Current status of agrometeorological services in South Asia, with special emphasis on the Indo-Gangetic Plains

Working Paper No. 53

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

Y.S. Ramakrishna

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About the author

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Acronyms

AAS	Agrometeorological Advisory Service
ADA	Austrian Development Agency
ADPC	Asian Disaster Preparedness Centre, Bangkok
AEC	Agro-Enterprise Centre, Nepal
AICRPAM	All India Coordinated Research Project on Agro-Meteorology
AIR	All India Radio
AMC	Agro-Meteorological Centre
AMFU	Agro-Meteorological Field Unit
AMIS	Agricultural Management Information System, Nepal
APFISN	Asia Pacific Forest Invasive Species Network
APSIM	Agricultural Production Systems Simulator
APT	Automatic Picture Transmission
ARG	Automatic Rain Gauge Station
ATMA	Agricultural Technology Management Agency
AWS	Automatic Weather Stations
BARC	Bangladesh Agricultural Research Council
BBS	Bhutan Broadcasting Service
BMD	Bangladesh Meteorological Department
CABI	Centre for Agriculture and Biosciences International
CCAFS	Climate Change, Agriculture and Food Security
CCNDPPE	Causes and Consequences of Natural Disasters and the Protection and Preservation of the Environment
CD	Compact Disc
CEDPA	Centre for Development and Population Activities
CGIAR	Consultative Group on International Agricultural Research
CRIDA	Central Research Institute for Dryland Agriculture
CSC	Central Seed Committee
DAC	Department of Agriculture and Cooperation
DAE	Department of Agricultural Extension
DD	Door Darshan (Government of India Television service)
DHM	Department of Hydrology and Meteorology
DHMS	Department of Hydro-Meteorological Services
DMC	District Meteorological Centre
DMO	District Meteorological Office
DoE	Department of Energy
DSSAT	Decision Support System for Agro-Technology Transfer
DST	Department of Science and Technology, India
DWD	Deutscher Wetterdienst, Germany
ECMWF	European Centre for Medium-Range Weather Forecasts
ET	Evapo-Transpiration
ET0	Reference Evapo-Transpiration
FAO	Food and Agriculture Organization
FES	Foundation for Ecological Security
FFWC	Flood Forecasting and Warning Centre

FRA	Forest Resource Assessment
FSI	Forest Survey of India
FYP	Five Year Plan
GDP	Gross Development Product
GHI	Global Hunger Index
GIS	Geographical Information System
GKP	Global Knowledge Partnership
GNHC	Gross National Happiness Commission
GSN	Global Climate Observing System (GCOS) Network
GTS	Global Telecommunication System
GWP	Global Water Partnership
HMSD	Hydro-Met Services Department
HRM	High Resolution Model
HRPT	High Resolution Picture Transmission
ICAR	Indian Council for Agricultural Research
ICI	Institutional Cooperation Instrument
ICIMOD	International Center for Integrated Mountain Development
ICT	Information and Communication Technology
IIIT	International Institute of Information Technology
IMD	India Meteorological Department
INSAT	Indian National Satellite System
IRI	International Research Institute
IT	Information Technology
ITC	India Tobacco Company
IWMI	International Water Management Institute
JMA	Japan Meteorological Agency
KVK	Krishi Vigyan Kendra (Farm Science Center)
MDMHR	Ministry of Disaster Management and Human Rights
MetGIS	Combined Meteorology and Geographical Information System for Mountain Weather Forecasting
MFA	Ministry of Foreign Affairs, Finland
MINFAL	Ministry of Food, Agriculture and Livestock, Pakistan
MM-5	5th Generation Meso-scale Model
MoAC	Ministry of Agriculture and Cooperation
MoAD	Ministry of Agriculture Development, Nepal
MoEA	Ministry of Economic Affairs
MoEF	Ministry of Environment and Forests
MoES	Ministry of Earth Sciences
MoF	Ministry of Finance, Pakistan
MoFA	Ministry of Foreign Affairs
MOHC	Meteorological Office Hadley Centre
NAMC	National Agro-Met Centre
NAPA	National Adaptation Program of Action
NCMRWF	National Centre for Medium Range Weather Forecasting
NDMC	National Drought Monitoring Centre

NFCA	National Forecasting Centre for Agriculture
NGO	Non Governmental Organization
NICRA	National Initiative on Climate Resilient Agriculture
NMC	National Meteorological Centre
NOAA	National Oceanic and Atmospheric Agency
NWGM	National Working Group on Monsoon
NWP	Numerical Weather Prediction
PARC	Pakistan Agricultural Research Council
PMD	Pakistan Meteorological Department
R&E	Research and Extension
RAMC	Regional Agro-Met Centre
RBCN	Regional Basic Climatological Network
RBSN	Regional Basic Synoptic Network
RDMC	Regional Drought Monitoring Centre
RGB	Royal Government of Bhutan
RIMES	Regional Integrated Multi-Hazard Early Warning System for Asia and Africa
RRCAP	Regional Resource Centre for Asia and Pacific
SAARC	South Asian Association for Regional Cooperation
SACEP	South Asia Cooperative Environment Program
SAU	State Agricultural University
SMRC	SAARC Meteorological Research Centre
SMS	Short Message Service
SWC	Storm Warning Centre
SWOT	Strengths, Weaknesses, Opportunities and Technologies
UNCCD	United Nations Convention to Combat Desertification
UNEP	United Nations Environment Program
UNFCCC	United Nations Framework Convention on Climate Change
UN-ISDR	United Nations International Strategy for Disaster Reduction
UTC	Coordinated Universal Time
VERCON	Virtual Extension and Research Communication Network
VKC	Village Knowledge Centre
VLC	Village Level Coordinator
VRC	Village Resource Centre
WFO	Weather Forecasting Office
WFP	World Food Program
WMO	World Meteorological Organization
WRF	Weather Research and Forecasting
ZTBL	Zarai Taraqiati Bank Limited

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Executive summary

1. Background: South Asia's climatic, agricultural and food security-context

The climate of South Asia defies easy generalization, comprising a wide range of conditions across a large geographical scale and varied topography. India, for instance, hosts 6 major climatic sub-types, ranging from desert in the west, to alpine tundra and glaciers in the north, to humid tropical regions supporting rain forests in the southwest, and the island territories. Meanwhile, the climate of Bhutan varies with altitude, manifesting subtropical conditions in the south and a polar-type climate, with year-round snow, in the north.

Against this varied environment, South Asia is one of the poorest regions of the world. In 2005, more than 40 percent of the region's population lived on less than 1 dollar a day, as compared to 50 percent in sub-Saharan Africa (World Bank 2010). More than 75 percent of South Asia's poor live in rural areas and most rely on agriculture for survival. In addition, South Asia has one of the highest child-malnutrition rates in the world. In India and Bangladesh, the percentage of children who do not receive adequate food is 40 percent (Global Health Initiative 2010).

2. Status of South Asian meteorological services

The quality of meteorological services in South Asia varies by country. For instance, India's meteorological service, which was officially established in 1875 and has records dating back to 1844 (the first meteorological observatory was started at Kolkata in 1785), maintains a large number of weather stations and, more than 10 years ago, opened a National Centre for Medium-Range Weather Forecasting (NCMRWF). In contrast, the meteorological services of Bhutan, Nepal, and Sri Lanka are less well established. All three of these meteorological services could improve, both in their monitoring and forecasting abilities. Resources are also severely lacking in these three countries.

Encouragingly, the meteorological services of Pakistan and Bangladesh are in the process of developing their abilities. For instance, in addition to maintaining 35 meteorological observatories, the Bangladesh Meteorological Department hosts an Agrometeorological Observatory and a Flood Forecasting Warning Centre. Meanwhile, the Pakistan Meteorological Department – which maintains a range of monitoring and forecasting activities – offers professional training in various branches of meteorology through its Institute of Meteorology and Geophysics in Karachi.

3. Agricultural advisory services in South Asia

As with meteorological services, the quality and coverage of agricultural advisory services vary throughout the region. India leads the region in the provision of agricultural advisory services, maintaining a National Centre for Medium-Range Weather Forecasting, which provides weather forecasts at smaller spatial and temporal scales. The International Institute of Information Technology (IIIT) in India, on an experimental basis, initiated an innovative Meteorological Service providing agricultural advice to farmers in Andhra Pradesh. They make use of a unique system that allows village-level coordinators to photograph farmers' fields and send the photos back to headquarters for advice. Once experts at the IIIT have looked at the photos and consulted forecasts, they are able to communicate with the farmers about current and future weather conditions and possible management strategies. In this way, rural farmers are able to consult with experts in near-real time.

In other countries in South Asia, similar efforts are underway. For instance, the Bangladesh Meteorological Department (BMD) issues one-month long-range forecasts for agricultural planning and 10-day agrometeorological forecasts for regular agricultural operations. In addition, the BMD issues agricultural advisory bulletins based on specific crop conditions and the weather forecast at 10-, 30- and 90-day intervals.

In Pakistan, agrometeorological services have been in place since 1988, when the National Agromet Centre and 5 Regional Agromet Centres were established. Here, collaboration on agricultural advisories includes participation of the public universities, several research institutes and NGOs, and the National Agromet Centre. Such collaborations have resulted in advisory bulletins, an observational network and increased monitoring, as well as crop and harvest calendars.

While the Agromet Division of Sri Lanka’s National Meteorological Centre does collect data, it does not yet provide specific weather-based agricultural advisories to farming communities. However, several private organizations are providing specific crop-based advisories. This is somewhat similar to the case in Nepal and Bhutan, where the meteorological departments do not maintain a special division to deal exclusively with agricultural meteorological aspects, but where a few private organizations provide information to farming communities.

4. Challenges and opportunities

Because all the countries in South Asia are heavily dependent on agriculture, there is an urgent need to strengthen agrometeorological services in all of them. To support these activities, the network of weather observatories in each of these countries must to be strengthened and connections between agricultural and meteorological services must be improved.

Specific recommendations for improving agricultural advisory services in South Asia include:

- Each of the countries in South Asia must engage in a micro-level resource inventory and database of climate, soil, water, crop, economic, social, livestock and fisheries data.
- Contingency planning for all districts in these countries should be prepared to meet climate risks effectively.
- The weather forecasting capabilities, including medium-range weather forecast reliability, should be increased in all the South Asian nations. To accomplish this, expertise and information should be freely exchanged across the countries.
- The research wings of agrometeorological institutions should be strengthened in order to provide information on crop-weather-pest/disease relationships for agricultural advisory bulletins.
- Existing drought monitoring institutions of various countries should develop close linkages with their respective agricultural research institutions and state agricultural universities for providing the viable solutions to meet the challenges posed by droughts.
- The existing ability to monitor and forecast floods should be strengthened. In addition, the most vulnerable regions should be identified and measures should be taken to reduce this vulnerability.

Measures should be taken to increase awareness among the farmers regarding the importance of weather information for agricultural decision-making. The extension activities in these countries need to be strengthened further. Needs-based training and the use of information and communication technology to reach the farmers effectively on a near-real time basis with weather-based management strategies is urgently needed to meet the challenges facing the agriculture sector from climate change.

1. Background: South Asia's climatic, agricultural and food security context

Introduction

The South Asian countries, Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka, are bounded in the south by India Ocean, in the southeast by the Bay of Bengal, in the southwest by the Arabian Sea, and in the north by the Himalayas (Figure 1).

The region spans an area of 4.48 million square kilometres (km^2) (or 10 percent of the Asian continent) and accounts for a population of about 1.59 billion (http//en.wikipida.org/southasia), which is roughly 40 percent of Asia's population. The population density varies from 1099/km^2 in Bangladesh to 181/km^2 in Bhutan. In India, Sri Lanka, Pakistan and Nepal respectively, the average population densities are 365, 309, 225 and 200/km^2 (Table 1).

The topography of the region consists of mountains, plateaus, dry areas and intervening structural basins. World-famous natural sites, including the world's highest mountain (Everest) the largest mangrove swamp (Sunderbans), temperate forests, hot and cold deserts, river plains (Indo-Gangetic plains), and beautiful coral reef lagoons are located in the region. The region in general slopes from north to the east and to the west. The northwest part of the

Figure 1. South Asia.
(Source: www.freeworldmaps.net.)

Table 1. General information on South Asia.

Country	Area (km²)	Population (millions)	Density (per km²)	GDP millions of USD (2009)[1]	Per capita
Bangladesh	147,570	162.22	1099	$100,002	$551
Bhutan	38,394	0.69	181	$1269	$1832
India	3,287,240	1198	365	$1,235,975	$1122
Nepal	147,181	29.33	200	$12,615	$427
Pakistan	803,940	180.81	225	$166,515	$981
Sri Lanka	65,610	20.24	309	$41,323	$2068

region houses the Indus plains and deserts; the Greater Himalayas in the north tower over flat plains along the River Ganges. From east to west, Himalayan ranges cover a length of 2500 km and are the major source of many perennial rivers – a lifeline for millions of people in the Indo-Gangetic plains. This region also has a long coastline, running 10,000 km from Bangladesh to India and Pakistan.

A typical monsoon climate – wet summers and dry winters – prevails over greater part of the region. The southwest monsoon (June–October) brings maximum rainfall. However, some of the regions in peninsular India and also in Sri Lanka receive substantial rainfall during the post-monsoon season due to northeast monsoon activity. Also, some parts of northern end of the South Asian region receive winter rains from extra tropical systems moving west and south into these parts. Due to variation in land forms and their distance from the equator, rainfall and climate vary significantly across and within these countries. India experiences almost all types of climate, varying from extremely arid (hot and cold deserts) to highly humid. The rainfall among the countries varies from less than 200 millimetres (mm) in the desert region covering parts of Pakistan and India, to over 3000 mm in the southwest parts of Sri Lanka and Bangladesh and over 4000 mm in northeast region of India; the world's highest rainfall, above 11,000 mm at Mawsynram, is found in the region.

Monsoon and post-monsoon periods are characterized by cyclones and moderate to deep depressions crossing inland from the Bay of Bengal and Arabian Sea regions into coastal regions of India and into Bangladesh and Sri Lanka. These low-pressure systems provide the major part of the annual rainfall. In addition, rainfall associated with the movement of the monsoon trough across the Indian subcontinent also comprises the rainfall distribution over the study region. The movement of these systems onto the land mass brings copious rainfall, which means that rainfed agriculture is greatly influenced by these systems and the associated rainfall distribution.

The climate of the region varies from extremely arid to semi-arid in Pakistan, to humid to sub-humid in India, Bhutan, Nepal, Bangladesh and Sri Lanka. There is a wide variability in climate types across the countries of the region. This region also witnesses significant variations in temperature (more than –20°C in the cold desert region of Ladakh and Leh in winter to about 48°C to 50°C in desert regions of India and Pakistan and 45°C to 47°C in some plain regions during summer).

1 The $ symbol means US dollars throughout this paper, unless otherwise specified.

The region can be divided into two main land units: the ancient land mass of peninsular India and the young Himalayas and associated ranges. Sri Lanka forms a part of ancient land mass, while northwest Pakistan, the northern part of the Indian subcontinent, including Nepal and Bhutan, forms the young Himalayan range.

Several of South Asia's most important river systems originate in upstream countries and flow into the other countries. For example, the Indus originates in China and flows into Pakistan. While the Ganges originates in India, the Brahmaputra river system originates in China; both the rivers flow in to India and thereafter to Bangladesh. Some of the other major river systems – the Narmada, Godavari, Krishna and Kaveri – flow across the peninsular India. The Padma, Jamuna and Meghana are the three major rivers in Bangladesh, with innumerable branches that drain water into the Bay of Bengal. In Sri Lanka, about 103 rivers or rivulets drain water in a radial pattern across the country (SACEP 2012). The major river, the Mahaweli, caters to the needs of people in 16 percent of the country. Bhutan does not have a major river system; all of its minor rivers flow into major rivers in India or Bangladesh.

Vegetation

The monsoon rainfall pattern plays a significant role in determining vegetation type. Broadly, the following four types of vegetation based on rainfall are identified in this region:

1. Evergreen forests
2. Deciduous forest
3. Dry forests and scrubland
4. Desert and semi-desert vegetation.

About 15.6 percent of world's flora and 12 percent of its fauna are located in South Asia (State of the Environment, South Asia 2001). Approximately 39,875 species of flowering

Figure 2. Vegetation types of South Asia.
(Source: Amog, 2008 in wikimedia.org/Natural_vegetation_South_Asia.png.)

plants, 66 conifers and cycads, 764 of ferns and 6652 of higher plant species are identified in this region, according to various biodiversity sources. Similarly, the identified faunal diversity comprises 933 species of mammals, 4494 birds, 923 reptiles, 332 amphibians and 342 fresh water fish species, according to sacep.org. India and Sri Lanka is home to three of the world's 18 biodiversity hotspots: the eastern Himalayas in Nepal, Bhutan and northeast India, the western Ghats in India and the southwest Ghats in Sri Lanka. To protect endangered species in these hotspots, more than 200,000 km^2 have been reserved (UNISDR 2012).

The region's wetlands comprise flood plains, marshes, estuaries, lagoons, tidal mud flats, reservoirs, rice paddies, saline patches, fresh water marshes and swamps, over about 1.34m hectares (RRCAP 2001). South Asia is home to many wetlands. In India alone there are 25 Ramsar sites (wetlands of international importance designated under the Ramsar Convention: south-asia.wetlands.org) and 19 in Pakistan. Sri Lanka has five and Bangladesh has two Ramsar sites (SACEP 2011). While 54.5 percent of the region is agricultural land, 41.37 percent is arable (the region's arable land has decreased from 42.69 percent in 2000 to 41.37 in 2009 (World Bank data, 2010 and 2013)), the decrease being more in India and Bangladesh (59.9 to 58.6%). The availability of arable land for those dependent on agriculture has declined from over 1 hectare (ha) per person at the beginning of the 20th century to less than 0.1 ha today (GWP, IWMI 2011) .

Natural resources of the study region

Bangladesh

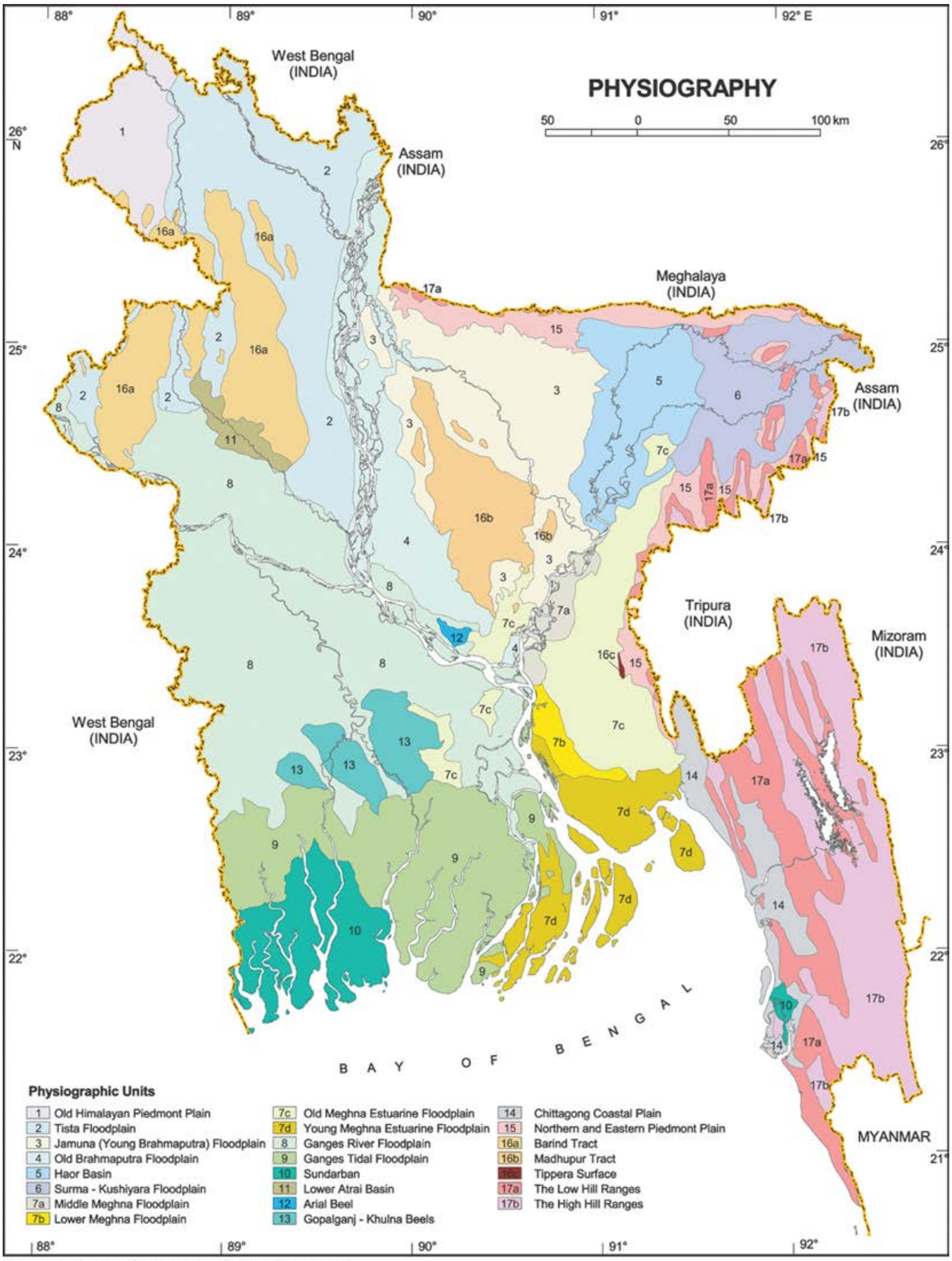
Except for the hilly regions in the northeast and southeast, the country consists of low flat lands with a good network of rivers and tributaries. The topography of the country is flat with a relief ranging from 1 to 2 metres. About 20 percent of the area is prone to tidal inundations. Due to flat terrain, rivers passing this country have extremely low gradients of 4–5 centimetres per kilometre (cm/km) for the Ganges, 6–10 cm/km for the Brahmaputra, and 3 cm/km for the Meghana (Rashid and Pramanik 1990). Most of the land area (64 percent) is occupied by the agricultural sector, while forests occupy 18 percent of the area (Figure 3).

The high growth rate of population and the country's low natural-resource base has resulted in a low land-to-person ratio, which is further threatened by natural hazards including severe cyclones and frequent floods. Agriculture, manufacturing industries and other small-scale industries are major contributors to country's economy. Among them, agriculture contributes roughly about 20 percent to GDP. However, in recent years agriculture's relative contribution has decreased while manufacturing sector's contribution has steadily increased.

The country is home to the largest delta in the world. Formed by the Ganges, Brahmaputra and Meghana rivers, it covers a huge catchment area of 1.554 million km^2. After crossing into Bangladesh from India, the Ganges and the Brahmaputra are known as Padma and Jamuna respectively. These rivers carry large quantities of sediment-laden water from the Himalayas and about 2.4 billion tons of soil is washed through these river system per year (Milliman and Meadu 1983). The country is also blessed with numerous perennial and seasonal water bodies that are locally known as *haors*, *beels*, *baors*, *khals*, *pukurs* and *dighies*.

The country's terrestrial and aquatic areas support a large number of plant and animal populations. Mangrove forests in Sundarbans present a unique environment of floral and fauna combinations. It supports 400 species of fish and 270 species of birds and 300 species of plants (MoEF 2001). Over 60 percent of the total land area in Bangladesh is cultivated, perhaps the highest percentage in Asia (Halls 1997). The country has attained self-sufficiency

Figure 3. Physiographic map of Bangladesh.

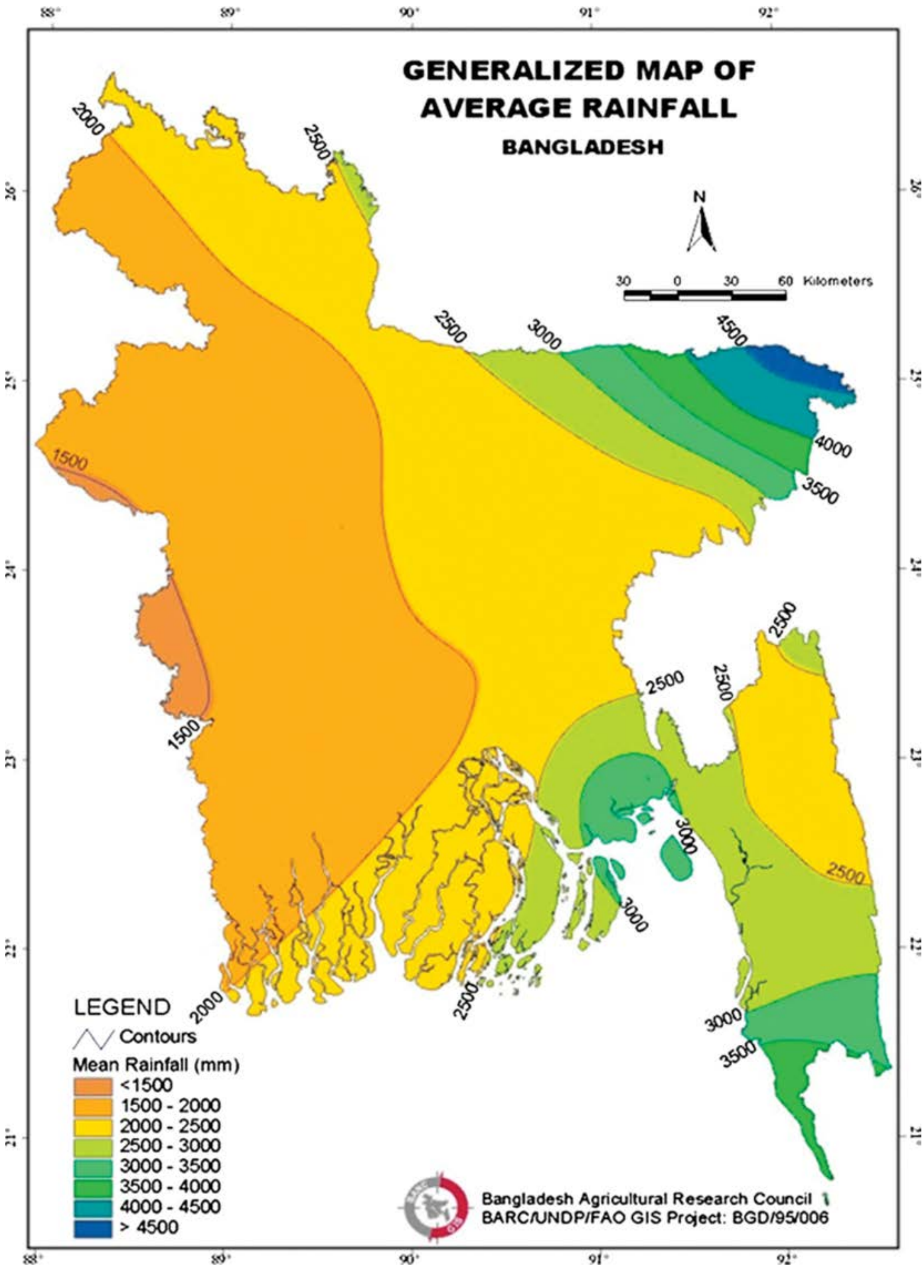


Source: Modified From *SRDI,1997; Rashid, 1991; Reimann, 1993*

in food production and has produced more than 25 million metric tons of cereals per annum since 2000 (World Food Programme 2010).

The climate of Bangladesh is characterized as warm tropical. Topographic conditions modify the distribution of rainfall (CCNDPPE 2011). The mighty Himalayas in the north greatly influence the climate of the country and make it more or less tropical. The country receives rainfall in three seasons: pre-monsoon, monsoon and winter. The main rainy season (monsoon) starts by the end of May and continues until October. The rainfall during this season varies from 1200 mm in the extreme west to 5800 mm in the east and northeast (Figure 4).

Figure 4. Average annual rainfall of Bangladesh.
(Source: Bangladesh Agricultural Research Council, Bangladesh.)



The highest recorded rainfall of 6500 mm is at Lalakhal in the northeast (Rashid 1991, MoEF 2001). In most places, more rain falls in June than in July and August. Though this region receives rainfall during pre-monsoon seasons, its contribution toward annual rainfall is less and highly variable. However, they are quite useful for the standing crops, including late *boro* (winter) rice and summer rice, and for field preparation for dryland crops. The winter rains are mostly confined to the northern part of the country, with rainfall ranging from 1 to 4 cm. Fog and mist are common from November to March. About 2 cm of dew falls in humid areas during December and January. The fog is confined to only higher ranges of hill tracts. Higher maximum daytime temperatures are recorded between the last week of March to end of April, with the values ranging from 24°C to 38°C in various parts. Average minimum temperature ranges from 11.1°C to 26.4°C (MoEF 2001).

The western part of the country records higher temperatures compared to other regions. The temperature during the hot summer season (March–June) may reach above 40°C for a period of 5 to 10 days. Temperature ranges from 20°C to 36°C during monsoon season. The mean maximum temperatures over most of Bangladesh are around 31°C and the mean minimum is around 25°C. The minimum temperature during winter season (November–March) ranges from 8°C to 15°C and can fall below 5°C in the northern part.

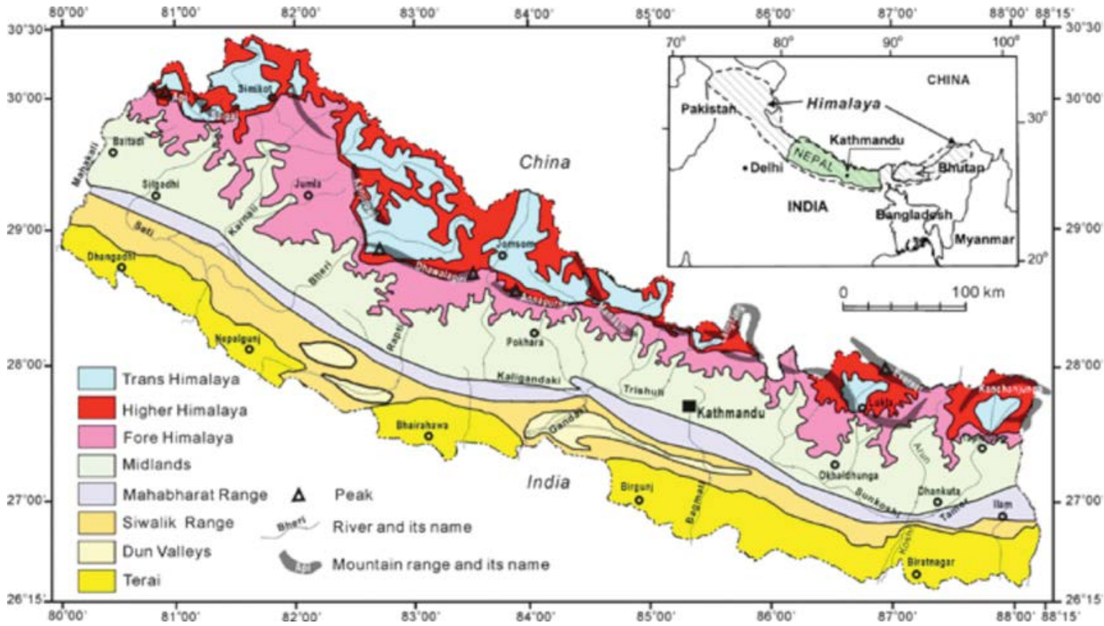
Nepal

Nepal is a land-locked country with rectangular shape, bordering India in east, west and south and China in the north. It represents a transitional mountain area, with approximately three-quarters of its land (76.9 percent) covered by rugged hills and mountains, and the rest of the area (23 percent) covered by plains (Figure 5). There are about 6000 rivers of different sizes and length. Among them around 1000 are only a few kilometres long and 100 are up to 160 km (Mahesh 2010).

The country has a population of 23.15 million (according to the 2001 census, while the 2011 census recorded 26.5 million) and the density is 157 people/km^2 (Nepal Population Report 2011). The population density varies among the ecological regions. For instance, the density is 330 and 167 people/km^2 in Terai and the hill regions respectively, while there are only 33 people/km^2 in the mountain region. The highest population density (more than 1700/km^2) is in Kathmandu district in Terai, and the lowest is (2.4/km^2) in Manang district in the mountains (Sudip Regmi 2012).

Only 2 percent of Nepal's mountain area is suitable for cultivation, whereas one tenth of the hill area is considered suitable for agricultural practices. The Terai area, which constitutes about 23 percent of the total landmass, is the major food-producing region. Land-use data indicates that 2.97m ha is under agricultural crops and 0.99m ha under non-agricultural crops,

Figure 5. Physiographic map of Nepal.
(Source: worldmapfinder.com.)



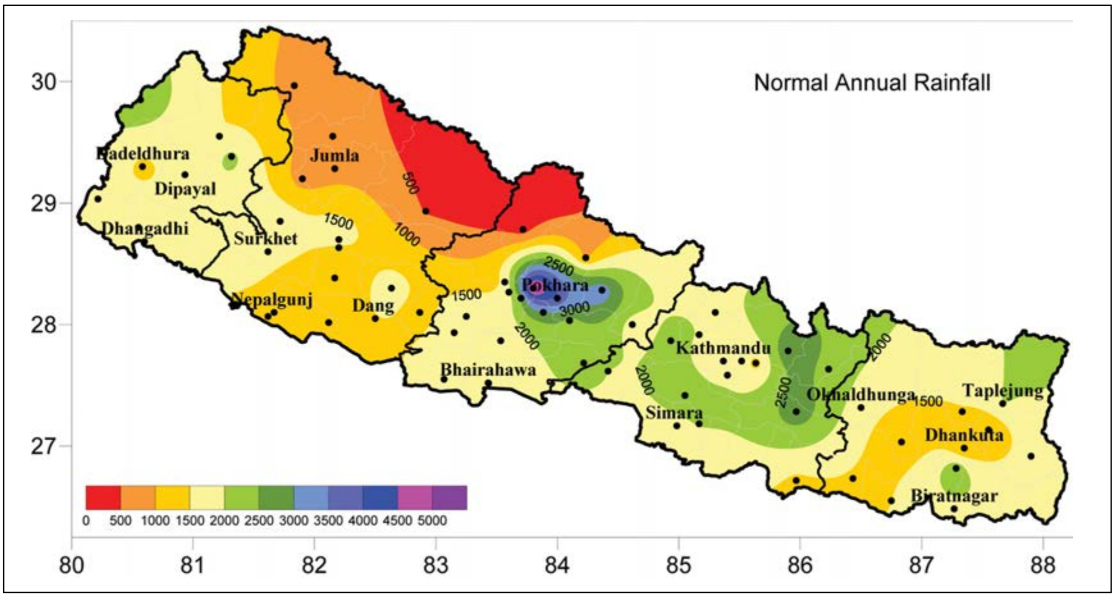
while 5.8m ha is forest and 1.7m ha pasture; 3.1m ha fall under other categories (UNFCCC 2004). About 29 percent of the total area of Nepal is covered under forests which are grouped under 4 categories: (1) tropical and sub tropical, (2) temperate and alpine broad leaved, (3) temperate and alpine conifer, and (4) minor temperate and alpine association (Stainton 1972). About 118 types of ecosystems have been identified in different physiographic zones of Nepal, with about 58 and 38 ecosystems in mid-mountain areas and highlands respectively. The country is also home to a range of wild plant species. About 7000 flowering plants, 380 species of petridophytes and 850 species of bryophytes have been reported in the country. This constitutes between 2 and 5 percent of world's flora. Nepal is also rich in wild animals. About 181 species of mammals and 844 species of birds are found in the country (United Nations Convention to Combat Desertification 2004).

Agriculture is the major source of income in Nepal, where more than 80 percent of the population depends on this sector for survival. While the country as a whole has surplus cereal production, disparity in food availability has been noticed among the different ecological zones. The contribution of agriculture, including forestry and fishery, to total Gross Domestic Product (GDP) was about 37 percent at the beginning of this century (Ministry of Agriculture and Cooperation 2001). Livestock contributes 30 percent of the total agricultural GDP (Durga 2012).

Nepal has a wide variety of climates, ranging from tropical in the southern part to alpine in the north. It has 5 climate types: subtropical monsoon, warm temperate, cool temperate, alpine and tundra. The country has 4 distinct seasons: pre-monsoon (April–May), monsoon (June–September), post-monsoon (October) and winter (November–March). Over 80 percent of the total rainfall is received during monsoon season. The country's highest annual rainfall of nearly 5200 mm is received in eastern parts (Figure 6), while the north western leeward portions (International Center for Integrated Mountain Development Climatic and Hydrological Atlas of Nepal 1996) receive less rain (250 mm a year).

The temperature sharply falls from south to north. In some areas in the plains, the summer temperature may vary beyond 40°C while it could fall below –10°C in the northern parts during winter months.

Figure 6. Annual rainfall in Nepal.
(Source: Department of Hydrology and Meteorology, Nepal.)



Bhutan

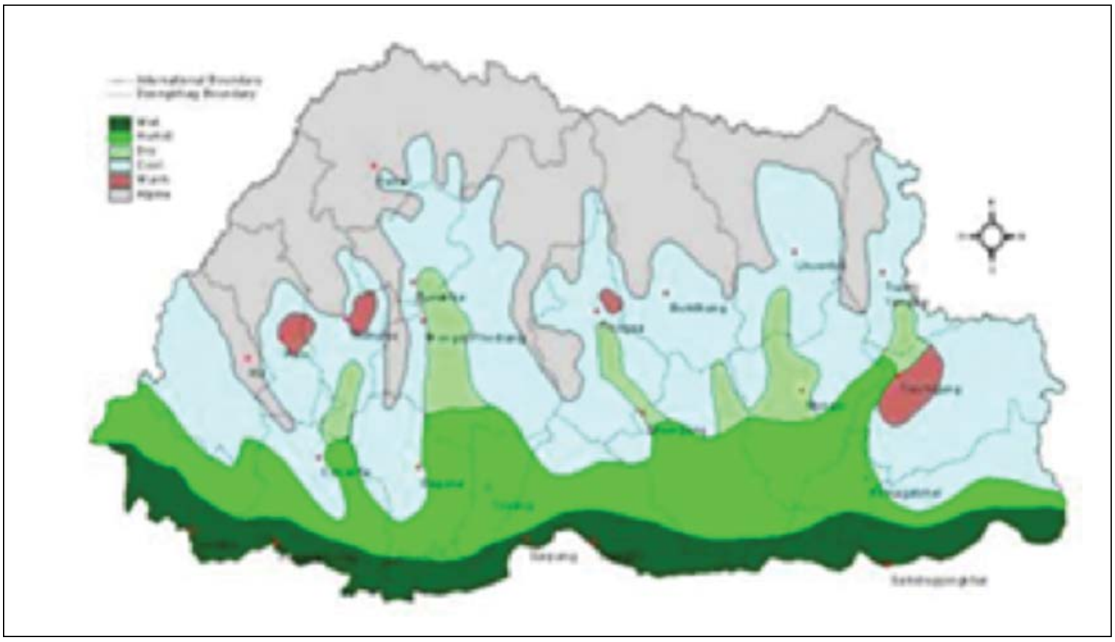
Bhutan has an area of 40,077 km^2. The terrain is mostly mountainous with extreme variations in elevations – from 100 metres (m) in south to about 7500 m in the north. Bhutan can be divided into three distinct physiographic zones: the southern foothills, the inner Himalayas, and the high Himalayas (CCNDPPE 2011). Seventy-seven percent of the area lies in the range of 600 to 4200 m altitude. It has population of about 690,000 people. Bhutan ranks in the top 10 percent of countries in the world with a large species diversity, allocating 26.3 percent of its land area to 5 national parks and 4 wildlife sanctuaries (FRA 2000). The country has been classified in to 6 agro-ecological zones (Figure 7):

1. Wet subtropical zone (150–600 m)
2. Humid subtropical zone (600–1200 m)
3. Dry subtropical zone (1200–1800 m)
4. Warm temperature zone (1800–2600 m)
5. Cool temperature zone (2600–3600 m)
6. Alpine zone (more than 4600 m).

Bhutan has three climatic zones: (a) the southern plains, which are subtropical and characterized by high humidity and heavy rainfall; (b) the central belt of flat valleys characterized by cool winters and hot summers, with moderate rainfall; and (c) high valleys with cold winters and cool summers (RGB 2006). These complex climatic conditions are experienced by Bhutan mainly due to the country's geographical location, at the periphery of the tropical circulation in the north and on the periphery of the Asian monsoon circulation in the south.

The southwest monsoon is active over the region during mid-June to September, contributing 60 to 90 percent of annual rainfall in different regions of the country. The annual rainfall varies from less than 500 mm in the alpine zone to up to 5000 mm in the wet subtropical zone in the southern border area (VIII FYP 1997). The mean annual temperature varies from 5.5°C to 23.6°C across these zones. The country experiences hot and humid subtropical conditions in the south to perpetual ice and snow in the high Alpine regions (CCNDPPE 2011). Severe thunderstorms and landslides are major natural hazards faced by the population of Bhutan.

Figure 7. Agro-ecological zones of Bhutan.
(Source: Dorji 1995.)



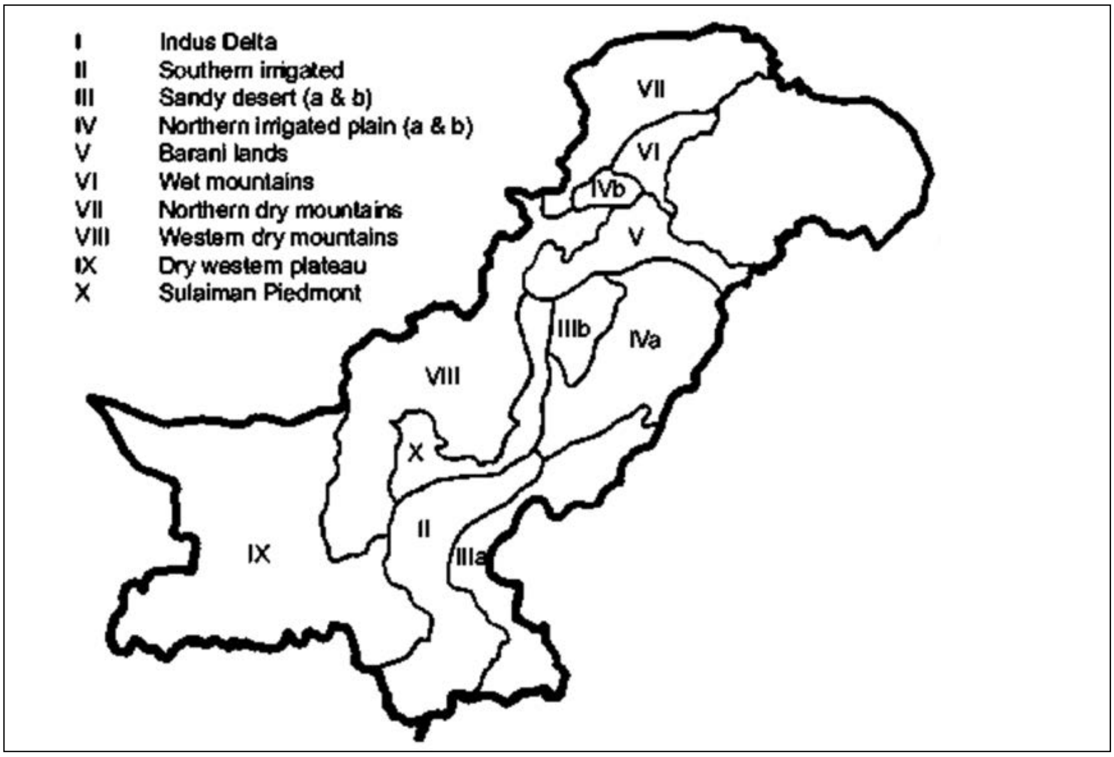
The steep slopes limit the expansion of agricultural activities. However, the natural streams with good slopes have the potential for generation of hydroelectric power and watersheds for increasing agricultural productivity. The country has 9 major watersheds; these are further divided into 42 sub- and 406 mini-watersheds (FRA 2000).

Bhutan's economy is primarily agricultural as approximately 70 percent of the population depends on agriculture for their livelihood. Since at least 69 percent of Bhutanese depend on subsistence farming, crop failure and livestock stressors affect the most vulnerable communities in the rural areas (National Adaptation Programme of Action 2012). Annual agriculture sector growth averaged 2.2 percent in real terms from 2000–2009 (FAO 2012). The share of the agricultural sector in GDP declined from approximately 55 percent in 1985 to 33 percent in 2003. Despite this, agriculture still remains the primary source of livelihood for the majority of the population (www.gnhc.gov.bt). Nearly 8 percent of the total land is used for agriculture and is being practiced as subsistence farming by growing mostly cereals (ICIMOD 2006). In recent years, strong, positive growth occurred among the high-value fruit and vegetable crops, while there has been a decline in the cereal crops that account for staple food production. The GDP contribution of maize, paddy, wheat and barley – the main food staples – has declined substantially and this decline has accelerated since 2007. Their weak performance has severely compromised overall crop-sector growth rates (FAO 2012).

Pakistan

Pakistan has a total area of 79.61m ha, out of which 27 percent (17.2m ha) is cultivated and 8 percent is covered with forests. It has a wide variety of geographical features including mangrove swamps in the south, deserts in the west, fertile plains in the central region, and snow-covered peaks in the north. The country has been divided into 10 agro-ecological regions (Figure 8): Indus delta, southern irrigated plains, sandy desert, northern irrigated plains, rainfed regions, wet mountains, northern dry mountains, western dry mountains,

Figure 8. Agro-ecological regions of Pakistan.
(Source: FAO 2002.)



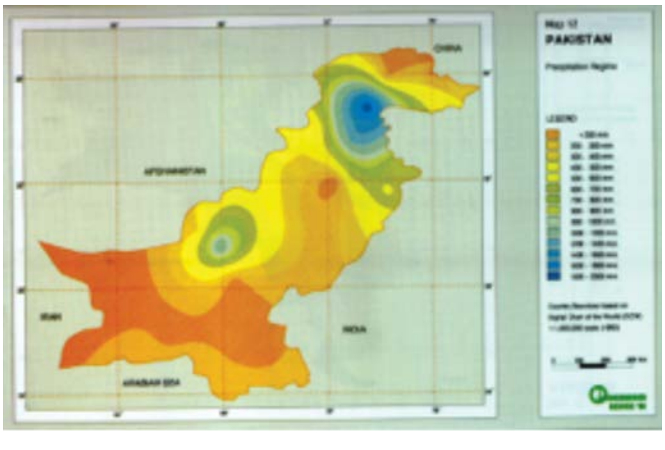
dry western plateau and Sulaiman piedmont (FAO 2002). Pakistan has a population of 135.3 million and agriculture contributes 24 percent to GDP (Afzal 2012).

Pakistan has a great variety of habitats among its various agro-ecological zones. About 6000 species of plants, 200 species of mammals, more than 650 species of birds, more than 500 species of fishes and 16 species of anuran amphibians have been identified. Food grains are grown on 56 percent of the cropped area, while cash crops are grown on 17 percent, pulses on 7 percent, oilseeds on 3 percent fruits on 2 percent vegetables and condiments on 1 percent each, and other crops, including fodder, on 13 percent area (MINFAL 1995). The majority of crops are grown under irrigated conditions. Seventy percent of irrigation is through canals and the rest from tube wells (Afzal 2012).

The country receives a significant part of rainfall through the southwest monsoon (July to September). The monsoon season is short as the country is located at the tail end of the monsoon current, with the result that the quantum of rainfall is low (Figure 9). Winter rains from western disturbances fall during January and February. Some contribution through snowfall occurs in the extreme northern regions of the country (Salman et al. 2012). The quantity of rain that falls during monsoon season varies from less than 125 mm in arid desert to more than 2000 mm in wet mountain areas. Similarly, winter rainfall varies from less than 100 mm in the southern region to above 100 mm in the wet mountain regions. Hence people in this region depend more on canals and groundwater for irrigation than their counterparts elsewhere in the South Asian region. The mean summer maximum temperatures vary from more than 40°C in most of the country, except the mountain regions (FAO 2004).

Agriculture is the largest generator of livelihoods. However, with increased industrialization and urbanization, its contribution to GDP decreased from 52 percent in 1950–51 to 21.9 percent in 2001–02 (Khan 2004). Next to agriculture, animal husbandry is an important occupation of the farming community, contributing more than 50 percent of the agricultural GDP. The country has the best livestock breed of the region. Rural poultry contributes 56 percent of total egg production. Poultry also contributes 23.8 percent of total meat production in Pakistan (Ministry of Finance 2012).

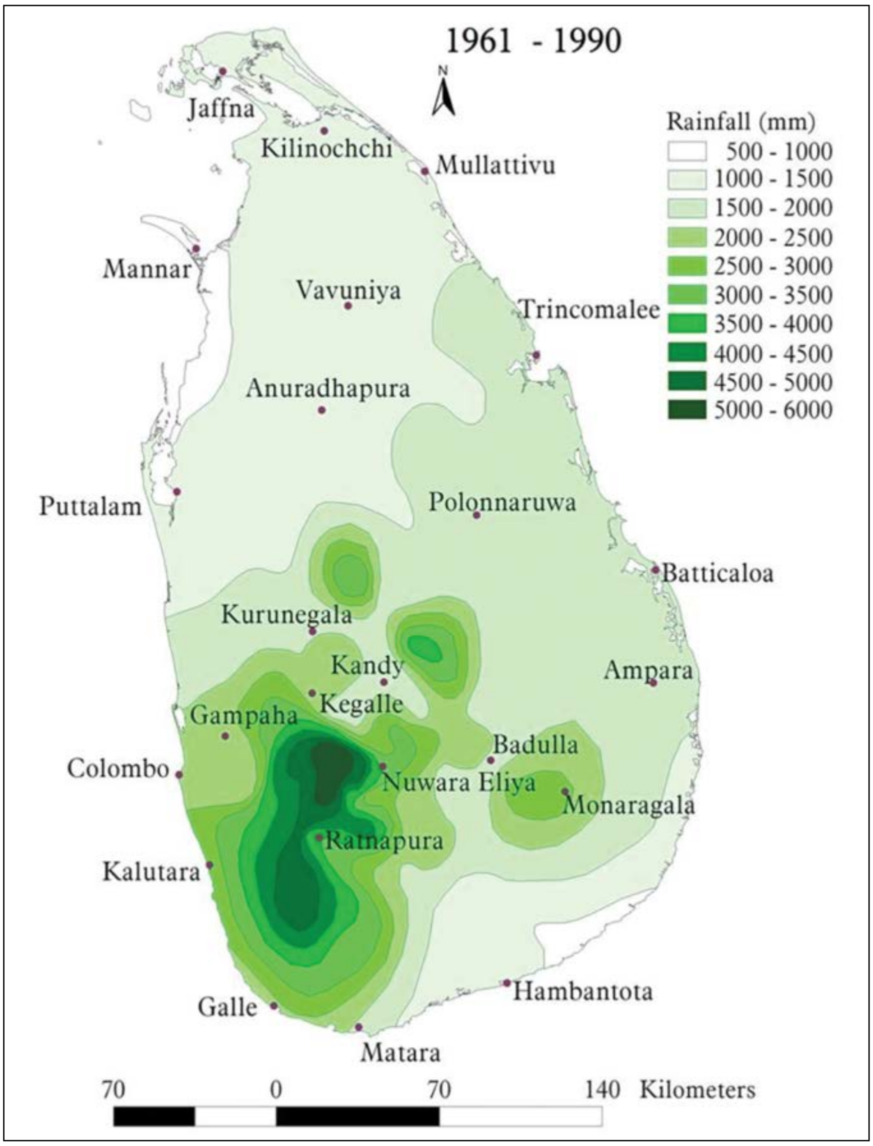
Figure 9. Mean annual rainfall in Pakistan.
(Source: UNEP.)



Sri Lanka

Sri Lanka is an island country at the base of Indian subcontinent. It has an area of about 65,610 km^2 with a population of 19.8 million. The country is broadly classified as tropical monsoon climate, which has almost constant weather throughout the year because of its proximity to equator. Sri Lanka has a varied climate ranging from semi-arid to mild temperate conditions (CCNDPPE 2011). It has been traditionally generalized into three climatic zones: dry, wet and intermediate zone, which are sub divided into 24 agro-ecological regions. The climate of Sri Lanka is divided into 4 distinct seasons: first inter-monsoon (March–April), southwest monsoon (May–September), second inter-monsoon (October–November), and northeast monsoon (December–February). The major cropping seasons, however, are the YALA, the minor growing (dry) season (March– August) and MAHA, the major growing (wet) season (September–February). Average annual rainfall is around 1630 mm, while the southwestern region records more than up to 5000 mm (Figure 10). The annual average maximum temperature is 31.7°C in the plains and 26.3°C in hilly regions. Similarly, the average minimum temperature is 24.4°C and 17.1°C in the plains and hilly regions

Figure 10. Annual average rainfall in Sri Lanka.
(Source: columbia.edu.)



respectively. Income from the agricultural sector contributes only 17% to the national GDP, while it employs around 33% of the labour force (Ministry of Environment 2008).

India

India's total geographical area is 3,287m km^2 or about 73.3 percent of the total area of South Asia. India supports about 16.2 percent of world's human population and 18 percent of its cattle population (Ramakrishna et al. 2000). It is a land of diverse topography, soils, climate and vegetation. It borders Pakistan, Afghanistan, China, Nepal, Bhutan, Bangladesh and Mynamar and has a coast line of 6083 km (CEDPA 2004). The country can be broadly divided into 4 regions: (1) the northern mountain region; (2) the great plains of the north; (3) the peninsular plateau; and (4) the coastal plains and islands. The population density varies from 202 people/km^2 on the Deccan plateau to 349 people/km^2 in the coastal plains and 456 people/km^2 in the great plains (APFISN 2006). Agriculture is the major source of income for about 80 percent of the population living in rural areas. However, agriculture's contribution to GDP has fallen from 29.93 percent in 1998–99 to 14.2 percent in 2010–11 (DAC 2011). Agricultural production in the country is strongly influenced by the southwest monsoon seasonal rainfall and also by El Niño/La Niña events (Ramakrishna et al. 2003).

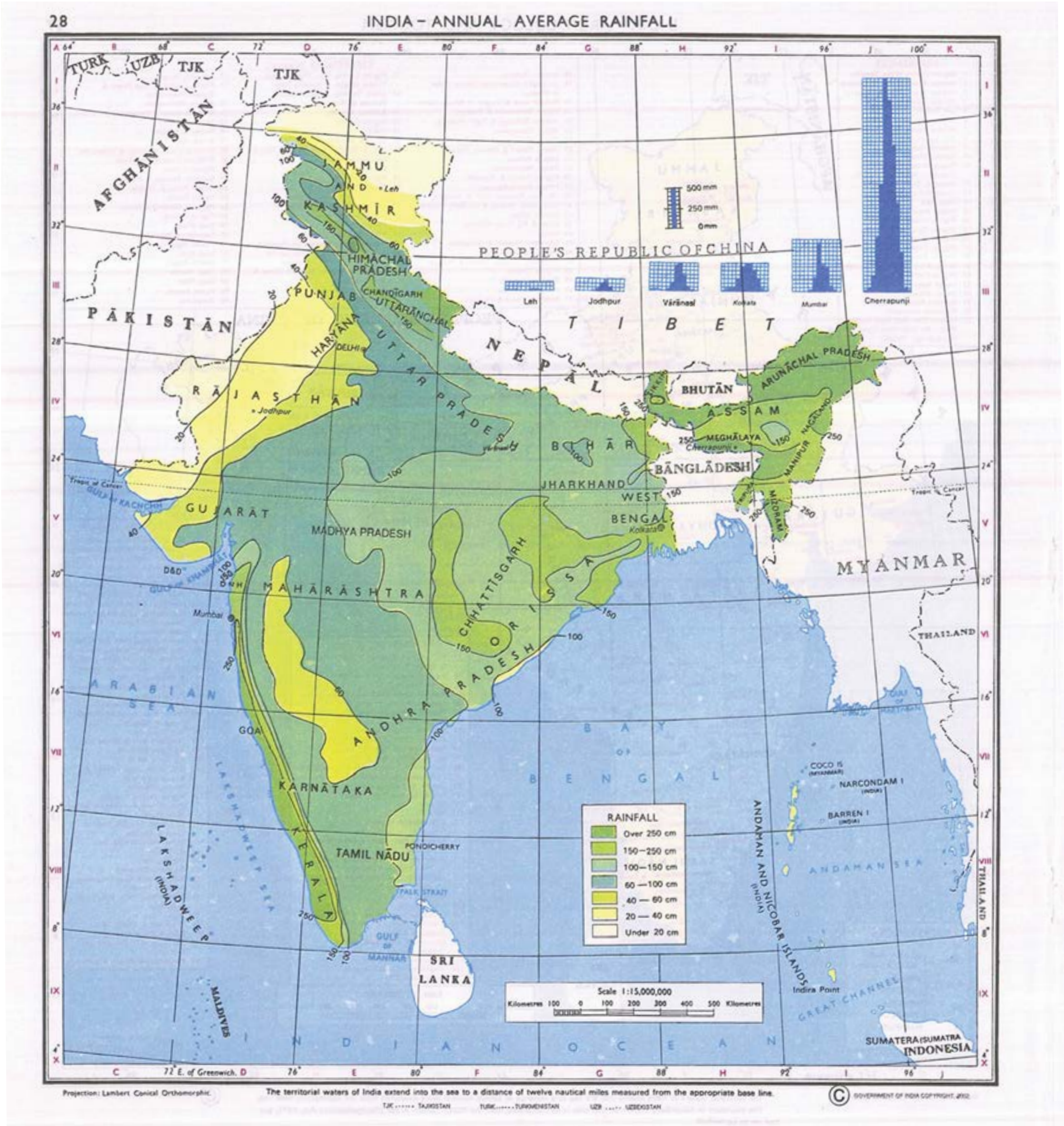
The total forest area is 51.73m ha and the spatial distribution of forests shows greatest variation from tropical rain forests to dry-thorn forests and mountain temperate forests (MoEF 1999). This figure has been revised by Forest Survey of India in its report of 2009 to 69.09m ha, including the area of 0.46m ha under mangroves (FSI 2009). About 16 types of forests have been identified. Among them tropical dry deciduous (30.2 percent) and moist deciduous (33.9 percent) are important (FSI 2009). The country is rich in biodiversity due to diverse physiographic and climate conditions. It is one of the 12 mega-biodiversity countries of the world (FAO 2000). It has 10 bio-geographical zones and about 20 percent of world's flora found in these areas. The country has approximately 15,000 species of flowering plants, 2546 species of fish, 197 amphibian species, 408 reptile species, 1224 bird species and 350 mammal species (FES 2005).

The country has been divided into 20 river basins and the average annual Indian river system is 1953 cubic kilometres (km^3) and the utilizable flow is estimated as 690 km^3 (Rakesh Kumar et al. 2005). Floods and droughts affects in some areas of the country in each year. It is estimated that one third of the country's area is prone to drought of different intensities, whereas floods affects on average up to 9m ha per year (Yedla and Peddi 2003). Ground water resources are about 325 km^3 (Shah 2001).

India is broadly a tropical country, but due to variation in elevations and latitudinal extension, almost all the world's climate types – temperate and extremely dry to extremely wet and hot – are found there (Ramakrishna et al. 2006).

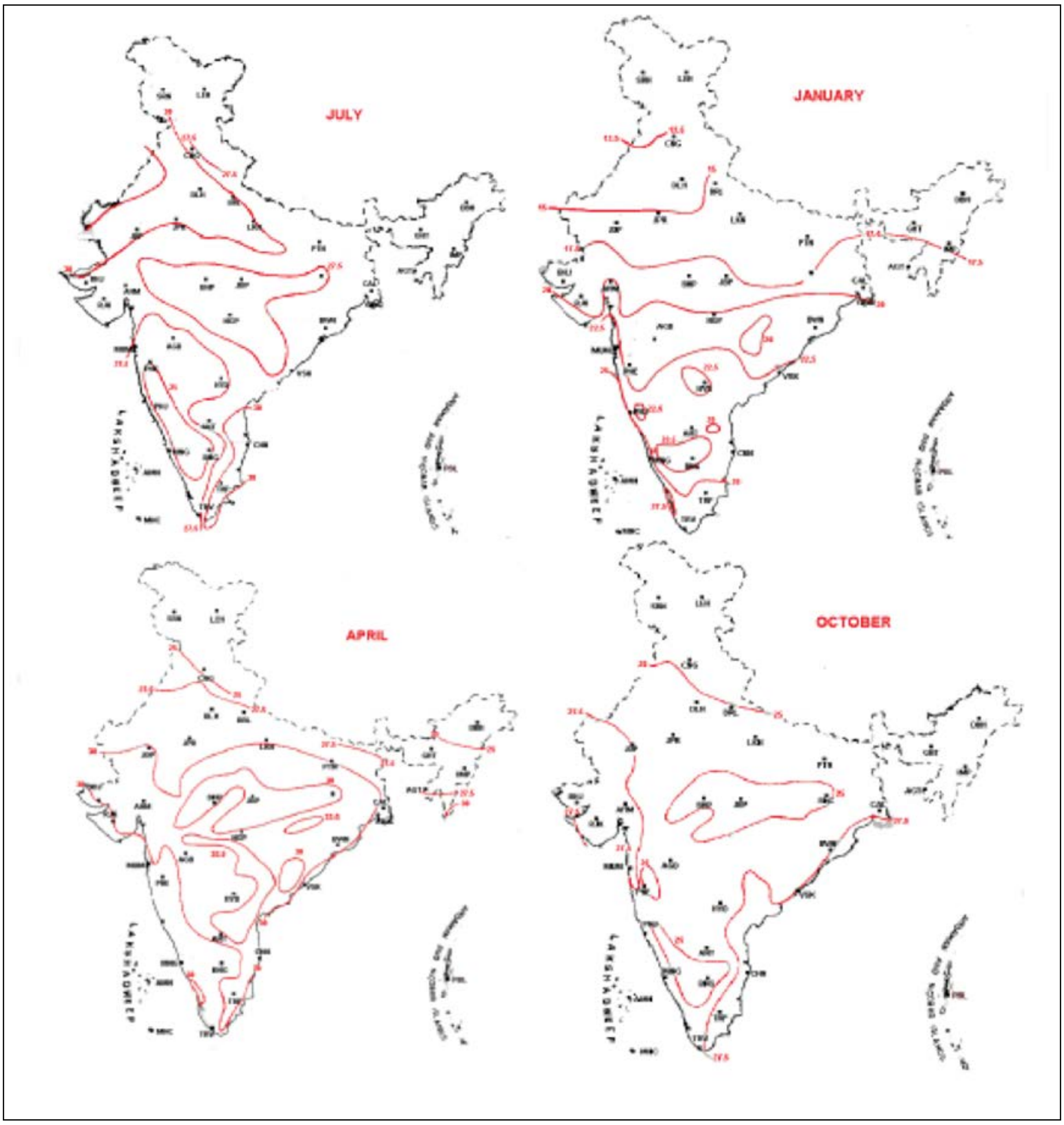
India has 4 distinct seasons: winter (December to February), summer (March to May), monsoon (June to September) and post-monsoon (October to November). Roughly 80 percent of annual rainfall is received during the southwest monsoon period. Winter rainfall from western disturbances is mainly restricted to the northern plains and hill regions, while occasionally they impact weather in larger parts of the country. Post northeast monsoon seasonal rainfall is more prominent in the peninsular India. The spatial distribution of rainfall (Figure 11) varies on average from 100 mm in the extreme western part of Rajasthan to 5000 mm in Meghalaya state in northeast India, where the world's highest rainfall (more than 11,000 mm) is recorded at Mawsynram.

Figure 11. Annual normal rainfall pattern (cm) of India.
(Source: Government of India.)



Maximum temperature is similar over a major part of the country during the southwest monsoon period, with higher values (above 45°C) being recorded in the arid region of northwest India. The temperature variability is observed more during winter than in summer season. Variability decreases from south to north in winter season. The mean maximum temperatures during peak cold season varies from 29°C in the peninsular region to 18°C in north and mean minimum varies from 24°C in extreme southern region to less than 5°C in north. The highest maximum daily temperatures of above 48°C are recorded in the north during May and June and with the arrival of the southwest monsoon, a rapid fall in maximum temperatures is noticed (Ramakrishna et al. 2000). The mean temperature distribution during 4 seasons namely monsoon, winter, summer, post monsoon is shown in Figure 12.

Figure 12. Seasonal temperature distribution over India.
(Source: India Meteorological Department 2010.)



2. Status of agrometeorological services in South Asia

Meteorological status

The status of meteorological services in various countries indicates that they are in different stages of growth. While in countries like India the progress can be categorized as good, it has picked up well in other countries like Pakistan and Bangladesh, whereas a lot is needed to be done to improve these services in countries like Bhutan, Nepal and Sri Lanka. The present status of the meteorological services in these countries is discussed below.

Bangladesh

The Bangladesh Meteorological Department (BMD) maintains a network of surface and upper air observatories, radar, satellite stations and agrometeorological observatories, etc. It has its headquarters at Dhaka with two regional centres, i.e. Storm Warming Centres (SWC), at Dhaka and a Meteorological and Geographical Centre at Chittagong. At present, weather observations are recorded at 35 meteorological observatories, 10 pilot balloon observatories, 4 radar stations (Country Report, JMA/WMO workshop, July 2010). The Meteorological Department collects 3-hourly synoptic data, 6-hourly pilot balloon data and 12-hourly agromet data in addition to daily Rawin-Sonde data. In the agromet observatories, measurements are made on soil moisture, soil temperatures, pan evaporation, solar radiation, evapotranspiration using lysimeters and bright sunshine hours, in addition to regular data collection on temperature (maximum and minimum), wind speed and direction and rainfall. The Meteorological Department maintains the database and has digitized all the 60 years of meteorological data collected at 35 meteorological observatories. The data is checked for its quality using World Meteorological Organization (WMO) guidelines. The BMD issues 4- and 12-hourly weather forecasts for river and sea navigations, 10-day agrometeorological forecasts and long-range (1-month) weather forecasts.

Floods are common in Bangladesh as the Ganges, Brahmaputra and Meghana rivers all discharge huge quantities of river waters from upstream regions and a Flood Forecasting and Warning Centre (FFWC) was established in 1972. During the monsoon period, daily flood bulletins, special flood reports, monthly flood reports and flood mapping are prepared and issued through mass media communication system. Similarly, during dry season, water levels in reservoirs and rivers besides rainfall are monitored regularly by the FFWC.

Nepal

Weather observations are maintained by Department of Hydrology and Meteorology (DHM), which has operated under the Ministry of Environment since 1962. They monitor all the hydrological and meteorological activities in Nepal. The Hydrology Division monitors water level and discharge of different rivers and lakes. It also monitors snow and glacier lakes, etc. The Meteorology Division is responsible for collection and analysis of weather data for agricultural planning, water resources, climate change, climatic atlases and preparation of crop calendars. It maintains a nationwide network of 337 rain-gauge stations, 154 hydrometric stations, 20 sediment stations, 68 climatic stations, 22 agrometeorological stations, 9 synoptic stations and 6 aero-synoptic stations (Country Report, JMA/WMO workshop, July 2010). Data are made available to users through published reports, bulletins and computer media outputs. Wireless system connects Khatmandu to 54 stations across Nepal for climatic and hydrological data whereas Global Telecommunication System (GTS) links DHM to the global meteorological community.

At present, the availability of weather information and the issuing of weather forecasts is rather inadequate. Except for few basic parameters like precipitation and temperature, the infrastructure for collecting data on wind regime, evaporation, sunshine and radiation is too limited and scattered to be of real use for operational forecasting. Most of the equipments need modernization and replacement. Further, there is need for the weather services to work round the clock to assist in providing timely weather warnings, as natural disasters cost some 500 lives on average every year. Since 2010 the Finnish government had come forward to finance the development of weather observation services under the Institutional Cooperation Instrument (ICI). It aims to modernize the technology of weather services in Nepal, and train Weather Department personnel. The ICI for regional cooperation in Himalayan region (for Nepal and Bhutan) is funded by 1m euros for the period 2013–15.

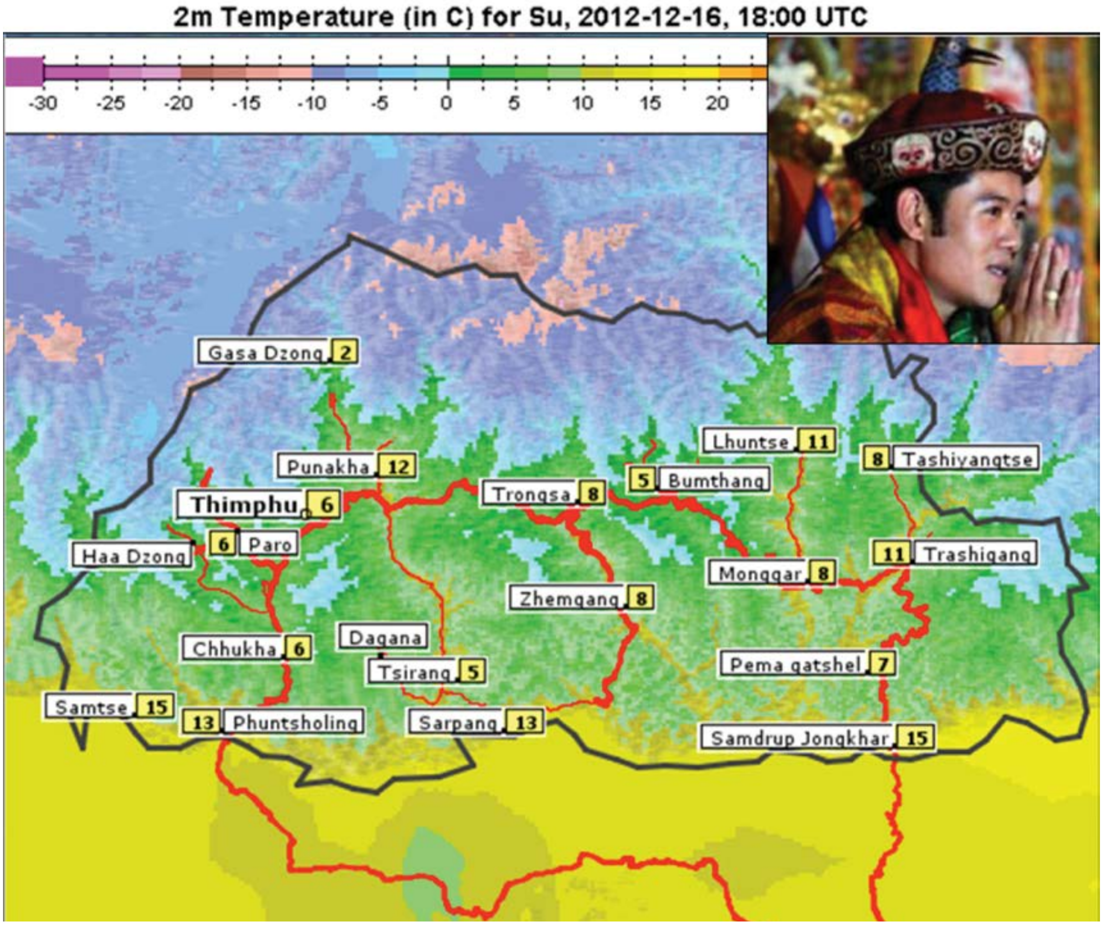
Bhutan

The Meteorology Department in Bhutan is a part of the Department of Hydro-Met Services under Ministry of Economic Affairs. Before 2007, the mandate of weather forecasting was under the Ministry of Agriculture and Forests, although all meteorological stations were under the Department of Hydro-Met Services (Initially it was called the hydro-meteorological services division under the Department of Energy, MoEA). The division was upgraded to a full department in December 2011 and the mandate for weather and seasonal forecasting has been transferred to this newly created Department of Hydro-Met Services (DHMS) under the Ministry of Economic Affairs. At present the department operates and maintains a network of 24 river gauging stations, 90 meteorological stations, 9 sediment sampling stations and 15 flood warning stations. However, most of these stations are located in the central and southern parts of Bhutan with almost none or limited climate monitoring stations in northern Bhutan (NAPA 2012). Further only two observations per day are recorded at most of these stations, manually. There is often a long delay in data transmission (NAPA 2012). The Department provides daily weather forecasting using satellite images given by the Indian Meteorological Department, NOAA, Thai met, etc., and numerical weather prediction products generated by them to give considerably accurate (80 percent) weather forecasts (Yendra 2012). Currently, the daily weather forecasting information to the Bhutan Broadcasting Service (BBS) is given by Meteorology Division for widespread transmission to people in the country. These efforts are needed to be strengthened further by the government and also by BBS, to create more interest and confidence in the forecasts by the farmers and people for operational use.

Being a country with a limited land available for cultivation, Bhutan focused on increasing agricultural productivity through increased efforts on strengthening the agricultural extension activities. Since the launching of the first five-year plan in 1961 and the establishment of the Agricultural Department, agricultural research and extension activities progressed gradually. During the following plan periods, substantial improvement for farmers had occurred with agricultural and limited weather information. By the 1980s the whole country was covered by the extension network. Extension service is currently the main source of information to farmers. The Virtual Extension and Research Communication Network (VERCON), a conceptual model of FAO, has been adopted by the Ministry of Agriculture. This enabled them to link research and extension (R&E) communities and using new information and communication technologies (ICTs) to improve communication of crop and weather information to the farming community.

Through a project sponsored by the Austrian Development Agency (ADA) in 2010–11, the MetGIS had started issuing weather forecasts for Bhutan which have been successfully adapted to its climate conditions (Figure 13) (Spreitzhofer et al. 2012).. This encouraged MetGIS to intensify its activities to become an invaluable help to support the daily forecasting activities of the Meteorological Division of the Department of Hydrometeorological Services (DHMS), the National Weather Service of Bhutan.

Figure 13. An example of a 2-metre temperature forecast for Bhutan issued by MetGIS.
(Source: MetGIS.)



It has also been trying successfully to generate weather forecasts on special occasions. These efforts are helping to enhance and strengthen agricultural advisory services.

In the next five-year plan, the DHMS is to work with the UNDP and will be planning to expand the meteorological station network and will also be collaborating with the community information centres to provide more reliable and easy access to weather information to their village groups. Currently (July 2013) officials from Meteorology and Hydrology Divisions of the Department of Hydro-Met Services are developing a road map and to develop work plan for next 5 years which can be executed for the effective implementation of the South Asian Association for Regional Cooperation (SAARC) Monsoon Initiative Programme, with support from the Ministry of Agriculture and Forests and other concerned ministries as part of the National Working Group on Monsoon (NWGM).

Pakistan

The Pakistan Meteorological Department (PMD) maintains 92 surface observatories (RBSN), 55 RBCN, 6 GSN and 50 Automatic Weather Stations (Country Report, JMA/WMO workshop, July 2010). There are about 500 rain gauge stations spread across the nation. Soil moisture and groundwater levels are monitored at 23 stations. In addition to the above, agrometeorological observatories are recorded at 32 stations. These observatories are used for aeronautical and marine forecasts, flood forecasts, farmers' weather bulletins, public utilities such as town planning, construction, crop insurance claims, and air pollution monitoring. The weather data collected at the observatories are checked by the officer-in-charge of the station before they are transmitted to National Meteorological Communication Centre. The data are further scrutinized by the Data Processing Centre before being stored. The PMD offers professional training in various branches of meteorology through its Institute of Meteorology and Geophysics located at Karachi (PMD, 2009). The PMD uses Meso-Scale Model Versions (MM-5) for numerical weather forecasting and is planning to use High Resolution Model (HRM) with a grid length of 7 km for further improvement of its efforts. Different weather products developed by PMD are (a) 24 hours Numerical Weather Prediction (NWP) charts – maximum and minimum temperature, daily total rain and snowfall, and (b) rainfall and 3-hourly NWP charts – precipitation, cloud cover, mean temperature, 200 millibar (mb) height wind, 500 mb height wind, 500 mb vorticity, 700 mb height winds, 700 mb vorticity, 850 mb height and winds, besides 850 mb vorticity and sea level pressure (WMO 2013).

Sri Lanka

Meteorological activities in Sri Lanka started in the mid-1860s under the aegis of the survey department, with the establishment of a network of rain gauges. The country maintains 45 meteorological stations spread across the island. This includes 5 RBCN, 20 GSN, and 20 manned stations. In addition, 33 Automatic Weather Stations (AWS) are presently operating for weather forecasting and disaster mitigation activities (Country Report, JMA/WMO workshop, July 2010). Aviation meteorological activities were initiated in 1946, whereas the Department of Meteorology and its Agrometeorology Division were established in 1948 and 1973 respectively, under the Ministry of Environment and Natural Resources. The National Forecasting Centre receives AWS data at 10-minute intervals. Upper-air observations are recorded only at 3 stations. Radar and radio sonde observatories are maintained in different parts of the country in collaboration with government and research institutes. Nearly 500 rain gauge stations are scattered over the island; these are manned by the government and by individual organizations. The department had established a satellite receiving centre to receive High Resolution Picture Transmission data from the National Oceanic and Atmospheric Agency in 1996 and satellite data from the India National Satellite System in 1998. From March 2005 the department is designated as the lead agency for Tsunami Early Warning (Ministry of Disaster Management and Human Rights 2006).

Currently the Sri Lanka Meteorology Department operates under the purview of the Ministry of Disaster Management and Human Rights (MDMHR). The daily rainfall data collected is thus being sent to this ministry’s data centre at the end of each month. The daily rainfall data from 60 locations is also collected over phone for the formulation of the weather forecast issued by Met Department. The National Meteorological Centre also provides weather forecasts and weather warning to the public, domestic aviation and shipping. The computer division of Sri Lanka Meteorological Department archives all the data collected over the country and the necessary climate statistics are computed and updated on regular basis. Quality control of the weather data is done at many levels: for coding errors, checking for spatial and temporal consistency across neighbouring stations and checking against self-recording charts (WMO 2013).

India

The India Meteorological Department (IMD) is the oldest department in the region. The first meteorological observatories were established by the British East India Company at Kolkata in 1785, Chennai in 1796 and Mumbai in 1804. Following the disastrous cyclone that hit Kolkata in 1864 and the failure of monsoon during 1866 and 1871, the then government of India established the India Meteorological Department in 1875 with H. F. Blanford as its Meteorological Reporter. Besides establishing one of the first Agrometeorology Divisions in the world at Pune in 1932, the IMD has generated huge data sets with respect to rainfall and other parameters in its archives, with some of the rainfall records dating back to 1844. The IMD had started Farmer's Weather Services in 1945 in the form of a weather bulletin broadcast on All India Radio.

Currently the weather observations network of IMD contains 82 RBSN, 33 RBCN and 20 GSN and 528 manned stations, 550 AWS (likely to increase to 675) and 324 ARG (likely to increase to 1350 in near future). It also has 261 Agromet Observatories and 41 ET (Lysimeter) stations, 43 soil-moisture stations, 330 pan-evaporation and 75 dewfall observatories (Country Report, JMA/WMO workshop, July 2010). Currently there are 709 surface meteorological observatories of different categories under the six regional meteorological centres of the IMD (WMO 2013). At present, the IMD is functioning under the Ministry of Earth Sciences (MoES).

Based on the recommendations of an expert committee in 1984 for the creation of a centre for medium-range weather forecasting in India, the National Centre for Medium Range Weather Forecasting (NCMRWF) was established in India in 1988. Thanks to the efforts of former Prime Minister Sri Rajiv Gandhi, India's first supercomputer for weather research was procured in the early 1989. This led to the operationalization of the National Centre for Medium Range Weather Forecasting (NCMRWF) in India in 1990. This had given a boost to the efforts in India, towards further improvement of the agricultural advisory services in India. A detailed report on the status of agricultural advisory services in India (compiled by Dr L.S. Rathore, IMD director general) is enclosed separately in the annex below.

3. Agricultural advisory services in the South Asian region

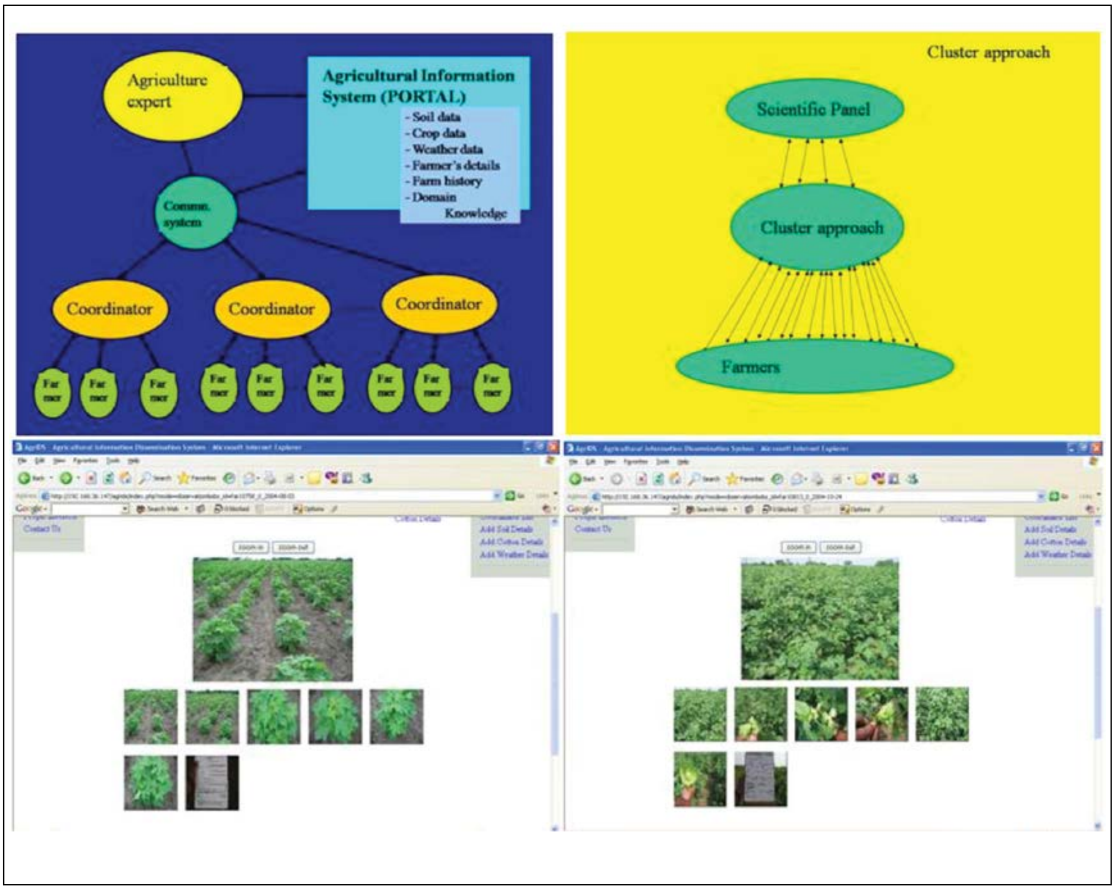
The importance of weather forecasts for effective agricultural operations was well recognized by all the countries in the region. Pre-independence India, inclusive of Pakistan and Bangladesh, initiated farm advisories in the mid-1940s, and in collaboration with the Indian (then Royal) Council of Agricultural Research special weather forecasts were issued for farmers. A separate division of agrometeorology was established by the IMD as early as 1932 to study weather-plant interactions and to prepare climate-based agricultural planning activities. With the advancement in global computing systems (i.e. the development of supercomputers) in the 1980s, and the launching of weather observatory satellites, the forecast accuracy for different regions increased considerably.

However, information for farmers on a 48- to 72-hour lead time is essential for planning any agricultural operations. Focus on this issue has increased and IMD in addition to issuing farmers' weather forecasts on a regional basis, began to initiate short- and long-range weather forecasts. Supplementing these efforts, with the introduction of the first supercomputer for weather services in India, the NCMRWF began activities on medium-range weather forecasts in the country and launched the agromet advisory services in India in 1991. Improvements in weather forecasts using latest weather forecasting models like MM-5 and Weather Research Forecast (WRF) enabled the country to provide weather forecasts for smaller grid regions (50 × 50 km for MM-5 initially and at 22 × 22 km presently and 9 × 9 km for WRF). Further, to meet the needs of researchers, a high resolution (0.5° × 0.5° lat/long) gridded daily rainfall data set for the Indian region was developed, utilizing the daily rainfall data of 6076 stations across the country, for the period 1971–2005 (Rajeevan and Bhate 2009). However, interpolation of the grid values was carried out using majority of those stations (3500 station data), which had a minimum 90 percent data availability during the period of analysis. The gridded area considered for interpolating the rainfall data was from 6.5°N to 37.5°N and 66.5°E to 101.5°E, covering major part of South Asia and beyond, using standard methodology for interpolation. The gridded data set was found to be more representative of the conditions experienced over the region and is being used for many meteorological research and analysis purposes.

To empower individual farmers with weather-based crop management information by providing agricultural advisory through the Internet, using a VLC, a pilot study in Andhra Pradesh by the International Institute of Information Technology (IIIT) at Hyderabad (Krishna Reddy 2004) known as e-Sagu (electronic-based support for cultivation). This innovative approach (Figure 14) has the potential to be put to use in other areas for effective utilization of agro advisories by the farmers. Under this approach, digital photos of farmers' fields taken by a VLC (an educated child in the village or a farmer with Internet knowledge) are sent to experts at headquarters by email or by CD for advice, and within a short period the advisories from headquarters are transmitted back to the VLC. These advisories are then made available to the farmers by VLC through internet or mobile SMS or explained to the farmers for immediate action. Such personalized approaches have not yet been reported anywhere else, including in other parts of India.

To cater to larger groups of farmers, e-Sagu classifies problems by region and a 'cluster approach' is adopted in which a group of farmers experiencing a common problem are provided with an answer applicable to that group. Through this cluster approach, the number of issues (many of them common) that technical advisors must address is lessened, while each farmer receives an individual reply corresponding to his problem. In this fashion, a larger

Figure 14. Agriculture Information System, Cluster approach and e-Sagu.
(Source: Krishna Reddy 2004.)



group of farmers can be served by a smaller advisory unit. There is a great potential in this approach if put to larger use by adding more weather components into the system.

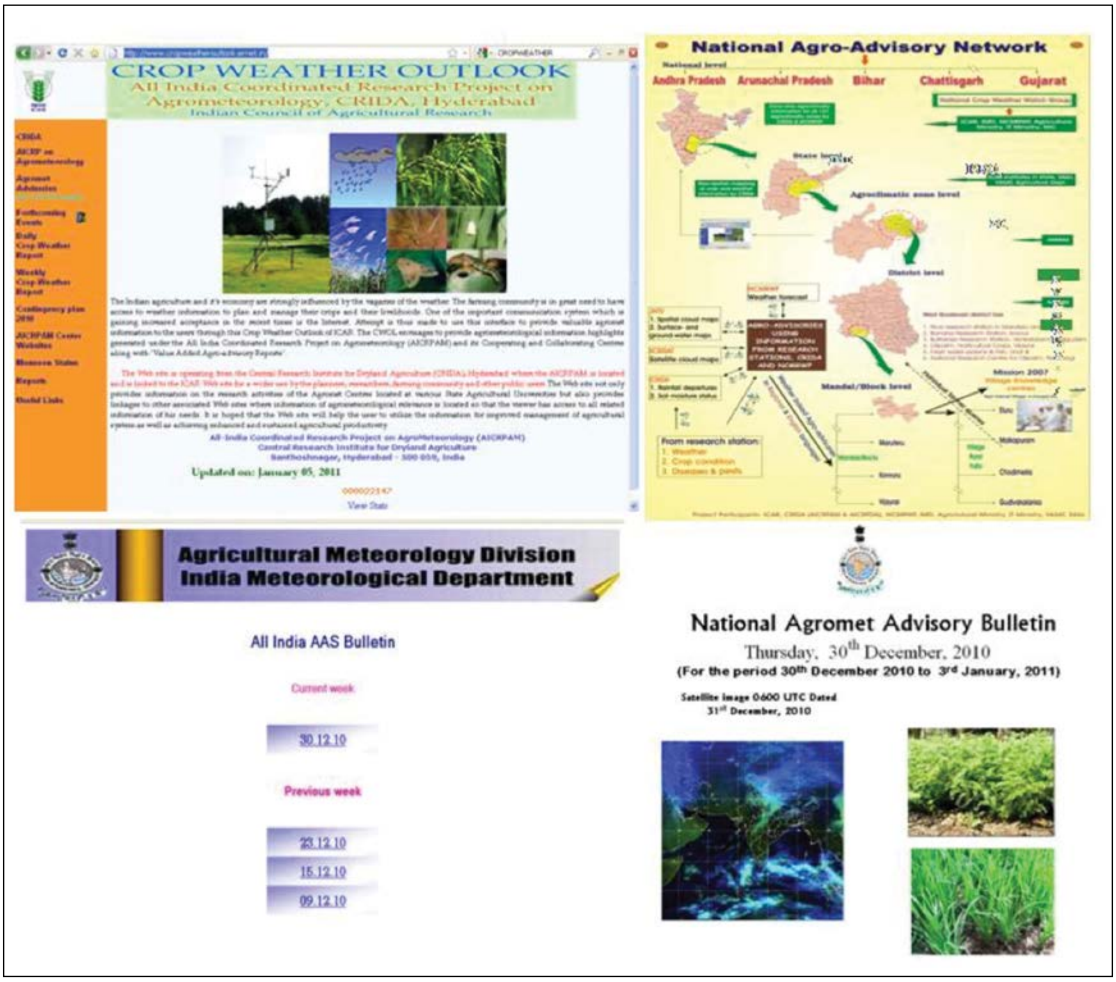
Another innovative approach that adopted by the state government of Andhra Pradesh in India was the involvement of progressive farmers in the villages for dissemination of advisories. Under this programme, one progressive farmer is selected in a village and he is paid an incentive of 1000 rupees per month. His job is to train other farmers in the village with modern technologies and to pass crop management information on to them. The idea here was that farmers are more receptive to their clan (another progressive farmer) than an outsider, and also because they are always available in the village for advice. This practice is also not yet reflected widely across the whole country. Perhaps the results from such innovative steps would be more beneficial to the farming community if the agricultural weather information/ advisories are also disseminated through such intermediaries in a participatory mode, through the active involvement of local talent.

These efforts were supplemented by the Indian Council of Agricultural Research (ICAR) through the establishment of teaching and research on agrometeorology in the state agricultural universities (SAUs) in 1980s. It also established an All-India Coordinated Research Project on Agro-Meteorology (AICRPAM) with a network of 25 centres across various SAUs, and with its coordinating unit at the Central Research Institute for Dryland Agriculture (CRIDA) in 1983. The research findings on the crop-pest-weather relations conducted by the various agricultural research institutes of ICAR and by the agricultural universities through AICRPAM made it possible to supplement the efforts of IMD and NCMRWF to provide valuable weather-based advisories to the farmers across the country.

Furthermore, the AICPRAM project at CRIDA, besides regularly providing weather information and agricultural advisories through its 25 centres across the country, is also providing weekly contingency crop plans for the different meteorological sub-divisions in the country. It also initiated a website, cropweatheroutlook.org, where this information is regularly uploaded. These contingency plans were also uploaded in the main ICAR website. In addition, many of the SAUs have started issuing district-level agricultural advisories in their states and are also providing sub-regional advisories for their states in their university web sites. Looking to the need for a coordinated approach, a plan for a national agro-advisory network, involving all local and regional agencies working together, even at district or block level, has also been proposed (Figure 15).

All these efforts across the country have helped in improving the agricultural advisory services in India to a great extent and in attempting to extend the agricultural advisories from regional to district level with attempts to extend further to block level at some places like Tamil Nadu, Orissa and Gujarat. In Tamil Nadu, the Regional Integrated Multi-Hazard Early Warning System for Asia and Africa (RIMES) has assisted an agro-advisory project in Tanjavur and Nagapattanam Districts using European Centre for Medium-Range Weather Forecasts (ECMWF) ensemble forecasts (15 days along with IMD and WRF outputs), with the Expert Intelligence System of RIMES to provide agro-advisories to farmers. Similar efforts were also made by IRI in Tamil Nadu (Hansen et al. 2001). A unique system was designed and successfully run by ITC in reaching soybean farmers through 'E-Choupal'

Figure 15. Crop weather outlook from the National Agro-Advisory Network and IMD Agromet websites.



(e-market) where the farmers not only receive weather and crop management information but also market information to sell their produce (Figure 15). Attempts are currently on to reach individual farmers also through SMS, providing them weather advisories. Nearly 600,000 farmers are receiving this service across the country mainly by IMD and also by various agencies.

More details on these and other efforts being made in India are provided in the annex.

Similar efforts were initiated in other countries in South Asia region, with at least some progress. In all these countries, governments and non-government agencies have been helping farmers with weather-based advisories. The details of the agricultural advisory services rendered by various countries in the South Asian region to their farmers are as follows.

Bangladesh

a) Meteorological and agrometeorological services

The Bangladesh Meteorological Department, through its network of weather observatories spread across the country, issues weather forecasts regularly for the benefit of various users. For agricultural crop planning, one-month long-range forecasts are issued. For regular agricultural operations, a weekly agromet forecast is issued. The information provided under this weekly forecast includes the rainfall departure (percent) maps of the previous week, cumulated rainfall forecast for the current week, and the extended outlook for the next week (Figure 16). It also provides information on highlights of the weather during last week and advisory for the current week. The advisory also gives the information on the expected evaporation and sunshine in the current week. In addition, the information on expected variations in temperature is also available in the forecast. However, there is very little specific information included in the crop management advisories (what the farmers should do) utilizing the forecast. An agricultural advisory society was established in 1989 as a civil society organization with the aim of helping farmers with sustainable production practices and efficient irrigation water management strategies. It had extended its activities to 642 villages with about 100 other NGO partners to reach large number of small farmers with technological developments and better crop varieties.

Bangladesh is a land of many rivers. Because the Ganges (Padma), Brahmaputra and Meghana discharge huge quantities of run-off, resulting in floods and sediment throughout the country, flood forecasting assumes significance in this region for better agricultural planning. Based on field observations, as well as information gathered from neighbouring countries, the Flood Forecasting and Warning Centre (FFWC) of Bangladesh issues daily flood forecast bulletins and flood maps. RIMES is also supporting these efforts through rainfall based flood forecasting using ECMWF deterministic forecast data (RIMES 2013). This information is sent to various government departments, including the prime minister's office. It is also disseminated through radio, TV, newspapers, NGOs and others, for the benefit of the public and farmers. The FFWC also displays flood information in its website. Special flood reports, monthly flood reports, annual flood reports and flood mapping are also issued by FFWC.

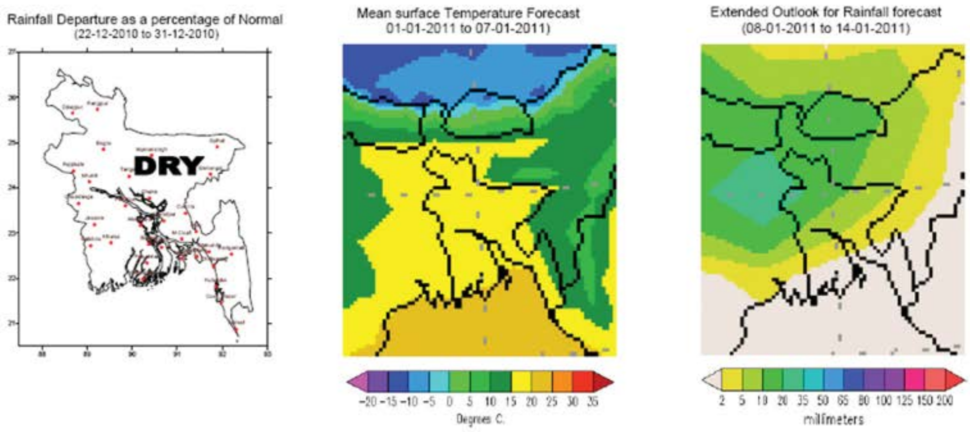
In addition, in order to minimize the colossal loss of life and property caused by all manner of natural disasters – including floods, cyclones, storm surges, droughts, earthquakes – in the South Asia Region, SAARC was initiated in 1985. As weather has no geographical and political boundaries, it was deemed necessary to establish a common centre to carry out research and mitigation on the disasters for sustainable socio-economic developments in SAARC countries. Under this programme, timely and accurate forecast of natural disasters

Figure 16. Bangladesh weekly agromet forecast.
(Source: BMD.)

Government of the Peoples' Republic of Bangladesh
Bangladesh Meteorological Department
(Meteorological Headquarter)
Meteorological Complex, Agargaon, Dhaka-1207.

Agm-3 (2)/2011/1 Dated: 02.01.2011

Forecast for the period: 01.01.2011 to 07.01.2011



Highlights:

Free water loss during 22.12.2010 to 31.12.2010 was averaged to 2.26 mm per day.
Sunshine hours during 22.12.2010 to 31.12.2010 were averaged to 7.08 hours per day.

Advisory for the period from 01.01.2011 to 07.01.2011.

Free water loss during the 1st week of January 2011 is expected to be between 2.00 to 2.50 mm per day.
Bright sunshine hour during the 1st week of January 2011 is expected to be between 5.50 to 6.50 hrs per day.

Weather:

- Seasonal low lies over South Bay.
- Weather is likely to remain mainly dry with temporary partly cloudy sky over the country with a chance of light rain/drizzle at one or two places over the northern part of the country during this period.
- Moderate to thick advection fog may occur over the country during the middle of this period.
- Mild cold wave may sweep over Rajshahi, Rangpur and Sylhet divisions and the regions of Jessore, Satkhira, Kustia and Mymensingh during the end of this period.
- Fungicides should be applied to potato crops to save it from late blight disease.
- Maximum temperature over the country is likely to fall by 2°-6° C and slight rise in minimum temperature is expected over the country during this period.

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has been given top priority. Further, a SAARC Meteorological Research Centre (SMRC) was established in Dhaka to conduct more research on weather forecasting aspects.

The major functions of the SAARC centres are (1) to undertake research on understanding monsoon; (2) climatic characterization for agricultural planning; (3) collection of data on special weather phenomena; and (4) to develop network system among the member-countries for free flow of data and to provide processed products to the members. In October 2003, SAARC reviewed its mission, adding research on climate change. This is carried out in association with the national meteorological services and research institutions in SAARC region. The centre has three divisions: (1) theoretical; (2) synoptic; and (3) documentation. It is supported by 8 scientific officers and 10 research assistants.

b) Status of agricultural advisory services

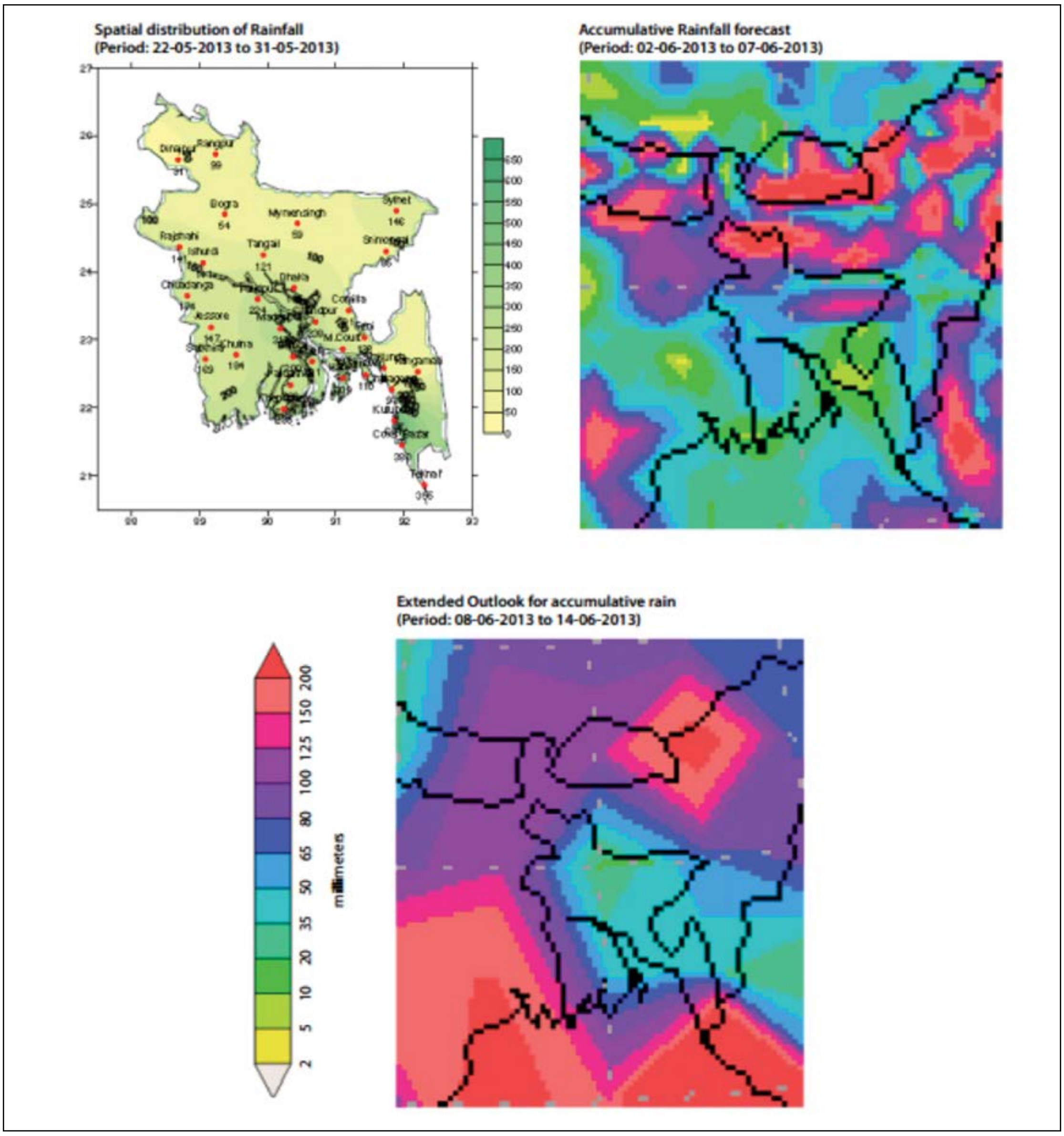
BMD issues agricultural advisory bulletins every 10, 30 and 90 days, based on the crop situation and the weather forecast. The 30 and 90 days agro-advisory bulletins are meant for planning purposes for the government departments associated with agriculture. These advisories are meant to help the farmers to make good decisions regarding irrigation schedules, sowing, spraying of pesticides, and fertilizer applications. The primary users of these bulletins are the Ministry of Food and Disaster Management, the Department of Agricultural Extension. Bangladesh's Agricultural Research Council, and other national research councils. BMD maintains a close collaboration with the national Agricultural Research Centre on the development of agrometeorological products for use in these bulletins. These bulletins are disseminated through news, Internet, websites, telephone and fax. Feedback from the farming community is obtained through the Department of Agricultural Extension. The network of agrometeorological observatories under the BMD is manually operated and conventional instruments are used.

However, the need for strengthening the agricultural meteorological services in Bangladesh has been realized and efforts were made in this direction by the Ministry of Defence. At its request, the WMO in 2009 reviewed the existing agrometeorological services in the Bangladesh Meteorological Department, including the scientific and other resources available and had developed recommendations to improve the existing agrometeorological station network and strengthen their capabilities for analysing weather information in respect to crop growth and to provide timely agrometeorological information and agro advisories to the farming community. WMO had come up with six major issues to lay focus on concerning the development of the agrometeorological services in Bangladesh: agrometeorological observation system; agrometeorological data management; weather forecasts and agrometeorological products; agrometeorological advisory services; information communication; human resource development and capacity building. As a result of these efforts there has been an increased focus on technical improvements in weather data acquisition and analysis, along with the use of modelling approaches and use of WRF outputs in weather forecasting (Basnayake et al. 2009, Met Office Hadley Centre 2010). The various types of weather forecasts currently being issued by the Bangladesh Meteorology Department include (Islam et al. 2013):

- Daily district weather forecast
- Weekly agrometeorological forecasts (Figure 17)
- Long-range weather forecast for one month
- Long-range forecast of three months for the Ministry of Agriculture, Bangladesh Agricultural Research Council, Department of Agricuture Extension and other departments
- Heavy rainfall warnings
- *Kalbaishakhi* (severe thunderstorm) and other squall warnings
- Coldwave and heatwave warnings

Efforts to update the agromet division with Automatic Weather Stations and to improve the computer capabilities for database management, adding latest computing technologies like crop simulation studies, increase the use of GIS and remote sensing in its research planning and other related agrometeorological activities, are being taken up to modernize agricultural advisory systems.

Figure 17. Weekly weather forecast by BMD.
(Source: Islam et al.)



Bhutan

Agriculture in Bhutan is strongly dependent on the weather conditions induced by the Himalayan mountain ranges and the southwest monsoon circulation. In spite of these important considerations, the country still does not have an adequate weather forecasting system for farmers and depends strongly on the global forecasts by the external sources, which do not meet their needs adequately. The Bhutan Hydrometeorological Service attempts to a certain extent to take care of the measurement of weather and maintenance of the climate records, besides assisting the water and agricultural sectors. As a country with rugged terrain, the organization of weather observation services and technical equipment are generally not of international standard in Bhutan. The Gross National Happiness Commission (GNHC) of the Royal Government of Bhutan has funded Asian Disaster Preparedness Centre (ADPC) Bangkok to enhance the capacity of the Hydrometeorological Service and the climate modelling by the Hydromet Services Division (HMSD) of the Department of Energy. The aim of this programme is to design and initially establish a 24/7 National Weather and Flood Forecasting and Warning Center for providing reliable weather and flood forecasting and early warning of related hydrometeorological hazards (ADPC 2010). Many private organizations also are attempting to provide weather advisories in this region, besides the national weather service, including MetGIS.

The UNFCCC has also proposed (in 2006) a National Adaptation Programme of Action (NAPA) project (over three years, with an input of $420,000) through which it has attempted to assist Bhutan set up a Weather Forecasting Office (WFO) under the Ministry of Agriculture, with necessary equipment and manpower to provide weather and seasonal forecasts for supporting production decisions of the farmers, and provide an agrometeorological early warning system against inclement weather conditions and provide special advisories at different production stages. Under this programme, they plan to set up one automated and telemetered synoptic station in 20 *dzongkhags* (districts) to provide three-hourly synoptic data; a link to the Global Telecommunication System (GTS) of the WMO to receive regular synoptic data; and a limited area weather model, such as WRF or MM5 to operationalize a computer-based weather forecasting system, similar to those in operation in the neighboring South Asian countries. They are also planning to train the scientific personnel in running these models and generate reliable agricultural weather forecasts and to train farmers and extension workers in the proper use of such information products and advisories for efficient weather based crop management. This NAPA programme is one of eight finally agreed upon (with a current proposed fund of $4.410 million) for implementation (NAPA 2012). Recently the Finnish government embarked on a financial and technical support to Bhutan and Nepal to improve their weather services and to train the weather service officials to enhance their capabilities, under the ICI programme (Ministry of Foreign Affairs 2013). This programme is likely to come into operation during 2013–15. The aim initially is to enable three-day forecasts in this region. Currently the extension programs of the agricultural ministry tries to reach the farmers with weather information and advisories, still in its infancy.

Pakistan

a) Agrometeorological services

In Pakistan, responsibility for the preparation and dissemination of agromet advisories primarily lies with Pakistan Meteorological Department (PMD). It monitors weather through a dense network of surface observatories, agromet observatories and upper-air observatories, and issues forecasts mainly from the farmers' point of view. As the rainy season is mainly restricted to July and August, information on rainfall forecast is crucial for rainfed crops. Droughts, which often critically hamper agricultural production, are common in the country. The PMD closely monitors the drought situation through its National Drought Monitoring Centre (NDMC). It has a separate section exclusively devoted to farmers' weather forecasts and agromet bulletins. Similarly, separate units for aviation, floods, marine weather, synoptic and seismological monitoring are operating within the purview of PMD. The PMD also has a research wing that has specialized in developing numerical weather prediction models and providing forecast for the next 72 hours for smaller regions, as well as good infrastructure to train staff.

The agromet service has been in operation since 1988 with the establishment of the National Agro-Met Centre at Islamabad and 5 Regional Agromet Centres (RAMC) at Rawalpindi, Quetta, Faisalad, TanJodan and Usta Muhammad. The functions of NAMC are (1) managing the agrometeorological network; (2) processing and analysing the data for improving the agricultural production; (3) developing location-specific crop-weather relationships, weather-based crop yields and production estimates for central planning and food production strategies at the national level (Jawed Iqbal 2010).

The responsibilities of RAMC are: (1) monitoring local agrometeorological conditions; (2) development of regional crop-weather studies; (3) liaison with agricultural institutions to determine the local requirements and research priorities; and (4) processing of agromet information on regional scale for onward transmission to NAMC, Islamabad (PMD 2013).

Considerable advances have been made by PMD on the collection and archiving and analysis of weather and climatic data and their conversion into weather-based agro-advisories. A perusal of the NAMC web pages (Figure 18 and 19) shows the type of information provided, which includes current week's precipitation analysis: the probability of rainfall and percent departure. Besides these, the other information provided includes soil moisture analysis, region-wise agromet advisories, seasonal precipitation and evapotranspiration (ETO), climate outlook for the next 10 days with respect to temperature, rainfall and soil moisture, forecast for farmers, separate forecast to cotton crop, crop vegetation index maps, weekly forecast and crop report, crop calendars, etc. Based on the analysis with respect to rainfall and soil moisture, the advisories are issued and disseminated through www.pakmet.com.pk and other electronic and print media. Advisory bulletins are issued at monthly, fortnightly and 10-day intervals.

b) Infrastructure facilities

i) Agro-Meteorological Field Units (AMFUs) and collaborating organizations

Pakistan has a well-distributed network of recording rain gauge stations (80 Nos) and Automatic Weather Stations (50 Nos) spread across the country (Figure 20), and a large number of participating organizations/departments collaborate to run the Agrometorological Advisory Service.

Figure 18. National Agromet centre website of Pakistan.

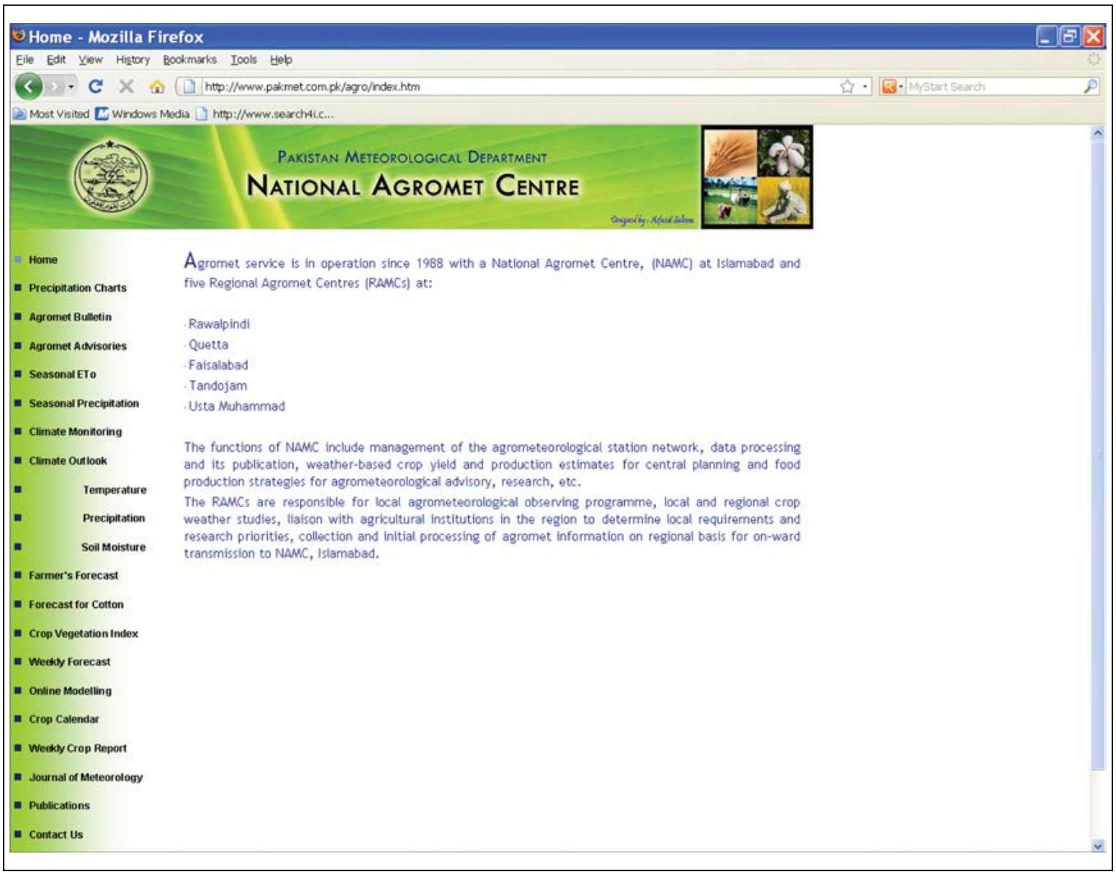


Figure 19. Agromet advisory bulletin of Pakistan (monthly and 10 days).

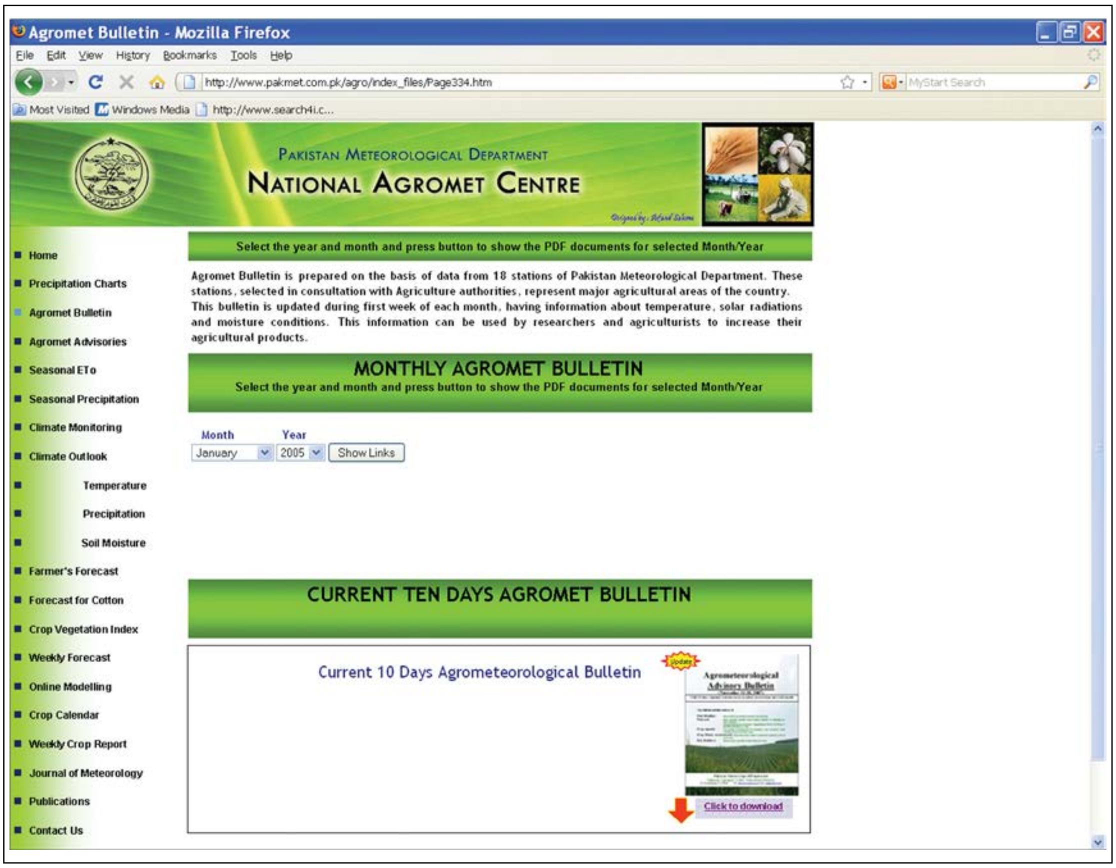
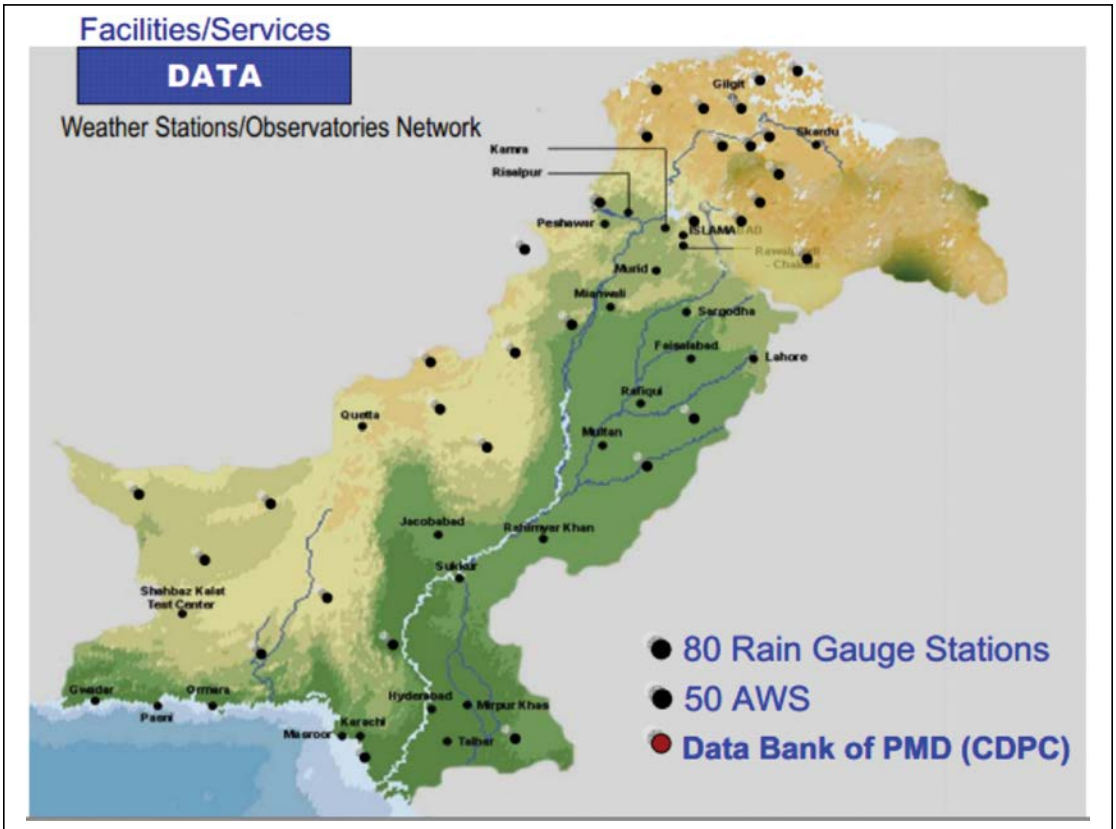


Figure 20. Rain gauge and AWS network in Pakistan.
(Source: PMD.)



Currently there are 26 Agro-Meteorological Field Units (AMFUs) established in Pakistan covering all agroclimatic zones of the country (Table 2). The following departments/

Table 2. List of AMFUs covering all agroclimatic zones of Pakistan.

Province		AgroMet Field Unit	Agroclimatic Zone	Longitude (°E)	Latitude (°N)	Elevation (m)
Khyber	1.	Peshawar		71.58	34.02	232
Pakhtunkhwa	2.	D. I. Khan		70.92	31.82	173
Punjab	3.	Kamra	Potohar Plateau of North Punjab	72.40	33.82	303
	4.	Murree	Potohar Plateau of North Punjab	73.41	33.85	2167
	5.	Ranwalpindi	Potohar Plateau of North Punjab	73.10	33.62	507
	6.	Jhelum	Potohar Plateau of North Punjab	73.72	32.93	232
	7.	Mundi B.D.	Irrigated Plains of Punjab	73.45	32.55	253
	8.	Noor Purtha	Irrigated Plains of Punjab	71.90	31.97	182
	9.	Surghoda	Irrigated Plains of Punjab	72.67	32.05	187
	10.	Jhang	Irrigated Plains of Punjab	72.53	31.47	152
	11.	Faisalabad	Irrigated Plains of Punjab	73.10	31.43	183
	12.	Lahore	Irrigated Plains of Punjab	74.40	31.52	213
	13.	Sahiwal	Irrigated Plains of Punjab	73.16	30.95	172
	14.	Okara	Irrigated Plains of Punjab	73.43	30.80	181
	15.	Multan	Irrigated Plains of Punjab	71.43	30.20	122
	16.	Khanpur	Irrigated Plains of Punjab	70.68	28.65	87
Sindh	17.	Rohri	Irrigated Plains of Sindh	68.90	27.70	66
	18.	Larkana	Irrigated Plains of Sindh	68.20	27.53	174
	19.	Padidan	Irrigated Plains of Sindh	68.13	26.85	46
	20.	Dadu	Irrigated Plains of Sindh	67.78	26.72	38
	21.	Mir Pur Khas	Irrigated Plains of Sindh	69.13	25.67	15
	22.	Tandu Jam	Irrigated Plains of Sindh	68.33	25.25	
Baluchistan	23.	Quetta	Arid Plains of Balochistan	66.88	30.25	1600
	24.	Usta Muhammad		66.20	28.10	
	25.	Uthal	Irrigated Plains of Balochistan	66.37	25.48	45
	26.	Skarand		68.16	28.80	

organizations are working as participatory agencies under Integrated Agromet Advisory Service launched by the Pakistan Meteorological Department:

- Public Agricultural Universities in four provinces and the Global Change Impact Studies Centre, Islamabad
- Pakistan Agricultural Research Council (PARC)
- Provincial Agriculture Departments
- National Agro-Met Centre (NAMC).

Being a multi-disciplinary and multi-institutional project, the Agrometeorological Advisory Service (AAS) involves all stakeholders and functionaries, as an integral part of various agencies: National Forecasting Centre for Agriculture (NFCA), NAMC, National Drought Monitoring Centre (NDMC), RAMC and RDMC, District Agro-Met Offices. The network of AWS and rain gauge stations and their interlinkages are depicted in Figure 21. This project is being implemented through five-tier structure to set up and provide different components of the service spectrum. It includes meteorological (weather observing and forecasting), agricultural (identifying weather sensitive stress and preparing suitable agro-advisories using weather forecasts (Zaraimedia.com 2012), extension (two-way communication with user) and information dissemination (media, information technology, telecom) agencies (Figure 22). The weather data recorded by district level AWS, surface observations and field

Figure 21. Collaborating organizations and linkages under integrated agromet advisory services.

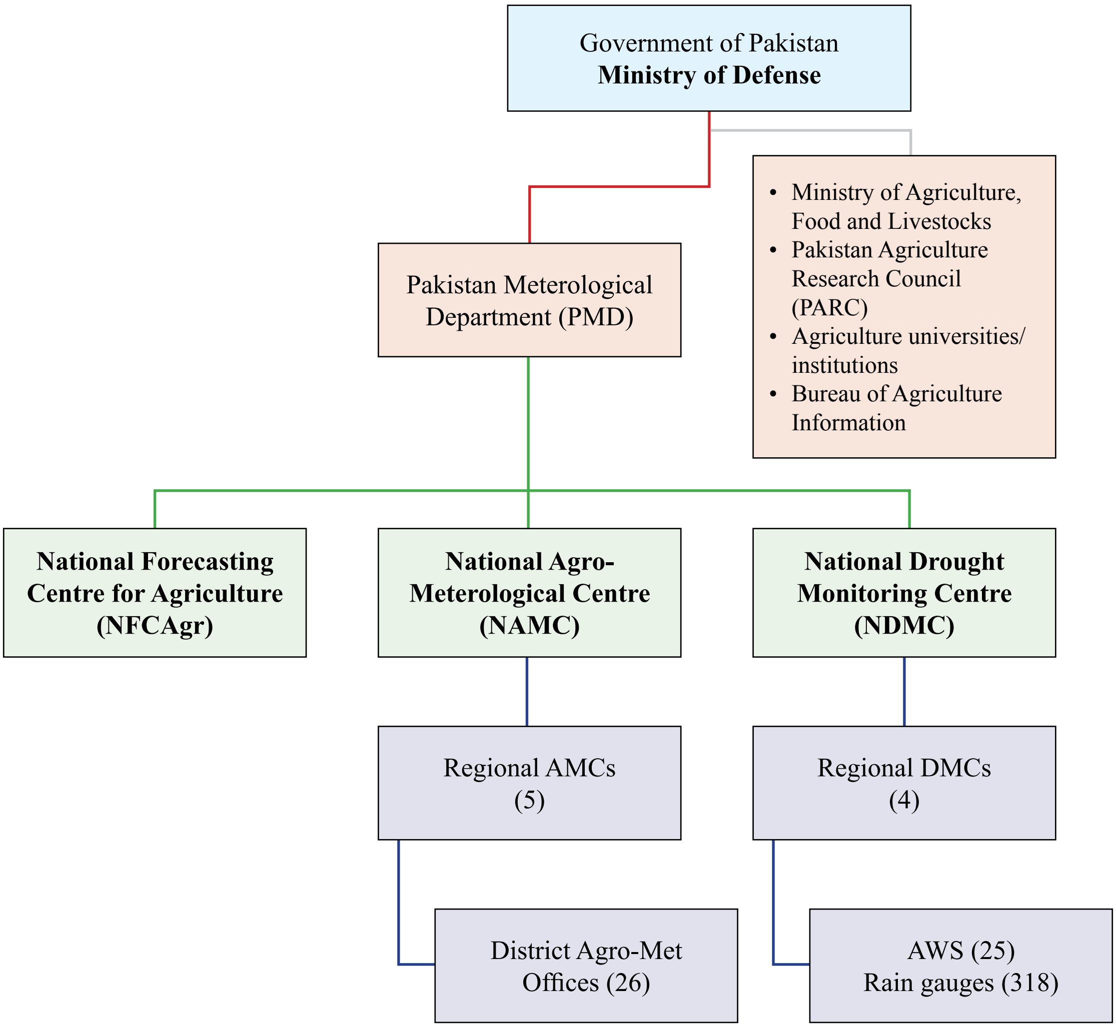
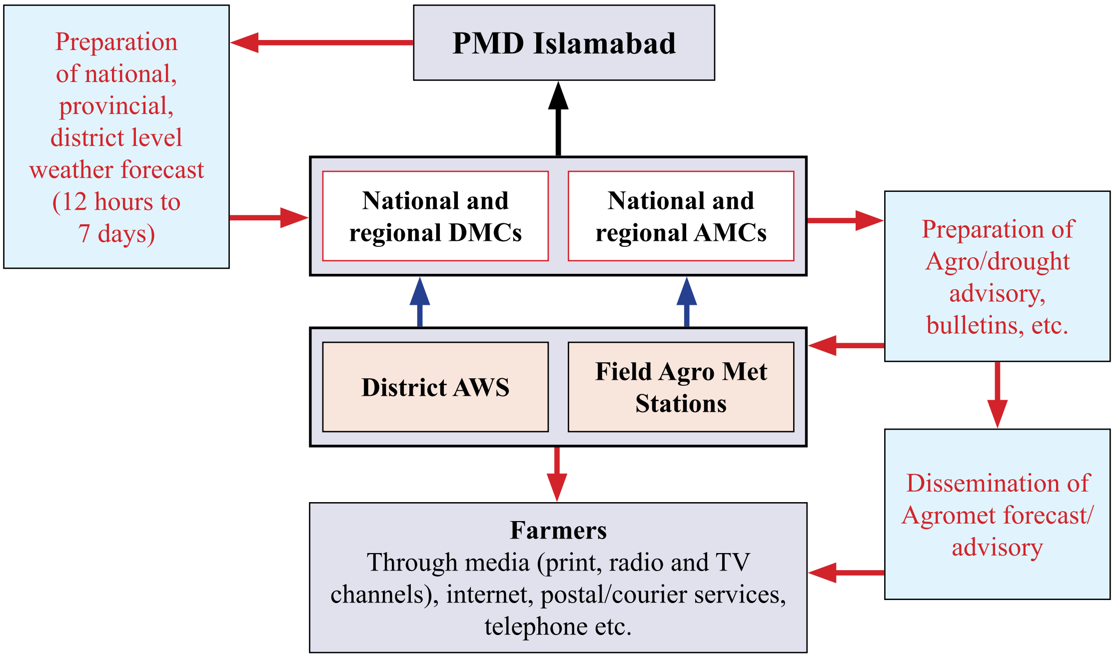


Figure 22. The flow chart for the district-level agromet advisory service system.



agromet stations are being used for preparation of district-level forecasts for between 12 hours and 7 days by PMD and send the same to national and regional AMC and DMO for the preparation of weekly and 10-day bulletins for dissemination to regional AMCs and DMCs, and to farmers online and through the mass media.

ii) Agrometeorological services: weather forecasting system for AAS

The PMD is using conventional methods as well as a Numerical Weather Prediction (NWP) approach to forecasting the weather. Using the conventional method, the forecaster attempts to predict future changes in the state of the atmosphere from its initial state, taking into account both theoretical as well as experience of the weather situation. During this exercise, the forecaster also analyses and studies upper-weather charts, and uses weather radar and APT images.

The PMD uses MM5 for numerical weather forecasting and is also preparing to use HRM with a grid length of 7 km in near future. The HRM is developed by DWD (the National Meteorological Service of Germany).[2] The models have been installed at Research and Development Division of PMD. DWD data is being used in HRM for the numerical weather forecasts, to improve the weather forecasts issued by PMD and also enhance the accuracy of weather predictions.

iii) Agrometeorological advisory bulletins

From the reports on crops raised by farmers, the crop conditions, the incidence of pests and diseases supplied by provincial agricultural departments, the RAMC regularly advise the farming community through electronic and print media, on issues like sowing time and irrigation schedules (Khan and Hanif 2007). Detailed weather data and the forecast are also available on internet at the site http://www.pakmet.com.pk .

2 Deutscher Wetterdienst.

Below are the types of information included in a typical agromet advisory bulletin prepared by the PMD:

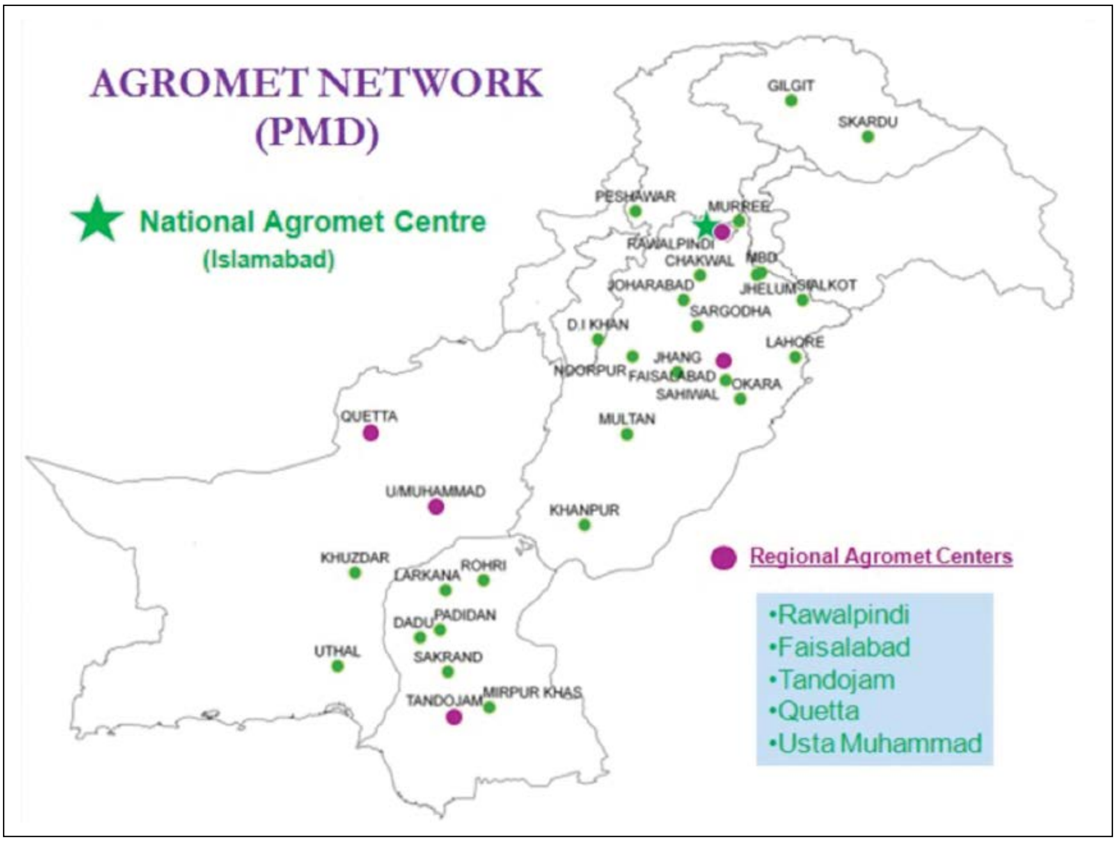
- District specific weather forecast, in quantitative terms, for the next 10 days for rainfall, cloud, maximum/minimum temperature, wind speed/direction and relative humidity, including warning of hazardous weather likely to cause stress on standing crops and suggestions on how to protect them.
- Information on soil moisture status and guidance for application of irrigation, fertilizer and herbicides, etc.
- Advisories on dates of sowing/planting and the suitability of carrying out intercultural operations.
- Warnings of major pests and diseases of principal crops and advice on plant protection measures.
- Manipulation of crop microclimates, e.g. shading, mulching, other surface modification, shelter belt, frost protection, etc., to protect crops under stress.
- Advisory on the judicious management of land, water and farm inputs, particularly pesticides, herbicides and fertilizers.
- Advisories for livestock on health, shelter and nutrition.

(http://zaraimedia.com/2012/09/11/weekly-weather-advisory-for-farmers)

iv) Observational network for AAS

The current number of agrometeorological observatories is 32. The availability of agrometeorological data of some stations (RAMC) goes back to 1990 and others from the date of their establishment (Figure 23). The PMD provides forecasts for rainfall, maximum and minimum temperature, humidity, frost and soil moisture availability during the crop-

Figure 23. Agromet network of Pakistan.
(Source: http://namc.pmd.gov.pk/zone.php?type=o.)



growing season for scheduling irrigation requirement of crops. It also provides information on heatwaves and coldwaves and special weather advisories for farmers.

In order to compile the weather data of each crop development stage, careful, precise and timely recording of the following parameters (Table 3) are undertaken as routine: at 03:00, 09:00 and 12:00 (UTC). Crop data including phenological and soil moisture observation are collected according to World Meteorological Organization criteria (PMD 2013).

Table 3. Observed meteorological parameters.

S. No.	Observed Meteorological Parameters
1.	Maximum and Minimum temperature (°C)
2.	Soil temperature (°C) at 5, 15 and 30 cm
3.	Relative Humidity (percent)
4.	Precipitation (mm) (0300 and 1200 UTC)
5.	Pan Evaporation at (0300 & 1200 UTC)
6.	Bright Sunshine Hours of past 24 hours (0300 UTC)
7.	Wind Speed (km/hr) & Wind Direction
8.	Soil Moisture (percent)

v) Soil moisture observations

Soil samples are taken on 7th, 17th and 27th of each month, soil samples were also taken in next day if some anomalous events occur in any month in four replications at depths of 5, 10, 20, 30, 50, 90, 110, 120 and 140 centimetres. The observations at below 90 cm are made once every 20 days because the soil moisture is considered not to vary greatly at these depths. The soil samples were taken with the help of soil auger and then weighed and dried in the oven for about 3 days. Variations in moisture content over the time period provides information on moisture stress periods and able to assess the duration of soil water availabilities that can support the crop.

vi) Soil-temperature observations

Soil temperature plays an important role in crop growth from germination to maturity. To measure soil temperatures, the soil thermometers are placed at various depths to monitor the thermal regime of the soil. The soil temperatures in Celsius are recorded three times a day at 03:00, 09:00 and 12:00 UTC, which is 5 hours behind Pakistan Standard Time (PST). The centimetre depths at which the soil temperatures are observed on daily basis include 5, 10, 20, 30, 50 and 100.

vii) Research tools for generating weather-based farm advisories

The DSSAT (Decision Support System for Agrotechnology Transfer, Version 4.0) is being used (Jones et al. 2002) to translate weather information into agromanagement decisions. It provides an experimental approach to access the productivity of crops and also identify the causes and stages where the yield of crops suffered due to extreme weather conditions or lack of nutrients. It also simulates the crop water requirements at every stage, not only in rainfed areas but also in irrigated areas. These experimental analysis will help in better assessment towards the productivity of crops.

- In addition, the Pakistan Agricultural Research Council (PARC), established in 1981, conducts research, especially of a basic and long-term nature, in agricultural areas of national importance, besides setting up research establishments to fill in the gaps in existing programmes of agricultural research and arrange training of high-level scientific manpower in agricultural sciences. Its main objective is to strengthen Pakistan's agricultural research system, comprising the federal and provincial components. It also takes up research on agricultural issues of importance which are neglected or inadequately covered, or beyond the resources of the provincial institutions. Some of these require sophisticated and costly equipment and facilities as well as highly qualified but scarce manpower and frequent interaction with international agricultural research institutions. PARC also maintains database on medicinal plants, plant genetic resources and and insect database at the National Insect Museum.

PARC has established meteorological stations in Karachi, Murree and Pir Sabak. The weather data collected at these sites are used for the development of models for predicting crop yield and for disease forecasting.

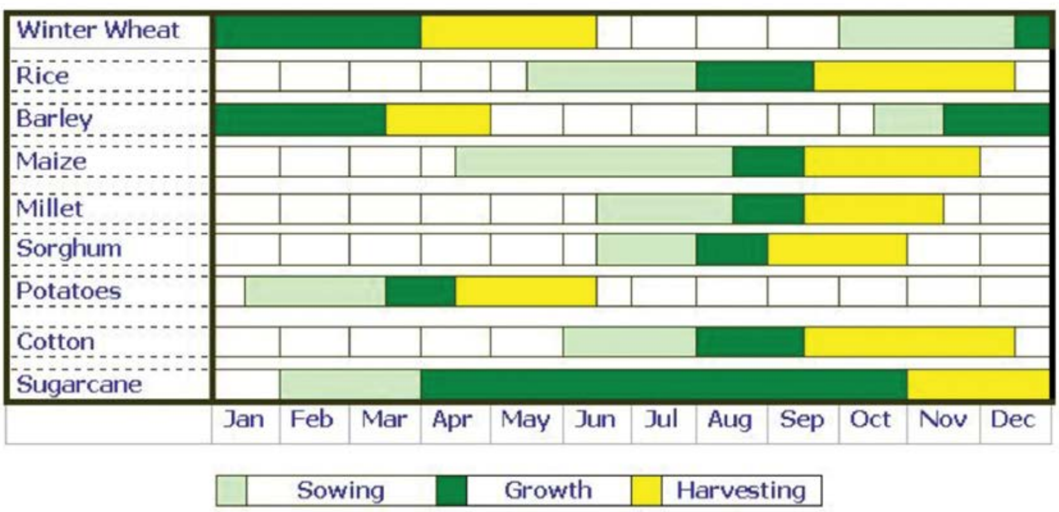
viii) Crop evapotranspiration observations

Reference crop evapotranspiration (ETO) is a measure of evaporative demand of the atmosphere and considered to be the most reliable tool for calculation of crop water requirement (Allen et al. 1998). ETO measures the rate of evapotranspiration by using different methods such as Penman-Monteith, Blaney-Criddle, radiation, etc., by using air temperature, solar radiation, wind speed and humidity. PMD also uses CropWat software, developed by the FAO in 1992, for calculating reference crop evapotranspiration and crop water requirements, followed by irrigation scheduling computations.

ix) Crop and harvest calendars for Pakistan

From the average monthly climatic conditions and the optimum weather requirements of major crops grown in the country, the crop calendars for major crops were prepared by the Research Division of the Government of Pakistan for better agricultural planning: wheat, rice, barley, maize, millets, sorghum, potatos, cotton and sugarcane. A perusal of the crop calendar (Figure 24) shows that from October to mid-November is suitable for sowing wheat. Similarly

Figure 24. Crop calendar of Pakistan.



for rice crop, the optimum transplanting dates are from mid-May to July. The harvest calendar for fruits and vegetables grown in the country are given in Figure 25.

c) Strategies for dissemination of agrometeorological advisories

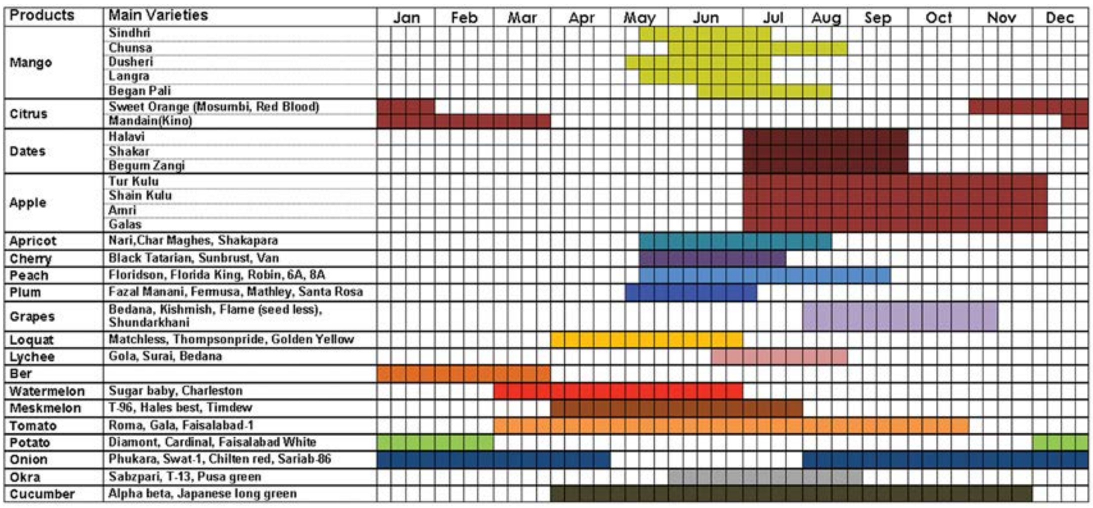
The AAS is an instrument to provide relevant meteorological information to help the farmer to use it for improving agricultural production. The main emphasis is to collect and organize climate/weather, soil and crop information, and to amalgamate them with weather forecast to assist farmers in taking management decisions. This has to be done immediately after the generation of the weather forecast as there may be an emergent situation requiring farmers to take management action in view of forthcoming weather situation. Critical factors for successful dissemination of agro-advisories include relevance of information to weather and climate-sensitive decision-making in agriculture, followed by good outreach.

i) Dissemination of AAS

Timely dissemination of agrometeorological information online and through mass media is part of a process that empower the farmers with scientific knowledge and to take appropriate action for enhancing agricultural production. Sohni Dharti is the first agricultural TV channel of Pakistan that provides information relating to agriculture and rural development (http://www.sohnidharti.tv/). A TV channel and an FM radio station are also being set up in the public sector to educate farmers about modern farming technology suiting their needs. The channel will reach an estimated 6.6 million farmer households across the country and will mainly telecast agriculture-related programmes.

The Internet is a new and cost-effective technology that can provide research and technological development information in an accurate and timely manner. Additionally, the Internet can also be effectively used to offer training modules to agrometeorologists and help them improve the quality of their products. Besides the National Agromet Centre through which agromet bulletins are disseminated, there are few other agencies providing bulletins through their websites or radio services. Farm advisory services are issued in Sindh province on the radio. The impact assessment of farm advisories was made by Dr. Zaheeruddin Mirani (2007) of the Department of Agricultural Education and Extension, Sindh Agricultural University, Tandojam. His studies, however, reveal that currently the farmers are not receiving any new agricultural information due to irregular visits by technical personnel or non-receipt of bulletins. Reliance on traders and suppliers of fertilizers and pesticides are more among the farmers.

Figure 25. Harvest calendar of major fruits and vegetables of Pakistan.



A similar assessment of the long-running (since 1966) farm programme, 'Agriculture and Livestock' (Karkeela aw Maldari in Pashto) by Radio Pakistan of Peshawar, was made by some extension scientists. It was found to be a favourite program among farmers. The extension scientists advocated the revival of farmers' listening clubs for enhancing effective interaction with the farmers on agricultural issues.

The Fauzi Fertilizer Company has also been providing AAS in Multan and Nawabshah in Lahore province since 1982. The advisories include multifarious services like crop demonstration, farm visits during crop field days, etc. Under the Department of Agricultural Extension, the University of Agriculture, Faisalabad, has conducted various research projects: (1) An in-depth analysis of electronic media for the development of strategy to enhance their role in agricultural technology transfer in Punjab; (2) An impact analysis of communication interventions of extension field staff with farmers under newly introduced decentralized extension in the Punjab; (3) An in-depth analysis of conventional and modern agriculture information sources for the development of strategy to promote cyber extension environment in the Punjab; (4) Privatization of agriculture extension system in the Punjab: A SWOT analysis; (5) Analysis of the obstacles to gender mainstreaming in agriculture decision making and extension work in the Punjab.

ii) Zarai Taraqiati agricultural development bank

The agricultural development bank of Pakistan, known as the Zarai Taraqiati Bank Limited (ZTBL), is the premier financial institution geared toward the development agriculture through the provision of financial services and technical knowledge (www.ztbl.com.pk/). The aim of the bank is to boost farm productivity, streamline institutional credit, and increase the income-generating capacity of the farming community. ZTBL provides affordable, agriculture financial/non-financial services to rural Pakistan, which comprises 68 percent of the total population. Farmers can visit ztbl.com.pk for information on the bank's financial products. ZTBL also publishes a magazine entitled *Agri-Business Field Reports*.

Sri Lanka

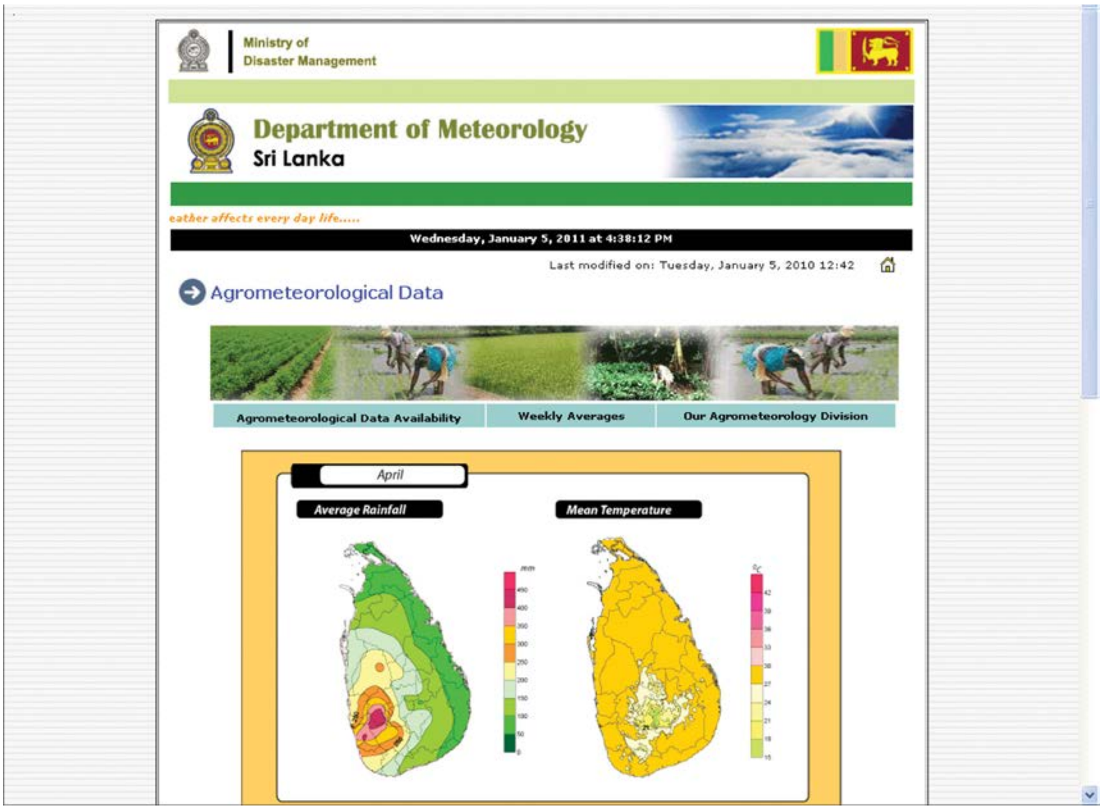
Status of agro-advisories in Sri Lanka

Sri Lanka's National Meteorological Centre (NMC) is primarily responsible for the collection and processing of weather data it receives from field units. The issue of regular weather warning to the farmers, fishermen and to the general public is carried out by Agromet Division, which collects data from 37 units, quality checked, and processed to generate averages. As such the NMC at present is not providing any specific weather based agricultural advisories to the farming community, except warning on adverse weather conditions (Figure 26). However, some private organizations and the DAE (department of agricultural extension) are providing agricultural advisories on a limited scale to the farming community. The Sri Lankan Meteorological Department does not have an adequate data-archiving facility. It is planning to modernize the storage system with the latest computing facilities and train its staff to meet the country's needs to improve its weather database.

Perhaps the earlier political instability and internal disturbances may be one of the reasons for limited agrometeorological activities in the country. Some of the private organizations that are providing specific crop-based advisories in Sri Lanka are:

1. CIC Agro-Lanka (http://www.cic.lk/our_business/agriculture_livestock.php)
2. Haleys Ceylon Ltd
3. Lankens (DVP)

Figure 26. www.meteo.gov.lk.



4. Bauer and Co. Ltd
5. Jinesena
6. Brown and CTC.

The exact working conditions and mode of dissemination of the agricultural advisories by these organizations are not very clear. However, these private agencies seem to focus more on farmers growing crops of their specific interest (rice, tea, etc.) than catering to all the farming community needs.

Nepal

Status of agro-advisories in Nepal

The Department of Hydrology and Meteorology (DHM) is responsible for weather data collection and forecasting management in Nepal. Its website suggests there is no special division which is dealing exclusively with agricultural meteorological aspects. No special bulletins or agricultural advisories are available for farming communities (Figure 27). However, some organizations like the Agro-Enterprise Centre in Kathmandu monitor all aspects of agricultural production, including market, financial and other information that is relevant for the farmers' community (http://www.aec-fncci.org/).

A website, www.datameteo.com provides a 7-day forecast to parts of South Asia, including Nepal. They produce charged-for 'agro-meteo-grams' on 7 basic weather parameters which can be used to prepare weather-based agricultural advisories by any local entrepreneurs (Figure 28). This is another project that operates under National Information Technology, linked to Global Knowledge Partnership (GKP) net projects. Under this project, agricultural advisories are being currently issued through telephone or through the Internet in 21 villages in eastern Nepal.

Figure 27. http://www.dhm.gov.np.

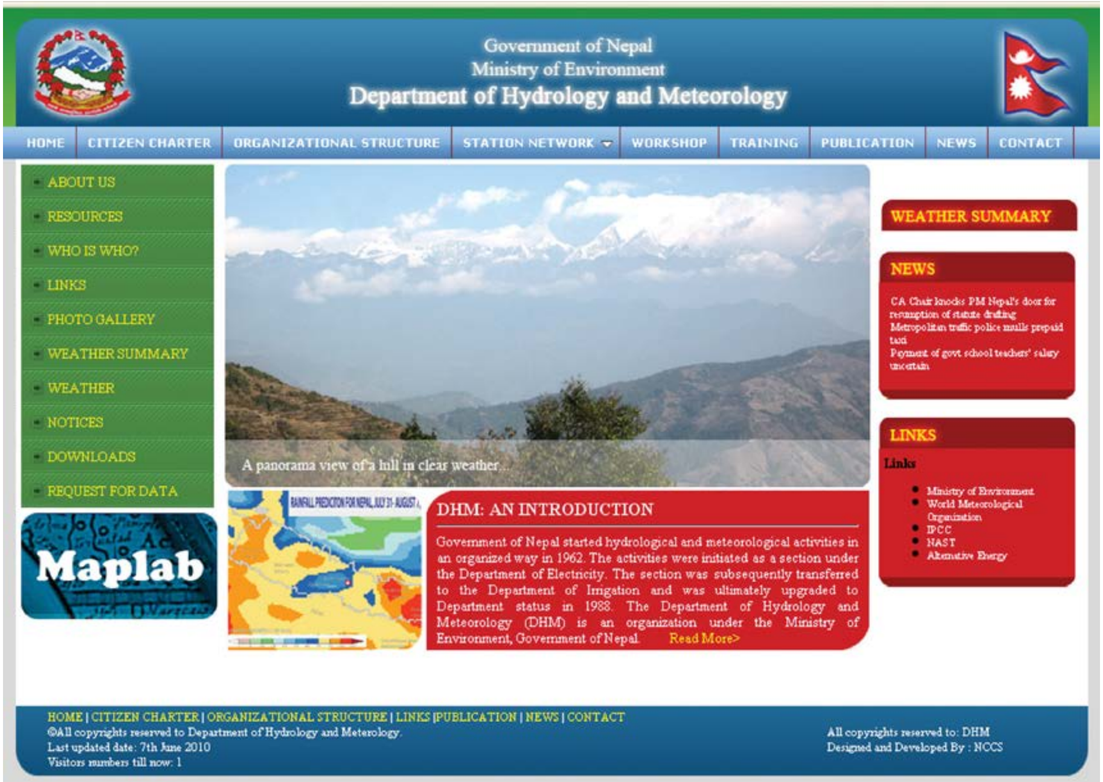
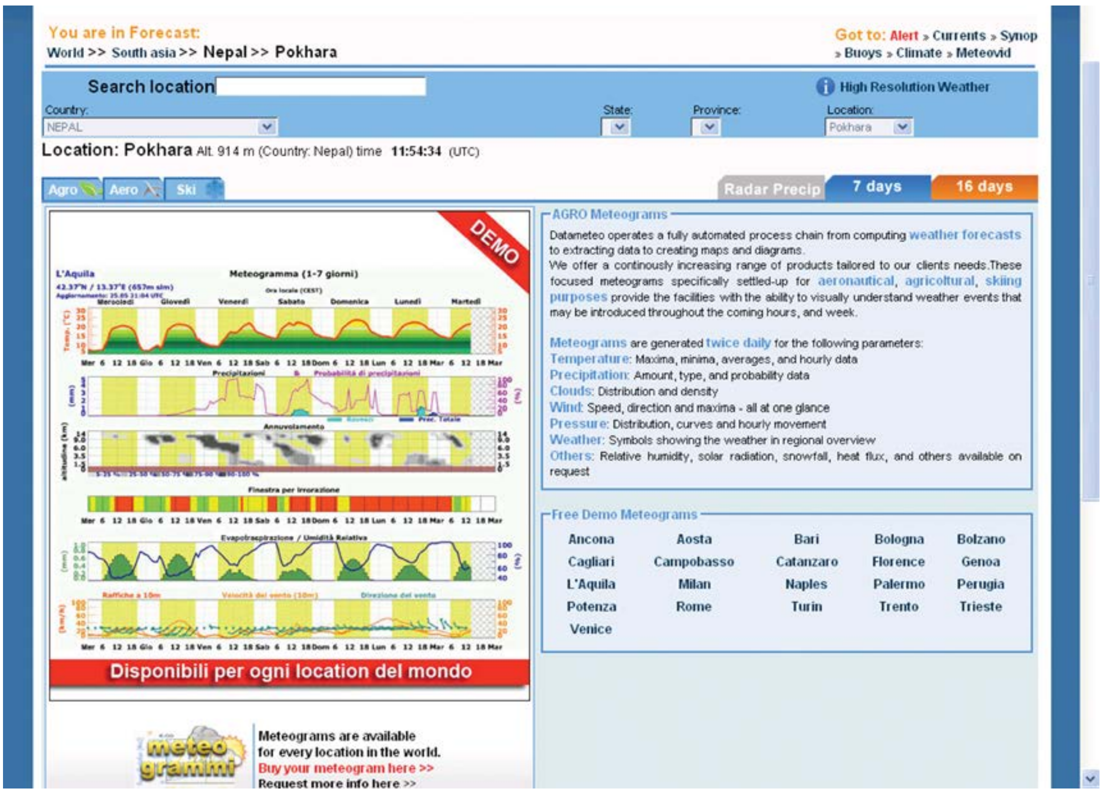


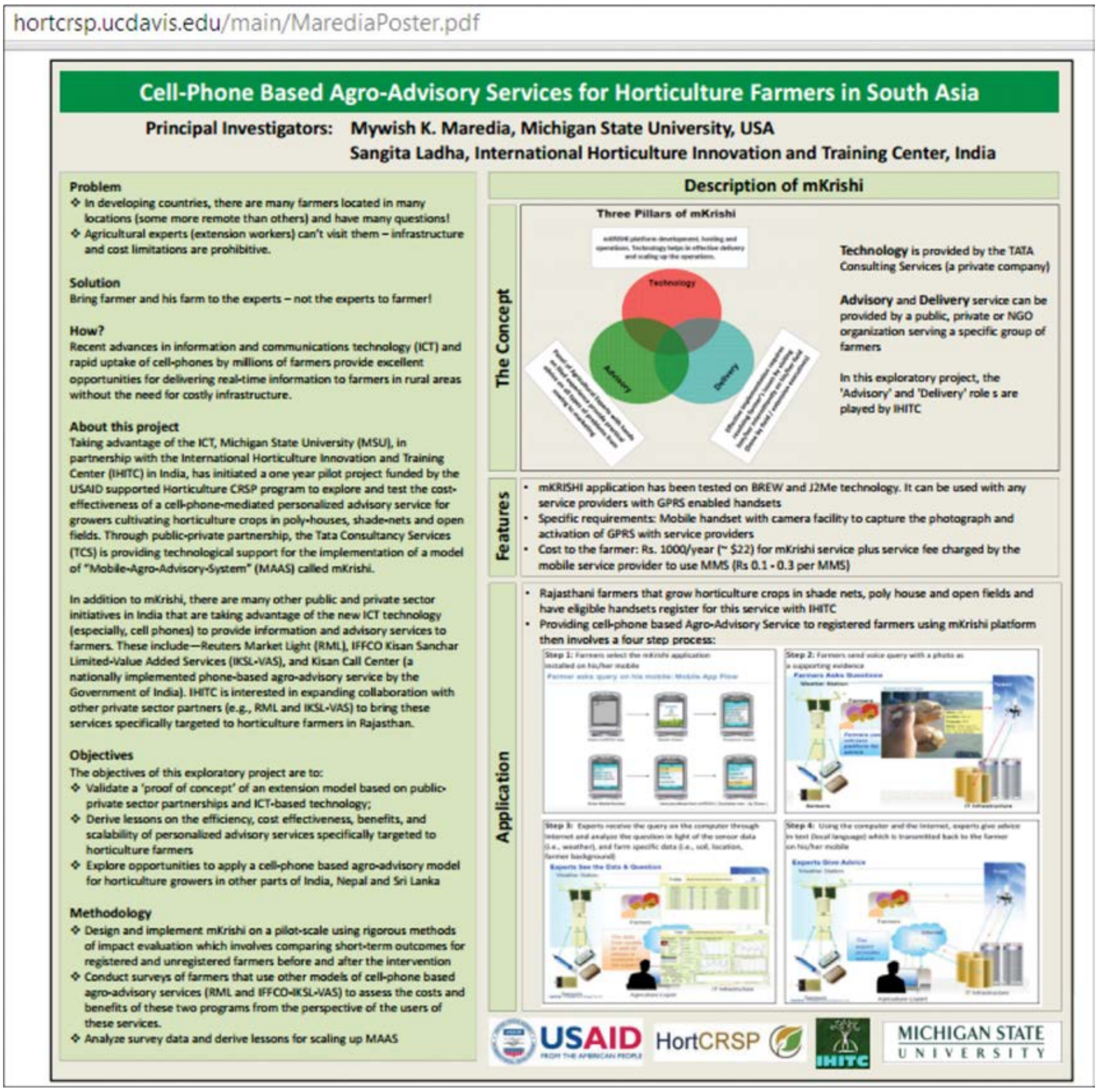
Figure 28. Agro-meteo-grams for *pokhara* in Nepal (www.datameteo.com).



The Asian Disaster Preparedness Centre (ADPC) in Bangkok is also providing support for strengthening DHM capacity for managing climate change and the environment. It is assisting the department in climate data digitization and downscaling of climate change projections in Nepal (ADPC 2011) (http://www.adpc.net /2012/CCCRM /Default.asp). The 2013 RIMES has also been assisting Nepal through the application of weather forecasts from ECMWF through monsoon forums and seasonal forecast applications for weather in Terai, mountain and hill regions, and in working out the durations of likely dry spells in the country.

A cell-phone based agro-advisory system for use in horticulture has been developed (Figure 29) by Michigan state University (Sangita et al. 2011) intended to be of practical use in countries like India, Nepal and Sri Lanka.

Figure 29. Cell phone-based agro-advisory approach for Nepal, Sri Lanka and India.



4. Challenges and opportunities

The preparation and dissemination of agricultural advisories is at different stages of development across the South Asian region. Countries like India, Pakistan and Bangladesh have made considerable progress in developing their agricultural advisory networks and extension systems in reaching the farmers through the Internet and mobile phones. In these advanced countries, the major concern is the content of these agricultural advisories and their usefulness in minimizing the climate risks and increasing agricultural production. Meanwhile, agricultural advisory services in other countries in the region, including Nepal, Bhutan and Sri Lanka, are still in preliminary stages of growth.

A close scrutiny of the type of information being provided in agro-advisory bulletins prepared by the respective organizations in South Asia indicates that the information provided is mostly of generalized in nature and at times vague. The weather component in relation to crop growth or pest development and the relevant advisory is often missing. At present, India is a leader in providing district level agricultural advisories through its 130 AMFUs and is planning to expand the services to lower administrative regions through the village resource and knowledge centres. Pakistan is planning to strengthen the agromet units by building stronger linkages between agricultural research and extension agencies and training centers.

On the other hand, Bangladesh has been aware of the importance of providing agricultural advisories to the farming community. The delivery of farm management advice and agricultural extension services is largely the job of the Department of Agriculture Extension (DAE). The DAE's aim is to provide need-based extension services to all categories of farmers, to enable them to optimize their use of resources and to promote sustainable agricultural and socioeconomic development. It is now teaming up with the Bangladesh Meteorology Department, which initiated web-based information on weather conditions and generalized information on what the farmers should do. However, specific agricultural advisories as needed by the farming community are not yet being issued on an operational scale.

In Sri Lanka also, little progress has been made to develop a weather-based agricultural advisory system, though a strong desire can be seen to initiate such a network system both by the Ministry of Agriculture, the Ministry of Disaster Management and Human Rights and the Meteorology Department. Many private and international agencies are coming forward to assist farming communities in South Asia including Sri Lanka by initiating ICT use in agriculture for agro advisory dissemination and adopting good agricultural practices. One such attempt has been made by Centre for Agriculture and Biosciences International (CABI) by starting 180 plant clinics in various countries including Sri Lanka (CABI 2010). India is also supporting Sri Lankan activities by supplying instruments for surface meteorological measurements and upper air radio sonde equipment to the meteorological services of Sri Lanka (DST 2005).

In Nepal, a small and mountainous country, there are few specific attempts at providing agricultural advisories to its farmers. With increased awareness on the likely impacts of climate change on the Himalayan region, attempts to improve agricultural meteorological services and provide weather advisories to farmers are picking up in DHM. As a start an attempt has been initiated by DHM, with support from CCAFS to revise the Agro-Climatic Atlas of Nepal (CCAFS 2013) and provide more specific details of need, for agricultural development and management. Further, a clear awareness on the climate change impacts on their region has induced the youth to form a nationwide youth group on climate change, Nepalese Youth for Climate Action (NYCA). This group also organized a Nepalese Youth

Summit on Climate Change in November 2008 in coordination with the Ministry of Environment, Science and Technology and the Ministry of Youth and Sports. The basic aim of this programme was to make students and local people aware of climate change and its likely impacts on Himalayan region. However, there are at present no sustained efforts to develop weather-based agricultural advisories to help farmers manage their activities more effectively under the variable climatic conditions experienced in this region. The Ministry of Agricultural Development (MoAD) is now planning to develop an IT-based system to provide the agro-advisory to farmers in Nepal. The ministry is proposing to develop an Agricultural Management Information System (AMIS) within four years that will let the farmers get an SMS on their cell phones about the weather forecast alerts for 5 days, and market price alerts. This programme will be one of 4 components of a pilot programme on the climate change resilience project funded by the World Bank (MoAD 2013).

In case of Bhutan, progress is in its infancy and now being initiated by support from some external agencies and Finland and Austria. There is a need to establish good networks of weather observatories in these Himalayan regions, and then to integrate efforts of government agencies, researchers and private organizations to develop effective agricultural advisory systems.

Since in South Asia agriculture is the main livelihood, there is an urgent need to strengthen the agrometeorological services everywhere. To support these activities, the network of weather observatories need to be strengthened in each country, and a link-up between the agricultural and meteorological services need to be improved, to work in tandem to convert the weather information into appropriate agro-advisories.

After reviewing the status of agricultural advisories in South Asia the following issues have been identified and some solutions have been suggested below:

- The reliability and usefulness weather-based agricultural advisories depends upon the current status of crop, pest and disease information collection across the district. The role and the responsibility of block- or district-level agricultural officers in providing the crop phonology and pest/disease status information is currently not clear in any of these countries. Even within the district, the variability on the above information is not accounted while formulating the AAS. These officials need to play a key role in supplying the information and also in the dissemination of advisories to farmers, who themselves cannot gather this information directly, because of their lack of IT knowledge and accessibility. Since the local government officials have the necessary infrastructure, their role is critical but at present not clearly identified in any of these countries.
- The exchange of information between AMFUs and agricultural department officials need to be further strengthened. The district-level forecasts issued by the National Meteorological Departments (e.g. IMD) still needs to be strengthened for creating confidence on weather-based advisories with farmers. The forecast should not be provided in a formal (general) manner for a larger area, but it needs to add value with local-level agroclimatic information generated from normal climatic data and real time satellite and synoptic charts. The grid-level forecasts using weather forecasting models need to be evaluated with the synoptic chart forecast for the local region by the local AMF unit in-charge, for improving the value of the forecast. This will take care of the prevailing local weather conditions and local weather variability patterns in that region of forecast. The concerned scientists managing the AMFUs need to be trained for this purpose. The role of traditional knowledge in improving the AAS is not clear and its utility may be considered, in whichever region appropriate.

- Advisories are often routine in nature rather than weather- or crop-oriented. Crop-specific agricultural advisories can be very limited or totally absent, except in regions like those where rice, cotton or wheat is a predominant crop over a large area and the crop status information is available. Also, advisories are not specific to different types of farmers such as progressive, marginal and small farmers. Therefore, there is a need to address all these issues related to this different status of farmers.
- Research information on crop-weather relations at different phenophases of growth is limited and also is not available for different regions of these countries. Quantification of assessment of impacts of weather parameters on crop growth is yet to be developed for different agroclimatic regions in each of these countries, wherever some information is available. At district- and block-level, such information can be put to more effective use and the AMFU staff must be trained to convert these research results into operational agromet advisories with information of relevance, interest and direct use to farmers growing a specific crop or adopting a specific cropping system.
- The evaluation of AAS by farmers and the economic benefit accrued by the farmers need to be analysed critically. Most of the information is based on small number of samples. There is a need to survey a wider area within the zone and analyse the economic benefits, rather than limiting the study to one village or few farmers.
- Pakistan's and Bangladesh's agricultural advisory status is very similar to India's. They are, however, providing the agricultural advisories at 10-day intervals through special bulletins prepared by the respective regional meteorological centres. The current status of medium-range weather forecasting in South Asia region is reliable up to 3 days; after which the reliability slightly decreases up to 5 days. The technology has not yet reached a stage to reliably provide a 10-day forecast with confidence. With the drop in the reliability of 10-day forecasts, an agricultural advisory becomes redundant in view of the changing/variable weather. Therefore, they may also, at the current stage, shorten the advisory period from 10 days to 5 days, as in India.
- A perusal of the forecasts that appear in the websites of some of the smaller countries like Nepal, Bhutan and Sri Lanka in the South Asia region does not contain concrete information or advice on any of agricultural operations to be taken up by farmers. It simply gives a forecast for next two days. The agricultural advisories by these countries thus need to be more focused and prepared separately, indicating the appropriate response for farmers cultivating specific crops, taking into account forecast weather and the phenological stage of the crop. Further, agricultural advisories, at present, are issued by agroclimatic zone in many of these countries. There is a need to further expand the advisory network to smaller regions (district/block level) for better services to the local farming communities.
- The evaluation system of AAS in Pakistan, Bangladesh, Nepal, Bhutan and Sri Lanka countries is not clear. The mode of collection of information on crops, growth stage, pest status etc., and its use in the preparation of AAS by AMFUs is also not clearly defined. Similarly, the role of agricultural research organizations in Bangladesh, Sri Lanka, Nepal and Bhutan providing research information on crop-weather relationships for crops grown in different agroclimatic regions and its use in AAS, is mainly missing . More elaborative and collaborative efforts are needed on this important aspect, in these countries.
- Also the number of AMFUs responsible for preparation of AAS and their constituent members of agro-advisory boards are to be identified by sub-region in each country where such efforts were not yet taken up. The current pattern being followed in India could be adopted by other countries with suitable modifications, according to availability of regional scientific and technical staff.

- The private agencies and other NGOs who can play a positive role in extension activities need to be identified and their collaborative efforts in dissemination of AAS to farmers defined. Appropriate linkages are then developed for an effective public-private partnership, avoiding contradictory advisories for the same region.
- In the countries which are providing 10-day weather forecasts, efforts need to be made on validating them. Also, the coverage of these forecasts and the number of AMFUs spread across the country using them is not clear. If the forecast is for a larger agroclimatic region, the relevance of AAS using the above forecast and conversion of this information for smaller areas using micro-level models need to be evaluated carefully.
- While climate change is an issue of great concern to agricultural productivity and food security in most South Asian countries, the Farmers Awareness Program on Climate Change and the training modules for farmers and to AMFU members, to prepare them to meet the challenges of climate change, is not being seriously taken up in many countries. In India, AICRPAM, ICAR and IMD experience and the prime minister's initiative on creating awareness in farming community on climate change, National level programs like NICRA (National Initiative on Climate Resilient Agriculture) could be an example for other countries.
- Forecasts issued by meteorological organizations often do not predict extreme weather events, thus putting farmers at greater risk. Therefore, there is a need to improve the predictability of extreme events and their impacts on different crop-growth stages. Contingency plans for different regions are required to be put in place, and timely input availability to farmers is taken care of.
- The role of agricultural departments in providing the district/block level crop status and their linkages with the regional meteorological services for timely exchange of crop status information is to be clearly defined and efforts strengthened. The advisories can be useful only if such information is made available in a timely way across these departments, both of which cater to the needs of the farming community.
- Where extension research or extension information is not currently available, based on the current crop species, future contingencies of possible occurrence could be visualized (such as flood, drought, heatwaves and coldwaves, cyclone damage, etc.), with reference to significant growth stages and remedial action. Such plans need periodic assessment and correction based on changes in crop varieties and cropping systems and practices. However, instead of waiting for a contingency to occur, a plan should be kept ready in hand. Past experience (of agricultural departments, local authorities and farmers) with such contingencies can be documented; new plans can be formulated since weather systems do not respect political boundaries. Exchange of information within the South Asian region would be of value not only for weather system movement but also about agricultural contingencies and remedial action. Hotlines could be established and activated during specific weather hazard periods and not necessarily on daily basis. The SAARC programme is one such avenue that can be beneficially used by these countries, as they are already coordinating in various mutually beneficial ways.
- Satellite-based information could be supplemented by information from neighbouring countries. Being the big neighbour to all these countries, India can play a positive role to initiate and support such activity. A regional seminar on "weather hazards to agricultural crops, animal husbandry and the formulation of contingency plans and remedial action" could be taken up as a starting point for the exchange of past experiences and develop a plan of action, suitable to each of the member

countries. This should lead to future cooperation and streamline activity to meet such contingencies within any individual season.

- Except for individual efforts, there is no consolidated information on potential utility of crop-weather forecast models for use with weather based agro-advisories, including pest and disease warnings. An 2- or 3-strong expert group could review and consolidate usable agriculture-weather forecast operational models requiring minimal input. Research models could be elaborate, but operational models might not need much generic information such as those required for Decision Support Systems for Agrotechnology Transfer (DSSAT), InfoCrop, the Agricultural Production Systems Simulator (APSIM) and other such models currently in use.
- The governments of Nepal, Sri Lanka and Bhutan have only recently started providing agricultural advisories to farmers, but these countries have good infrastructure facilities and regional (SAARC) support to record weather data, and also are aware of the urgent need to scale-up. However, the agricultural advisory programme in these countries cannot be achieved without the active involvement of their respective meteorological departments and the agriculture research and extension agencies working in tandem and collaborating closely with a commitment and urgency. The farm-based advisories should be prioritized and additional supportive activities taken up by conducting further agrometeorological research in crop-weather relationships in their respective regions for strengthening the agricultural advisory service. Experiences from countries like India and Pakistan can help these countries adopt a fast-track approach to build up these facilities quickly.
- There is an urgent need for timely and crop-specific advisories, as well as enhancing the efforts by extension agencies to create awareness in the farming community on the effective use of agro-advisories. Weather based agro-advisory information and its dissemination by a well-trained extension worker or a progressive farmer, in countries where it is yet to take off, can be effectively initiated through gatherings of farmers at a central place in the village. It would be useful as an interactive response process. Such workers can be provided with a cash incentive. They could visit 3 or 4 villages every week (not on the same day but at farmers' convenience). For some years to come, this would be the best option, where TV or radio dissemination of weather-based advisories would still leave some doubts over the contingent situation. Looking to the vast areas to be covered by a limited number of officials, such efforts are of great relevance.
- Where agricultural advisories are being provided through a web page, an interactive page has to be provided to enable the farmers to get answers. These will also of use to other farmers who are experiencing similar problems (like pest/disease incidence, and soil fertility and water-management issues, etc.)
- These efforts towards strengthening the weather-based agricultural advisory services in the the South Asian region and efforts for country-to-country cooperation will enable farmers to make better use of the good weather conditions in improving productivity, and adopt sustainable crop production strategies as well as manage adverse weather conditions more effectively. Such an integrated effort can help in enhancing the confidence of farmers in the SAARC nations to use advisories for the timely management of their crops, leading to higher crop productivity, and improve both their own economic status and the food security of the region.

Conclusions

With diverse climates, crops, cropping systems, land-use patterns and economic status of rural population in the South Asian region, providing weather-based agricultural advisories is a great challenge. A great disparity has been observed among the countries that are large and better developed compared to small nations like Nepal, Sri Lanka and Bhutan. Therefore, there is an urgent need for greater cooperation among these densely populated SAARC countries to provide agricultural advisories in a timely way so farmers can achieve sustainable agricultural production.

In order to achieve this, the following suggestions are made for greater stability in food grain production by effectively managing the climate:

- A micro-level resource inventory with respect to climate, soil, water, crop demographic, economic, social, livestock and fisheries must be carried out and contingency planning for all the districts in these countries be prepared to meet out the climate risks effectively.
- The success of agricultural advisories is dependent on the reliable weather forecast and the crop information. The weather forecast capabilities of all the South Asian nations should be increased. Efforts should be made to enhance medium-range weather forecast reliability. A great cooperation across the countries in the region is essential. Experience across the countries and help from international research agencies has to be combined and information freely exchanged. To the extent possible the smaller countries are supported by their big neighbours in developing a good weather information base over their country. Also traditional knowledge on weather forecasting in different regions needs to be documented and related to advanced systems.
- To make available the crop conditions in different locations, the respective governments responsible for monitoring the above, must increase their staff and dedicate them, exclusively for this purpose. The role of NGOs, other social organizations and Krishi Vigyan Kendras (KVKs) or such similar agencies under Ministry of Agriculture and Extension in these countries, in providing such information at district/block level may be looked into for sharing this burden. Also the research wings of agrometeorological institutions in all these countries need to be further strengthened to provide the necessary scientific information on crop-weather-pest/disease relationships and contingency plans to be used in agro-advisory bulletins.
- Droughts are common during the cropping season, especially in semi-arid and arid regions of South Asian region. Similarly, floods are common in Bangladesh, on the Indo-Gangetic plains, and states of eastern coastal regions in India. The existing drought monitoring institutions under the meteorological departments of various countries should develop close linkages with their respective agricultural research institutions and universities for providing the viable solutions to meet the challenges posed by droughts and floods. A simple water-balance approach worked out at weekly intervals and preparation of soil-moisture status maps can provide information on the stress experienced by different crops. The expertise available in International Research Institutes under CGIAR in the South Asian region must also be utilized, and these institutes must play a greater role in providing research.
- Similarly, flood forecasting assumes greater significance in the flood-prone regions of South Asia in agricultural advisory systems. The existing infrastructure for monitoring floods and their forecasting through models needs to be further strengthened. Identification of the regions most vulnerable to floods and measures to reduce their

intensity and duration must be carried out as a priority. The use of satellites may be stepped up. Likewise understanding between meteorological departments, remote sensing agencies, and water resources and flood forecasting units in providing timely help to the farmers. Also there should be more cooperation on the exchange of flood information for taking advance measures.

- Farmers in these countries are mostly poor and the income from agriculture is not sufficient to meet requirements. Still traditional agriculture is practiced in remote regions and technological innovations have not yet penetrated for various administrative and political reasons. A majority of the farmers are ignorant about weather and weather-based agricultural advisories and weather insurance. An awareness campaign on the importance of weather, how it is measured, its influence on crops, livestock and horticulture need to be explained, possibly with residential courses. This program must continue throughout the year. The lead taken in India by IMD and ICAR in conducting awareness training can be adopted by other nations.
- Expertise in weather forecasting, agricultural research, the preparation of agricultural advisories and infrastructure availability may be shared to improve the capabilities of small nations like Nepal, Sri Lanka and Bhutan. Attempts by agencies like ADPC, CABI in providing such support to some parts of Southeast Asia can be extended to South Asia.
- The international research organizations in these regions may play a much more active role in conducting a mass campaign on awareness and provide necessary research inputs for improving agricultural advisories by expanding their activities into different agroclimatic regions, and integrating research with local NGOs and other organizations. They may concentrate on less developed nations in improving their agrometeorological capabilities and transfer knowledge and experience gained from working with developed countries.
- Such concerted effort needs great commitment from forecasters, researchers and extension officials and governments to enhance the confidence of farmers and enable them to effectively deal with weather conditions, and sustain and enhance their productivity.

References

Afzal M. 2012. Pakistan: Country Paper. Animal Health Institute. (Available from: http://ilri.org/InfoServ/Webpub/fulldocs/wana/Pakistan.htm.)

Allen RG, Pereira LS, Raes D, Smith M. 1998. *Crop evapotranspiration: Guidelines for computing crop water requirements, Irrigation and drainage paper 56*. Food and Agriculture Organization.

Asian Disaster Preparedness Centre. 2011. Nepal: Strengthening Capacity for Managing Climate Change and the Environment. ADB-assisted programme. (1 January to 31 December 2011.)

Asia Pacific Forest Invasive Species Network. 2006. *Status of forest invasive species in India*. (Available from: http://apfisn.net/sites/default/files/India.pdf.)

Attri SD, Tyagi A. 2010. *Climate profile of India*. Government of India, Ministry of Earth Sciences.

Government of Bangladesh, Ministry of Environment and Forests. State of the Environment 2001. Available from http://www.moef.gov.bd/html/state_of_env/pdf/overview.pdf.

Basnayake BRSB, Das S, Das MK, Rahman M, Sarker MA, Akand MAR. *Composite characteristics of severe thunderstorms over Bangladesh simulated by WRF-ARW Model*. 5th European Conference on Severe Storms, 12–16 October, 2009, Landshut, Germany.

Bhutan National Adaptation Programme of Action. 2006. Available from: http://unfccc.int/resource/docs/napa/btn01.pdf.

Government of Bhutan, Ministry of Planning. Five Year Plan 1997–2002.

Government of Bhutan, National Environment Commission. 2012. National Adaptation Programme of Action (NAPA): Update of Projects and Profiles.

Bormann U. 2005. Biomass and Biodiversity Studies in Satkosia Gorge Wildlife Sanctuary, Orissa, India. Internship Report. Foundation for Ecological Security.

CCAFS. 2013. *Agroclimatic atlas of Nepal for innovative climatic information easily available for agricultural development inspirations for increasing climatic resilience of the agricultural community comprising rural poor – progress report*. Department of Hydrology and Meteorology, Ministry of Science, Technology and Environment, Government of Nepal.

Das DK. Regional Integrated Multi-Hazard Early Warning System for Asia and Africa, Applications of ECMWF Forecast. Available from: http://www.ecmwf.int/newsevents/meetings/forecast_products_user/Presentations2013/Das.pdf.

Dost M. 2002. *Country Pasture/Forage Resource Profiles: Pakistan*. (Updated by SG Reynolds.) UN Food and Agriculture Organization.

Duba S, Gurung TR, Ghimiray M, eds. 2006. *Assessment of SARD-M [Project for Sustainable Agriculture and Rural Development in Mountain Regions] Policies in the Hindu Kush – Himalayas: the Case of Land Use Policies in Bhutan*. Food and Agriculture Organization.

Durga D, Poudel, Thakur RP, Singh AP, Tiwari MR, DeRamus A. 2012. *Capacity-building and Strengthening of Livestock Production Systems While Adapting to Climate Change in*

Nepal. Adapting Livestock Systems to Climate Change Collaborative Research Support Program. Fort Collins: Colorado State University.

Food and Agriculture Organization. 2012. *Bhutan: Agricultural sector review, Vol. 1: Issues, institutions and policies*.

Food and Agriculture Organization. 2004. *Fertilizer Use by Crop in Pakistan*. (Available from: http://www.fao.org/docrep/007/y5460e/y5460e06.htm.)

Food and Agriculture Organization. 2000. *Asia and the Pacific National Forestry Programmes: Update 34*. (Available from: http://www.fao.org/docrep/003/x6900e/x6900e0c.htm#TopOfPage.)

Food and Agriculture Organization. 2000. *Global Forest Resources Assessment 2000*. (Available from: http://www.fao.org/docrep/004/Y1997E/Y1997E00.HTM.)

Global Hunger Index. 2010. International Food Policy Research Institute.

Global Water Partnership-International Water Management Institute 2011. Synthesis of workshop discussions: climate change, food, and water security in South Asia: critical issues and cooperative strategies in an age of increased risk and uncertainty. (Available from http://issuu.com/gwp-publ/docs/colombo_synthesis_report_climate_change_food_and_w.)

Hails AJ, ed. 1997. *Wetlands, Biodiversity and the Ramsar Convention: the role of the Convention on Wetlands in the Conservation and Wise Use of Biodiversity*. Gland, Switzerland: Ramsar Convention Bureau.

Hansen JW, Meinke H, Selvaraju R, Aslam Gill M, Gadgil S, Krishna Kumar K. 2001. *Tailoring cropping systems to seasonal climate forecasts in South Asia's semi-arid tropics*. American Society of Agronomy.

Government of India, Department of Agriculture and Cooperation, Ministry of Agriculture. Annual Report 2010–11. (Available from: http://agricoop.nic.in/Annualreport2010-11/AR.pdf.)

Government of India Meteorological Department, Research Report No: 9/2008.

Government of India, Ministry of Environment and Forests. 2009. *India State of Forest Report*.

Government of India, Department of Science and Technology, Annual Report 2004–05. Meteorology Mapping and Survey, IMD: Observational Support.

Iqbal MJ. 2010. Concept note on current state of agrometeorological services in Pakistan. (Personal communication with author).

Islam AS, Attwood S, Braun M, Kamp K, Aggarwal PK. 2013. Assessment of Capabilities, Needs of Communities, Opportunities and Limitations of Weather Forecasting for Coastal Regions of Bangladesh. WorldFish (Penang, Malaysia) project report.

Japan Meteorological Agency/World Meteorological Organization workshop on quality management in surface, climate and upper – air observation in RA II (ASIA). 2010. Tokyo.

Jones JW et al. 2003. The DSSAT cropping system model. *European Journal of Agronomy* 18: 235–265.

Khan AG. 2004. *Characterization of the agro ecological Zones of Pakistan*. (Available from: cgspace.cgiar.org/bitstream/handle/10568/.../AgroEcologicalZones.pdf?)

Khan UI, Hanif M. 2007. *Weather and wheat development in Faisalabad region: rabi season (2006–2007)*. National Agrometeorological Centre, Islamabad, Pakistan.

Krishna Reddy P. 2004. *eSagu: The Next Generation IT-based Query-less, Cost effective and Personalized Agro-Advisory System*. International Institute of Information Technology, Hyderabad.

Ladha S, Maredia M, Weebadde C, Joshi N, Urkude R. 2011. *Cell Phone Enabled Personalized Agro-Advisory Services for Horticultural Crops in South Asia*. Poster presented at the University of California Horticulture Collaborative Research Support Program. Spring 2011 conference. Available from: http://hortcrsp.ucdavis.edu/main/22cellphone.html.

Met Office Hadley Centre. 2010. *Climate Modelling in Bangladesh, A Model for Capacity Building in Developing Countries*.

Milliman JD, Meade RH. 1983. Worldwide delivery of river sediment to the oceans. *Journal of Geology* 91 (1).

Government of Nepal, Ministry of Agriculture and Cooperatives, Agribusiness Promotion and Statistical Information Division. 2001. Statistical information on Nepalese agriculture, 2000–2001.

Government of Nepal, Ministry of Population and Environment. 2004. Initial National Communication to the Conference of the Parties of the United Nations Framework Convention on Climate Change.

Government of Nepal, Ministry of Population and Environment. 2004. National Action Programme on Land Degradation and Desertification in the context of United Nations Convention to Combat Desertification. Available from: http://www.forestrynepal.org/publications/67.

Government of Pakistan, Ministry of Finance. 2012. Chapter 2: Agriculture, available from www.finance.gov.pk/survey/chapter_10/02_Agriculture.pdf.

Government of Pakistan, Ministry of Food. Agricultural Statistics of Pakistan 1994–95.

Pangeni R. IT-based agro-advisory within 4 years. Available from: http://www.myrepublica.com/portal/index.php?action=news_details&news_id=58514.

Rajeevan M, Jyoti Bhate. 2009. *A High Resolution Daily Gridded Rainfall Data Set (1971–2005) for Mesoscale Meteorological Studies.* India National Climate Centre.

Rakesh K, Singh RD, Sharma KD. 2005. Water Resources of India. *Current Science* 89 (5). p. 794 –811.

Ramakrishna YS, Rao GGSN, Kesava Rao AVR, Vijaya Kumar P. 2000. Weather Resource Management. In: Yadav JSP, Singh GB eds. *Natural Resource Management for Agricultural Production in India*. Indian Society of Soil Science. p. 245–370.

Ramakrishna YS, Rao GGSN, Rao VUM, Rao AVMS, Rao KV. 2006. Water management and water use in rainfed regions of India. In: Sivakumar MVK, Motha RP, eds. *Managing Weather and Climate Risks in Agriculture.* New York: Springer-Verlag. p. 245–263.

Ramakrishna YS, Singh HP, Nageswara Rao G. 2003. Weather based Indices for Forecasting Foodgrain Production in India. *Journal of Agrometeorology* 5 (1). p. 1–11.

Rashid H. 1991. Geography of Bangladesh. Dhaka: University Press.

Rashid H, Pramanik MAH. 1990. Visual interpretation of satellite imagery for monitoring floods in Bangladesh. *Environmental Management*. Vol. 14, issue 6. p. 815–821.

Regional Resource Centre for Asia and the Pacific. *State of the Environment – South Asia 2001, Part 1 – Regional Overview*. Available from: http://www.rrcap.ait.asia/pub/soe/sa_part1.pdf.

Regional Study on the Causes and Consequences of Natural Disasters and the Protection and Preservation of the Environment. 2011. South Asian Association for Regional Cooperation publications, Chapter 2. Available from http://goo.gl/IHt3FI.

Salman S, Rehman S, Shaw MA. 2012. Rainfall Trends in Different Climate Zones of Pakistan. *Pakistan Journal of Meteorology*, Vol. 9, issue 17. p. 37–47.

Schwoebel MH, Menon G. 2004. *Mainstreaming gender in disaster management support project, A Report for The Women In Development IQC Task Order, New and Expanded Opportunities for Vulnerable Groups in India.* Centre for Development and Population Activities and Chemonics International Inc. (Available from: http://gdnonline.org/resources/DMS%20Report_WID%20India_6%2007%2004.pdf.)

Shah T. 2001. *Wells and Welfare in the Ganga Basin, Public Policy and Private Initiative in Eastern Uttar Pradesh, India*. Colombo: IWMI.

South Asia Co-operative Environment Programme 2011. *Regional Cooperation for the Conservation and Wise Use of Internationally Important Wetlands in South Asia.* Available from: http://www.ramsar.org/pdf/cop11.

Spreitzhofer G, Sperka S, Steinacker R. 2013. MetGIS: combination of Meteorological and Geographic Information Systems to produce high resolution mountain weather forecasts. In: *Meteorological Applications*. Vol. 20, issue 3. p. 371–378.

Government of Sri Lanka, Ministry of Disaster Management and Human Rights. 2006. Towards a Safer Sri Lanka: A Road Map for Disaster Risk Management. Project Proposals, April 2006, UNDP.

Government of Sri Lanka, Ministry of Environment. 2008. Sri Lanka: Environment Outlook 2008: Book-3-Part-1, available from http://www.environmentmin.gov.lk/web/pdf/annual_reports/Book-3-Part-1.pdf.

Government of Sri Lanka, Department of Meteorology, 2013. *Climate in Sri Lanka*. (Available from: http://www.meteo.gov.lk/index.php?option=com_content&view=article&id=106&Itemid=81...)

Stainton JDA. 1972. *Forests of Nepal*. London: John Murray.

Sudip Regmi. 2012. Population Density Map of Nepal. (Based on 1990 government survey data: personal communication.) Available from: http://en.wikipedia.org/wiki/File:Population_density_map_of_nepal.png.

UNFCCC. 2006. Bhutan: NAPA Project Profile. Project-3. Weather Forecasting System to Serve Farmers and Agriculture. Available from: http://unfccc.int/files/adaptation/napas/application /pdf/03_bhut_pp.pdf.

United Nations International Strategy for Disaster Reduction. 2012. Biodiversity and ecosystem management in South Asia: current status of coastal and marine areas. Working draft.

World Food Programme Food Security Atlas. Available from http://www.foodsecurityatlas.org/bgd/country/availability/agricultural-production.

World Meteorological Organization. 2013. Final Report of 40th Session. WMO/ESCAP Panel on Tropical Cyclones. Available from: http://www.wmo.int/pages/prog/www/tcp/documents/PTC40_FinaReport_final.pdf.

World Meteorological Organization. 2008. Bangladesh to strengthen weather and climate services for the agricultural community. Available from: http://preventionweb.net/go/7851.

Yedla S, Peddi S. 2003. India Environment National Assessment. In: *Roles of Agriculture*. Available from: ftp://ftp.fao.org/es/ESa/roa/pdf/2_Environment/Environment_IndiaNA.pdf.

Yendra. 2012. Tshering Tobgay's Blog: Life and Politics in Democratic Bhutan: Weather Service_ Posted on October 11, 2012. 9 Responses to "Weather Service". Yendra: October 11, 2012 at 3:09 pm *www.tsheringtobgay.com/*.

Zaheeruddin M. 2007. Assessment of the Impact of Farm Advisory Services in Sanghar and Mirpurkhas Districts of Sindh Province of Pakistan. *Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Science* 23 (1).

Zhang Q. *Promoting effective agricultural extension. CABI's role and experiences*. CABI. 2010. Available from: http://www.syngentafoundation.org/__temp/10_Zhang_Promoting_effective_agricultural_extension_CABI%E2%80%99s_role_and_experiences.pdf.)

Websites:

Agricultural Extension and Advisory Services: www.worldwide-extension.org/asia/bhutan

Agricultural research portal, Pakistan: zaraimedia.com

Bangladesh Meteorological Department: www.bmd.gov.bd/index.php

Crop Weather Outlook, India: www.cropweatheroutlook.ernet.in

Gross National Happiness Commission, Bhutan: www.gnhc.gov.bt

India Meteorological Department: www.imd.gov.in

Metgis forecast system: www.metgis.com/en

Nepal Meteorological Forecasting Division: mfd.gov.np

Pakistan agromet service: namc.pmd.gov.pk/intro.php.

Pakistan Meteorological Department, training site: www.pmd.gov.pk/training

Pakistan weather: www.pakmet.com.pk

Pakistan wildlife: www.wildlifeofpakistan.com

South Asia Co-operative Environment Programme: www.sacep.org

Sri Lanka Department of Meteorology: www.meteo.gov.lk

World Bank Group research site: iresearch.worldbank.org

Annex:
The Status of Agrometeorological Advisory Services in India

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Introduction

Weather and climate information play a major role before and during the cropping season and if provided in advance can help farmers apply resources in order to take advantage of favourable conditions and mitigate potential losses in unfavourable ones. Hence, agrometeorological information may help farmers make the most efficient use of natural resources and farming inputs, with the aim of improving agricultural production both in quantity and quality. In an environment of increasing weather and climate variability under climate change, farmers are in greater need of agrometeorological information blended with weather sensitive management advisories before the start of cropping season to support adaptation of agricultural practices. In this context, agrometeorological advisories based on short and medium range weather forecasts become vital to stabilizing yields through management of agro-climatic resources as well as other inputs such as irrigation, fertilizer and pesticides. The Agrometeorological Advisory Service (AAS) of the India Meteorological Department (IMD), Ministry of Earth Sciences (MoES) is intended to contribute to weather information based crop/livestock management strategies and operations dedicated to enhancing crop production and food security. The main emphasis of the existing AAS system is to collect and organize climate/weather, soil and crop information, and to integrate them with weather forecast information to assist farmers in their management decisions. The programme has helped to develop and apply operational tools to manage weather related uncertainties through agrometeorological applications for efficient agriculture in rapidly changing environments.

The information support systems under AAS include:

- provision of weather, climate, crop/soil and pest disease data to identify biotic and abiotic stress for on-farm strategic and tactical decisions;
- provision of district-specific (pan-India) weather forecasts (rainfall, cloudiness, maximum/minimum temperature, wind speed, wind direction, maximum/minimum relative humidity) up to 5 days with outlook for rainfall for the remaining two days of the week;
- translation of weather and climate information into farm advisories using existing research knowledge on making more efficient use of climate and soil resources through applications of medium range weather forecasts, in order to maximize benefits of benevolent weather conditions and alleviate the adverse impacts of malevolent weather events. A broad spectrum of advisories provide information on: weather-sensitive farm operations such as sowing/transplanting of crops, fertilizer application based on wind condition and intensity of rain, pest and disease control, intercultural operations (operations carried out on the soil between sowing and harvesting, e.g. weeding, pesticide application, etc), amount and timing of irrigation using meteorological thresholds and advisories for timely harvest of crops;
- introduction of technologies such as crop simulation model-based decision support systems to support adaptation of agricultural production systems to weather and climate variability and to the increasing scarcity of inputs such as water, seed, fertilizer, pesticide etc.;

- developing effective mechanisms for timely dissemination of agrometeorological advisories to farmers;
- effective training, education and extension on all aspects of agricultural meteorology.

To achieve this, MoES sought and promoted cooperation between national agriculture and meteorological agencies and those responsible for dissemination of agrometeorological information and advisories. In addition to setting up a good agrometeorological observation network, numerical weather prediction (NWP) methods including multi-model ensembles (MME) have been developed to prepare district-specific 5-day weather. A network of 130 Agro-meteorological Field Units (AMFUs) has been set up to translate weather forecasts into agro-advisories. These units have been set up at State Agriculture Universities (SAUs), institutes of the Indian Council of Agriculture Research (ICAR), Indian Institute of Technology (IIT) and other organizations working in the sphere of the agricultural sciences. A multi-media system for dissemination of agrometeorological advisories to the farming community has been put in place in which, in addition to use of the conventional modes of communication (e.g., radio, television and print media), concerted efforts are made to reach farmers through emerging modes of communication such as mobile phones and the Internet. Short message service (SMS) and voice messages are being sent to subscribing farmers by private companies such as Reuters Market Light, IFFCO Kisan Sanchar Limited, MahaAgri, and Handygo. Besides these companies there are many companies such as Mahindra and Mahindra, Infosys, NOKIA etc. that are likely to start providing these services in the near future. AAS has also developed a mechanism to assess users' needs and strives to meet them in order to play an efficient role for the improvement of agricultural production. A study aiming to assess the economic impact of AAS carried out 2003-2007 at 15 AAS units covering 3 *kharif*[1] and 3 *rabi*[2] seasons concluded that farmers could avoid significant losses of farm inputs like seeds, water, pesticides and fertilizers and reaped better harvest and made their farming more profitable by using the AAS. In general there is a net gain ranging from 8 to 10 percent by those farmers who used the information provided by the AAS system.

Infrastructure currently available for agrometeorology

Agro-Meteorological Field Units (AMFUs) and collaborating organizations

As agrometeorology is a multi-disciplinary subject, the weather based advisory service involves collaboration across multiple organizations. A network of departments/agencies works together to issue need-based agro-advisories in real time. The following departments and organizations participate in AAS:

- SAUs, IITs etc.
- ICAR and its Research Institutes
- State and Union Departments of Agriculture
- Department of Space (NRSI, NADAMS)
- Prasar Bharati and other media (Radio, TV and print)
- Department of Information Technology
- State, District, Tehsil and Village Level Administration including Krishi Vigyan Kendras (KVKs – agricultural science extension centres) and Agricultural Technology Management Agency (ATMA)
- Non Governmental Organizations (NGOs)

Being a multidisciplinary and multi-institutional project, AAS involves many stakeholders. The AAS system is implemented through a five-tier structure composed of different

1 *Kharif* crops are grown June-October on the Indian subcontinent.
2 *Rabi* crops are grown November-April on the Indian subcontinent.

components of the service spectrum: meteorological (weather observing and forecasting), agricultural (identifying weather sensitive stresses and preparing suitable advisories using weather forecasts), extension (two-way communication with users) and information dissemination (media, information technology, telecom) agencies (figure 1).

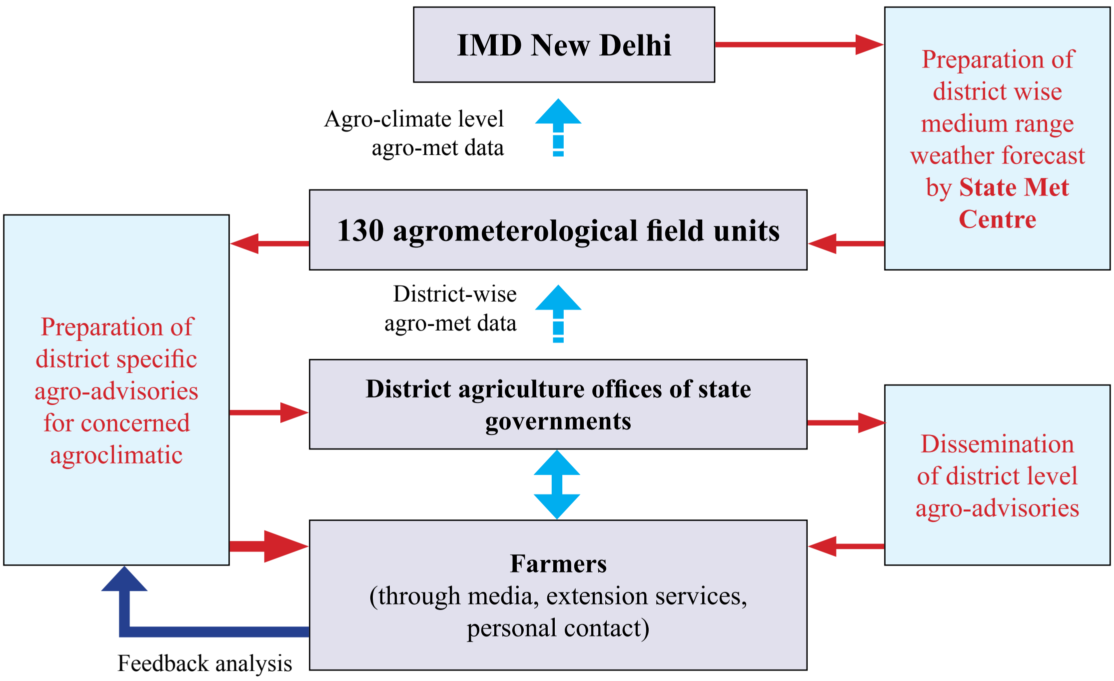
The MoES of the Government of India has set up a network of 130 AMFUs covering all agroclimatic zones of the country. These are operated at SAUs, ICAR institutions, and IIT by providing grant-in-aid from IMD. These units are responsible for recording agrometeorological observations, preparing medium range weather forecast-based agrometeorological advisories for the districts falling under the precinct of the concerned agroclimatic zone, and dissemination of the same. Participating units have appointed a Nodal Officer and Technical Officers, who prepare the advisory bulletins in consultation with a panel of scientists drawn from various disciplines at these units.

Agrometeorological support for farm management

Weather-based farm advisories as a support system are based upon background information including characterization of agroclimatic zones, length of crop growing period, moisture availability period, distribution of rainfall and evaporative demand of the regions, weather requirements of cultivars and weather sensitivity of farm input applications. The ingredients of a typical Agro-meteorological Advisory Bulletin are the following:

1. district-specific 5-day weather forecast, in quantitative terms, for rainfall, cloudiness, max/min temperature, wind speed/direction and relative humidity, including forewarning of hazardous weather events likely to cause stress on standing crops and suggestions to protect the crop from them;
2. weather forecast-based information on soil moisture status and guidance for application of irrigation, fertilizer and herbicides etc;
3. advisories on dates of sowing/planting and suitability of carrying out intercultural operations covering the entire crop spectrum from pre-sowing to post harvest to guide farmers in day-to-day operations;

Figure 1. The flow chart for District Level Agro-Meteorological Advisory Service (DAAS) System.



4. weather forecast-based early warning system for major pests and diseases of principal crops and advice on plant protection measures;
5. techniques for manipulation of crops' microclimate, e.g. shading, mulching, other surface modifications, shelterbelt (windbreaks), frost protection etc. to protect crops under stressed conditions;
6. techniques for reducing the contribution of agricultural production systems to global warming and environment degradation through judicious management of land, water and farm inputs, particularly pesticides, herbicides and fertilizers;
7. advisories on livestock health, shelter and nutrition.

Support for the above is rendered through preparation of district-specific agrometeorological advisory bulletins that are tailored to meet farmers' needs and are made relevant to his/her decision-making processes. The suggested advisories contain advice on farm management actions designed to take advantage of good weather and mitigate the stress on crop/livestock, and generally alter operations in a way that improves outcomes. Hence, while formulating the bulletin officers and scientists should be aware of current crop conditions. Ideally, farmers should place requests for information to the AMFU/IMD either directly or via the extension officer. But more often than not, such information has to be assessed through field observation, media reports, farmers' feedback, and remote sensing observations (vegetation indices such as the Normalized Difference Vegetation Index, etc.) The desired information is also obtained by exploratory surveys or participatory methods of personal interactions with farmers. The critical issues with regard to tailoring information for farmers, as summarized by Hansen (2002), include: a) site specificity – that farmers are aware of spatial variability in weather and climate and can recognize scale mismatches between the forecasts and their on-farm decisions; b) temporal specificity – including timing relative to decisions and impacts, highlighting factors such as onset of rainfall, dry spell distribution, and weather conditions during harvest; and, c) skill of the forecast – which needs to be presented in different terms from those given by the forecasters and rather relative to the other risks within farming operations.

The bulletins are encoded in a format and language that is easily understood by the farmer. The agrometeorologists first interpret the immediate past weather and the 5-day forecast and translate it into layman's terms so that the farmers can understand it. Thus, the agrometeorologists play a vital role in the translation of messages from the meteorologists to the agricultural sector. Also, interaction between the AMFUs and farmers to identify weather-sensitive decisions is promoted under the service. This step enables a relationship between the IMD, AMFUs, and the farmers so that they can identify or diagnose the gaps in weather information available from the IMD. As the interaction between weather and agriculture is complex, it is not just a case of applying a simple solution and expecting implementation by the farmers. So, an awareness-building process to understand the influence of weather and climate on sustainable agricultural production as outlined by Sivakumar, et al (2000) is followed.

The Agro-meteorological Advisory Bulletins are issued at district, state and national levels to cater to the needs of local to national level users. The district-level bulletins are issued by AMFUs and include crop-specific advisories for field crops, horticultural crops and livestock. At present these bulletins are issued for 539 districts in the country. The State Level bulletin is a composite of district bulletins helping to identify the distressed districts of the state as well as planning the supply of appropriate farm inputs such as seeds, irrigation water, fertilizer, pesticides etc. These bulletins are jointly prepared by the State Meteorological Centres of IMD and AMFUs and mainly used by State Government functionaries. They are also useful to the fertilizer and pesticide industries, the Irrigation Department, seed companies, transport services and other organizations that provide agricultural inputs. This bulletin is a significant input to the State-level Crop Weather Watch Group (CWWG) meeting. Presently, these bulletins are issued for all the states of the country. National Agro-meteorological Advisory Bulletins are prepared by the National Agro-meteorological Advisory Service Centre, Division of Agricultural Meteorology, IMD in Pune, using inputs from various states. This bulletin helps identify stress on various crops for different regions of the country and supports suitable incorporation of advisory information into management and planning decisions at the national level. The Ministry of Agriculture is prime user of these bulletins, which support important decisions in CWWG meetings at national level. The national-level bulletins are also used by a large number of other organizations including fertilizer and pesticide companies.

Database and models used in agrometeorology

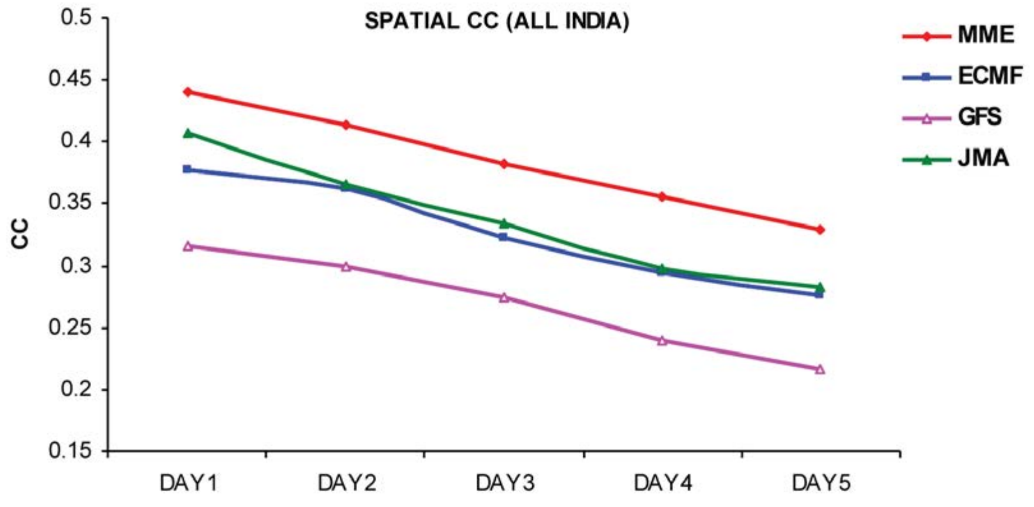
Weather forecasting system for AAS

In the recent past, IMD has made enormous improvements in the accuracy and lead time of forecasts for various usages including AAS, due to the introduction of advanced numerical weather prediction models (NWP), improved data (both conventional and non-conventional) and its assimilation, and high speed computers. This trend is expected to continue as more sophisticated numerical models of the atmosphere and oceans are developed. Using inputs from extensive observation networks and employing a host of global, regional and meso-scale models, IMD has provided quantitative district-level (612 districts) weather forecasts up to 5 days in advance since 1 June 2008. Forecast products include quantitative forecasts for 7 weather parameters: rainfall, maximum temperature, minimum temperatures, wind speed, wind direction, relative humidity and cloudiness. In addition, a weekly cumulative rainfall forecast is provided. IMD in New Delhi generates these products using a Multi Model Ensemble (MME) technique based on forecast products available from a number models from India and other countries. These include: T-254 model of NCMRWF, T-799 model of European Centre for Medium Range Weather Forecasting (ECMWF), and models from the United Kingdom Met Office (UKMO), National Centre for Environmental Prediction (NCEP), USA and Japan Meteorological Agency (JMA). The products are disseminated to Regional Meteorological Centres and Meteorological Centres of IMD located in different states. These offices undertake value addition to these products using synoptic interpretation of model output and disseminate them to 130 AMFUs every Tuesday and Thursday.

Results show that MME forecasts have better capability (compared to individual member models) to capture large-scale rainfall features of the summer monsoon, such as the heavy rainfall belt along the west coast, over the domain of monsoon trough and along the foothills of the Himalayas. The model inter-comparison reveals that the ensemble forecast is able to provide more realistic spatial distribution of rainfall by taking advantage of the strengths of each constituent model. The mean error as well as Root Mean Squared Error (RMSE) is found to be lowest in the ensemble forecasts both in magnitude and in the spatial area coverage. Results of error statistics have clearly demonstrated the superiority of the MME over the individual member models. Among the member models ECMWF is found to be the most skilful followed by JMA and NCEP Global Forecast System (GFS). The forecasts for other parameters, namely maximum and minimum temperature and morning and evening relative humidity, have also shown reasonably good skill. The results of the district-level performance of the ensemble rainfall forecast show that the technique, in general, is capable of providing reasonably good forecast skill over most states of the country, particularly over the districts of the Central Zone where the monsoon systems are dominant. Though the procedure shows appreciable skill in predicting the occurrence or non-occurrence of light to moderate rainfall at the district level, it has certain limitations in capturing heavy rainfall events.

Inter-comparison of the country's mean spatial correlation coefficient (CC) of rainfall forecasts by MME and member models is presented in Figure 2. The results show that MME is superior to each member model at all the forecast levels (day 1 to day 5). Inter-comparison of the threat scores (a measurement of the fraction of forecast events that were correctly predicted) of rainfall forecasts by MME and member models at different rainfall thresholds was also computed. The results indicate that at all rainfall thresholds, MME is more skilful than each individual model.

Figure 2. Inter-comparison of country mean spatial CC of day 1-day 5 rainfall forecasts by MME and member models for the period from 1 June to 30 September 2008.



The MME technique is constantly being updated and at present work is underway to compute weights for each of ECMWF, JMA, NCEP, NCMRWF and UKMO based on 2008 monsoon data for the five MME members to be used for weather prediction. Development work is also underway to design a MME method for issuing a probabilistic 3-day forecast based on very high resolution non-hydrostatic meso-scale models to estimate risk for districts, making use of the new observations and infrastructure that would be available from the ongoing modernization programme of IMD. Data sources used in numerical weather modelling include upper air soundings, land surface instruments (including the network of automatic weather stations (AWS) and automatic rain gauge stations (ARG) at the sub-district scale), marine surface instruments, buoys, aircraft observations, wind profilers, non conventional data from satellites- wind and radiances, rain rate etc. In the future the network density of AWS/ARGs will be further enhanced so as to automatically record meteorological observations at near block[3] level. In addition, installation and commissioning of a network of 55 Doppler Weather Radar towers is in progress. Techniques have been developed to assimilate large volumes of satellite-derived information from the INSAT-3D satellite. Through improvement in observing systems, there will be further improvement in defining the initial conditions input into NWP models, which may lead to further improvement in skill of weather forecasts. There is a plan to use geographic information systems (GIS) in the near future for generating customized agrometeorological products.

The value addition to NWP model outputs is undertaken along with preparation of district level weather forecasts at Meteorological Centres, which are located in different states and are

3 Block is an administrative sub-division below the district level used in rural areas of India.

responsible for issuing the final forecast to the AMFUs. The MME output may be modified by the Field Forecaster using inputs from very high-resolution meso-scale Weather Research and Forecasting (WRF) models, synoptic knowledge, bias correction of district forecast etc. These Centres run the WRF model using initial conditions generated from global models for detailed analysis of rain-bearing systems at a higher resolution.

Translating weather forecasts into agrometeorological advisory bulletins

An inter-disciplinary group of agricultural and extension specialists at each AAS Unit formulates weather-based farm advisory bulletins upon receipt of medium range weather forecasts from IMD. These bulletins contain location and crop-specific farm level advisories prepared in local languages and incorporate the available knowledge on crop-weather relationships. Weather-based agro-advisories take into account the prevailing weather, soil and crop conditions, and based on the weather prediction suggest measures/practices to minimise losses and optimise inputs in the form of irrigation, fertiliser or pesticides. Real time weather and climatic information are essential ingredients for development of agro-advisories.

Application of weather forecasts to generate crop advisories is linked to accuracy, spatial domain of validity and temporal range of the forecasts. In view of the requirements of the farming community, district level forecasts are issued for the above listed parameters for the next 5 days and are translated into crop specific advisories keeping in view their phenological stages to guide farmers on cultural practices.

District-specific medium-term forecast information and advisories help farmers maximize output and avert crop damage or loss. They also help growers anticipate and plan for chemical applications, irrigation scheduling, disease and pest outbreaks and many more weather related agriculture-specific operations. Such operations include cultivar selection, dates of sowing/planting/transplanting, dates of intercultural (weeding, pesticide application etc.) operations, dates of harvesting and also performing post harvest operations. Agrometeorological advisories help increase profits by consistently delivering actionable weather information, analysis and decision support for farming situations such as: pest management through forecasts of relative humidity, temperature and wind; irrigation management through rainfall and temperature forecasts; and protecting crop from thermal stress through forecasting of extreme temperature conditions etc.

Under the AAS system, more focus is now being given to the use of crop/soil simulation models to assess and recommend crop management strategies for a given weather condition. Agricultural scientists at AMFUs have started using crop simulation models as a decision support tool for making weather forecast based farm management recommendations, as they are more objective. For example, the AMFU can objectively assess the impact of skipping irrigation at a particular phenophase of a crop on its dry matter yield, though with some uncertainties. Agrometeorologists can consider many of the factors involved, and answer the farmers' questions with a reasonable estimate. The crop models are also being used as tools for prediction of the duration of different phenophases and final yield.

Decision support tools for generating weather-based farm advisories

Technological tools are required to translate weather information into agricultural management decisions. Accurate simulation of phenological stages with the necessary details for practical applications and management strategies helps considerably in scheduling of management actions. The management decisions that can be directly linked to weather forecasts are irrigation management, fertilizer application, herbicide application, pest/disease control, and harvest. For this crop-soil simulation models are employed to predict crop-level responses to different weather situations and soil moisture conditions. Such models are useful to develop decision support information for weather-based crop management. At the farm level, a series of short-term decisions must be made on the basis of knowledge or forecasts of parameters that are derived from weather forecasts, e.g. soil moisture, phenological development stage etc. In such a case, it is important that the farmer is forewarned about the likely impacts and enabled to mitigate negative impacts through an objective understanding of the interaction between various factors influencing the crop growth and development, water and nutrient supply, biotic stresses and the time of planting and harvesting of the crop. The AAS system has started using crop models to support crop management decision-making, but substantial improvements in modelling capabilities are needed. CERES and CROPGRO models, for different crops, have been incorporated in the Decision Support System for Agro-technology Transfer (DSSAT) crop systems model for use in crop and irrigation management in some agro-climatic zones. Examples on these aspects have been demonstrated by Aggarwal et al (2006), for tropical regions including Asia, where related user-friendly software has been developed.

Agrometeorological observatories and data for advisory services

Agrometeorological data form the basis of any agricultural pursuit, whether planning, development, operations or research. The Agriculture Meteorology Division of IMD has been providing assistance to various agricultural universities/institutions, State Departments and other organizations to set up agro-meteorological observatories by way of on farm siting and installation of instruments and maintenance of the observatories. The data recorded in agro-meteorological observatories are being utilized for research and development (R&D) as well as operational services such as AAS, and by a number of organizations for research, planning and management. This data is also used for used for preparation of routine charts and as input for crop models. To meet these needs the Agriculture Meteorology Division maintains a network of 261 agrometeorological observatories in farm environments. Beside this network, there are 42 evapotranspiration stations, 330 pan evaporation stations, 43 soil moisture observatories, and 75 dewfall observatories. Agro-meteorological Automatic Weather Stations (Agro-AWS) have been installed at 127 AMFUs and installation of Agro-AWS is planned for all KVKs in the country.

The data received from these observatories are scrutinized, archived and supplied to scientists, planners etc. The following types of agrometeorological observatories are in operation:

1. Principal agricultural meteorological stations
2. Ordinary agricultural meteorological stations
3. Auxiliary agricultural meteorological stations
4. Micromet stations (desert locust meteorological stations)
5. Evapotranspiration stations
6. Soil moisture stations.

Strategies for dissemination of agrometeorological advisories

Critical factors for successful dissemination of advisories include relevance of the information to weather and climate sensitive decision-making in agriculture, and good outreach. The goal is to provide information to help farmers make the best possible use of weather and climate information (Aggarwal 2002). To ensure delivery of information to the farming community, a multi-mode dissemination system is essential in which in addition to the conventional modes of communication (radio, television and print media), emerging modes of communication such as mobile phones and Internet are also deployed.

Advisories are disseminated to farmers through following the multi-channel system:

i. All India Radio (AIR) and Door Darshan (Government of India television service)
ii. Private TV and radio channels
iii. Newspaper
iv. Mobile phone/SMS
v. Internet
vi. Virtual Academy/Virtual Universities/NGOs
vii. Kisan (Farmer) Call Centres/ICAR and other related Institutes/SAUs/State extension networks
viii. Krishi Vigyan Kendra (KVKs)

In general, the use of more than one channel offers a greater chance of reaching the client or user. AAS advisories are primarily disseminated to farmers by mass modes of communication, with additional outreach at the village level and contact with extension agents. Group methods at the village level involve addressing the needs of clients that have similar needs and can benefit from similar information. This method uses uniform advisories for targeted groups formulated to address critical decisions and provide the desired agrometeorological information using the same format and language. The groups allow farmers to be exposed to other farmers' successes as well as realize that they may encounter similar problems or obstacles. This encourages them to consider alternatives that may have been used by others. It also helps to share experiences and opinions and identify gaps in the knowledge or information flow (Joyce 2003). The groups can be used in follow-up on both mass media dissemination and previous individual contacts. The individual contact method can be time consuming but also build good rapport and help maintain credibility between the role-players. It is a vital part of the participatory technology and training method of extension.

To improve the service through continuous refinement a flow of information from farmers on quality and relevance of information and/or demand for specific products is required. Hence two-way communication with farmers must be an integral part of the dissemination system. Deployment of the communication model should be in accordance with user needs and convenience. AAS has considered different aspects pertinent to the flow and content of information and accordingly developed an evolving strategy for dissemination of agrometeorological information. Although concerted efforts are being made to set up two-way communications, as of now the information flow is largely one-way. Although AMFUs have limited interaction with the farmers, good communication and working relationships have been set up with the agricultural extension system via KVKs and Kisan (Farmer) Call Centres etc. to promote participatory methods for interactions with farmers. The agrometeorological bulletins contain dynamic information so repetitive dissemination is needed. This iterative process also helps to address the large temporal and spatial variability in weather and climate and its complex relationship with agriculture (Carlson 1989).

The dissemination of agrometeorological information illustrates the vital parts of communication. Communication includes five fundamental factors: initiator, recipient, mode or vehicle, message, and effect. The communication begins with the farmer who formulates a request to the initiator. The initiator must be able to translate it into a scientific formulation to perform data analysis and prepare a message in a format and language that the farmer can understand. The process includes a) identification of the clients or target groups, and b) identification of weather and climate-sensitive decisions that are made during the course of day-to-day farm management. This step enables a relationship between the meteorologists, agricultural scientists, extension personnel and the farmers so that they can identify or diagnose the gaps in weather information available from the National Meteorological and

Hydrological Services, and c) choose the right media among those available to the targeted user groups.

The use of electronic media such as e-mail or the Internet depends on the availability and access of these methods to the users. Access is increasing in India, in particular through an initiative of the Department of Information Technology, which is in the process of to setting up a network of common service centres (CSC). AAS is a scalable system that can be incrementally developed and extended to cover all the farmers and crops of India in a cost-effective manner. It enables the farmer to receive both crop and location-specific expert advice in a timely manner. With the advent of computers and Internet, emphasis is often being given to electronic communication systems. However, TV and radio services are still the best ways of communicating advisories among rural people as these are not only fast methods, but also large and illiterate masses can be contacted. Broadcasting of advisories in vernacular language increases their accessibility relative to other means of communication. Under the AAS scheme efforts are being made to strengthen the outreach of the agrometeorological advisories as per the need of the farmers.

Dissemination of AAS advisories through the Internet

Disseminating agrometeorological information is part of a process that begins with scientific knowledge and understanding and ends with evaluation of the usefulness of the information to users. The Internet is one of the new and cost-effective technologies that can provide this information in an accurate and timely manner. Additionally, the Internet can also be effectively used to offer training modules to agrometeorologists to help them improve the quality of the products they produce. Agrometeorological bulletins are available on the India Meteorological department and Agricultural Meteorology Division websites and websites maintained by collaborating agencies.

Dissemination of AAS advisories through mobile phone

AAS advisories are also disseminated to the farming community in India through SMS and IVR (Interactive Voice Response Technology). Under the SMS system an information platform has been created which allows AMFUs to provide information to farmers in a convenient and timely manner. The advisories are crop and location-specific and delivered within an actionable time frame to the farmers. Under the IVR system the information from AMFUs for each state is collected and then stored, and converted into voice messages. Farmers can then call in and receive the desired information.

Public-private partnerships for agrometeorological advisory dissemination

In the era of the emerging Information Technology (IT) arena in India, many private companies have joined hands with IMD to deliver weather-based agricultural information to farmers using multiple modes of information communication. As some farmers are willing to pay for the information, IMD has formed partnerships with different public and private organizations that are already working to disseminate agricultural information to rural villages. Dissemination technology employed under these schemes is mainly based on IT and includes Internet and mobile phone based communication systems. The most advantageous feature of mobile phone-based systems is that farmers can communicate with the web-based systems while in the field and thus are able to request advice concerning newly discovered problems.

i. IMD has so far partnered with Reuter Market Light (RML), Handygo, NOKIA, IFFCO Kisan Sanchar Ltd. (IKSL), National Bank for Agriculture and Rural development (NABARD), Maharashtra State Agriculture Department (Government of Maharashtra). Existing linkages with these organizations are described below.

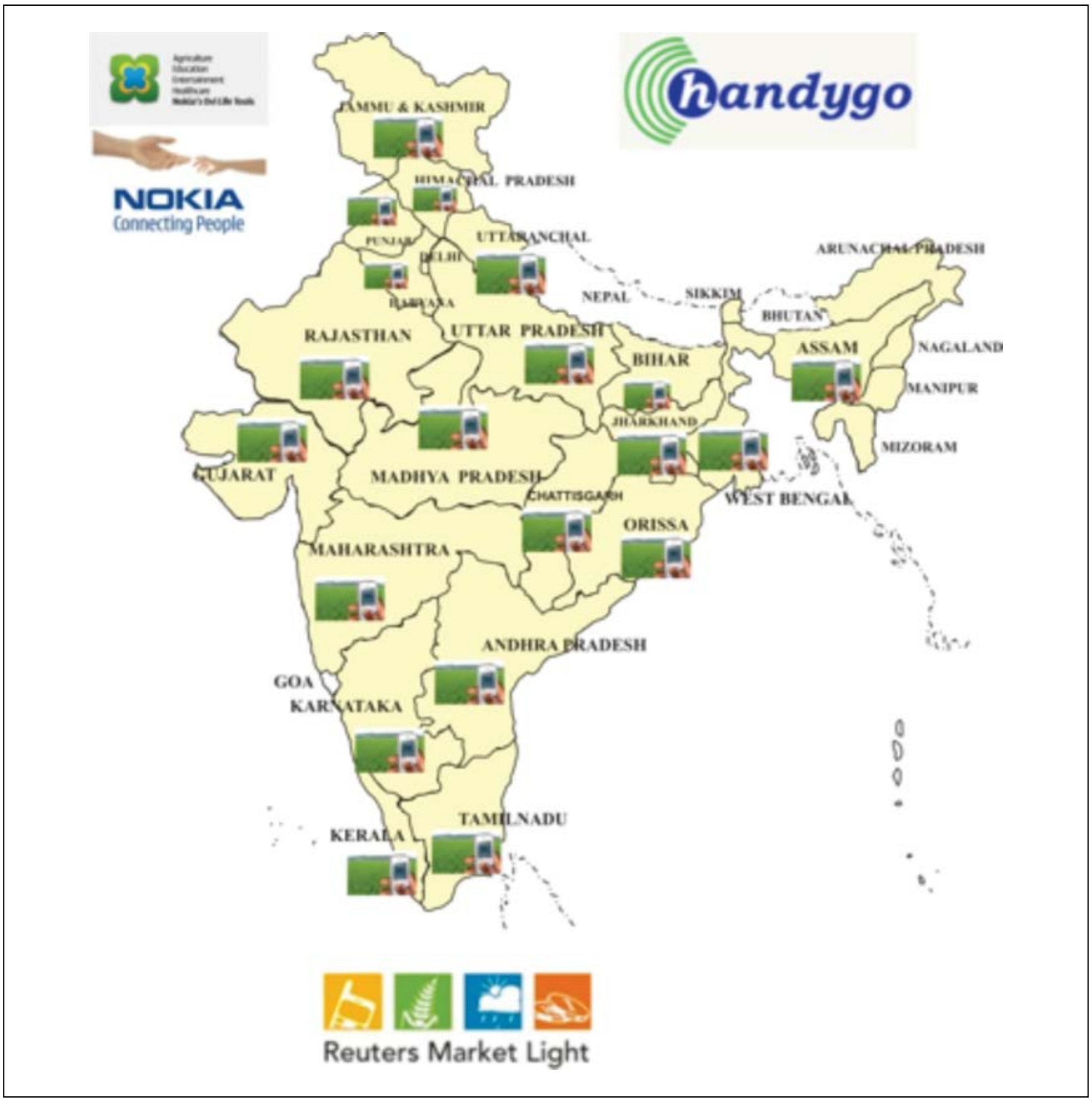
ii. Reuter Market Light: IMD and Reuter Market Light (RML) are working together to disseminate weather and agro-meteorological crop/livestock advisories in regional languages. Through RML, the advisories are being disseminated to five states namely Maharashtra, Gujarat, West Bengal Punjab and Haryana. RML is interested in creating a scalable model that can expand across India and utilize the information developed for all the 640 districts of the country.

iii. Handygo: Handygo is a telecom value added services company based at New Delhi. The company is disseminating agrometeorological advisories through an IVR system to Punjab, Haryana, Maharashtra, Gujarat and West Bengal.

iv. NOKIA: Nokia Life Tools Agriculture services provide agrometeorological advisories to farmers on a regular basis. IMD in collaboration with NOKIA had started service in 10 states: Maharashtra, Andhra Pradesh, Karnataka, Gujarat, Uttar Pradesh, Tamil Nadu, Madhya Pradesh, Kerala, Rajasthan, and Punjab.

v. IFFCO Kisan Sanchar Limited (IKSL): IKSL provides value added services to farmers in 18 states through mobile phones, sending five voice messages per day to farmers free of cost. The project is underway in Andhra Pradesh, Bihar, Jharkhand, Madhya Pradesh, Chhattisgarh, Gujarat, Punjab, Haryana Maharashtra, West Bengal, Himachal Pradesh, Karnataka, Orissa, Rajasthan, Tamil Nadu, Uttar Pradesh, Uttarakhand, and Kerala.

Fig. 3 Coverage of SMS and IVR system in the country.



vi. National Bank for Agriculture and Rural development (NABARD): Collaboration between NABARD and IMD has been started to provide location-specific weather forecasts and AAS information to 50, 000 farmers in Maharashtra through 10 KVKs and the Farmers Club of NABARD. Presently, 10 KVKs in Maharashtra are linked with the AMFUs for preparing and sending the SMS.

vii. State Department of Agriculture, Government of Maharashtra: IMD is also sending SMS to the farmers in the villages of the state through State Department of Agriculture, Government of Maharashtra through the website (www.Mahaagri.gov.in).

The outcome of the pilot programme has proven to be very positive and as a result to at present, 3.4 million farmers across 20 states namely Uttar Pradesh, Punjab, Haryana, Rajasthan, Madhya Pradesh, Orissa, West Bengal, Gujarat, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Bihar, Maharashtra, Himachal Pradesh, Assam, Uttarakhand, Chhattisgarh, Jharkhand and Jammu and Kashmir have benefited from the updates and timely crop advisories.

AAS awareness programme

Efforts made by Ministry of Earth Sciences, IMD, ICAR, SAUs, Union/State Departments of Agriculture and other collaborating agencies through AAS have demonstrated the role of weather forecasting in increasing the overall preparedness of farmers, leading to substantially better production outcomes overall. However, more efforts are needed to assist farmers to further develop their adaptive capacity with improved planning and better management decisions. Hence, a more effective participatory, cross-disciplinary approach to the delivery of climate and weather information to farmers is being carried out through enhancing awareness of information user groups. The approach involves organizing farmer awareness programmes, known as 'roving seminars', which bring together research and development institutions, experts in relevant disciplines, and farmers as equal partners to reap the benefits from weather and climate knowledge. Given the current concerns with climate change and its impacts on crop productivity, there is an urgent need to sensitize farmers about the increased weather variability, in their regions, and different adaptation strategies that can be considered to cope with the extreme weather situations. Examples of more general decisions that can be aided by targeted weather information include strategic and tactical crop management options, agricultural commodity marketing etc.

Such programs help increase the interaction between the local farming communities and the Meteorological Centres (MCs), AMFUs and KVKs. A large number of such seminars are organized in different agroclimatic zones of the country to sensitize farmers about the weather and climate information and its applications in operational farm management. These are jointly organized by IMD, ICAR and SAUs, local NGOs and other stakeholders.

In order to improve the linkage with the AAS system and develop a local (village) level rain measuring network, 5 rain gauges are distributed to a selected group of 'progressive' farmers during the seminars, who are trained to record and report the rainfall observation to the concerned AMFUs. AMFUs in turn communicate the data to IMD. So far such programmes have been organized at 104 AMFUs.

An Agromet Brochure highlighting the activities of AAS was prepared in 14 regional languages for the benefit of the Indian farmers. For general awareness and easier access to the services of IMD, the brochure is being circulated to concerned organizations/institutes including the Ministry of Agriculture (Central and State), ICAR, SAUs, Regional Research Institutes, KVKs, Department of Space, NGOs and all other organizations directly and indirectly related to the agricultural services in the country.

In addition, farmers are being made aware of the service through participation in *kisan melas* (farmer fairs), field visits, field demonstrations, farmer field days, and farmer field schools. During these programmes farmers are provided with information on various services in local languages and taught to record weather observations using various weather instruments. Discussions include the importance of the service and farmers' existing skills and gaps, and allow for familiarization of the agrometeorologist with the problems faced by the farming community and their expectations from the service providers.

Feedback mechanism on AAS

Regular feedback from farmers, State Agricultural Departments, SAUs, ICAR and other related institutes is being collected and processed for further improvement of services. Feedback information are also been collected from regional and national broadcasting stations of Door Darshan (Government of India television service), All India Radio, and FM channels, KVKs, ATMA, Central Seed Committees, NGOs, and Village Resource/Knowledge Centres.

Capacity building in agricultural meteorology

Training is one of the key elements for constant improvement in the service; thus it forms an integral part of an agrometeorological service. Periodic training programs for forecasters, scientists, agrometeorologists, extension workers, media and farmers at appropriate levels sharpen their skills and improve the service delivery. Improvement in skill of all involved in the programme for understanding the weather processes and their impact on crops/animals should form an integral part of Human Resource Development process. Regular updating of knowledge on crop/pest disease simulation, GIS, use and interpretation of remote sensing data for agrometeorological purposes etc. are important areas for training the staff working for an agrometeorological service. Development of techniques for combining extended/seasonal forecast and crop models in agriculture risk management is required. Different training programmes organised periodically at IMD are as follows:

1. Foreign trainees courses
2. Agromet core course
3. Summer placement course
4. Agromet observer course
5. Meteorologist grade II training course
6. Refresher course
7. Basic agromet course
8. On the job training
9. Operational agrometeorology
10. AMFU scientists' course on livestock and animal health.

Impact of AAS on climate risk management

Impact assessment of the weather forecast based agro-advisory service was carried out by NCMRWF at 15 AAS units representing different agroclimatic zones. The report assesses the impact of the use of weather-based agro-advisories on production of cereals, millets, pulses, oilseeds, fruits, vegetables and cash crops selected for the study. The study period was spread over three years comprising of 3 *kharif* and 3 *rabi* seasons. The National Centre for Agriculture Economics and Policy Research (NCAP) was engaged as a consultant for the project, and helped to formulate the study plan, including devising sampling methods, preparation of questionnaire, monitoring its implementation and data analysis.

In general it is difficult to assess the economic benefit of any advisory service. A general simulation model for the evaluation of the economic benefits of meteorological assistance to agriculture does not exist; however, evident effective benefit, probable effective benefit, and theoretically maximum possible benefit can be defined. When user-focused weather based advisories are made available and used by farmers, losses resulting from adverse weather and climatic conditions are minimized, thereby improving the yield and quality of agricultural products. Also, the favorable weather is harnessed to its potential. The requirements that must be met if farmers are to manage the risks posed by weather and climate include: access to early warning and forecast conditions, awareness that weather and climate variability will impact on farm operations, and ability to apply the agrometeorological information in decision making. Farmers may have more than one option for managing the risks they face, and most use a combination of strategies and tools. Some strategies deal with only one kind of risk, while others address multiple risks. This complicated the task of assessing the economic value of agrometeorological information. Agricultural impacts of weather include changes experienced by farmers that have meaning or value that is positive (a beneficial effect) or negative (an undesired effect), helping them to decide selections of crop/variety, sowing/ harvesting time, irrigation management, fertilizer management, pest/disease management and other intercultural operations. This formed the backbone of the economic impact study carried out by NCMRWF in collaboration with the AAS units.

The study was conducted with the following primary objectives:

- to encourage adoption of the forecasts by the user community, helping understanding of the linkages between information, users and impacts;
- to assess the effectiveness and potential benefits of agro-advisory services by taking into account the AAS contact and non-contact farmers;
- to work out weather-based farming strategies based on the economic impact of AAS;
- to assess the needs of the farming community for increasing farm production;
- to assess the economic impact of the AAS services in various crops under different agroclimatic conditions.

The concept of the study is based on the assessment of the ability of forecast-based advisories to influence farmers' decisions on various farm management operations, find out economic and other benefits resulting from use of advisories in farm management decisions, and assess impacts of advisories on overall crop yields. The economic assessment found that there is 10–25 percent economic benefit obtained by the farmers due to the adoption of agrometeorological advisory services (Rathore & Maini 2008).

The agrometeorological advisory services provided by IMD through various channels have resulted in significant increases in farm productivity, resulting in increased availability of food and higher income generation. At present only 10 to 15 percent of the farmers are benefitting from the SMS services and about 24 percent of farmers are aware of AAS. The economic benefit of these services is estimated by National Council of Applied Economic Research (NCAER) at rupees 50,000 crores per year is extrapolated to rise to rupees 211,000 crores, if the entire farming community in the country were to apply agrometeorological information for their agricultural activity. Thus there is significant opportunity for expanding the impact of AAS.

All India Coordinated Research Project on Agro-meteorology (AICRPAM)

With an aim to bring stability in food grain production in the face of varying weather conditions, the Government of India recognized the research needs in agrometeorology and started strengthening these at its various research institutes functioning under ICAR. The National Commission on Agriculture (NCA) (1976) strongly recommended for establishment of Departments of Agricultural Meteorology at each SAU for strengthening teaching and research in Agricultural Meteorology. The inception of the All India Coordinated Research Project on Agro-meteorology (AICRPAM) in 1983 at the Central Research Institute for Dry-land Agriculture (CRIDA), Hyderabad was the culmination of the prompt response of ICAR to the recommendations of NCA for strengthening agrometeorological research.

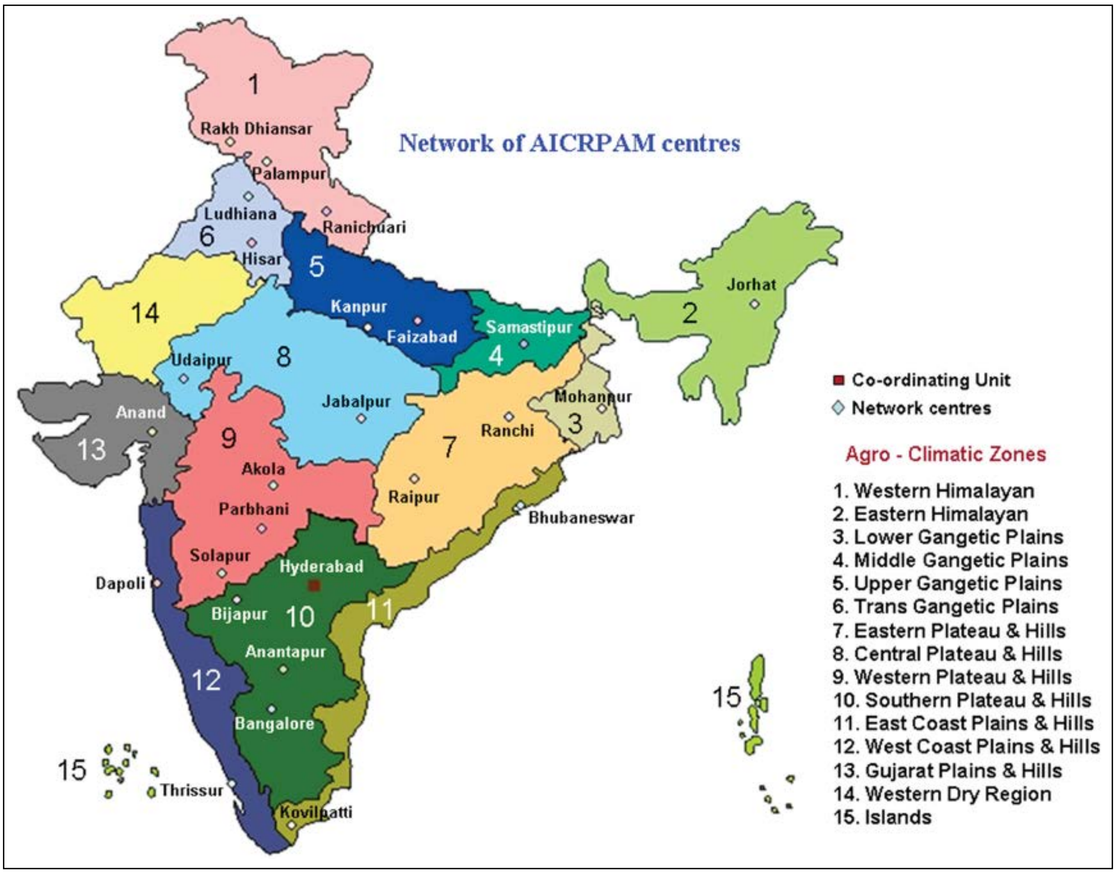
AICRPAM was launched in 1983, by setting a Coordinating Centre at CRIDA and 10 Cooperating Centres at different SAUs across the country. Initially the project came into operation at six centres: Anand, Anantapur, Bangalore, Hisar and Ludhiana, which were already engaged in teaching and research in the discipline of Agricultural Meteorology. The network was further widened in 1985 by inclusion of four more centres: Solapur, Jabalpur, Mohanpur and Ranchi. During the VII Plan period, i.e., two more centres, one at Kovilpatti in Tamil Nadu and another at Ranichauri in hilly region of Uttarakhand, were added to the network. In 1990, Varanasi centre was closed and in its place, Faizabad (Uttar Pradesh) was included as Cooperating Centre of the project. In 1988 through USAID funding on Indo-US sub-project entitled 'Strengthening Agro-meteorological Research to Enhance Food Production' the project was augmented to equip the Cooperating Centres with modern agrometeorological instruments and also provided specialized training to project scientists in USA for six months on identified priority areas of agrometeorological research. Considering the good progress made by AICRPAM, the ICAR sanctioned 13 additional centres during the VIII Plan period and these centres came into operation in 1995–96. In 1998, the AICRPAM project established an Agro-met Databank with the financial support from the Department of Science and Technology to cater to the needs of agrometeorological data requirement of ICAR Institutes, SAUs and its scientists. It is being maintained by CRIDA and continues to serve its purpose. During 2001 to 2005, the sanction of 5 external funded research projects of high budget allocation under National Agricultural Technology Program (NATP) of ICAR, further strengthened AICRPAM in terms of infrastructure and human resource development, especially at the Coordinating Unit. For strengthening of research capabilities of agrometeorologists, about 22 training programmes on agrometeorological analysis were also conducted over the period.

Presently the project is operating with its Coordinating Unit at CRIDA, Hyderabad and has Cooperating Centres in 25 SAUs spread across all the agroclimatic regions of country (Figure 4). This is the first and only network project on agrometeorological research in India. The project maintains its uniqueness among other network projects by not being confined to a single commodity or crop and a particular ecosystem or climatic condition. The research domain of the project cuts across all the four agro-ecosystems: rainfed, irrigated, hill and mountain and coastal island. Unlike other network projects on agrometeorology elsewhere in the world, which are mostly focused on data collection and operational research, AICRPAM is engaged in both basic and operational research in the discipline of agrometeorology. Each centre conducts agro-meteorological research on one or two main crops of its region in addition to analysing long-term weather data for agroclimatic characterization and climate change studies. All the centres support AAS with research results obtained over the years.

The broad R&D domain of AICRPAM is:

- to study the agricultural climate in relation to crop planning and assessment of crop production potential in different agroclimatic regions;
- to establish crop-weather relationships for all the major rainfed and irrigated crops in different agroclimatic regions;
- to evaluate the different techniques of modification of crop micro-climates for improving the water use efficiency and productivity of the crops;
- to study the influence of weather on the incidence and spread of pests and diseases of field crops;

Figure 4: Network of AICRPAM centres.



- to provide weather-based agro-advisories using medium range weather forecast and ICT;
- to collect and update weather data in the Agromet Databank at CRIDA.

Thematic research areas to achieve the objectives include: agroclimatic characterization, crop–weather relationships, crop–weather modelling, effect of weather on pests and diseases, and support to AAS.

Significant achievements of AICRPAM

Over the past two and half decades, network centres of AICRPAM have generated data on growth, development and yield of crops that were assigned to each centre, besides collecting historical weather data for their respective regions. Each centre also collected historical crop yield data and the corresponding weather data in different districts of their respective agroclimatic regions/states. Data on disease and pest incidence of the main crop(s) of each centre were analysed in relation to weather conditions. Validations of crop simulation models were undertaken at some centres. AICRPAM was also associated with the National Project on Climate Change (NPCC), which focused on the impacts of climate change on crops, livestock and fisheries besides biodiversity impacts. Currently the AICRPAM project is also linked to the ICAR sponsored Mega National Project 'National Initiative on Climate Resilient Agriculture' (NICRA) launched during 2010–11 with CRIDA as the nodal agency, where it is contributing to two of the major research themes on i) vulnerability assessment of major production systems to climate change and ii) linking weather-based agro-advisories to contingency planning.

Future Plan:
Although AAS is being provided efficiently at the district level, there is a need to strengthen observations, seamless weather forecasting, human resources, real time information flow, R&D, dissemination, and other areas. There is need to develop methodologies for remote sensing and conventional data merging. Concerted efforts are needed for ground-based data collection, satellite data collection, GIS software applications, operational applications of meteorological satellite data, weather radar and the monitoring of the cropping season by meteorological and remote sensing data to equip AAS units to generate better advisories. Though district level medium range weather forecasts are being prepared for AAS, there is an urgent need to develop and issue high resolution accurate weather forecasts at the block level to help tailor crop planning advisories for farmers at village level. Thus there is a need to scale up the service from the district to the block level with dissemination at the village level across the country to meet end user needs. Based on this idea, the new concept of establishing the Gramin Krishi Mausam Sewa (GKMS) scheme under AAS in the country during the XIIth Five Year Plan was developed.

The main objectives of the proposed project would be:
1. enhance the existing district-level AAS operating under MoES/IMD throughout the execution of the XIIth Five Year Plan, with the goal of delivering crop and location-specific agrometeorological advisories to farmers at the block level with village-level advisories;
2. establish district-level Agromet Units that would be multi-purpose centres for catering to needs of agriculture as well as other sectors of the economy;
3. communicate weather-based agrometeorological advisories online to the farmers at the block/taluka/village level;
4. establish an agrometeorological data centre that will store weather, crop and soil data etc. collected and generated across various centres and agrometeorological observatories in India, and make available in a relational database the basic and derived agrometeorological parameters and crop information to users through the IMD website after scrutiny and quality checking;
5. create a Centre for Research and Excellence in Agro-meteorology that will work to channelize R&D products and tools for their applications in AGROMET sectors in areas.

References

Aggarwal PK. 2002. Climate Change and Agriculture: Information Needs and Research Priorities. International Conference on Capacity Building for Climate Change, 21 October 2002.

Carlson JD. 1989. The Importance of Agricultural Weather Information – A Michigan Survey. *Bulletin of American Meteorological Society* 70 (4) p. 366–380.

Hansen JW. 2002. Realizing the potential benefits of climate prediction to agriculture: Issues, approaches, challenges. *Agricultural Systems* 74 (2002) p. 309–330.

Joyce LA. 2003. Improving the flow of scientific information across the interface of forest science and policy. *Forest Policy & Economics* 5 (2003) p. 339–347.

Maracchi G, Dunkel Z, Orlandini S. 2002. European Agrometeorological Applications. In: *Improving Agrometeorological Bulletins*. Proceedings of WMO Inter-Regional Workshop, October 15–19, 2001.

Rathore LS, Parvinder M. 2008. *Economic Impact Assessment of Agro-Meteorological Advisory Service of NCMRWF* (National Centre for Medium Range Weather Forecasting, report NMRF/PR/01/2008), Ministry of Earth Sciences, Government of India.

Sivakumar MVK, Gommes R, Baier W. 2000. Agrometeorology and sustainable agriculture. *Agricultural & Forest Meteorology* 103 (2000) p. 11–26.

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