includes water for agriculture, farm forestry, aquaculture, livestock and wetlands. The non-irrigation sub-sectors include largely the domestic and industrial water sub-sectors.

6.1. Present and Future Irrigation Water Needs

The net irrigation water requirement for crops in Pakistan is around 107 billion m^3 for the year 2007. Rainfall was disregarded in estimation of net irrigation water requirement, where assumption was made that rainfall contribution (15 percent) in the basin is required for leaching purposes to maintain salt balance in the root-zone.

Agriculture growth rate targeted by the Ministry of Food, Agriculture and Livestock for the current decade (2000-2010) is 5 percent per annum. This would be achieved through increasing the cropping intensity of 0.5 percent per annum and increase in productivity of 4.5 percent per annum. The increase in cropping intensity would require additional water of around 0.5 percent per annum mainly through saving of water from existing losses because new storage reservoirs will not be available prior to 2020, even if the construction started today. Rather there will be reduction in available storage capacity in the Indus basin due to continuous sedimentation of Tarbela and Mangla reservoirs. Beyond 2010, the growth rate of 3 percent per annum is possible

Increase in productivity of 4.5 percent per annum would also require more reliable and adequate availability of water. Thus additional water requirement will be around 1 percent (1.26 billion m^3) of existing canal supplies. An annual loss of storage capacity of 0.30 billion m^3 per annum was used.

Current mean annual canal diversions to the Indus basin irrigated command area are around 126.8 billion m^3. Additional canal supplies required to meet 3 percent growth in agriculture beyond 2010 and to meet annual loss of live storage capacity of existing reservoirs due to sedimentation come to around 6.6 and 12.2 billion m^3 for 2010 and 2025, respectively.

In 2025, the additional irrigation water required to achieve the growth in agricultural productions of 70 percent would be around 32.9 billion m^3 (based on 1.82 billion m^3 per annum), which is a considerable amount of water. Thus, systematic efforts are needed to find new resources of water through improved management of water. The new resources of water would come from construction of new dams by 2025 (15 billion m^3 storage from Basha and Kalabagh dams) and saving of existing losses. The future net irrigation water requirements for crops for the year 2010 and 2025 are around 111.9 and 139.9 billion m^3, respectively (Table 16).

Table 16

Water Requirement and Availability for 2000, 2010, and 2025 for Pakistan

Requirement/Availability	Year		
	2007	2010	2025
Net Water Requirement			
Net Irrigation Water Requirement	107.0	111.9	139.9
Net Non-Irrigation Water requirement	8.5	8.9	11.2
Total Net Water Requirement	115.5	120.8	151.1
Net Water Availability			
Mean Annual Canal Diversions	126.8	125.9	136.2***
Canal Water Availability for Consumptive Use	52.6*	52.2*	76.9
Groundwater Availability for Consumptive Use	62.00	62.0	62.0
Total Surface and Groundwater Availability	114.6	114.2	138.9
Shortfall	0.9	6.6	12.2

*Based on 79, 70 and 75 percent of canal, watercourse and field application efficiencies.

**Based on 85, 83 and 80 percent of canal, watercourse and field application efficiencies.

***Additional storages of 15 billion m^3 will be available after constructing the two large hydro-power dams at Basha and Kalabagh.

Assumption was made that no additional storage will be available for the year 2010 compared to the year 2007, because construction of large storage reservoirs would require a period of 10-12 years. Thus water management will be the only workable option for the next decade.

Water budget presented in Table 16 seems quite different than the budgets presented by other authors including the Water Vision 2025 [PWP (2000)]. Actually the problem arises when experts estimate gross water requirement without considering the efficiency and improved operational management of canals and efficient water use. Thus, water budget has to be seen in the context of net water requirement. The budget made on the basis of gross water requirement supports the need for further water development and under-estimates the potential for improved water management. In addition, we have to live within the available mean annual river flows and sustainable level of groundwater abstraction.

6.2. Present and Future Non-irrigation Water Needs

Gross water requirement for non-irrigation needs was 8.5 billion m^3 for the year 2007. This would increase to 8.9 and 11.2 billion m^3 for the years 2010 and 2025, respectively, which is based on growth rate of around 1.5 percent per annum for the increase in non-water needs due to increase in population and increased coverage of domestic and industrial water supply (Table 16).

6.3. National Plans and Programmes

Shortfall in water use would increase from 0.9 to 12.2 billion m^3 in 2025 even with increased in overall irrigation efficiency of 56.19 percent compared to the current efficiency of 41.5 percent. Thus, water resources development and management in the short-term will not make the country self-sufficient in irrigation and non-irrigation water needs. On the one-hand, intra-sectoral demand for additional water is increasing rapidly while on the other, opportunities for further development of water resources or maintaining their use to existing levels are diminishing faster than the expected pace. Thus the challenge for 2025 will be the effective implementation of state-of-the-art management cum development strategy.

Approach encompassing the development of additional reservoirs, integrated water management and use, water efficient techniques, containment of environmental degradation, institutional strengthening, capacity building and human resource development will have to be implemented [Planning Commission (2001)].

7. KEY ISSUES

Planning Commission of Pakistan under the water sector strategy has outlined the issues related to water, which are listed as under:

- Shortage of freshwater both from surface and groundwater sources;
- Variability and seasonality in precipitation and availability of surface water resources;
- Rigid design and inflexibility in operation of canal irrigation system—continuous flows and fixed rotation irrigation system;

- Inequity in water distribution – tail-end farmers are receiving almost half or less of the allocated amount of canal water;
- Lack of innovative approaches for modernising the irrigation schemes – design of canal irrigation systems to suit high efficiency irrigation systems (sprinkler and drip irrigation);
- Inadequate O&M funding and extremely poor cost-recovery;
- Increase in waterlogging and salinity hazard due to poor maintenance;
- Excessive groundwater pumpage in certain regions and resulting in secondary salinisation in the Indus basin and mining of groundwater in Barani areas and Balochistan;
- Effluent disposal and related environmental issues;
- Absence of conducive environment required to introduce and implement water efficient irrigation techniques and practices (i.e. subsidy on agricultural tubewells in Balochistan resulted in wasteful use of water and energy and extremely low Abiana rates in the canal commands);
- Inadequate and ineffective participation of the private sector;
- Deteriorating institutional capacity of key water sector institutions; and
- Poor linkages among water, agriculture and rural development policies and strategies.

Objectives of the next decade (2010-2020) plan are to have sustainable development and integrated management of water resources and use to meet the shortfall in water availability and needs. This would be achieved through a comprehensive strategy of development cum management in the light of key issues identified for the sector.

8. CHALLENGES

8.1. Agriculture Sector

The research and development community is facing three challenges. The first challenge faced by irrigated agriculture is to raise production and productivity in favoured environments. The second challenge is to enhance production and productivity in less favoured environments like Balochistan valley agriculture, Rod-Kohi, Barani lands, Riverine areas, etc. The third challenge faced by the country is that in the process of productivity enhancement the resources have to be upgraded rather than degradation of the resources.

Population by the end of 2010 will be around 168 millions based on medium projections and would increase to 209 millions by the end of 2025. The increase of 31 percent in population would require at least same level of increase in food and fibre production to meet the country’s requirement. Coupled with country’s objective of increasing export, reducing import bill and fighting for hunger and malnutrition, it is more realistic to achieve a level of 70 percent increase in agricultural production, which would require an increase in water of 32.9 billion m^3. This additional water will come through development of new storage reservoirs and savings of existing losses.

8.1.2. Domestic and Industrial Sectors

Urban and industrial sectors' development community is facing three challenges. The *first challenge* faced by the urban and industrial sub-sectors is to raise level of quality of service and reliability in water supply in large metropolitans and industrial states. The *second challenge* is to extend the access to piped water supply in small towns rural areas and isolated settlements. The *third challenge* faced by the country is that in the process of provision of safe water supply to the urban areas and industrial states the water resources have to be upgraded rather than degradation of resources in terms of environmental concerns like treatment of sewage and industrial effluents. Rather the sources of sanitary and industrial effluents have to be blocked prior to entry into freshwater ways.

Population by the end of 2010 will be around 168 million based on medium projections. This would increase to 209 millions by the end of 2025. The increase of 31 percent in population would require at least same level of increase in domestic water supply to meet the country's requirement. Coupled with country's objective of alleviating poverty and quality life, it is more realistic to achieve a level of 50 percent increase in access to safe water supply and would require additional water of around 19 percent.

REFERENCES

Afzal, M. (1999) Water for Agriculture. Paper for Water Vision Pakistan.

Ahmad, N. (1993b) *Water Resources of Pakistan*. Lahore: Publisher Shahzad Nazir.

Ahmad, S. (1990) Soil Salinity and Water Management: Keynote Address. *Proceedings of the Indo-Pak Workshop on "Soil Salinity and Water Management"*. IWASRI, UNDP and PARC, Islamabad. Vol. II, p. 3–18.

Ahmad, S. (1993a) Viability of Agriculture Resource Base: A Critical Appraisal. In Agricultural Strategies in the 1990s: Issues and Options. Pakistan Association of Agricultural Social Scientists, Islamabad. p. 449–466.

Ahmad, S. (1999a) Achievements and Issues of Irrigation in the 20th Century. Proceedings of the National Workshop on "Water Resources Achievements and Issues in the 20th Century and Challenge of the Next Millennium", Islamabad. PCRWR/UNESCO, June 28–30, pp. 188–201.

Ahmad, S. (2000) Background Paper on Water Resources. In *Tarbela Dam and Related Aspects of the Indus River Basin Pakistan.* Prepared for the World Commission on Dams (WCD) by: Asianics Agro-Dev. International (Pvt.) Ltd. Secretariat of the World Commission on Dams. Cape Town 8018, South

Ahmad, S. (2005) Background Paper on Evapotranspiration and Water Balance. Water Country Assistance Strategy. Pakistan Economy Getting Dry. World Bank Resident Mission, Pakistan.

Ahmad, S. (2007) Growth of Agricultural Tubewells and State of Energy in Pakistan—Is Subsidy a Sustainable Option for Helping Farmers? Water for Balochistan. Quetta, Balochistan, Pakistan. *Policy Briefings* 3:8,

Ahmad, S., S. Mulk, and A. Mohammad (2001) Groundwater Management in Pakistan. Country Report. Prepared for the Global Water Partnership and Pakistan Water Partnership.

Ahmed, S. and M. F. Joyia (2003) Northern Areas Sustainable Development Strategy. NASDS Background Paper: Water IUCN Pakistan, Northern Areas Programme, Gilgit. xiv+67 pp.

Alurrade, J. C., C. A. Gandarillas, and G. V. Skogerboe (1998) Application of Crop Based Irrigation Operations to Chashma Right Bank Canal, Lahore. (IIMI Report No. R-66).

Ashraf, M., W. D. Kemper, M. M. Chaudhary, B. Ahmad, and T. Trout (1977) Review of Watercourse Loss Measurement in Pakistan. MONA Reclamation Experimental Project, MONA, Bhalwal. Pub. No. 71.

Balochistan, Government of (2006) *Integrated Water Resources Management Policy*. Department of Irrigation and Power. Government of Balochistan.

Bhatti, M. A. (1999) *Water Resource System of Pakistan*: *Status and Issues.* Pakistan Science Foundation, Islamabad. 72 p.

Bhutta, M. N. (1999) Vision on Water for Food and Agriculture: Pakistan's Perspective. Regional South Asia Meeting on Water for Food and Agriculture Development. New Delhi.

Harza Engineering Co. Ltd. (1963) Distribution Losses.

IACA (1966) Lower Indus Project Report. Harza International Agricultural Consultants Association.

ICIMOD, PARC, APN, UNEP and START (2005) Indus Basin. Pakistan Himalaya. Inventory of Glaciers and Glacial Lakes and the Identification of Potential Glacial Lake Outburst Floods (GLOFs) Affected by Global Warming in the Mountains of Himalayan Region. Pakistan Agricultural Research Council, Asia-Pacific Network for Global Change Research Global Change System for Analysis, Research and Training, International Centre for Integrated Mountain Development, United Nations Environment Programme/ Regional Resource Centre for Asia and the Pacific.

IPD (2006a) Assessment of Water Resources Availability for Balochistan. Department of Irrigation and Power. Government of Balochistan.

IWASRI (1997) Integrated Surface and Groundwater Management Programme for Pakistan. (Surface Water Interim Report No. 98/1).

Kijine, J. W. and E.J. Jr. Vander Velde (1992) Irrigation Management Implications of Indus Basin Climate Change, Case Study, IIMI, Lahore.

Kijne, J. W. and M. Kuper (1995) Salinity and Sodicity in Pakistan's Punjab: A Threat to Sustainability of Irrigated Agriculture. *Water Resources Development* 11.

LIP (1966) Lower Indus Report. Part Two, Hunting Technical Services and Sir Mac Donald and Partners

Mohtadullah, K., A. Rehman and C. M. Munir (1991) Water Use and Misuse. NCS, Islamabad.

NESPAK (1991) Contribution of Private Tubewells in Development of Water Potential. Final Report, Ministry of Planning and Development, Islamabad.

NESPAK (1998) Sub-regional Water Supply on Private Sector Involvement in the Development and Management of Water Supply and Sanitation System. Pakistan Country Report.

NIPS (2007) Projections of Population for the Year 2025. National Institute of Population Studies. Government of Pakistan.

Pakistan, Government of (1998) *Population Census of Pakistan.* Population Census Division. Government of Pakistan.

Pakistan, Government of (2003) *Draft National Water Policy*. First Draft. Office of the Chief Engineering Advisor/Chairman Federal Flood Commission, Ministry of Water and Power.

Pakistan, Government of (2006a) *Agriculture Statistics of Pakistan*. Economic Wing of the Ministry of Food, Agriculture and Livestock, Government of Pakistan.

Pakistan, Government of (2006b) *Draft National Water Policy.* (Final Draft). Office of the Chief Engineering Advisor/Chairman Federal Flood Commission, Ministry of Water and Power.

PARC-FAO (1982) Farm Water Management. Proceedings of Expert Consultation on Farm Water Management. Islamabad, Pakistan Agricultural Research Council and Food and Agriculture Organisation of the United Nations.

Planning Commission (2001) Three Year Plan for the Pakistan Sector Development Programme. Planning Commission, Government of Pakistan.

PWP (1999) Watershed Management. In National Workshop to Formulate Pakistan Water Vision. Global Water Partnership, Pakistan Water Partnership and Swiss International Development Agency, 24-25 May, Best Western Hotel, Islamabad.

PWP (2000) Framework for Action for Achieving the Pakistan Water Vision 2025. Pakistan Water Partnership. 75 p.

Saleemi, M. A. (1993) Environmental Pollution: Keynote Address at the International Symposium on Environmental Assessment and Management of Irrigation and Drainage Projects for Sustained Agriculture Growth. Lahore.

Trout, J. T. and W. D. Kemper (1980) Watercourse Improvement Manual. Colorado State University, Fort Collins, Colorado. (Water Management Technical Report No. 58.)

WAPDA (1979) Revised Action Programme. Master Planning and Review Division, WAPDA, Pakistan.

WAPDA (1986) Waterlogging and Salinity in the Indus Basin. WAPDA, Lahore.

WAPDA (2006) Waterlogging and Salinity in the Indus Basin. WAPDA, Lahore.

Warsi, M. (1991) Indus and other River Basin of Pakistan, Stream Flow Records. Case Study Report, WAPDA.

WCD (2000) Tarbela Dam and Related Aspects of the Indus River Basin Pakistan. Final Report: November 2000. Prepared for the World Commission on Dams (WCD) by: Asianics Agro-Dev. International (Pvt.) Ltd. Secretariat of the World Commission on Dams. Cape Town 8018, South Africa. Website: http://www.dams.org

World Bank (1988) SCARP Transition Pilot Project—Project Implementation Report. The World Bank, Washington, DC.

World Bank (2005) Pakistan Economy Getting Dry. Pakistan Water Strategy. World Bank.

WRRI, MONA, and IIMI (1999) Spatial Analysis of the Groundwater in SCARP Areas. A Case Study of the MONA Unit. Water Resources Research Institute, MONA Reclamation Experimental Project and IIMI, Islamabad.

WSIP (1990) *Water Sector Investment Planning Study.* Vol. IV. WAPDA.

Zuberi, F. A. and A. B. Sufi (1992) State of Art of Groundwater Exploration, Exploitation, Management and Legislation. IWASRI, WAPDA, Lahore, 26 p.