Climate Variability and Its Impacts on Water, Energy and Food Systems in South Asia:

Adaptive Water Management Approaches within the Framework of IWRM

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The Manual

This manual is to equip the researchers, development practitioners and policy makers working on issues linking climate variability and change on water, energy and food security to help analyze the impacts of climate variability on water, energy and food systems in South Asia and identify the adaptive approaches for water, energy and food security. The manual deals with specific problems prevailing in South Asia. However, it would have more generic application, as: it would discuss the theoretical/ conceptual frameworks for analyzing the climate impacts on water, energy and food; and the South Asian region represents a wide variety of physical (climatic, environmental), socio-economic conditions, institutional and policy settings, and political regimes, which exist elsewhere in other parts of the developing world, such as Sub-Saharan Africa and Latin America, and as a result the empirical studies identifying the problems and solutions would be very much relevant for other regions of the world.

The Context

Scientific studies show significant impacts of a potential change in climate on the natural resources and consequently on the lives and livelihoods of people, through changes in water, energy and food systems. Such impacts will be more on people in the developing countries, which are in semi-arid and arid tropics, due to their high dependence on the natural resource base and lower resilience to environmental shocks. The poor are more vulnerable to such changes. Climate change will have different implications for different parts of South Asia due to the variations in topography and bio-geographic features, and spatial and temporal variability in hydrology and climate. Extreme variations in climate from year to year cause unprecedented changes in almost all major ecosystems with the type, nature and degree of impacts varying across different regions.

The question is–how does climate variability impacts on water insecurity? Population growth, long term economic growth and rising per capita income, fast urbanization and high growth in the manufacturing sector are resulting in exponential growth in water demand for competitive use sectors and more so in the naturally water-scarce arid and semi- arid regions of South Asia. This, compounded by indiscriminate dump of municipal and trade effluents from fast growing cities into freshwater bodies and return flows from intensively irrigated crop land, is causing enormous stress on freshwater resources. The mounting water resource related problems in the region are manifested by groundwater depletion, quality deterioration and widening gap between water demand and supplies, environmental water stress in major rivers, growing inequity in access to water, and increasing competition and conflicts over water use.

Extreme variations in climate add fresh challenges to already aggravated water management problems in South Asia. It can impact on hydrological systems of the country's river basins by affecting runoff, groundwater recharge and moisture in the soil profile, with significant implications for net water availability in them. It can affect the demand for water in many competitive use sectors, especially in agriculture by changing crop water requirements. Given the inextricable link between water and energy, climate variability can impact on energy systems also. The overall impact can be on freshwater availability for basic survival needs, and food and energy security. The way water resource systems are designed need attention to this impending catastrophe. Along with this, the socio-economic systems affecting the demand for water and energy also need to be changed through institutional and policy instruments.

Rationale

There is a vast literature now available globally on the theoretical and empirical aspects of climate change, and adaptation, particularly on the use of IWRM approaches, mostly developed by Cap-Net. But, climate variability is as serious a challenge as climate change, in the Asia Pacific region, which experience monsoon weather patterns, causing droughts, floods resulting in vast devastations of human, social and natural capital. Some literature is also available on the theoretical and empirical aspects of climate variability at the national and sub-national level in countries like India, though for very few climate parameters. The understanding regarding 'climate variability' in general, and an analysis of the nature and degree of variability in various climate parameters in different regions could help inform better how they interact in a climate system. This is a new area for water resource professionals working on climate related issues.

There is a lot of conceptual and theoretical understanding of how climate change can affect precipitation and therefore hydrological systems and water resource availability in different types of climates, like temperate and tropical regions. But, there is limited knowledge, based on empirical evidence or hydrological simulations, of the impact of climate change on hydrology and water resources specific to river basins. Most river basins in arid tropics experience very high variability in climate parameters, viz., rainfall, temperature, humidity and wind speed. A good understanding of hydrological regimes changes resulting from climate variability in such regions can provide strong leads on the kind of impacts climate change can induce on water resources in such river basins. For this, empirical analysis of a few typical river basins would enhance the understanding.

Far less is understood about how the climate induced impacts on water resources affect the energy and food systems. For both the hot& arid tropics and the humid, sub-tropical climates which exist in the region, agriculture is a major source of food security and rural livelihoods. Droughts impact adversely on food production through crop failures through heat stress and irrigation water scarcity. Floods have a devastating effect on crops in many areas, particularly eastern India and Bangladesh. Droughts and floods cause food shortages, and affects nutritional security for hundreds of millions of poor farm households in the region. Droughts upset our energy balance also. Demand for energy in rural areas increase manifold during droughts when both crop water requirement and irrigation demand increase on the one hand, and the groundwater table declines on the other. Energy production declines during droughts, when the production from hydropower plants sharply decline. Availability of biomass, which is a key energy source for rural socio-economic production functions--cooking, feeding animals etc. is determined by water availability through precipitation and soil moisture.

As regards the socio-economic, gender and environmental impacts of climate change, again, the understanding is very generic, and is not grounded on robust field evidence. The communities in South Asia region have been exposed to the impacts of climate variability in the form of droughts and floods for many millennia, and hence developed mechanisms to cope with it in varying degrees. The way climate induced changes in water resources affect the socio-economic systems depends highly on the physical environment, the socio-economic system characteristics, cultural settings and the institutional and policy environment. Even in South Asia, significant variations in the latter are visible across regions and sometimes within regions.

Therefore, it is likely that the impact of climate variability or change on communities in one region could be remarkably different from that in another region. Unless we know how the communities are going to be affected by different types of climate shocks, effective strategies for adaptation are unlikely to come forth. Therefore, knowledge from quantitative and qualitative research needs to be synthesized.

There is a growing body of literature on adaptive water management in the context of climate change. They cover physical/technical options, institutional interventions and economic and fiscal instruments. Here again, the issue is that they are too generic to be applied to any specific context. This is true for both physical options for water management and institutional and policy choices.

In South Asia region, the water systems are very complex, with large surface water systems, decentralized groundwater based systems and small water bodies. Many water supply systems (sources) are private and decentralized, be it for irrigation or for rural drinking water supplies or urban water supplies. Several of the technological options which are generally applied to formal and centralized water supply[1] are unlikely to work here, due to the unfavourable institutional and policy frameworks. More importantly, in the poor countries of South Asia, economic viability and financial feasibility of many standard technological solutions are questionable, due to poor willingness of people to pay for water and environmental management services. As regards market instruments for demand management, poor monitoring and weak enforcement of legal and regulatory framework reduce their effectiveness. Political acceptance of market instruments such as pricing of water, and energy are major issues for some of the democratically elected governments in South Asian region. So, the viable alternatives based on research of innovative models need to be explored under the larger IWRM framework.

In many developed countries, the legal and institutional regimes governing the access to and use of water are different from those in developing countries of Asia and Africa. In developed countries, there are institutions responsible for water resource management and inter-sectoral water allocation such as river basin organizations (RBOs). Well defined water rights exist for groundwater and surface water, recognized by national or provincial laws, and are part of IWRM approaches. Such institutional options do not exist in most developing countries, particularly in the South Asia region. The capacities (in terms of knowledge, information, human resource capacities, and financial, legal and regulatory powers) of line agencies in water also vary widely between developed countries and developing countries of South Asia. The ability of the existing institutions to adapt to changes induced by climate shock could be severely limited because of these factors. Hence, the general prescriptions made in the context of developed work might not work. Alternative institutional models which fit the socio-ecological and institutional and policy context need to be explored through case studies of innovative models experimented elsewhere in similar situations.

The need was felt for developing a full-fledged training manual from the available scientific and empirical research (both published and grey literature) on topics related to climate change and variability, the impact of climate variability on water resources, energy and food systems and their socio-economic and health consequences in South Asia, and adaptive water management approaches within the larger framework of integrated water resources management.

Objective

The overall objective of developing the training manual is to create a South Asia level platform for informed debate on the ways to reduce the vulnerability of the region's water, energy and food systems to the impacts of climate variability. The ultimate aim will be to build

[1] Concept of replacement water, water recycling & reuse and efficient water use technologies.

the capacities of key stakeholders of the region for evolving adaptive water management within the overall framework of IWRM. The specific objectives are to have an informed debate on the following three areas:

1. How climate variability impacts on water resources and the manner in which they affect the water, energy and food systems in the region;

2. Their impact on the socio-economic systems, particularly the poor and the vulnerable sections (vis-à-vis water security, food and nutritional security, livelihood security and health); and

3. The adaptive water management approaches in the larger framework of integrated water resources management that would mitigate these impacts.

Scope and Content

The training manual contains the following:

A] Development of a conceptual framework to analyze the impact of climate change and variability on water, food and energy systems in the South Asian context

B] Present state of the art knowledge on climate variability in South Asia for the range of climate variables, and the impact of climate variability on hydrology and water resources in the country, using empirical analysis of macro and micro level data

C] Illustrate the impact of climate variability on water supplies, energy systems and food production in South Asia, with empirical analysis of micro and macro level data

D] Analysis of the socio-economic and health consequences of extreme hydrological events, particularly droughts and floods

E] Analysis of the impacts of climate variability on women, poor and other vulnerable sections of the community

F] Technological strategies for adaptive water management which are capable of internalizing the negative implications of climate variability on water supplies and demand for water in the key water-demanding sectors of the economy, under different physical, socio-economic, institutional and policy environments

G] Institutional interventions and economic instruments for adaptive water management for water, food and energy security in South Asia

The manual would equip the water sector and climate science professionals with the tools to deepen their understanding of issues related to climate variability and change and the manner in which they can affect water availability and demand in different regions in South Asia that is characterized by spatial variability in climate. It would also provide tools to analyze the impact of climate variability and change on water resource availability, access to water, demand for water, water-related livelihoods and human health. It would also familiarize them with adaptive water management approaches in the context of climate variability and change, particularly the specific technical, economic and policy instruments to deal with the stresses induced by the same on water resources, socio-economic and environmental systems, and institutional capacity building needs.

The manual would also discuss the analytical framework and tools for distinguishing: 1] global/regional changes in climate from localized changes in climate variables; 2] short-term changes/variability in climate from long term changes in climate; 3] changes in basin hydrology caused by local externalities such as land use changes from climate induced impacts on hydrology. This would be done using real life examples, backed by empirical data. It would also provide key resource base on water, energy and food security in key river basins of South Asia.

Modules

The manual contains seven modules, which encompass all the aspects covered in the 'scope and content of the work'. They are as follows:

Module 1: Variability in the Range of Climate Parameters for South Asia and its Impacts on Hydrology and Water Resources

Module 2: Conceptual framework for analyzing the impact of climate variability on water, energy and food systems in distinct typologies of South Asia

Module 3: Impact of Climate Variability on Water, Energy and Food Systems in South Asia

Module 4: Socio-economic and Health Impacts of Climate Variability, particularly Droughts and Floods in South Asia

Module 5: Impacts of Droughts and Floods on Women, Poor and Vulnerable Sections of the Community

Module 6: Technological Strategies for Adaptive Water Management within the framework of IWRM for mitigating the Impacts of Climate Variability

Module 7: institutional alternatives and economic/fiscal instruments for adaptive water management for water, energy and food security in South Asian region

Approach

Experts working on climate impacts on water-food-energy systems and adaptation issues in two South Asian countries, viz., Nepal and Sri Lanka, in addition to India were involved in the exercise. For this a task group consisting of 10 members was formed. Each member worked on one or two modules, in some cases independently and in some other cases in a small group of 2-3 persons, depending on the scope of the module and the disciplines they cover. The experts, who are assigned the task of preparing the modules, decided on their exact content and the methods to be employed for developing them. Though there was no representation from Pakistan and Bangladesh, extensive research done in these countries was used.

Ways Forward

Cap-net had developed a large body of scientific literature, which are relevant for the present theme. They are:

1] Integrated water resources management as a tool for adaptation to climate change;

2] Integrated urban flood management;

3] Groundwater in Integrated Water Resources Management;

4] Conflict resolution and negotiation skills for IWRM;

5] Economics in sustainable water management;

6] IWRM for river basin organizations

7] Hydro-climatic disasters in water resources management.

Besides this, there are training materials developed by other international organizations, which cover topics such as water demand management. They together help enhance the theoretical understanding of the drivers of climate change and its impact on water use sectors, natural disasters associated with climate extremes, and the options for climate risk mitigation, and adaptation.

But, theoretical/conceptual framework to analyze how climate variability impacts on energy and food systems is extremely limited. In terms of empirical evidence on the actual impact of climate variability on water-climate-food systems, and the socio-economic systems in terms (impacts of droughts and floods on the communities), not much is available for South Asia region. They were generated through brainstorming discussions.

The technological alternatives discussed for mitigation and adaptation (land use planning, water supply rationing, increasing multi-annual storage of reservoirs) in the Cap-net modules are more suited to developed countries, where not only the level of awareness of environmental problems and impacts is high within societies and ruling class, but also the economic conditions of the people, is generally sound. Their implement-ability, particularly the economic viability and social acceptability for the South Asian context, was investigated.

The economic and financial instruments and institutional alternatives for water resources management available from Cap-Net modules/manuals (flood warning systems, water pricing, volumetric water rights, quota, groundwater tax, groundwater permits and pollution tax) and work ideally in western societies, which are developed in terms of knowledge, information, human resource capacities and financial conditions, and are well endowed with powerful laws and regulatory frameworks. Amongst these, the options that are most viable for South Asian conditions were identified, through a rigorous review of available scientific research on the related topics.

The materials developed for the training programme held on February 25-March 01, 2013 on climate variability and water insecurity, and the synthesis of the discussions during the training programme could be used as inputs for preparing the training materials. Subsequently, gap filling research was undertaken, wherever needed, to address specific knowledge gaps. A workshop was jointly organized by SaciWATERs and IRAP on February 18-19, 2014 in Hyderabad which was attended by 10 resource persons, comprising the teams from SaciWATERs and IRAP, one expert on climate adaptation from Nepal and one expert on IWRM from Sri Lanka. During the workshop, presentations were made by the participants covering different modules developed under their leadership. They are included in separate PPT presentations, while some key messages from the presentations are being used in this compendium. However, more would be required to synthesize all the important data and analysis used there.

Module 1: ***Variability in the Range of Climate Parameters for South Asia and its Impacts on Hydrology and Water Resources***

Climate Variability in South Asia

V. Niranjan, M. Dinesh Kumar and Nitin Bassi

1. Introduction

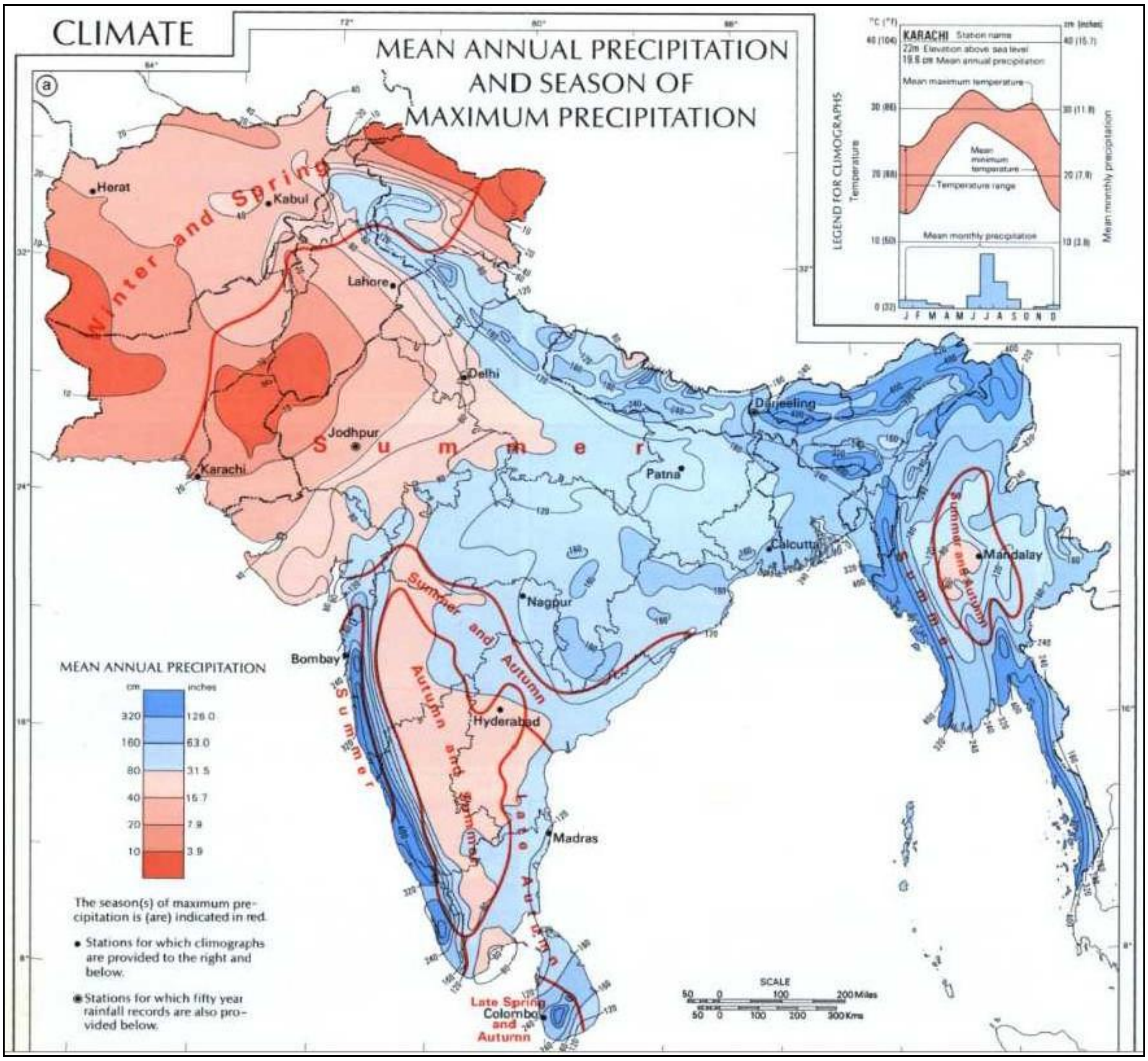
South Asia remains home to four out of every 10 of the World's poor. Nearly 1.5 billion people in South Asia live in less than $1.25 per day. Imbalances in economic growth; inequality among castes, classes, genders and a region inundated by disasters have added to the suffering of the poor and those most vulnerable and marginalized. Climate change is predicted to have adverse impacts in South Asia, particularly in agriculture. Some of the predicted impacts of climate change include increased variability in both monsoon and winter rainfall patterns; increase in average temperatures, with warmer winters; increased salinity in coastal areas as a result of rising sea levels and reduced discharge of major rivers (Oxfam, 2011). Climate change will also significantly impact water supply and demand due to altering future temperature and precipitation patterns (Kenneth *et al*., 2011). Adaptation efforts in South Asia are not enough as they are fragmented and there is no strong link between national climate change strategies, plans, existing disaster risk reduction, agricultural, and other relevant policies (Oxfam, 2011). It is often found that anticipatory adaptation would be lot less costly compared to reactive adaptation (APN, 2004).

In India, studies on Yamuna River Basin reveal a considerable difference in the monsoon and non-monsoon rainfall patterns in terms of persistence and periodicity (Rai et al., 2010). Understanding the cause of monsoon is crucial to deepening our understanding of how monsoon in India would change as a result of larger changes occurring in global and regional climate. There are contesting theories about the cause of Monsoon. Halley (1686) suggested that the primary cause of the monsoon was the differential heating between ocean and land. This is still considered as the basic mechanism for the monsoon by several scientists (e.g., Webster 1987). In an alternative hypothesis, monsoon is considered as a manifestation of the seasonal migration of the inter-tropical convergence zone (ITCZ; Charney 1969). The two hypotheses have very different implications for variability of the monsoon (Gadgil, 2003). For example, in the first case, we expect the intensity of the monsoon to be directly related to the land-ocean temperature contrast. Simpson (1921) pointed out that the observations of the space-time variations of the monsoon over the Indian region are not consistent with the first hypothesis. Vulnerabilities due to water related diseases are predominantly due to climate variability and extremes which are manifested by both spatial and temporal distribution of water resources throughout the IGP. Frequent droughts in the Western part and frequent occurrence of high intensity floods in the eastern parts of IGP are the two specific climate problems that may be observed (APN, 2004).

It is well understood that from a utilitarian perspective, 'climate variability' has significant implications for the way climate change predictions need to be made for the sub-continent, and understanding of 'climate variability' (spatial and temporal) and its impact on hydrological systems would also help understand the likely impact of the change in climate over time on the hydrological system and water resources. Unfortunately, these concerns were very narrowly addressed by the advocates of climate change, with the key contention being the variability in precipitation would increase with greater frequency of extreme events such as floods and droughts. There are several other important climate parameters one needs to deal with for analyzing climate variability issues. They are: number of rainy days; wind speed and wind directions; humidity; and, temperature and solar radiation.

2. Rainfall Variability in South Asia

The mean annual precipitation and season of maximum precipitation across South Asian countries is depicted in the map below. The mean annual rainfall across South Asia varies from 100mm to 3200mm. The rainfall and other physical characteristics of major South Asian countries including India, Srilanka, Pakistan, Nepal and Afghanistan and Bangladesh are explained below.

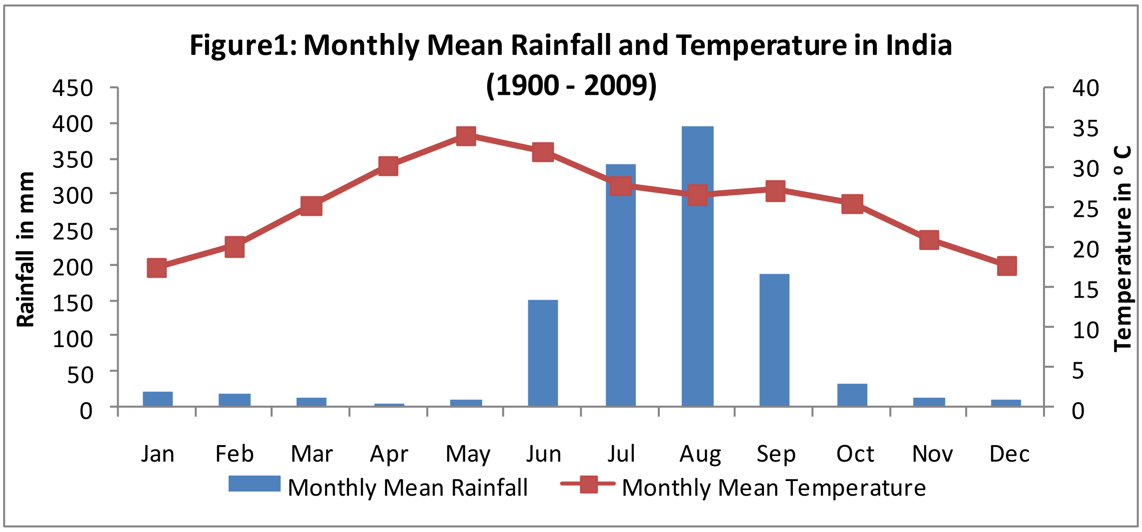


Source: http://www.columbia.edu/itc/mealac/pritchett/00maplinks/overview/rivers/rivers.html

India

The lion's share of the precipitation in India is from rainfall, and the occurrence of snowfall is limited to the sub-Himalayan region. Indian monsoon is characterized by high degree of spatial and temporal heterogeneity. The mean annual rainfall varies from less than 100mm in the western part of Rajasthan to around 11,700mm in Chirapunji in Meghalaya. The magnitude of annual rainfall is large in north eastern states and south western regions, which experience both south west and north-east monsoons. The unique characteristics of rainfall are as follows: the regions which receive low mean annual rainfall experience high year to year variation, whereas the regions which receive high mean annual rainfall experience low year to year variation. The number of rainy days is large in high rainfall regions, and small in low rainfall regions. The coefficient of variation in rainy days shows more or less the same spatial pattern as the mean annual rainfall.

Maximum mean rainfall value of 395.02mm (Figure1) was observed during the month of August, which is also the peak time of south-west monsoon. Similarly the minimum mean rainfall value of 5.47mm was observed in the month of April, which is again the peak summer season. India has diverse climates, and varies from hyper-arid to arid to semi arid to sub-humid to humid. It has mountainous regions, middle mountains, plateaus, plains, deserts, and coastal plains and deltas.

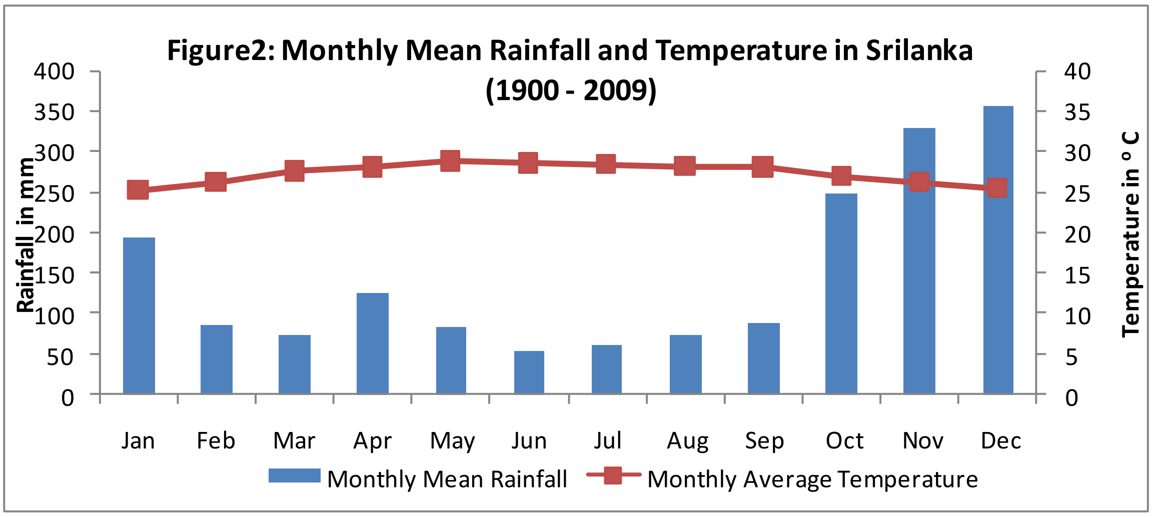


Source: World Bank

Sri Lanka

Annual rainfall in this island country is 2540 mm to over 5080 mm in south west of the Island. The rainfall is less than 1250mm in the north-west and south east of the inland. Hence, there are two rainfall zones in the country, viz., the dry zone and the wet zone. The South West monsoon is from May to August, whereas the North East monsoon is from November to February. Rainfall pattern in Sri Lanka is influenced by orographic features. Being an Island country, Sri Lanka has coastal climate in many parts. It also has mountain in the central and south central regions with cold climate, and the remaining low lying regions have humid tropical climate.

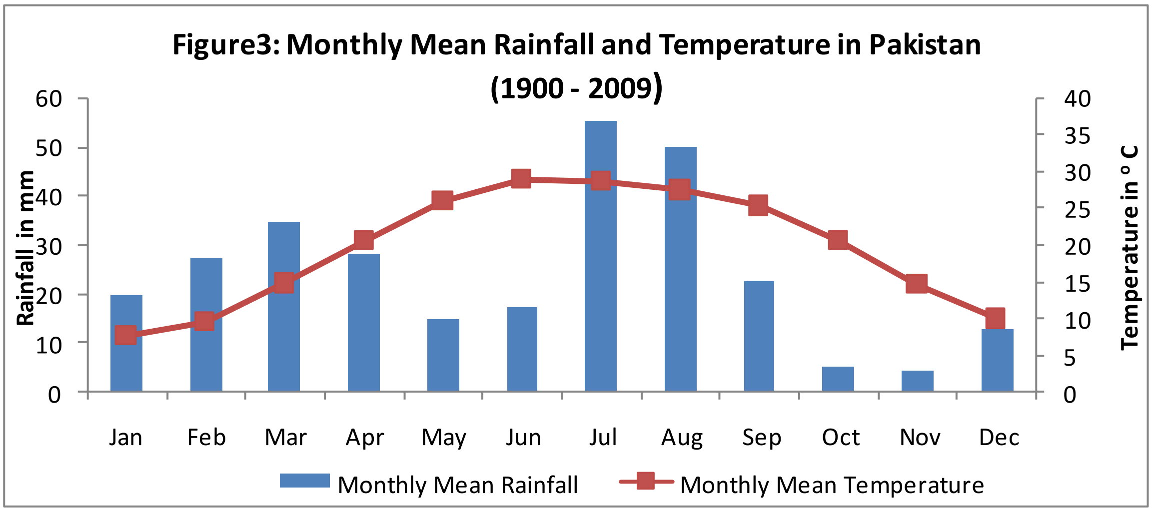
In Srilanka, the monthly mean rainfall value of 355.19mm (Figure2) was observed in December while minimum value of 52.76mm was observed in the month of June.



Source: World Bank

Pakistan

There is significant spatial variation in the rainfall in this sub-tropical country, though most of the country receives very low rainfall. The whole of Sindh, most parts of Baluchistan, the major part of the Punjab and central parts of Northern Areas receive less than 250 mm of rainfall in a year. Northern Sindh, southern Punjab, north-western Baluchistan and the central parts of Northern Areas receive less than 125 mm of rainfall. True humid conditions occur after the rainfall increases to 750 mm in plains and 625 mm in the highlands. There are two sources of rainfall: the monsoon from July to September, and the western depression from December to March. As depicted in Figure3, the maximum and minimum monthly mean rainfall was observed during July and November respectively.

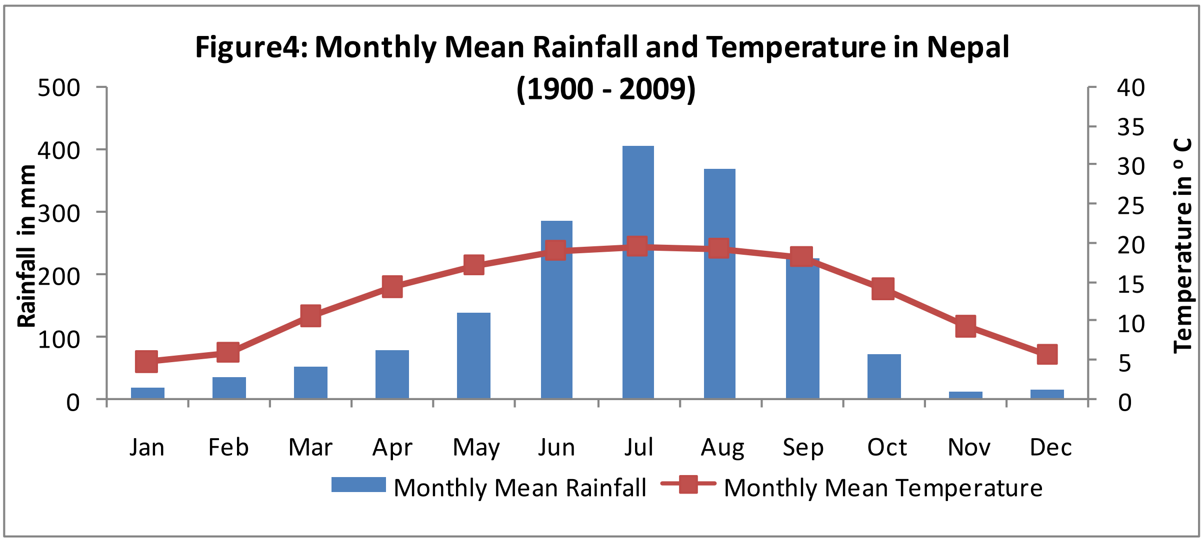


Source: World Bank

Nepal

The monsoon season in Nepal is from June to September. Autumn, from September to November, is cool with clear skies. In winter from December to February, it is cold at night and can be foggy in the early morning but afternoons are usually clear and pleasant, though there is occasional snow in the mountains. Rainfall in Nepal varies from region to region. The annual rainfall in Katmandu generally exceeds 1300mm. The mean annual precipitation ranges from more than 6000mm along the southern slopes of the Annapurna range in central Nepal to less than the 250mm in the north central portion near the Tibetan plateau. Rainfall amounts ranging from 1500mm to 2500mm is predominant over most parts of the country. On an average, about 80% of the precipitation is confined to the monsoon period from June to September (also see Figure4).

Vast areas of Nepal fall in high altitude mountainous region. High mountains cover nearly 35% of the geographical area, followed by middle mountains covering nearly 42% and Tarai region covering nearly 23 per cent. The climate varies from Alpine to sub-Alpine in the higher Himalayas to temperate in the lesser-Himalayan region to sub-tropical in the Terai and Siwalik regions of the south within a distance of 200km.

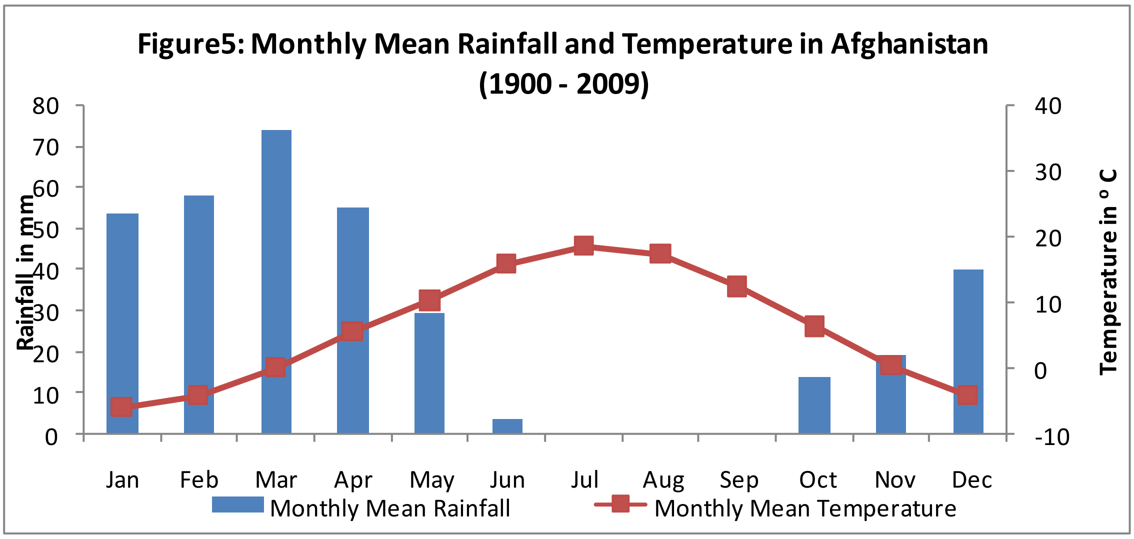


Source: World Bank

Afghanistan

Precipitation in Afghanistan has a very pronounced annual cycle with a dry period in summer, generally from June to September, except for the western region where dry season starts in May and lasts till October. Annual precipitation is ranging from 50mm in the southwest to 700mm in the region of Salang and about 300mm in the capital Kabul, and therefore shows a significant variation. The areal average of annual precipitation is less than 300mm. Towards the eastern part of the country, the total annual precipitation decrease to about 100mm. It has the central highlands, which are part of the Hindukhush Himalayan range, northern plains and south western plateau, which consists of sandy desert and semi desert.

As per World Bank data (Figure5), negligible or no rainfall was observed during the months July, August and September. Maximum rainfall was observed during March.

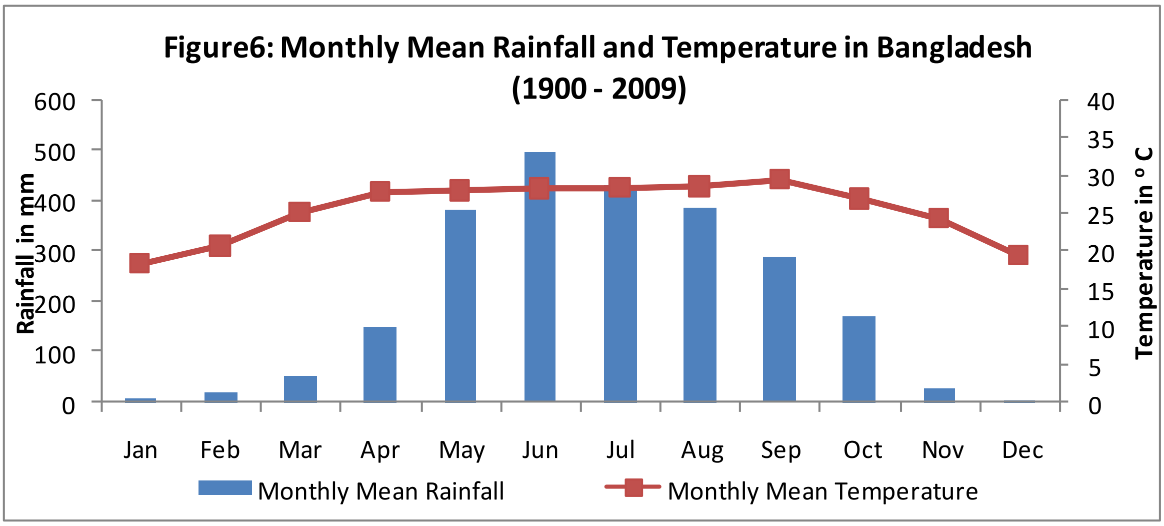


Source: World Bank

Bangladesh

Bangladesh has tropical monsoon climate characterized by high seasonal rainfall, high temperature and high humidity. The average annual rainfall varies from a maximum of 5,690 mm in the northeast of the country to minimum of 1,110 mm in the west. The groundwater, however, provides adequate storage to compensate for annual variations in rainfall and stream flow. Most of Bangladesh is alluvial plains formed by the delta of Ganges, Brahmaputra and Meghna river systems, except the south eastern and north eastern hills.

Maximum amount of rainfall was observed during the months May to September with minimum rainfall during December (Please see Figure6 below).

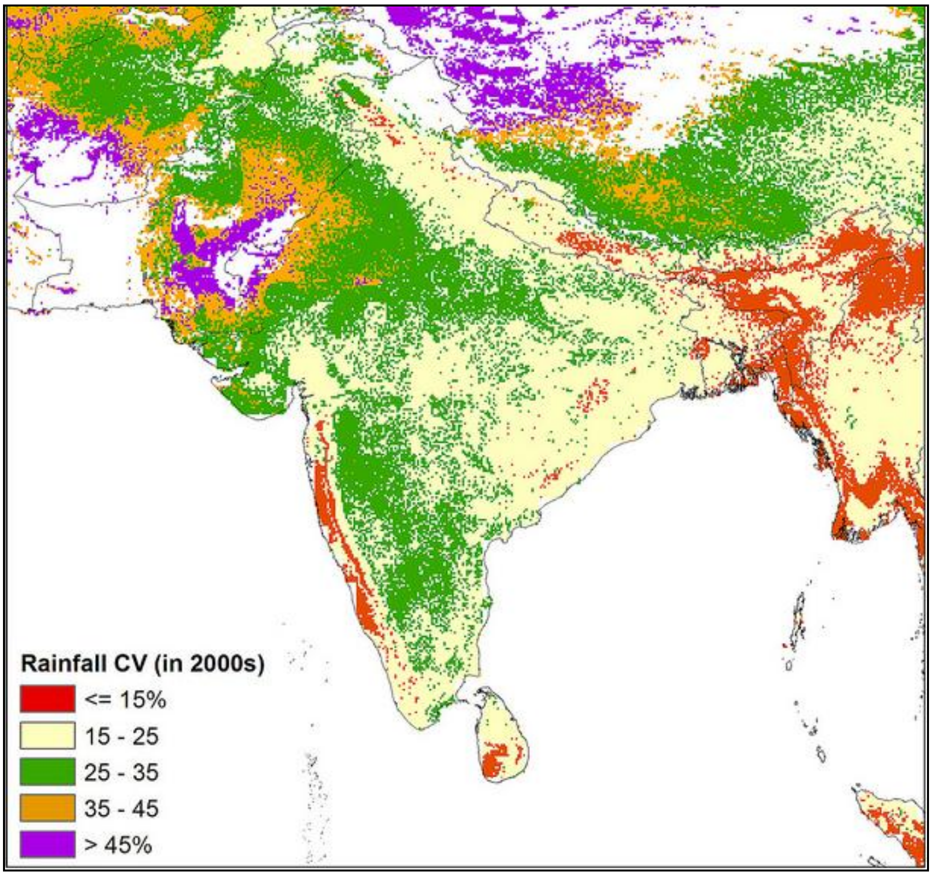


Source: World Bank

Temporal Variability in Rainfall

The map below depicts the average coefficient of variation (CV) in rainfall in South Asia. Indian monsoon is characterized by significant inter-annual variability. Analysis of monsoon rainfall carried out by Physical Research Laboratories shows that the inter-annual variability, expressed in terms of coefficient of variation (CV), in annual rainfall is high in regions of low rainfall and low in regions of high rainfall. Map 1 shows the spatial variation in the coefficient of variation in annual rainfall in India. In regions such as western Rajasthan and Kachchh, the coefficient of variation in the rainfall is as high as 50 per cent and above. In the north eastern region and in the western Ghat region, the coefficient of variation in rainfall is very low, meaning high dependability.

As Table 1 indicates, a large percentage of the total geographical area of Gujarat and Rajasthan (72% and 68%, respectively) has high to very high (30-40% and above) variability in rainfall. A significant portion of the geographical area of the states, viz., Maharashtra, Madhya Pradesh, Andhra Pradesh, Karnataka and Tamil Nadu (37% to 92%) experience medium variability in rainfall; the rest of the area experiences low variability. The entire Orissa and Chattisgarh experience only low variability in rainfall. In nutshell, more than 50% of the total geographical area of all the states put together experience medium variability; nearly 25% experience "high to very high variability"; and nearly 20 per cent experience "low variability" in rainfall. They coincide with "medium rainfall-medium to high evaporation", "low rainfall-very high evaporation" and "high rainfall- medium evaporation" regimes, respectively.



Source: CGIAR Climate maps

Table1: Rainfall Variability Regimes of Selected Indian States

Name of State	% Area with Rainfall Variability in the range of				
	<25% (low)	25 - 30% (medium)	30 - 40% (high)	40 - 50% (very high)	> 50%
Gujarat	0.24	27.12	44.30	17.11	11.22
Rajasthan	8.33	24.08	23.04	30.71	13.84

Maharashtra	37.67	62.33			
Madhya Pradesh	49.71	50.29			
Andhra Pradesh	62.64	37.36			
Karnataka	29.15	70.85			
Tamil Nadu	7.73	92.27			
Orissa	100.00	0.00			
Chattisgarh	100.0	0.0	0.0	0.0	0.0

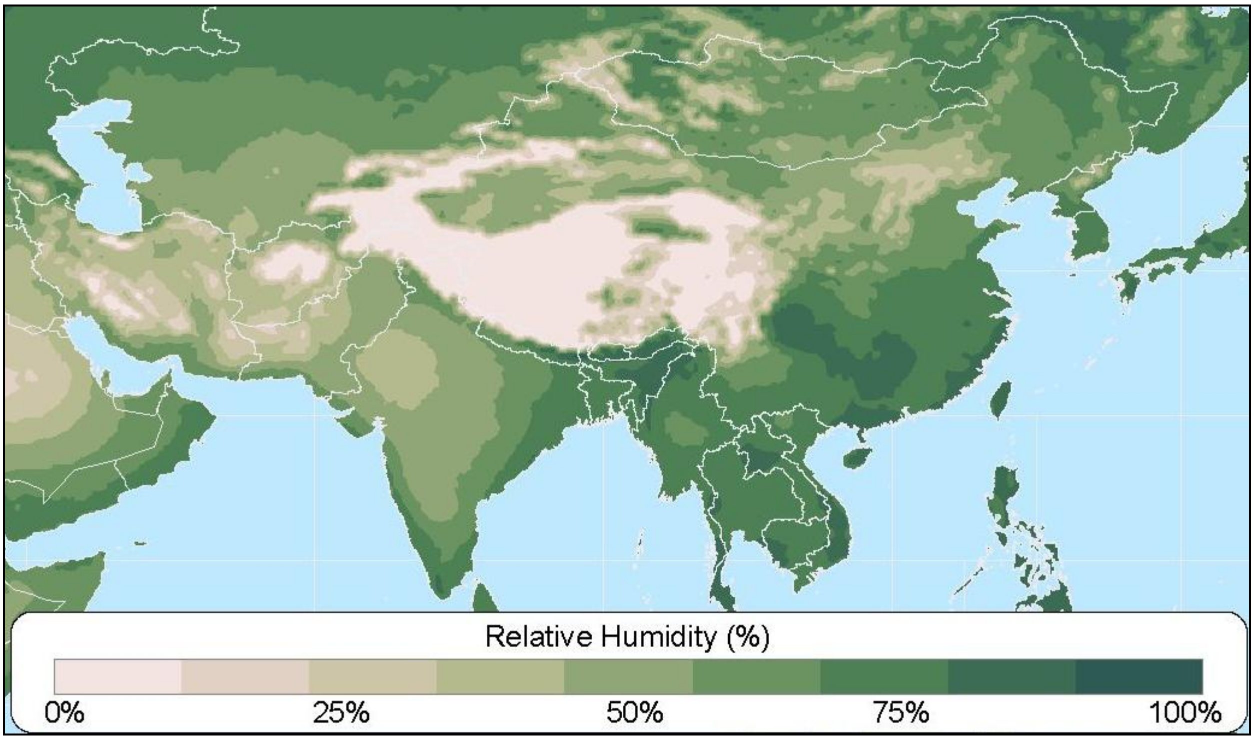
Source: authors' own estimates based on Pisharoty (1990) using GIS

3. Variability in Climate in South Asia

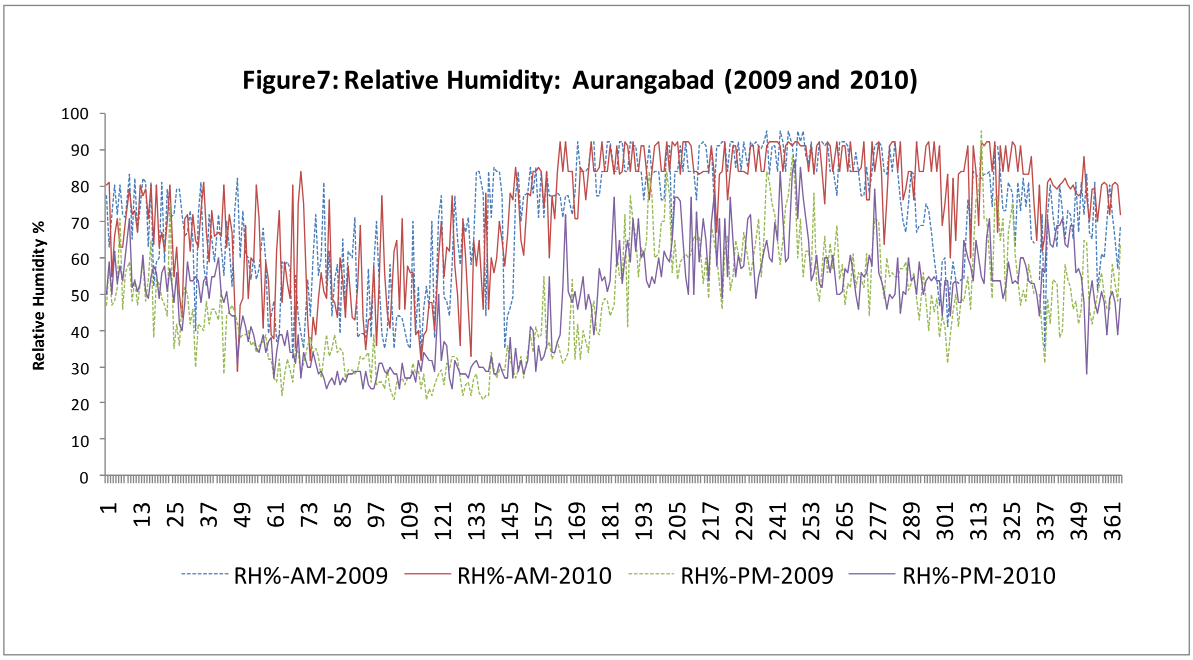
Climate is the net effect of the interplay of precipitation, humidity, temperature of the atmosphere and winds (speed) and rainfall. Atmospheric temperature and temperature on the surface of the earth is the effect of solar radiation. The other climate parameters also vary from region to region, influenced by their geographic positioning with respect to oceans, mountains, desert and the latitude and longitude (particularly the distance from the equator), and would change with change in seasons, i.e., rainy season, winter and summer.

3.1 Humidity

Humidity is a measure of the amount of vapor in the air, and is measured in terms of vapor pressure of the air (measured in KPa/m^2). While humidity itself is a climate variable, it also interacts strongly with other climate variables. The relative humidity (RH) is the measure of the vapor pressure of the air measured as a percentage of the saturated vapor pressure. The humidity is affected by winds and by rainfall. At the same time, humidity affects the energy budget and thereby influences temperatures in two major ways. First, water vapor in the atmosphere contains "latent" energy. During transpiration or evaporation, this latent heat is removed from liquid surface, cooling the earth's surface. This is the biggest non-radiative cooling effect at the surface. It compensates for roughly 70% of the average net radiative warming at the surface. Second, water vapor is the most important of all greenhouse gases. Water vapor, like a green lens that allows green light to pass through it but absorbs red light, is a "selective absorber". Along with other greenhouse gases, water vapor is transparent to most solar energy. The following map depicts the Average Annual relative humidity (%) across the South Asian countries. The relative humidity ranges from <25% to 100% across the south Asia.



Source: Atlas of the Biosphere, Centre for Sustainability and the Global Environment, University of Wisconsin, Madison.



But it absorbs the infrared energy emitted (radiated) upward by the earth's surface. Because of this reason, humid areas experience very little night time cooling unlike dry desert regions. This selective absorption causes the greenhouse effect. Coastal areas are generally more humid than inland areas, so are the areas receiving higher rainfall over extended time periods. Normally, if the amount of moisture in the air remains the same, then an increase in temperature would reduce relative humidity as warmer air can hold more moisture than cold air. But, in humid tropics, increase in temperature would also result higher evaporation adding to the atmospheric vapor content, and hence there would be no reduction in relative humidity. Normally, in any region, the relative humidity in an area would increase during monsoon, though the variation would be much higher in hot climates. Figure 7 shows the daily values of relative humidity (morning and evening) in Aurangabad over a period of two years, i.e., 2009 and 2010.

Figure 7 illustrates the following points: 1] the highest difference encountered in the relative humidity values between morning (RH-AM) and evening (RH-PM)of any day over the entire year during 2009 and 2010 (74% and 68% respectively) is higher than the difference in relative humidity values for both morning and evening between the most humid day and the least humid day of the year (63 and 74% for 2009, and 63 and 63 for 2010); 2] relative humidity is excessively high in the range of 80-90 per cent during the rainy season; and, 3] the RH values for both morning and evening for the same day of the month can vary significantly between years.

Table2: Characteristics of Relative Humidity (Location: Aurangabad, Maharashtra, India)

Year of Monitoring	Relative Humidity		
	Diff between max of daily RH-AM and min of daily RH-AM	Diff between max of daily RH-PM and min of RH-PM	Highest difference between daily RH-AM and daily RH-PM over the year
2009	63	74	74
2010	63	63	68

Source: author's own estimates based on data presented in Figure 7

3.2 Temperature

Atmospheric temperature change is a result of change in energy balance, which is the net effect of the incident and reflected solar radiations. The radiation flux is measured in MJ (Million Jules) per m^2 per day. The energy received by the earth's surface from solar radiation in a particular place is a function of the distance of the place from the Earth's equator. In terms of temperature, the weather in India varies from very cold and cold to warm, hot and very hot. The same region can experience hot and cold weather conditions, depending on the season. During summer, the northern, western and north western regions in India are hotter than the southern and eastern regions. However, during winter, these regions are colder than the southern and eastern regions. lowering of temperature during night and also during early morning and evening, and the temperature variations within a day can even be higher than the variation in temperature in the same locality across seasons, it is observed throughout the day (24 hours) and is expressed as 'minimum daily temperature' and 'maximum daily temperature'. The various derivatives of this climate variable used in describing the climate of locality are: monthly average of daily minimum temperature, monthly average of daily maximum temperature; seasonal average of maximum and minimum daily temperatures; and annual average of daily minimum and maximum temperatures.

The mean monthly temperatures for over 109 years (historical) are presented in Figures 1 – 6, for the South Asian countries. The average temperatures for some important stations across these South Asian countries are also presented in Annexure1. Table3 represents the maximum and minimum monthly mean temperature values in major South Asian Countries.

Table3: Monthly Mean Temperatures (for 109 years) in major South Asian Countries

Sr. No	Country	Monthly mean temperature values (1900 – 2009)			
		Maximum		Minimum	
		Month	Value °C	Month	Value °C
1	India	May	33.87	January	17.53
2	Srilanka	May	28.76	January	25.2
3	Pakistan	June	28.9	January	7.53
4	Nepal	July	19.56	January	4.67
5	Afghanistan	July	18.4	January	-6.12
6	Bangladesh	August	29.47	January	18.39

Source: author's own analysis based on Figure1-6.

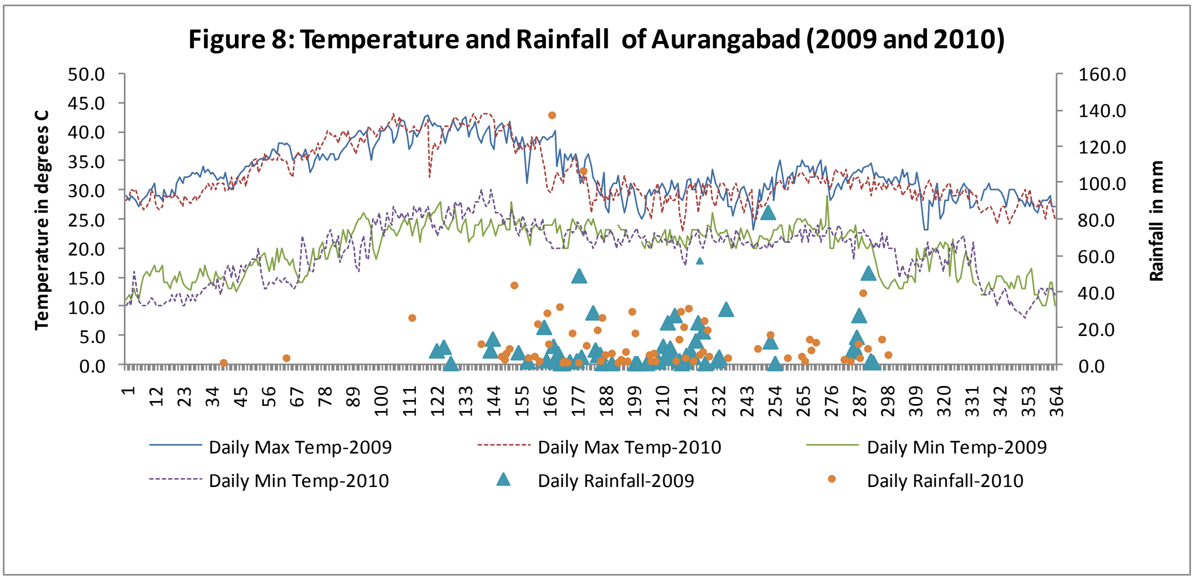


Figure 8 illustrates the following points: 1] there is wide variation in the temperature between the hottest day and the coldest day of the year; 2] the maximum difference between the daily maximum and the daily minimum temperature recorded in the entire year (32.8°C for 2009 and 35° C for 2010) is higher than both the difference between the highest of the daily maximum or minimum temperature and the lowest of the daily maximum or minimum temperature (19.8° C for max. and 19° C for min. 2009 for max. and min. temperature, respectively); and 3] the decline in daily maximum temperature owing to occurrence of rainfall over a period of time is higher than the decline in minimum temperature over the same time period; and, 4] finally there can be significant variations in temperature (daily maximum or daily minimum) on the same day of the month, between two years, and this difference can be in the order of 4-5 degrees.

Table4: Characteristics of Temperature (Location: Aurangabad, Maharashtra)

Year	Temperature (° C)		
	Difference between max of daily max and min of daily max	Diff between max of daily min and min of daily minimum	Max difference between daily max and daily minimum
2009	19.8	19.0	32.8

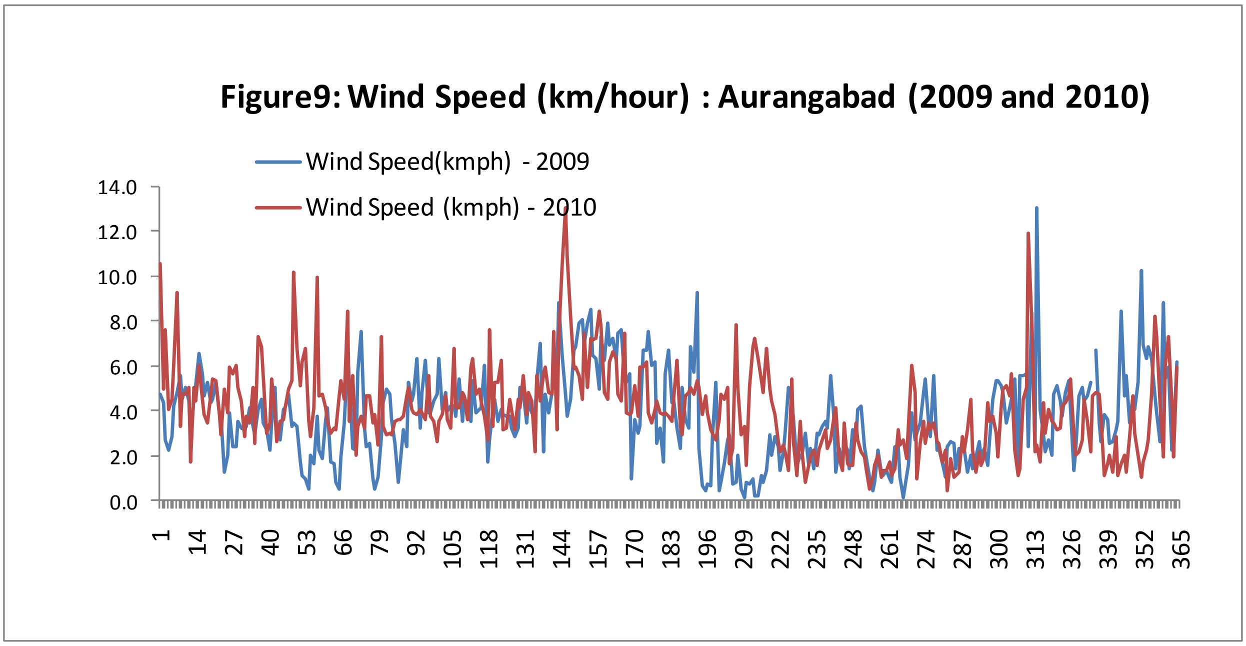
2010	20.2	22.0	35.0

Source: author's own estimates based on data presented in Figure8

3.3 Wind Speed

It refers to the mass movement of air. Speed of winds, which occur as a result of atmospheric pressure gradients, is an important climate parameter as it can change the humidity of an area. The evaporation from water bodies under low relative humidity, high temperature gets sustained when the vapor produced is removed by the speed of the wind. Winds are generally measured in terms of their direction and speed. From the point of view of climate induced impacts, both the direction and speed (knots/hour) are important. Depending on the speed, wind can be classified as calm wind (less than 4.0 knots per hour), breeze (4-27knots/hour) to gale (28-55 knots/hour) to storm (56-64 knots/hour) to hurricane (above 64 knots/hour). Using the 'beau fort scale', winds are classified into 17 different categories based on the speed.

As per IMD (Indian Meteorological Department) classification, winds are categorized as: low pressure areas (up to 16 knots per hour (1 knot = 1.605 km); depression (17-27 knots/hour); deep depression (28-33 knots per hour); cyclonic storm (34-47 knots/hour); severe cyclonic storm (48-63 knots/hour); very severe cyclonic storm (64-119 knots/hour); and super cyclonic storm (above 120 knots/hour).

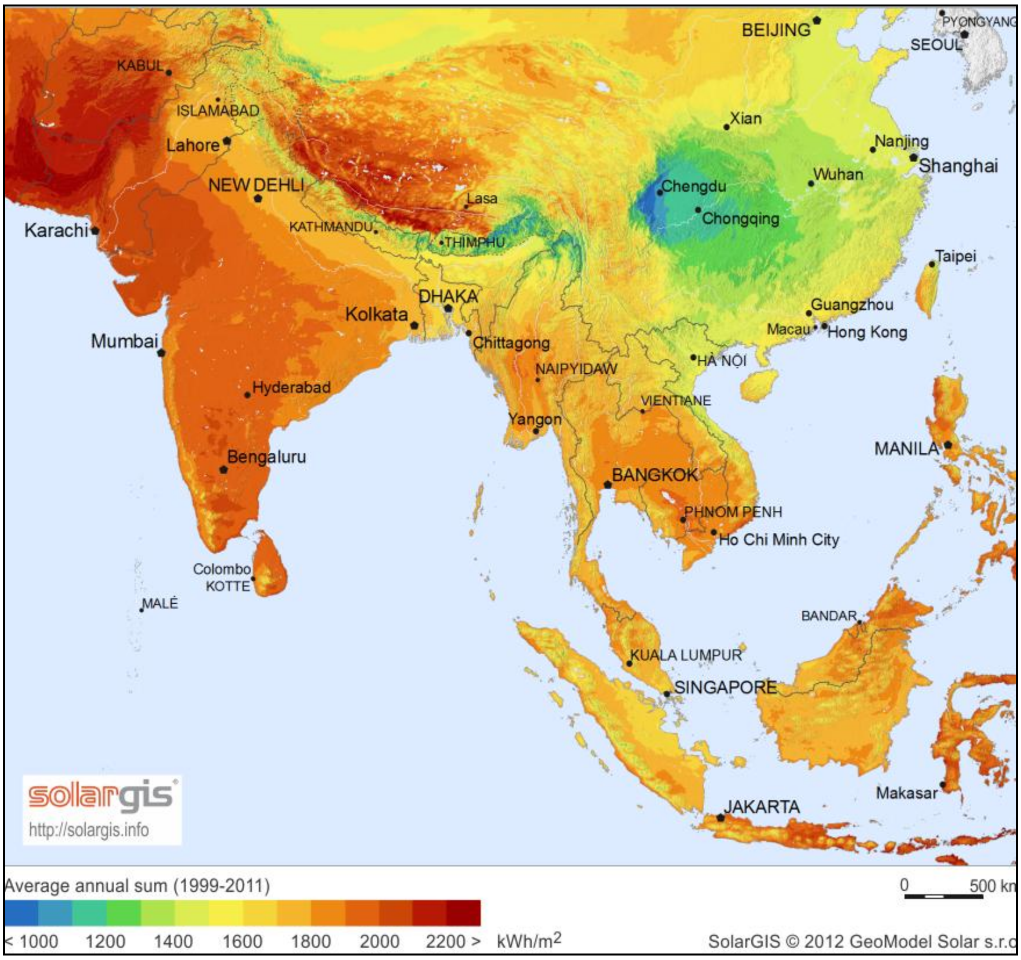


Wind energy, which is the kinetic energy of the wind, is a function of the density of the air, the volume of air and the density of the air. Figure9 shows that the wind speed in a particular location can change across the year and can also vary from year to year. Across the country, strong winds, storms and cyclones are experienced in the coastal areas, due to development of low pressure zones (depressions). Storms and cyclones also result in localized heavy precipitation.

Wind has a huge impact on the plant biophysical processes, and management of water bodies. High winds can increase crop evapo-transpiration and evaporation from reservoirs even with solar radiation, and air humidity remaining the same.

3.4 Solar Radiation

Energy received by the earth's surface from solar radiation in a particular place depends mainly on its latitude. Normally, the total incoming solar radiation is balanced by an equal amount of outgoing terrestrial radiations. Atmospheric temperature change is due to change in this energy balance. But, there are other factors which influence the solar radiation at a given location, which can cause variations in the amount of solar radiation in two places situated at the same latitude. They are: atmospheric effects, including absorption and scattering; and local variations in the atmosphere, such as water vapour, clouds, and pollution. The incident solar radiation at a locality also depends on the season of the year and the time of day. There is significant variation in solar radiation flux across South Asia.



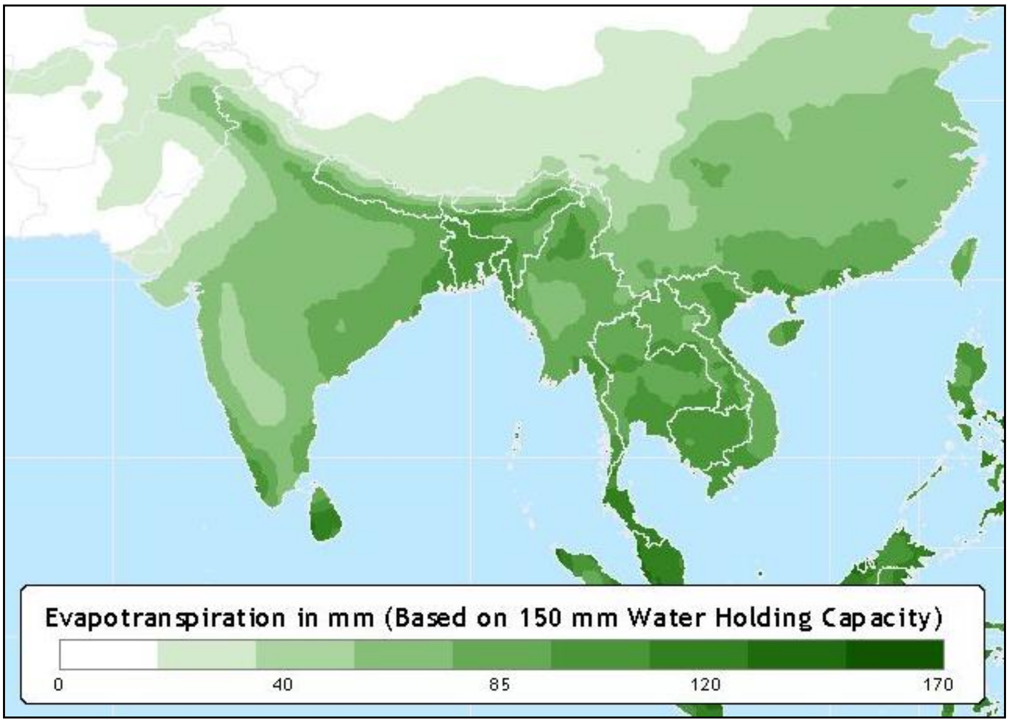
3.5 Spatial Variability in Climate

Potential evaporation (expressed in mm), the amount of water an open water body can evaporate in a year, for a particular location is a net result of the solar radiation flux, wind speed and relative humidity experienced in that location and to a lesser extent the temperature, and is a strong indicator of the location's climate, along with rainfall. It is the mechanical process by which water in the liquid form gets converted into vapor. The energy for the same is provided by the solar radiation and to a lesser extent the ambient temperature, and the driving force is provided by the difference in vapor pressure between evaporating surface and the surrounding atmosphere, and the winds. This parameter is extensively used in hydrology for estimating water losses from open reservoirs and water requirements for crop physiological processes[2]. The

[2] The related terms are reference evapo-transpiration (ET_0), potential evapo-transpiration (PET). For detailed discussions on the physics of the processes, please see Terry Howell and Steven Evett (undated).

variations in solar radiation, air temperature, wind speed and relative humidity across space in India ultimately results in significant variation in potential evaporation (PE). Lower rainfall, coupled with higher PE reduces the runoff potential and high evaporation from the impounded runoff, thereby increasing the dryness (Hurd *et al*., 1999).

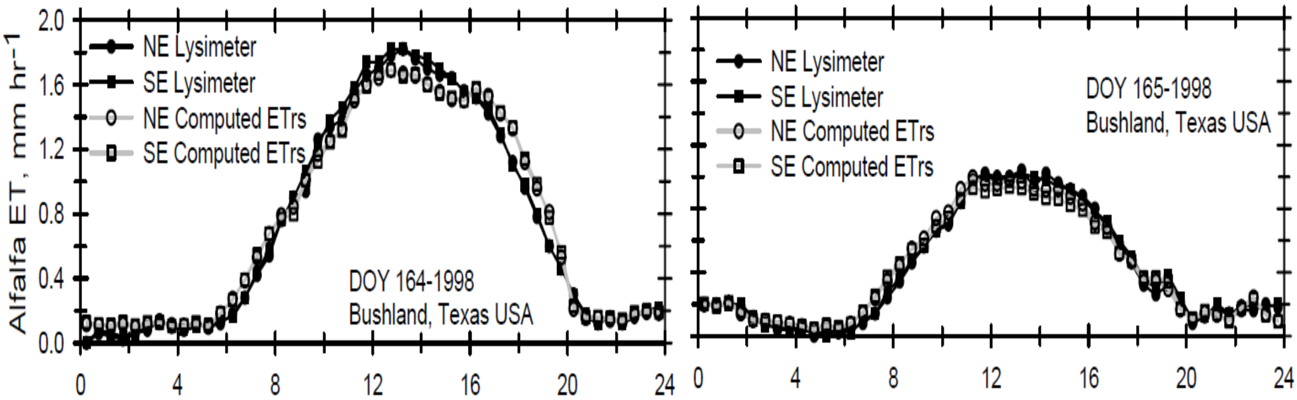
Variation in these parameters with respect to space and time also results in significant variation in ET_0 values and potential evapo-transpiration (PET) for the same crop across regions and also within the same regions with time, respectively.



Source: Atlas of the Biosphere, Centre for Sustainability and the Global Environment, University of Wisconsin, Madison.

For instance, an experiment conducted in an alfalfa field in Bushland, Texas, United States, showed the estimated daily PET value for alfalfa field to be ranging from as high as 17.7 mm during a day (on July 13th, 1998), to almost half (9.9mm) during the next day, i.e., July 14th, 1998 (see Figure10a and Figure10b, based on Terry Howell and Steven Evett, undated). This was mainly due to strong advection from high winds and low humidity on the first day, as compared to a more typical environment on the next day.

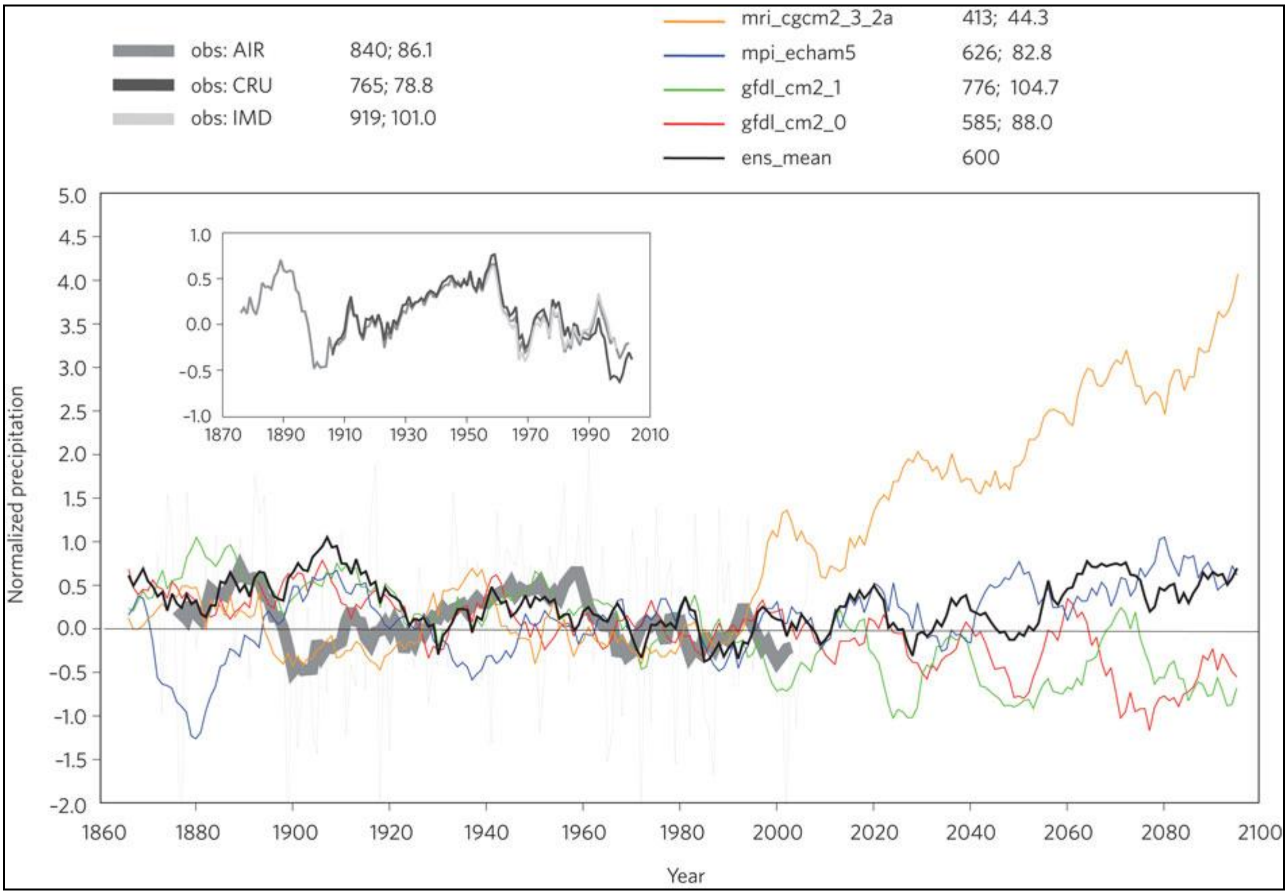
Figure10a and Figure10b: Charts Showing the Variation in Evapo-transpiration between Two Consecutive Days



Potential evaporation is measured using pan evaparometers. Whereas crop ET can be measured using a lysimeter. In this section, we examine the percentage area of each state falling under different PE regimes (< 1500mm, 1500-2500mm, 2500-3500mm and >3500mm). It is understood that regions with relatively low rainfall have higher potential evapo-transpiration due to relatively low humidity, and higher number of sunny days (Pisharoty, 1990).

4. How South Asian Rainfall Has Been Changing over Time?

Understanding how the monsoon will change in the face of global warming is a challenge for climate science, not least because our state-of-the-art general circulation models still have difficulty simulating the regional distribution of monsoon rainfall (Turner and Annamalai, 2012). Figure11 presents historical and projection of South Asian monsoon rainfall[3].



Source: Turner and Annamalai, 2012

3 Time series of mean summer (June–September) precipitation averaged over land points within 60–90° E, 7–27° N in the historical (20c3m; 1861–1999) and SRES A1B (2000–2100) future projection CMIP3 experiments. Only four models, shown to have a reasonable simulation of the spatial pattern, seasonal cycle and inter-annual variability of monsoon rainfall, are depicted; the black curve shows their ensemble mean. Observations from the AIR index based on gauge information are also shown for the 1871–2008 period as a proxy for South Asia rainfall. All curves are first normalized by their mean and standard deviation measured over 1961–1999 and are passed through an 11-year moving window. The faint black curve shows the observations without this smoothing. The inset compares the AIR with area-mean averages over the same domain as above from 1951–2004 IMD daily gridded data and 1901–2009 monthly gridded CRU data. The values listed in the legend are for June–September mean rainfall and inter-annual standard deviation, in mm. Obs, observations.

The analysis by the Indian Institute of Tropical Meteorology (IITM) is the only work which comprehensively examines the long term variations in physiographic rainfall across India. The study by IITM (Sontakke *et al*., 2008) divided the geographical area of the country into fourteen physiographic units and 49 sub-units and the area-averaged rainfall values for 316 well spread rain-gauge stations were used for their analysis, for the period from 1901 to 2006. For years prior to 1901, simple objective techniques were used for the limited rain gauge stations, the oldest recorded corresponded to 1813.

The different physiographical regions made are: The Western Himalayas; The northern Plains; The Eastern Plains; The Indo-Gangetic Plains; The North-Eastern Range; The Western Plains; The North Central Highlands; The South Central Highlands; The North Deccan; The South Deccan; The Eastern Plateau; The Western Hills; The Eastern Hills; The West Coastal Plains; and the East Coastal Plains. Within each physiographic region, sub-regions were identified for the analysis, totaling 49.

The method involved analysis of the changes in rainfall of each physiographic unit, and finding out the time periods for changes in rainfall trends. The analysis showed that there is no consistent trend in rainfall across regions and over the entire time period for which analysis was carried out (i.e., 1813-2006). The trend in annual rainfall kept on changing from 'positive' (meaning increase in rainfall) to 'negative' trend to 'no trend', after a particular time period, though the time duration corresponding to this change kept on varying not only for the same physiographic unit, but also across physiographic units (Source: based on Sontakke *et al*., 2008).

As regards the spatial variation in the most recent trend in the monsoon rainfall in the country, the findings were as follow: "24.1% *area of the country shows increasing trend (Bengal Basin, Vindhyan Scarp lands, Maharashtra Plateau, Chhotanagpur Plateau, North Sahyadri, Kathiawar Peninsula, Gujarat Plains, Konkan, Utkal Plains, Andhra Plains), 74.7% decreasing trend (South Kashmir Himalaya, Punjab Himalaya, Kumaun Himalaya, Punjab Plains, Ganga-Yamuna Doab, Rohilkhand Plains, Avadh Plains, North Bihar Plains, South Bihar Plains, Bengal Plains, Assam Valley, Meghalaya, Purvanchal, Marusthali, Rajasthan Bagar, Aravalli Range, East Rajasthan Uplands, Madhya Bharat Pathar, Bundelkhand Upland, Malwa Plateau, Vindhya Range, Narmada Valley, Satpura Range, Karnataka Plateau, Telangana Plateau, Baghelkhand Plateau, Mahanadi Basin, Garhjat Hills, Dandakaranya, South Sahyadri, Nilgiri, Eastern Ghats (North), Eastern Ghats (South), Tamil Nadu Uplands, Karnataka Coast, Kerala Plains) and remaining 1.2% no trend (Central Sahyadri, Kachchh Peninsula, Tamil Nadu Plains) (Figure 68c). The summer monsoon rainfall over the country from 1931-1964 to 1965-2006 has decreased by 4.72%*" (Sontakke *et al*., 2008: p35).

As regards the temporal change in rainfall trend in the same location, the data for Western Himalayas can be used to illustrate. The chief features of rainfall trend in the Western Himalayas were as follows: "*annual* (read as annual rainfall)*l-1845-1894 increase, 1895-1902 decrease, 1903-1960 increase, 1961-2006 decrease; winter-1845-1893 increase, 1894-1963 decrease, 1964-2006 increase; summer-1845-1938 decrease, 1938-2006 increase (1983-2006 above normal but decreasing tendency); summer Monsoon -1844-1960 increase, 1961-2006 decrease; post-monsoon-1844-2006 increase; June- 1844-2006 decrease; July-1844-1959 increase, 1960-2006 decrease; August-1844-1885 increase, 1886-2006 decrease; and September-1844-1961 increase, 1962-2006 decrease*" (Sontakke *et al*., 2008: p8)

5. Conclusion

We have discussed the various climate variables for South Asia, but to discuss their key features in the South Asian context, and within that focus on a few of the climate variables, viz., rainfall, rainy days, relative humidity, temperature, wind speed and solar radiation. We have seen that there is substantial inter-annual and inter-regional variations rainfall. There is also substantial variation in the annual potential evaporation rates, which is the result of variations in key climate variables with respect to space. We have also seen that there is significant variation in climate variable such as relative humidity, temperature and wind speed across seasons and years. These together can induce major changes in the physical and biophysical processes such as evaporation from soils and water bodies, and evapo-transpiration from plants, grass and trees. Understanding these characteristics is important as it has significant implications for the way climate change predictions need to be made for the sub-continent. Understanding of the impact of 'climate variability' on water resources and water demand would also help understand the likely impact of the change in climate over time on the hydrological system and water resources

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Module 2: ***Conceptual framework for analyzing the impact of climate variability on water, energy and food systems in distinct typologies of South Asia***

Conceptual framework for analyzing the impact of climate variability on water, energy and food systems in distinct typologies of South Asia

M. Dinesh Kumar, Neena Rao and Nitin Bassi

Figure 1 captures the dynamics of interaction between climate and water resources systems; water and biomass production (food and agriculture); nexus between water and energy; and energy and food. Most of these interactions are two way. Let us explain this.

Climate-Water Nexus

It is now established that variable precipitation and long term changes in the same manifest as floods and (hydrological) droughts and extreme events in river basins. However, it is not fully known how different trends in the key climate parameter (i.e., temperature) affect precipitation and water resources in different regions and localities. This is particularly important for South Asia, given the heterogeneous climatic and hydrological conditions that exist in the sub-continent. Needless to say, such predictions are not amenable to simple modelling. As regards climate change, increase in temperature in semi-arid and arid regions can cause reduction in rainfall, and faster depletion of soil moisture, and resultant reduction in stream-flows and groundwater recharge. In humid tropics with high rainfall, increase in atmospheric temperature can result in greater amount of precipitation (as there would be more vapour moving into the atmosphere from the soil profile, water bodies and vegetation), with resultant proportional increase in runoff and groundwater recharge. Greater precipitation, with prolonged rainy season, can also bring down temperature locally.

Whereas lowering of atmospheric temperature in semi-arid and arid regions would reduce the soil moisture depletion and therefore the same amount of precipitation would generate greater amount of runoff and groundwater recharge. In humid tropics, such changes in temperature might reduce the precipitation only marginally, but this is unlikely to impact on the hydrological balance negatively, as lowering of temperature at the regional level would mean reduced rate of soil moisture depletion, with greater proportion of the rainwater getting converted into runoff and recharge. Essentially, the impact of temperature decline at the regional level can offset the marginal rise in local temperature owing to reduced precipitation.

As regards the impact of climate variability, precipitation fluctuation, which occurs annually in most regions in South Asia (also known as inter-annual variability in rainfall), can affect temperature and humidity in a locality during the rainy season, thereby altering hydrological system remarkably. Lower precipitation causes droughts, owing to increased temperature and higher aridity, resulting in reduced runoff and groundwater recharge. Higher rainfall, followed by temperature dip and increased humidity, causes excessive runoff and floods.

On the other hand, water can have a direct impact on climate too, though locally. Large water bodies and vast tracts of irrigated crop land can influence the micro climate of an area significantly by bringing down temperature and increasing humidity through evaporation from water bodies and soils, a phenomenon observed in canal command areas and large reservoirs.

Climate-Water-Biomass Nexus

Water is required to produce biomass and food. But, the amount of water required to produce a unit quantum of biomass would change with changes in amount of water lost in non-beneficial uses (non-beneficial evaporation and non-recoverable deep percolation), which is the amount of water consumed/depleted in crop production over and above crop ET. Water would also be required for leaching salts in soils, an important component of irrigation water requirement in salt-affected soils of Indian and Pakistan Punjab. Water is also required in the processing of agricultural produce.

On the other hand, the amount of water required by human populations in a region can be affected through important of agricultural commodities (virtual water trade), from regions which are abundant in land and water resources, as agriculture accounts for a major share of the total water demand in most regions. The exceptions are highly developed countries in cold and temperate climates, whose dependence on agriculture for livelihoods and economic growth is negligible. Examples are Germany, Norway and Sweden. Biomass availability, on the other hand, can affect water availability in an area, through proper water management strategy. Biomass can also be used to increase the carbon content in the soils thereby reducing the soil moisture retention capacity. Leafy biomass can also be used for mulching to prevent water loss from soil through evaporation.

The climate impacts on biomass in several different ways. The water demand for crops would increase if the temperature increases owing to rise in evapo-transpirative demand of the crops, and water lost in non-beneficial uses. The rise in ET occurs to the direct effect of increase in air temperature and also through the effect temperature will have on atmospheric humidity. Sudden rise in air temperature can also severely affect plant metabolism, thereby resulting in crop damage. With temperature rise, more water would be required to produce the same amount of crops.

But, the rise in temperature can be the result of annual variation (like during droughts, owing to reduced precipitation) or long term changes in atmospheric temperature. The impacts of droughts on crop production would be severe than that of impact of mere temperature rise, as not only the water demand would increase but also the availability of water to produce the crops would be less during droughts. This can have a direct impact on food security and livelihoods in regions which do not have buffer stock of water, and where people are dependent on agriculture as the major occupation.

On the contrary, with lowering of temperature, the water demand for crops can come down owing to lower aridity. However, as the initial discussion on effect of climate on precipitation suggests, such effects of temperature change on crop water demand would be more pronounced in semi-arid and arid regions, and not so much in high rainfall, humid regions. Floods caused by excessive rainfall, characteristic of regions which experience high inter-annual variability in rainfall, on the other hand, can damage crops. This can threaten food security and safe water supplies. The latter happens because of easy contamination of shallow groundwater, which is a major source of water supplies in rural and urban areas, in with faecal matter during droughts. Eastern India (Bihar, eastern UP) and Bangladesh, which are part of the eastern Gangetic plains, are examples.

Intensive afforestation over large geographical areas can result in significant effect of carbon sequestration and atmospheric cooling, but can deplete a lot of water resources, particularly when it is in arid and semi-arid areas.

Climate-Biomass-Energy Nexus

Biomass can affect energy supplies. Biofuel is a renewable source of energy, which can be produced using water, solar energy and fertilizers and other energy inputs. Cellulose provides energy for humans and animals. Conversely, energy is required for producing fertilizers, an input for crop production. Draught power of animals, human labour and machine power are required for ploughing fields, sowing, weeding and harvesting crops. Solar energy is essential for plant growth. In regions which receive higher amount of solar radiation, the potential crop yields are higher, for the same variety. This means, if the plant nutrient regime and water supply are controlled, in the former region, the actual yields would be better.

There is an inextricable link between energy production and use and climate. Fossil fuel based energy production is a major source of carbon emission into the atmosphere. Electricity generation in thermal power stations using coal and natural gas, burning of diesel/kerosene for running pumps and generators, and running of air conditioners are the major sources of greenhouse gases, which cause the atmospheric temperature to go up. Conversely, change in climate can affect the energy demand and supplies. Rise in temperature in colder climates can reduce the energy required for heating, thereby reducing the carbon footprint. Lowering of temperature in warmer climates will result in lesser use of air conditioners for room temperature control, thereby reducing its carbon footprints.

Climate-Water-Energy Nexus

Finally, there is a strong nexus between water and energy as well. Flowing water can be impounded and used for producing hydropower, the cleanest form of energy, if hydrostatic head is available. Water is needed for cooling in thermal power stations. Water is also needed for extraction of fossil fuel--coal, petroleum. Conversely, energy is required for pumping water from aquifers. Energy is required for piping water to supply for irrigation, domestic and other uses. Energy is required for desalination, be it reverse osmosis, flash distillation or electrolysis to produce freshwater. Energy is also used for treatment of sewage to obtain purified water.

Climate variability can alter the water-energy nexus. It can strongly influence the energy requirement for pumping groundwater, through its effect on groundwater levels in an area. Climate variability and change can have direct impact on hydropower generation, by affecting the quantum of stream-flows in snow and glacier-fed rivers. For countries which are dependent on hydropower from such rivers as a major source of energy supplies, temperature increase can threaten energy security in the long run, as a result of excessive snow melting and glacier retreat. Examples are Norway and Bhutan. Climate can also influence the amount of energy required for treatment of sewage, as the energy required for aerobic and anaerobic processes is a function of the temperature. While anaerobic process is favoured by rise in temperature, aerobic process is adversely affected by it.

Managing the Climate-Water-Energy Nexus

These nexus need to be managed for reducing the impact of climate change and variability on water, energy and food systems. First, the negative impacts of climate on water resources in terms of reduction in availability for meeting water requirements in various sectors need to be reduced by reducing the demand for water in the most water-consuming sector, i.e., agriculture. This can be achieved through improvements in water productivity in agriculture, consisting of both rain-fed and irrigated agriculture, or in other words by producing more biomass per unit of water depleted in crop production. The other option is to enhance the economic value of water use in agriculture, by getting higher income return from every unit of water consumed in crop production (Rs/m^3 of water), in regions where food security is not an issue.

We need to explore the technical options and policy instruments for achieving this, and identify the areas and conditions under which they work. While technical strategy for improving water productivity are many, they alone may not help reduce water consumption, as farmers in many cases will have the option of expanding the area. The policy options would include: volumetric pricing of water, rationed water allocation, water and pollution tax.

Theoretically, one can also achieve water demand reduction through import of agricultural commodities from regions which are land and water-abundant, and which have the comparative advantage of producing food at lower cost and with higher water use efficiency. But, this option seems to have several limitations, as in most instances the countries that are producing surplus food are water-scarce, and are able to do so because of availability of arable land.

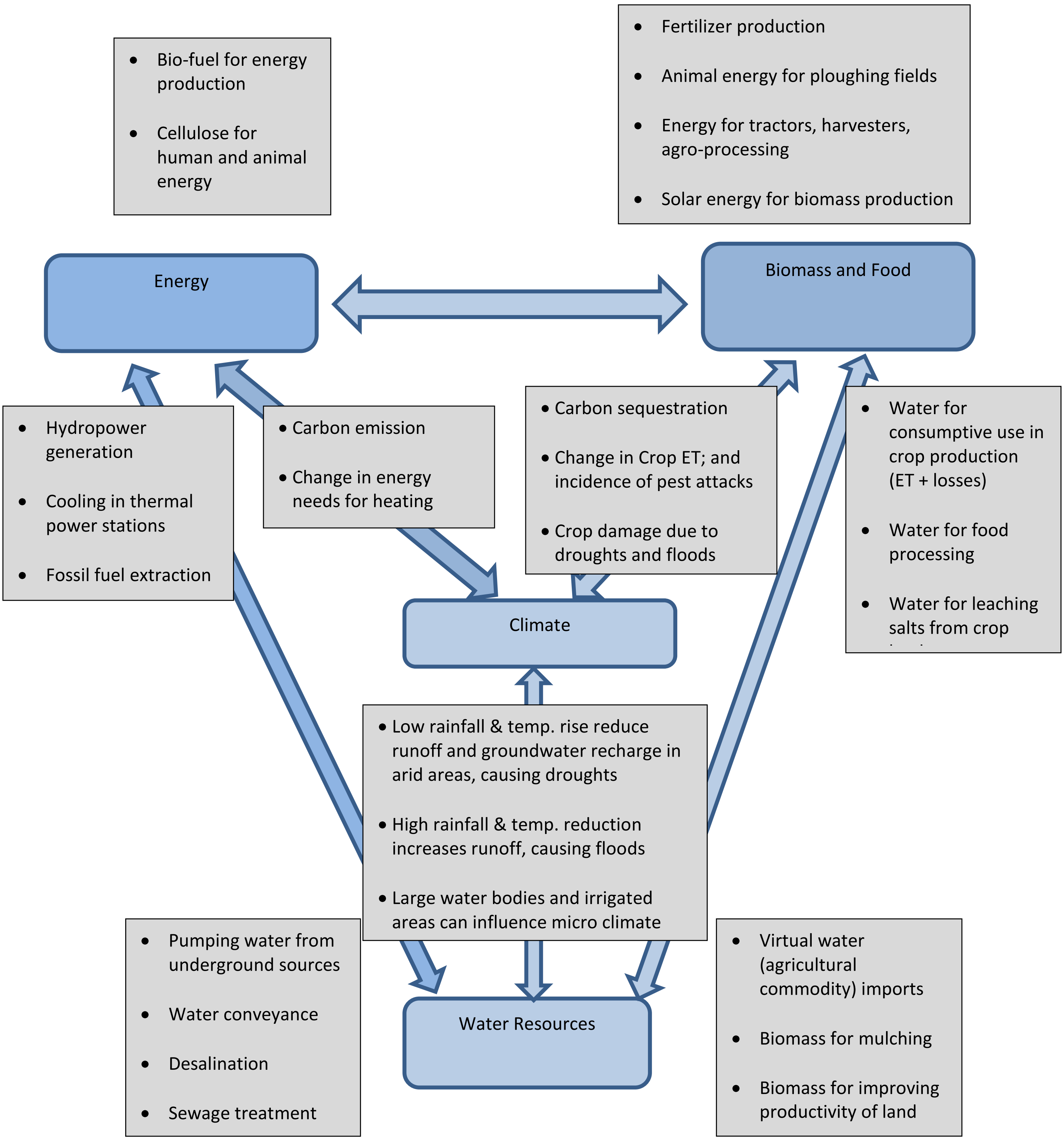
As regards managing energy-water-climate nexus, South Asian countries, particularly India, Pakistan, Bangladesh and Nepal are currently facing severe energy crisis. New energy production systems which would minimize the carbon footprints, and which are dependent on water as source, need to be explored for in the South Asian region. Hydropower generation offers enormous scope in the Himalayan region, in the upper catchments of Indus, Ganges and the Brahmaputra and western Ghat region, which would benefit India, Nepal and Bhutan. While bio-fuel has been taken up by many countries including United States, Sweden and Brazil, this doesn't appear to be the option for South Asian countries as the conditions are not favourable. First of all, the cropping intensity is already very high in the region. The regions in the sub-continent, where cropping intensity is low and land is available, are poorly endowed in water resources and climate is semi-arid to arid. Allocating land for bio-fuel in such regions would mean reallocating freshwater resources from crop production. The evidence from the United States suggests that the land under cereal crops is likely to be occupied by bio-fuels. In South Asian situation, this can threaten food security.

On the other hand, the energy security is critical to ensuring water security in South Asia. Energy demand for groundwater pumping, which is a major consumer of fossil fuel and electricity, in South Asia region needs to be managed. Most of the energy consumed for groundwater pumping is in agriculture sector. Amongst all regions, South Asia has the largest irrigated area in the World. Groundwater is the largest source of irrigation in South Asia in terms of percentage contribution to the total irrigated area. Energy use efficiency in groundwater pumping for both diesel engines and electric pumps is quite low at present. The Indo-Gangetic plains (in India, Pakistan and Bangladesh) have the largest number of irrigation pumps in the World. Enhancing pump efficiency in this region can make a dramatic impact on use of electricity and fossil fuel in agriculture, thereby reducing carbon emissions.

While improving technical efficiency of pump sets would help reduce energy consumption for pumping a unit volume of water, such technical measures without being complemented by policy instruments of efficient pricing of electricity would only lead to farmers pumping out more water from wells. At the same time, mere introduction of pro-rata tariff would encourage farmers to first improve the efficiency of pump sets with their own investments, and then go for improving the efficiency of use of water as the next step to reduce the consumption of electricity in an attempt to reduce the costs. The question is of implementing such policy measures with reduced transaction cost, as the idea of metering is often fraught with the criticism that the transaction cost of doing this option is prohibitively high.

Better utilization of solar energy and climatic advantages for crop production would also help save water used for agriculture. There are certain regions within South Asia which receive higher amount of solar radiation, by virtue of their position vis-à-vis latitude, as compared to certain other regions. Because of this, the crop yields could be much higher in the former as compared to the latter. If such regions also experience lower aridity as compared to the latter, crops grown in such regions will also have much higher water productivity (kg/ET), with increase in yield on one hand and reduction in ET on the other. If they are also endowed with sufficient amount of arable land, they become ideal for growing food crops that are required in large quantities such as wheat, rice and sugarcane. Regional water allocation strategies for agriculture should be driven by these considerations, and water should be made available for such regions through physical transfer from water-rich regions. Whereas the crops that are high water demanding (in terms of ET), but required in less quantities such as banana and mangoes, could be grown in regions that are water-rich, but do not have climatic advantage. They would also be ideal for raising fish and prawn farming.

Figure 1: Conceptual framework for analyzing the impact of climate variability on water, energy and food systems



Module 3: ***Impact of Climate Variability on Water, Energy and Food Systems in South Asia***

Water Resource Systems and Scarcity and Pollution Problems in South Asia:

M. Dinesh Kumar, Nitin Bassi, K Shiv Rama Kishan and Niranjan Vedantam

1. Introduction

South Asia accounts for nearly 4.5 per cent of the global freshwater resources, but one fourth of its population (Babel and Wahid, 2008: X). Some of the oldest civilizations of the World flourished and perished on the banks of the rivers of this region. But, the region displays high heterogeneity with respect to hydrology, climate, topography, culture and socio-economic milieu. It has some of the most productive farming systems of the world, and also regions of precariously low productivity. The economic conditions vary drastically with eastern gangetic plains having more poor people than in sub-Saharan Africa.

With a predominantly agrarian population and tropical and sub-tropical climate, irrigation development was necessary for sustaining agricultural production. Irrigation is through surface and groundwater systems. Today, the region is the world's largest user of groundwater. However, with excessively high demand for water for agriculture and limited freshwater resources, some agriculturally prosperous regions face physical scarcity of water. In contrast, some other regions, in spite of being water-rich, face economic scarcity of water owing to extreme poverty of the farming communities. The poor peasants pay prohibitively to well owners for accessing water for protective irrigation.

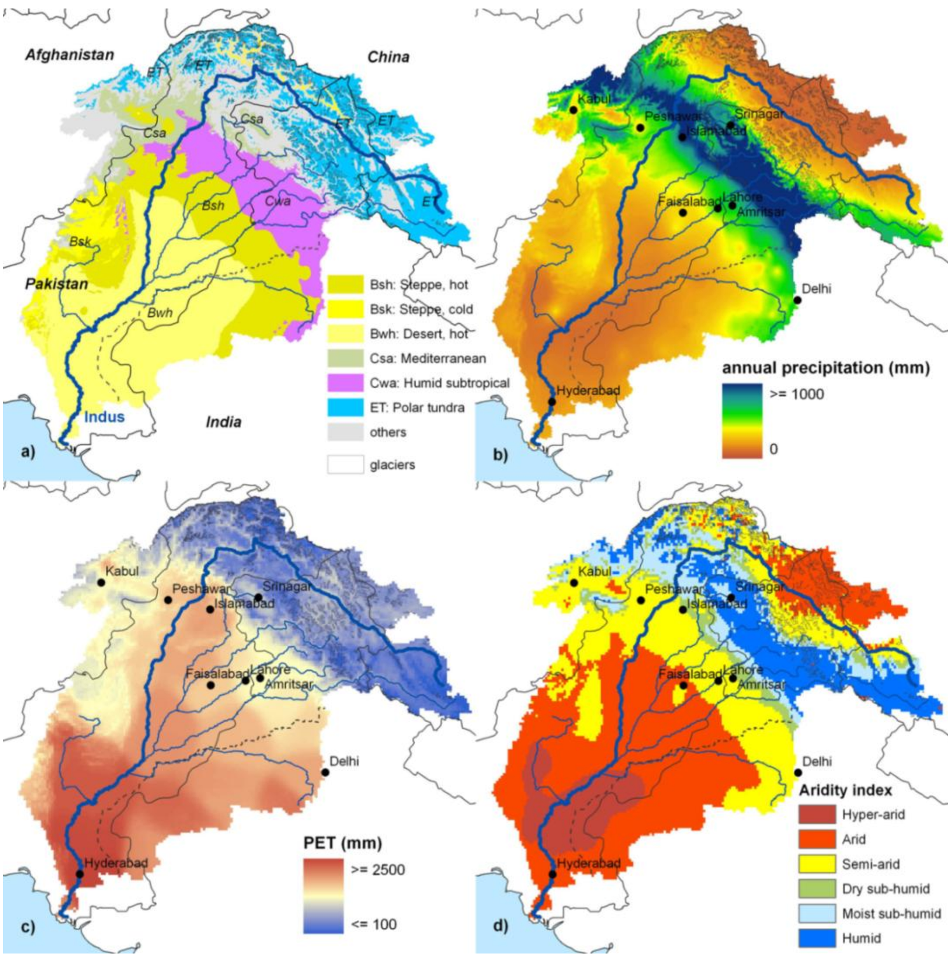
With rapid economic growth, demand for water for urban and industrial uses is also growing rapidly, resulting in not only increased withdrawal of water from rivers and aquifers, but also pollution of rivers and lakes from indiscriminate disposal of untreated and partially treated effluents. This seriously threatens the ecosystem health and water security of millions of rural and urban households which have no access to formal water supply systems to meet their basic survival needs. The ecosystem deterioration is not confined to naturally water-scarce basins alone, but also exists in relatively water-rich basins. The hydrological and ecological changes occurring in South Asia's river basins as a result of the rapid socio-economic drivers and the way they ultimately impact on the society can offer important lessons for certain countries of Southeast Asia, which, though have abundant water resources, lack institutional capability to deal with problems caused by poor access to water for human health and livelihoods, water pollution and water-related disasters such as floods and droughts.

The second section discusses the hydrological regime of South Asia, focusing on the inter-regional variability. The water resources availability in the region is analyzed from an anthropogenic perspective, showing how the per capita annual renewable water resources vary across countries. The socio-economic factors driving the demand for water, such as the structure of the economy, the proportion of people dependent on agriculture, population distribution between rural and urban areas and access to arable land are analyzed in Section 3. The water supply systems for agriculture and other sectors, and water withdrawal for agriculture are analyzed and discussed in the fourth section. In Section 5, we discuss the water security challenges of South Asia through the lens of the three remarkable river basins of South Asia, viz., Ganges-Brahmaputra-Meghna, Indus and the Helmand, which constitute nearly 45 per cent of the region's geographical area and more than 50 per cent of its population, and represent the region's diversity. Emerging water management challenges are covered in Section 6.

2. Hydrological Regime of South Asia

South Asia is one of the most water-rich regions of the World, but also displays the highest spatial variability (Source: FAOSTAT data). Monsoon being the largest source of water, the region is also characterized by very high seasonal variation in water resource availability. The role of institutions and policies in managing water resources for human wellbeing is very important in this region, where poor management of water cost millions of lives in floods, water borne diseases and malnutrition. It is also one of the most water and food-insecure regions of the world, second only to Sub-Saharan Africa.

High spatial variability in rainfall as discussed in the first module, climate, soils and topography result in remarkable variations in water resource endowment in South Asian river basins. Variations are also seen in the water endowment within river basins. The high spatial variability in water resource endowment in South Asia is evident from the climate characteristics of Indus, one of the most important river basins of the sub-continent, feeding three countries (Laghari *et al*. 2012: 1066). Within the same basin, there are regions which receive more than 1000mm of water, and with humid and sub-tropical climate. There are also regions which receive less than 100mm of rainfall, with hot desert climate. For instance, the map of Indus basin in India-Pakistan shows the remarkable variation in rainfall and other climatic parameters, which causes major variation in reference evapo-transpiration from the upper to the lower basin areas.



But, the population density also varies remarkably from region to region. The regions which have poor natural water endowment such as western Rajasthan in India have extremely low population density. Mountainous regions like in the North Eastern part of India and the Sub-Himalayan region (in Nepal, Pakistan and Afghanistan) also have very low population density.

Whereas those which are naturally water-rich but with warm climate such as eastern Gangetic Basin in India and Bangladesh, have very high population densities. Therefore, it is important to look at freshwater resources in per capita terms. The per capita renewable water resources vary drastically from region to region and from country to country (Figure 1). It varies from 89 m^3 per capita per annum in Maldives to 39,700m^3 per capita per annum the mountain Kingdom of Bhutan. The per capita renewable water resource per annum is around 1,700m^3 in India, around 1,400m^3 in Pakistan and 8,000m^3 in Nepal. Except for Bhutan, renewable water resource availability in South Asia is below the global average which is around 20,000m^3 per capita per annum (Source: FAOSTAT data). But, these figures are not indicative of how much water the population currently can access, which is determined by how much of this water is actually utilizable, the access to financial resources, and technologies.

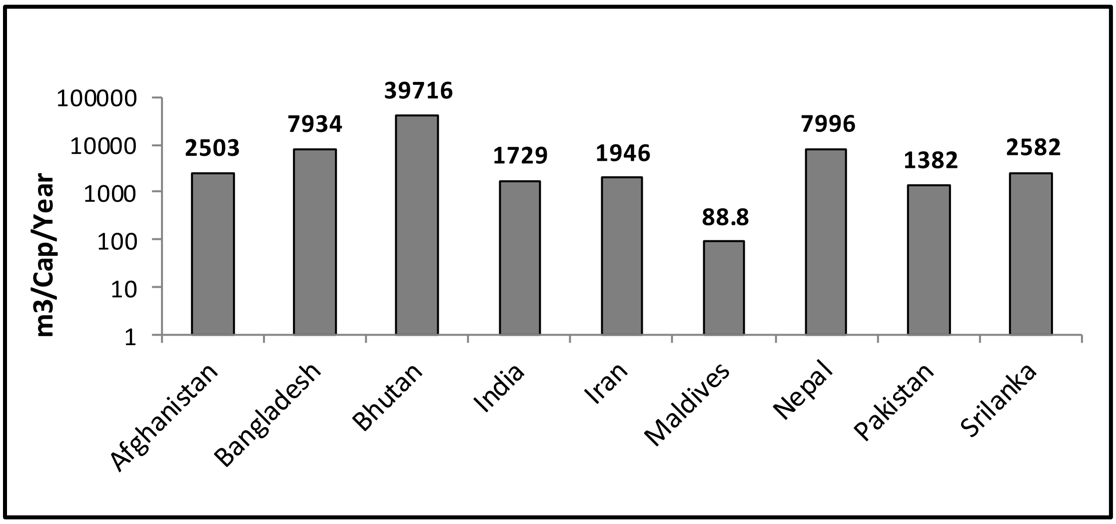
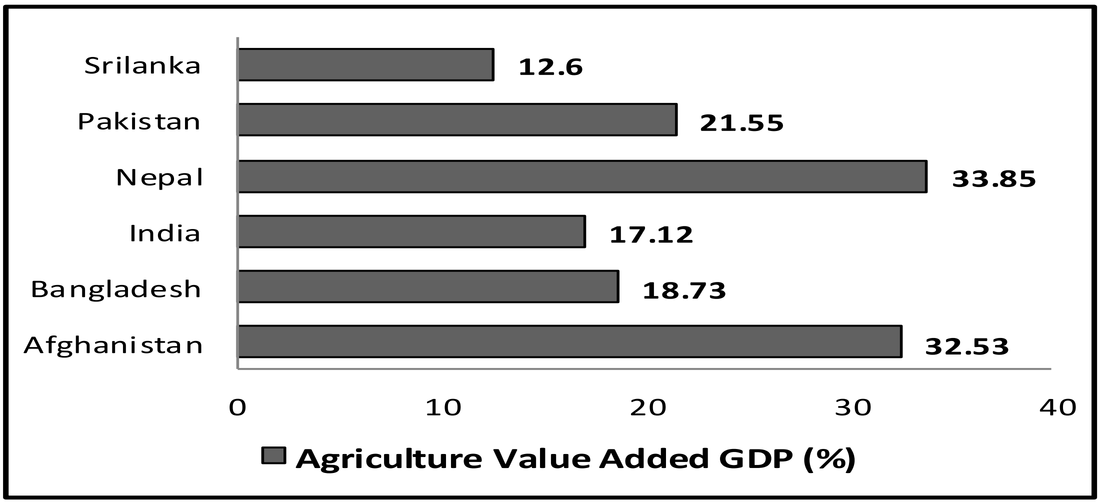


Figure 1: Annual per capita renewable water resources in South Asia
Source: Authors' own analysis using FAOSTAT data

3. Drivers of Water Demand in South Asia

In South Asia, the agricultural component of GDP ranges from 17.1% in India to 33.9% in Nepal (Figure 2). The region is experiencing the fastest growth in population amongst all regions of the World. The region is also experiencing considerable economic growth, most of which is driven by India, which accounts for a major chunk of the sub-continent's population. Both population growth and rising per capita income resulting from economic growth would act as



major drivers of growth in water demand. As regards the impact of population growth, more water would be required to produce food for the growing population, and more water would be required to meet the water supply needs in rural and urban areas. Rising income levels on the other hand would change the consumption patterns towards food items which are higher up in the food chain such as meat and dairy products (FAO, 2009: 5). But for food demand to get translated into water demand, arable land availability is a pre-requisite. Since South Asia has one of the highest land use intensities in the world in terms of the proportion of arable land under cultivation (Table 1), the additional food production can come from intensifying land use through expansion of irrigated area, which is quite low in countries like India. Only, nearly 40% of the total arable land of 157 m. ha is irrigated in India. The per capita agricultural water demand would be determined by the per capita arable land and climate. It is considerably high in countries which experience hot and arid climatic conditions (Figure 3). While the per capita arable land is 0.13 ha and 0.12 ha for India and Pakistan, it is as high as 0.25 ha for Afghanistan, whereas it is very low in water-rich Bangladesh.

Figure 2: Contribution of agriculture to GDP in selected South Asian countries
Source: Authors' own analysis using FAOSTAT data

Table 1: Land use intensity in South Asia

Sr. No.	Country	Total geographical area (000' ha.)	Total Arable land (000' ha.)	Gross cropped area (000' ha.)
1	Afghanistan	65,223	7,793	7,910
2	Bangladesh	14,400	7,509	8,549
3	India	328,726	157,923	169,623
4	Nepal	14,718	2,400	2,520
5	Pakistan	79,610	20,430	21,280
6	Srilanka	6,561	1,200	2,170

Source: Authors' own analysis using FAOSTAT data

Urbanization is yet another factor, which would drive the demand for water in the region. As average per capita water requirement for domestic uses in urban areas is more than that of rural areas (Kumar 2010: 26), demographic shift would mean higher average per capita water requirement for domestic uses. In India, rapid industrialization is posing new challenges of water quality deterioration along with very rapid and continuing increase in the demand of water for manufacturing.

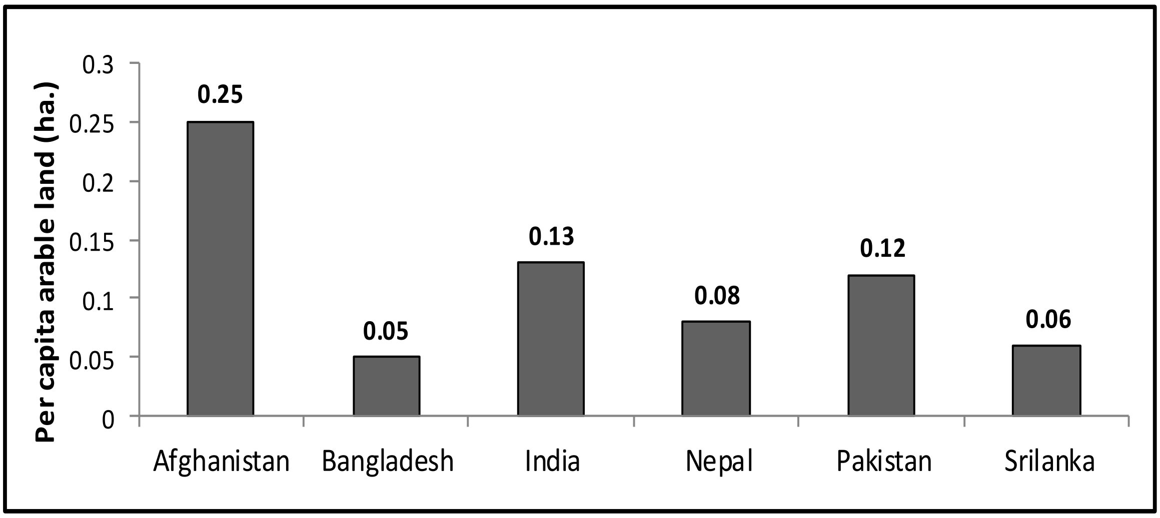


Figure 3: Per capita arable land in selected South Asian countries
Source: Authors' own analysis using FAOSTAT data

4. Water Resource Systems in South Asia

South Asia has a wide range of water supply systems which are both modern and traditional to cater to different water needs of the society, and which utilizes surface water resources, groundwater resources, water from springs and even soil moisture. South Asia has some of the largest man-made reservoirs and water diversion systems created through the construction of dams and barrages, for irrigation and water supplies. It also has large hydropower dams and reservoirs, particularly in India, Pakistan, Bhutan and Nepal. Countries like India and Bangladesh have a variety of traditional water harnessing systems such as tanks, ponds and lakes, which are used for multiple purposes such as irrigation, domestic water supply, livestock drinking, fisheries and recreation. For water supplies in rural areas, all these countries depend on many modern water systems such as hand-pumps, piped water supply schemes based on wells, bore wells and tube wells, tanks and lakes, traditional open wells and Persian wheels, though the extent of contribution of different types of sources depends on the hydrological and geo-hydrological regime.

Large urban areas in India are now depending on water imported from distant reservoirs, and their percentage contribution increases with increasing in size of the city. Regional water supply schemes based on surface water sources are also now replacing small, decentralized rural water supply schemes, based on wells (Mukherjee *et al*. 2010: 10-14). In Pakistan, about 10% of the total pumped groundwater (around 4 BCM) is used to meet domestic and industrial requirements. In the most populous province of Punjab, about 90% of the population depends on groundwater for their daily domestic needs. In Baluchistan province, about 4% of the population depends on groundwater (Qureshi *et al*. 2010:3).

Irrigation accounts for a major share of the water demand in South Asia (source: FAOSTAT data), and some of the world's largest irrigated areas are in this sub-continent. India alone has nearly 97 m. ha of gross area under irrigation. This is followed by Pakistan, which has a total of 19.02 m. ha of irrigation, mostly in the Indus irrigation system (MINFAL 2006-07). Agricultural water withdrawal data for selected South Asian countries is given in Figure 4. The per capita water withdrawal is highest for Pakistan (1012 m^3/annum), followed by Afghanistan and then India.

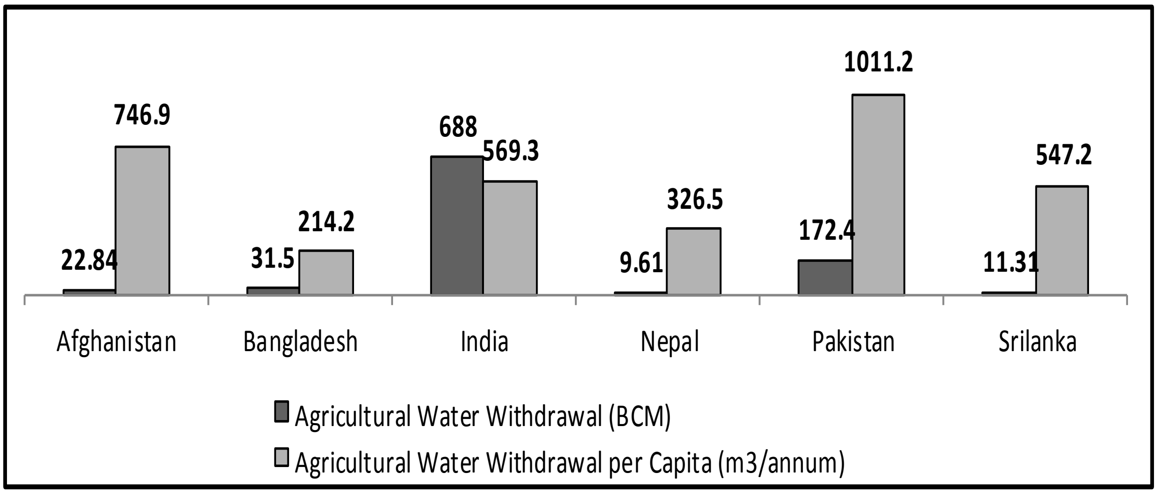


Figure 4: Agricultural water withdrawal for selected South Asian countries
Source: Authors' own analysis using FAOSTAT data

The irrigation water demand is met through many large, medium and minor irrigation schemes based on surface reservoirs, and gravity flow. The total reservoir storage created by surface water systems, which cater not only to irrigation but also domestic water supplies and hydropower generation in different countries, and also the storage in per capita terms for these countries, are given in Figure 5. The per capita reservoir storage is an important indicator of water security of nations, as argued by Kumar *et al*. (2008). Sri Lanka has the highest per capita storage amongst all the six countries, followed by India and Pakistan.

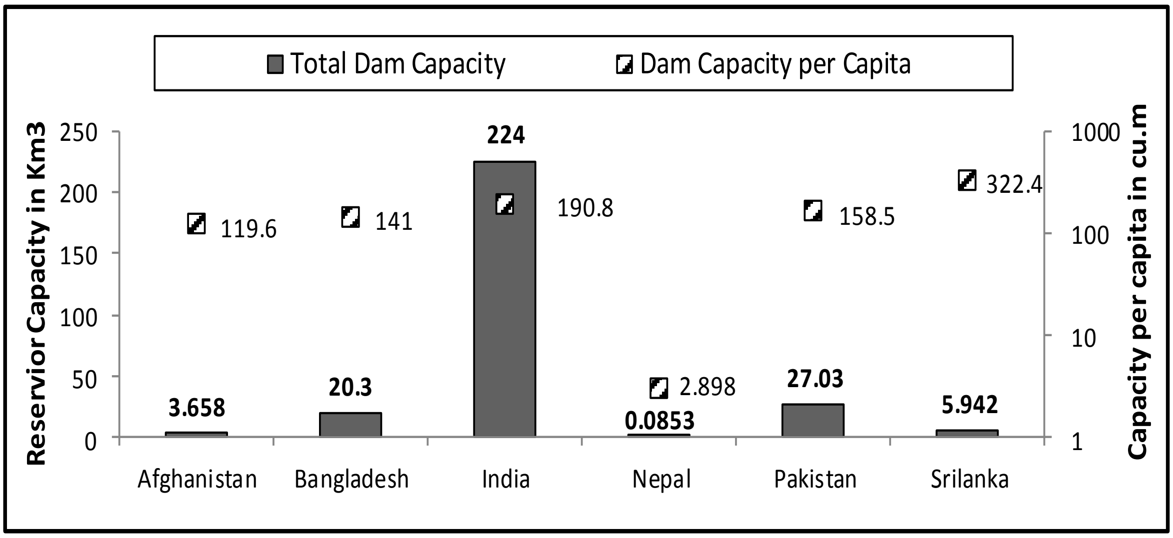


Figure 5: Reservoir water storage capacity of selected South Asian countries
Source: Authors' own analysis using FAOSTAT data

Another most fascinating feature of irrigation in South Asia is the well-developed groundwater irrigation systems. Many millions of wells, which irrigate small plots of land, dot the rural landscape of South Asia. It is the major source of irrigation for semi-arid and arid regions of the sub-continent, where surface water resources are extremely limited and public irrigation systems are inefficient. India alone has nearly 25 million groundwater irrigation structures. Groundwater accounts for nearly 64% of the net irrigated area in India, whereas it is as high as

76% in Bangladesh. In Afghanistan, it is only 15% and Sri Lanka has virtually no well irrigation (Figure 6). Tanks and large surface systems are the source of irrigation in this island country.

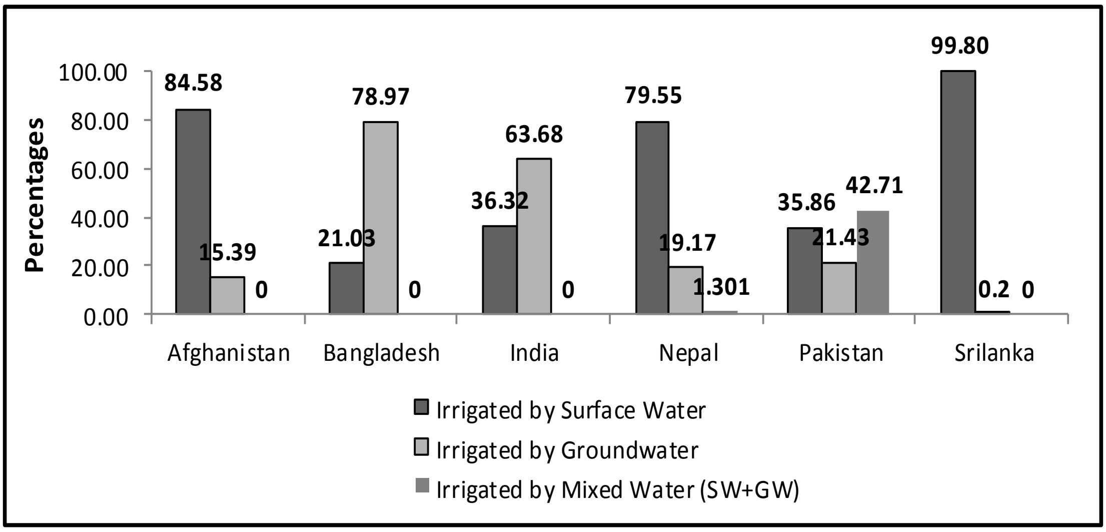


Figure 6: Proportion of area irrigated by different sources in selected South Asian countries
Source: Authors' own analysis using FAOSTAT data

However, interestingly, inefficiency of public irrigation systems, caused by heavy losses in conveyance, low on-farm water use efficiency under gravity irrigation and unreliable supplies, enriches groundwater significantly in the command areas in large gravity irrigation systems such as the Indus Basin Irrigation System (IBIS) in Pakistan (Qureshi *et al*. 2010: 2). The same groundwater is pumped out by farmers, including those who access canal water. IBIS also has vast area irrigated by both groundwater and surface water conjunctively, accounting for nearly 43% of the net irrigated area in Pakistan. The total groundwater pumping in Pakistan is estimated to be around 49.9 BCM, from around 0.13 million electric tube wells and 0.83 million diesel tube wells. There is extensive tube well irrigation in Indian Punjab also, which to a great extent is sustained by recharge from irrigation return flows, and canal seepage.

In the mountain county of Nepal, groundwater use is concentrated in the Terai region, which has extensive alluvial deposits. Shallow tube wells are used in this region to tap groundwater from the rich alluvial aquifers. In the remaining parts, both in the mid hills and mountainous areas, river flows and springs are tapped for meeting various water needs.

Large hydropower dams also add to the water resource system of South Asian region. The Himalayan region of India, Pakistan, Nepal and Bhutan provide ideal physical environment for tapping river flows for hydropower generation. The hydropower potential of Bangladesh is very poor owing to the fact that most parts of the country is in the deltaic plains of Ganges and Brahmaputra river systems. India also has hydropower potential in the western Ghat region. The hydropower potential of different countries in South Asia and the extent of utilization are given in Table 2. Most of the hydropower projects are of storage type, involving construction of dams. Submergence of forest land and displacement of population have been serious concerns associated with construction of most hydropower projects in these countries. Against a total hydropower potential of 305.8 giga watt, the current utilization is only 46.65 giga watt.

Table 2: Hydropower Potential and Utilization in Six South Asian Countries

Country	Estimated Hydro-power potential (in GW)	Currently exploited Hydro-power (in GW)	Extent of Potential Utilization (%)

India	149	37.5	25.00
Nepal	83	0.83	1.00
Pakistan	50	6.45	12.90
Bhutan	30	0.45	1.50
Bangladesh	0.8	0.224	28.00
Srilanka	2	1.2	60.00
Total	305.8	46.654	15.25

Source:

5. Energy and Food Production in South Asia

The energy production system in South Asia consists of both conventional and non-conventional systems. The conventional energy production system consists of coal, diesel, and natural gas based thermal power plants and hydropower. The hydropower stations consist mainly of storage reservoirs, and runoff the river hydropower stations are very few, though many of the recent hydropower projects in the north eastern states of India belong to the latter. Amongst these the only source of energy which is dependent on water resources is hydropower. Table 3 shows the installed capacity, power generation, losses and consumption in five South Asian countries. It can be seen from the table that contribution of hydropower to the total installed capacity is highest in Nepal, followed by Bhutan and then Pakistan.

Table 3: Electricity Generation and Consumption in Five South Asian Countries

Country	Installed Capacity (GW)	Hydropower Component/ (%) (GW)	Total Electricity Generation (000'Gwh)	Distribution Losses (%)	Per capita Consumption (Kwh)
India	177.38	37.50 (21.1)	785.53	24.66	566
Pakistan	19.77	6.45 (35.6)	87.74	21.87	436
Bhutan					
Bangladesh	5.45	0.224 (4.1%)	32.93	13.17	149
Nepal	0.83	0.83 (100%)	3.05	19.56	89
Srilanka	2.64	1.20 (45.5%)	8.89	11.33	414
Total	206.07		918.14	90.59	1654

The non-conventional energy sources include wind turbines, tidal power generators and solar power stations, though the capacity created is very small in comparison to the total installed capacity. There are large solar power stations being built in Ladak and Kachchh districts. Kachchh also has many wind turbines. Bio-fuels are another source of non-conventional, renewable energy, which is dependent on water, for production of plants yielding biofuel, but are yet not tapped in the region. The availability of land for bio-fuel production is an issue, in areas where sufficient water is available for growing bio-fuel plants. For instance, in India, the eastern region which has sufficient amount of excess water for diverting to growing more crops have very little arable land (in per capita terms) and land use intensity is already very high there. Whereas in regions, where there is sufficient amount of arable land lying un-utilized, water scarcity is a major problem. Both surface and groundwater resources are over-appropriated (Kumar *et al*., 012).

Now as regards energy use in agriculture, energy in the form of natural gas is used for manufacturing of fertilizers. Energy in the form of diesel is used in diesel pumps, for running wells. Diesel is used for operation of tractors. Amongst all these, direct consumption of fossil fuel in agriculture is very significant in the region. Millions of agro wells in the Indo Gangetic plains are energized by diesel engines. The high extent of use of diesel engines in groundwater pumping is prevalent in areas with shallow water table conditions. Whereas in areas with deep water table conditions, electric pump sets are used.

Table 4 shows the total gas-diesel oil consumption in agriculture in these South Asian countries. However, this includes the gas consumption as raw material for manufacturing of fertilizers. The actual direct consumption of diesel in agriculture including that for groundwater pumping, and running tractors and threshers is a small fraction of this. In the case of India, the total diesel consumption for groundwater pumping was estimated to be 400 million litres (Kumar *et al*., 2014). The amount of diesel consumption in agriculture has been on the decline in Pakistan with increasing cost of diesel and the availability of alternative source (i.e., electricity). In 2001-2 to 2005-06, diesel consumption was 186 million kilograms (Khan *et al*., 2005).

Electricity consumption in agriculture, mainly for pumping groundwater, is very in South Asia. For instance, in India, electricity consumption for groundwater pumping is estimated to be 107.7 billion units per annum for the year 2009-10. The consumption of electricity in Pakistan agriculture was 6.646 billion units in 2001-02 to 2005-06. The energy consumption in agriculture has been increasing in South Asia with expansion in irrigated areas, and more importantly the use of human and animal energy is getting replaced by electricity and fossil fuel, as a result of increasing mechanization of farms and energization of irrigation sources.

Table 5: Gas, Diesel Oil Use in Agriculture in South Asian Countries (Final Use)

Country	Gas-Diesel Oil Consumption in Agriculture in '000 metric ton (2009)
India	11,245
Srilanka	4
Bhutan	60
Nepal	99
Pakistan	40.597
Bangladesh	1,005

Source: United Nations,

As regards agricultural outputs, the data on output of major cereals for the year 2009 are presented in Table 6. Table 5 also shows the total output of pulses and milk in South Asian countries. The estimates of availability of major cereals, and pulses in per capita terms are also provided in the table. As regards availability of major cereals per capita, Bangladesh stands atop with 180.90 kg/capita per annum in 2009, followed by Nepal and India. A lion's share of the annual cereal production in Bangladesh is accounted for by rice. But, these figures need to be read with a lot of caution as they do not cover a wide variety of coarse cereals such as pearl millet, sorghum and barley, grown extensively in India. Among these, pearl millet and jowar are the stable diet of a large section of the rural population in Rajasthan, Gujarat, Maharashtra, Karnataka and Madhya Pradesh, though its percentage to the total cereal intake has been on the decline in the recent decades. The total cereal production in India stood at 221m. ton, against 34.02 m. ton in Bangladesh.

Over and above this, pulses form a major part of the dietary regime of people in South Asia. The per capita availability of pulses is highest in India, followed by Pakistan. The total food grain production in India was 235.42 m. ton in 2010, with a per capita availability of 192.24 kg/annum against 230 kg/annum for Bangladesh and 182.8 for Pakistan.

Also, India is the largest producer of milk in the world and among all the South Asian countries, the supply of milk in per capita terms is also one of the highest in India, with the figure touching at 89.9 litre per capita per annum, next only to Pakistan with has an average milk production of 195 litre per capita per annum. In Bangladesh, per capita milk production in 2009 was 20.7 litre per capita per annum.

Another major food item which consumes a large amount of water and land is sugarcane. Table 7 shows sugarcane production in South Asian countries, during 1995 to 2010 in 5-year time intervals. India produced 292 million ton of sugarcane in 2010, followed by Pakistan with 49.3 million ton. There has been no consistent growth in sugarcane production in India since 1995. Bangladesh has very little area under sugarcane, less than 1/100 of a million ha. The area under sugarcane had drastically declined in Bangladesh. Sri Lanka and Nepal do not produce sugarcane.

Table 6: Production of Food Grains in South Asian Countries

Country Name	Production of Major Food Grains in Million Ton (2007-08)			Production of Milk (m. ton) 2007,2009	Per Capita Availability of Major Cereals (kg/annum) in 2009	Production of coarse cereals (m. ton) In 2010	Per Capita Availability of Pulses (kg/annum)
	Rice	Wheat	Pulses				
India	94.29	78.35	14.44	107.59	152.60	43.40	12.20
Bangladesh	30.36	0.81	0.22	3.06	180.90	1.30	4.80
Pakistan	6.42	22.76	1.06	33.28	129.80	3.90	8.10
Srilanka	2.35	0.00	0.02	0.19	143.50	NA	8.00
Maldives	0.00	0.00	0.00	0.00		NA	
Nepal	2.76	1.48	0.24	1.48	171.30	2.40	4.00

Table 7: Sugarcane production in South Asian countries (in million ton)

Country	**2010**	**2005**	**2000**	**1995**
India	292.3016	237.0884	299.3239	275.54
Bangladesh	0.314976	0.342000	6.91	7.44565
Pakistan	49.3729	47.2441	46.3326	47.1684
Srilanka				
Nepal				
Source: FAOSTAT.FAO.ORG				

6. Water Security Challenges of South Asian Region

South Asia encompasses some of the most water-scarce regions of the world. The entire Pakistan, whose agriculture is heavily dependent on Indus basin irrigation system, is highly water stressed. Many regions in India have renewable water resources falling below the threshold of $1000m^3$ per capita. Here we analyze the water security problems of Ganges, Indus and Helmand basins using five major components, namely: i] water resource stress, which is reflective of the natural water resource endowment and its variability across the basin; ii] water development pressure; iii] the water access poverty; iv] ecological health of river basin; and, v] the management capacity that exists within these river basins to tackle these problems.

There is a clear pattern in spatial variation of rainfall and climate in South Asia. The regions of low rainfall have high aridity and regions of high rainfall have low aridity or high humidity (as in Indus river basin). Such unique patterns vis-à-vis spatial variations in rainfall and climate create regions of extreme water stress in terms of renewable water availability due to poor runoff rates and low groundwater recharge rates, and fast depletion of soil moisture (such as western Rajasthan, Punjab, Sindh and Baluchistan), and regions of water abundance (such as eastern Gangetic plains encompassing, Bihar, eastern Uttar Pradesh, most parts of West Bengal, and Bangladesh). Similarly, the regions of low rainfall also experience monsoon failure more frequently, causing extreme water stress resulting from hydrological droughts (Eriyagama *et al*. 2009: 16).

A river basin experiences a water resource stress when the available freshwater fails to support socioeconomic development and maintain healthy ecosystems. The availability of freshwater is expressed in terms of per capita water resources (1,700 cu. m per person per day is considered as the threshold for water stressed condition), and by variation of precipitation (a coefficient of variation of 0.3 is taken as the critical level, beyond which a water resources system is considered most vulnerable) in a basin (Babel and Wahid 2008: X). Indus basin experiences highest water stress owing to a renewable water availability falling below 1,700 cu. m per capita mark; but at the same time, Helmand basin experiences highest stress in terms of the water variability due to sharp spatial variation in rainfall across the basin. On both fronts, Ganges experiences the least water resources stress.

The level of exploitation of water is not uniform across regions in the sub-continent. For instance, in India, it is high in regions of poor water resource endowment, and vice versa. The level of exploitation of groundwater is very low in regions of water abundance, owing to poor availability of arable land, high rainfall and low aridity. Excessive withdrawal of groundwater results in drying up of wells in the hard rock areas where sufficient groundwater stock is not available (Kumar 2007: 55). Surface water is also over-appropriated in the semi-arid and arid regions of India, leaving much less water as ‘environmental flow’ for meeting the ecological functions of the river, downstream. Such areas experience ‘water development stress’ (Kumar 2010: 32).

The quality of groundwater in the Indus Plains varies widely (Qureshi *et al*. 2009: 5). Groundwater in areas receiving high rainfall in the upper parts of Punjab has low salinity. Similarly areas underlying Indus River and its tributaries and canals have wide and deep belts of relatively fresh groundwater. The salinity of the groundwater generally increases away from the rivers and also with depth. In Punjab province, 23% of the area has poor quality groundwater, while it is 78% in Sindh (Haider 2000, as cited in Qureshi *et al*. 2009: 8). In the lower parts of the Indus plain, the area of fresh groundwater is confined to a narrow strip along the river. In central areas of Punjab province, a layer of fresh groundwater floats over the saline water. Due to excessive pumping of this fresh groundwater lens, salt water intrudes into fresh groundwater areas. Groundwater resources are over-exploited for irrigation in areas where rainfall is low, climate is more arid, and groundwater quality is good (Qureshi *et al*. 2010: 8).

In Nepal, groundwater utilization is mostly confined to the lower Terai region, with farmers using shallow tube wells (Kansakar 2003: 95-96). The Indus basin area of Pakistan also experiences extreme environmental water stress resulting from excessive diversion for irrigation in the IBIS.

The water development pressure was assessed considering: total water use against the renewable water resources, which reflects the level of water exploitation; and, proportion of population having access to safe drinking water source, which reflects the level of water infrastructure development (Babel and Wahid 2008: 5). Water exploitation is highest in Indus basin (89%), the basin having the lowest renewable water resources in per capita terms. The water exploitation pressure is lowest for the Ganges, which has the highest renewable water resources and lowest level of use. But, the proportion of population without access to safe drinking water is highest for Helmand (57%), followed by Ganges (17%). Though water development pressure is the highest in Indus basin, a large majority of the people (from India and Pakistan) enjoy access to drinking water supplies. On the contrary, in spite of having plenty of water resources, nearly 17% of the people do not have access to safe drinking water sources in the Ganges basin, the reason for which can be attributed to the socio-economic backwardness of the region and the poor public investment in water supply sources.

Though richly endowed with water, South Asia experiences great difficulties in accessing it from the natural systems, for meeting irrigation needs. Some of the factors contributing to this 'water access poverty' are high degree of poverty among farmers in the region which reduces their financial capacity to invest in wells; the poor landholding size, which reduces the overall economic viability of having independent source of water like wells and pump sets for small and marginal holders; poor rural electrification which increases the fuel cost of accessing well water; and high monopoly power of well owners, which increases the price at which irrigation services are offered to farmers. These regions (comprising eastern Gangetic basin in India and Bangladesh, and Terai region of Nepal) therefore face economic water scarcity (Kumar 2007: 68).

As regarding ecological health, in India, with rapid industrialization and fast growing urban areas, even water rich river basins are heavily polluted due to indiscriminate disposal of effluents from industries located on the banks through sewers, and direct disposal of human and animal waste from rural areas. Ganges, which provides water to around 40% of India's population, receives around 2900 million litre of untreated sewage every day, while the existing treatment plants have capacity to treat only 1100 million litre per day (Source: Hindustan Times: April 17, 2012). In semi-arid and arid regions, the intensity of this pollution is exacerbated by excessive diversion of water from the rivers and streams, reducing the ability of the rivers to assimilate pollution, while causing ecosystem deterioration. In Pakistan, the pollution of the Indus River is caused by excessive salinity resulting from runoff from irrigated fields. Also, groundwater in the Indus basin irrigation command is increasingly becoming saline. Salinization in IBIS is due to two significantly different processes: (i) is by shallow saline water tables; and (ii) is due to irrigation with marginal quality groundwater (Aslam and Prathapar, 2006: 1).

The ecosystem health of the basins was assessed considering: water quality deterioration, which is evaluated as the volume of wastewater discharged into the basin's rivers; and, ecosystem insecurity, which is evaluated as the extent of (natural) vegetation cover as percentage of the basin area (Babel and Wahid 2008: 5). Very high levels of pollution were observed in Helmand and Indus river basins. The water quality deterioration is low in GBM, just because of the huge amount of renewable water resources these basins have. Further, a major share of the renewable water resources are in the Brahmaputra basin, which does not have any major polluting sources, though certain sub-basins of Ganges such as the Yamuna, which have much less renewable water resources, are highly polluted. On ecosystem insecurity, GBM is far more seriously deteriorated than the other two basins with only 20 per cent of the land area under natural vegetation.

Obviously, the capacity of the existing institutions to tackle water scarcity and pollution problems in these countries is precariously low, as is evident from low water use efficiency in agriculture sector, which consumes by far the largest share of the water, poor access to sanitation in rural and urban areas, and poor capacities for resolving conflicts which emerge out of the growing competition for water at times of scarcity. The institutional capabilities to charge for water in the agriculture and domestic sectors, in a manner which reflects the scarcity value of the resource, or introduce charges or taxes for producing wastewater or causing pollution of water bodies, are largely lacking in the water bureaucracies of South Asian countries. The regulatory framework for pollution control, which uses norms vis-à-vis quality for effluents being discharged into natural water bodies, is not effectively implemented. The 'polluter pay' principle is not practiced.

While competition amongst different uses of water such as between irrigation and urban water supply; and, industrial use and rural water supply are growing in many water-scarce regions in India (Kumar 2010: 37-39), there is mounting tension between India and Pakistan over sharing of water from Indus, as the flows in the river from upstream glacier-laden catchments reduce and India moves ahead with its decision to build a few more hydropower dams in its territory in Jammu and Kashmir. The countries have already been embroiled in two legal fights over water. In 2005, Pakistan challenged India's 450-megawatt Baglihar dam before a World Bank-appointed neutral expert and lost. In 2011, the countries went head to head at the International Court of Arbitration over India's 330-megawatt Kishanganga project in Jammu and Kashmir. The court ordered India to temporarily stop the dam construction while assessments are being made (Time 2012: April 16). There is institutional vacuum to resolve such conflicts within these countries.

Thus, in addition to the components (such as water resource endowment and ecological health) that focus on natural processes, management efficiency also plays an important role in sustainable development and use of water resources. The current management capacity to cope with mismatch between water demand and supply is assessed in relation to: water use efficiency, assessed as the ratio of total annual GDP per capita from activities using water against the total annual water use per capita; and, improved sanitation inaccessibility, assessed as an inverse function of the percentage of people having access to improved sanitation facilities (Babel and Wahid 2008: 5).While there isn’t much difference in water use efficiency, the inaccessibility to improved sanitation is high in both GBM and Helmand (about 60 per cent in each basin), and comparatively better in Indus (50%).

6. Emerging Water Management Challenges

Water resource development schemes are administered in a highly sectoral and segmented way in South Asian countries. Multiple agencies are engaged in water resource development in these countries for different sectors such as the irrigation department, rural water supply and sewerage department, urban water utilities etc. There is hardly any coordination amongst them in terms of policies and actions. Often, there is more than one agency to look after the same sector, be it irrigation or rural water supply, and they work in a segmented way. For instance, there are separate departments dealing with well irrigation and surface irrigation in these countries. Though groundwater and surface water systems are inter-connected, these agencies work at cross purposes, and their actions are not coordinated at the hydrological system level.

Often, the same line agency looks after multiple functions--water resource planning, water development, water resource management and water allocation, reducing their effectiveness in managing the resource (Kumar, 2010: 233). For instance, there is no separate agency concerned with catchment (basin) assessment in most Indian provinces. The same agency, which is engaged in irrigation development, is responsible for assessing the dependable yield of the catchments or groundwater resource assessment. This leads to a situation of over-assessment of the utilization potential and consequent over-development of water resources in the basin. Likewise, the agency which monitors water quality is also responsible for protection of water quality. This situation motivates them to downplay the magnitude of pollution problems.

These agencies neither pay for drawing water from the basins, nor are constrained by any limits on water diversion, in the absence of any agency for basin-wide allocation of water to different sectors and users within the sectors. They also do not have to pay for pollution of water, on the basis of the volume of effluent or the intensity of pollution, except being mandated to adhere to effluent standards. Hence, they have no special incentive in reducing their withdrawal or improving the efficiency of its use or reducing the intensity of pollution. At the same time, there is an absence of any legitimate agency to ensure sufficient flows in rivers and streams to meet the environmental flow requirements.

Another important issue is the lack of well-defined rights in groundwater. Though it is one of the most important sources of water to meet all human needs, the right to use this resource in the South Asian countries is attached to land ownership rights, and there is no restriction on the volume of groundwater that the landowners can pump. Again, most of the irrigation wells in India, Pakistan and Nepal (the countries where groundwater irrigation is significant) are in the private domain and very few wells are owned by government agencies.

Though groundwater is a major source of irrigation in India (Kumar 2007: 1) and electric wells accounts for a major share of the total number of groundwater abstraction structures (Scott and Sharma 2009), electricity used for groundwater pumping is not metered in most Indian states, with the exception of West Bengal in eastern India (Kumar *et al*. 2011: 382-383). In Pakistan, though farmers pay for electricity on the basis of consumption (pro rata pricing), farmers who use electric wells are a small fraction of the total well owners, owing to high electricity costs, and the rest use diesel engines for their tube wells (Qureshi *et al*. 2010: 11). Because of this, the well irrigator farmers in Pakistan are already confronted with 'positive marginal cost' (i.e., if farmers pump more water, it will cost them more) of using groundwater. Hence, one can presume that they are already using groundwater efficiently, particularly when we consider the fact that groundwater irrigation costs are very high there.

Many major river basins in South Asia are trans-boundary in nature. In spite of the vital role water resource management plays in the region's economic development, very little regional cooperation on water resources development and management exists amongst the co-basin countries (Brichieri-Colombi and Bradnock 2003: 47). This disables each region from making use of its comparative advantage over the other regions (in terms of climatic conditions, topography, water flows, presence of arable land and unique socio-economic features, finance, technology and human resources) in harnessing the resource for socio-economic development and sharing the benefits with their neighbours. The important trans-boundary basins are Indus, Ganges, Brahmaputra, Meghna and Kosi.

But, the regional cooperation on water resource development is limited to only hydropower development, and that too is very recent. For instance, in April 2013, Nepal, India and Bangladesh (NIB) have decided to cooperate and exploit the hydropower sector and use water resources management for mutual advantage, including jointly developing and financing projects in the Ganga river basin (The Hindu 2013: April 15). Instead, only limited legal agreements on water sharing agreements were signed in the aftermath of long standing disputes over the use of water from these basins.

The only two agreements that exist are the Indus Water Treaty, signed in 1960 between India and Pakistan over sharing of water from the Indus river Basin and its five tributaries viz., Jhelum, Chenab, Sutlej, Rabi and the Beas, and the Farakka Treaty of December 1996, signed between India and Bangladesh over sharing of water from Ganges at Farakka barrage in West Bengal. Since the construction of Farakka barrage by India in 1975, the Ganges waters have been a key source of conflict between India and Bangladesh. But, the Farakka Treaty hasn't been successful in resolving all pending issues between the two countries (Rahman 2005: 200). India had recently raised serious concerns over building of three hydropower dams by China in the Tibetan part of Brahmaputra basin due to their potential negative impacts on flows in the river in Arunachal Pradesh (The Economic Times 2010: November 16).

There are no basin-wide initiatives among the co-basin countries over utilization of water in these trans-boundary river basins for the region's economic development, which makes full use of the comparative advantage each country has with respect to climate, topography, availability of arable land, finance, technology and human resources. This is in spite of the fact that the ability of the lower riparian states (countries) to fully utilize the benefits of the water from the basin or manage water in the basin to protect their interests, depend on the actions by upper riparian states.

The emerging water management challenges are: creating river basin organizations for basin-wide water allocation across and within sectors and also water resources management including WQM, and institutional platforms for resolving water related conflicts between countries in trans-boundary (international) river basins; coordinated development and management of water resources within countries at the level of hydrological systems; integrated planning for development of surface water and groundwater resources; establishment of well-defined water rights for groundwater; removing electricity subsidies for pumping groundwater in farm sector; and taking care of the hydraulic interdependence between groundwater and surface water in trans-boundary water allocation decisions.

7. Conclusions

South Asia will have to deal with problems of extreme variations in climate, groundwater mining and environmental water scarcity. In terms of managing its international basins, South Asia countries could learn a few lessons from the Southeast Asia taking cues from the recent joint initiatives between ASEAN and Mekong River Commission in developing plans for development and management of the river basin and helping the member countries, which are also located along the Mekong river basin.

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Impact of climate variability and change on food systems in South Asia

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1. Introduction

The eradication of extreme poverty and hunger has been incorporated as one of the Millennium Development Goals (MDG) adopted under United Nations Millennium Declaration. The aim is to halve, between 1990 and 2015, the proportion of people who suffer from hunger. Though significant progress has been made on the target set under this MDG in some regions because of their political commitment, effective institutions, good policies, comprehensive approaches and adequate levels of investment, progress in some other regions has been tardy (FAO, IFAD and WFP, 2013).

In 2011-13, about 842 million people in the world continue to suffer from chronic hunger with South Asia alone consisting of 295 million undernourished people (35 per cent) (FAO, IFAD and WFP, 2013). The per capita current food production matches the requirement. However, due to spatial variability in the availability of and access to food, food security remains a major concern especially in many parts of South Asia and Sub-Saharan Africa. In coming decades, making South Asia food secure will be a major development challenge as the region as a whole is experiencing significant growth in population and large scale conversion of cultivable land for non-agricultural purposes. This challenge is also accentuated by the fact that agriculture production is still subject to climate vagaries in this region, in spite of large scale development of irrigation. Huge economic losses in terms of crop failure and loss of livelihood opportunities have already been reported from the region due to recurring floods in eastern India, Nepal and Bangladesh (GFCC, 2012) and droughts in north-western India, Pakistan and Afghanistan (SDMC, 2010).

2. Climate Variability and Change in South Asia

South Asia comprises nine countries viz., Afghanistan, Bangladesh, Bhutan, India, Iran, Maldives, Nepal, Pakistan, and Sri Lanka. The region lies between 5^{o} and 37^{o}N in tropical and equatorial latitudes with the Indian Ocean to the south, the Great Himalayas and Karakoram to the north, the Baluchistan highlands to the west, and the meridional chains of mountains to the east. South Asia mainly consists of four climate zones: 1] dry continental, subtropical climate (the northern Indian edge and upland and mountainous parts of Pakistan); 2] equatorial climate (southern part of India and southwest Sri Lanka); 3] tropical climate (hot semi-tropical climate in northwest India and cool –winter hot tropical climate in Bangladesh); and 4] semi-arid tropical climate (center of the peninsula) (Oliver, 2005).

The region display extreme variability in climate. Annual mean solar radiation decreases from 290 W/sq. m in Baluchistan (western side) to less than 240 W/sq. m in Bangladesh (eastern side). January mean temperature in the region varies from 10^{o}C in northern parts to about 20^{o}C in southern Indian peninsula. The warmest period is between March and mid-June when the mean temperature in the northern Deccan exceeds 35^{o}C. During October, monthly mean temperature is generally within the range of 27-29^{o}C. The range of annual temperature variation is about 1-5^{o}C for most parts of the region (Oliver, 2005).

Relative humidity varies from under 30-40 per cent in the Indus Plains, Punjab and Rajasthan during summer to over 80 per cent in Sri Lanka and Khasi-Jaintia hills in north-east India during winters. In July, relative humidity is over 80 per cent in the areas affected by the monsoon. Precipitation varies from nearly 50mm in the southwest of Afghanistan to around 11,000mm in Chirapunji in northeast of India. Pakistan and northwest India have the most arid areas in the region. The highest number of rainy days was recorded in southwest Sri Lanka (200 per year) followed by eastern Himalayas (170 per year), Malabar Coast (150 per year) and least in the Great Indian Desert (less than 5 days) (Oliver, 2005).

It is expected that global environmental changes (GEC) will have major impacts on the climate in South Asia due to its large population, predominance in agriculture and its limited resource base (Aggarwal et al., 2004; Sivakumar and Stefanski, 2011). Further, it will increase climate variability and alter scales of temperature, rainfall and wind velocity and periodicity. Across South Asia, surface air temperature has already shown a significant warming trend of 0.7^{o}C per 100 years (Lal, 2003). Diurnal temperatures range has also decreased with night-time temperature increasing at twice the rate of day-time maximum temperature (Sen Roy and Balling, 2005).

Changes in water cycle are projected to occur in a warming climate which will affect both natural and human systems in South Asia. Such changes can lead to changes in precipitation, evaporation, relative humidity, E-P, run-off and soil moisture (Figure 1), but will not be uniform, with some regions experiencing increase in rainfall, and others with decreases or not much change in rainfall at all. For instance, under scenario of a warmer climate, the high latitudes are likely to experience greater amounts of precipitation due to the additional water carrying capacity of the warmer troposphere. Many mid-latitude arid and semi-arid regions will likely experience less precipitation (Source: IPCC Fifth Assessment Report). South Asia may experience increased occurrence of flooding in Eastern India, Nepal and Bangladesh and droughts in parts of western and southern India, Pakistan and Afghanistan.

Both the monsoon and tropical cyclones, the two prime drivers of flood events in the region, appears to be influenced by GEC (Douglas, 2009). It is projected that this will enhance summer monsoon precipitation; increased rainfall extremes of landfall cyclones on the coasts of the Bay of Bengal and Arabian Sea (Source: IPCC Fifth Assessment Report). Future changes in precipitation regime due to environmental changes will have four distinct implications on floods. First, the timing of occurrence of floods may change, with a possible change in seasonality of the hydrological cycle. Second, an increase in monsoon precipitation in Gangetic and Brahmaputra-Meghna basins may increase the magnitude, frequency, extent and duration of floods. Third, changes in the timing of peak flood flows descending the major rivers may alter the likelihood of synchronization of flood peaks of the major rivers. And fourth, increase in the magnitude, depth and duration of floods will lead to dramatic modifications of land use patterns in all the major deltas of the sub-continent (Douglas, 2009).

Similarly, there has been increasing frequency and intensity of droughts in South Asia. Decreased land precipitation and increased temperature that enhance evapotranspiration and drying are important factors that have contributed to more regions experiencing droughts in the past three decades (Sivakumar and Stefanski, 2011). The observed and projected changes in frequency of occurrence of floods and droughts will have a tremendous impact on human systems in South Asia where majority of population is agrarian in nature.

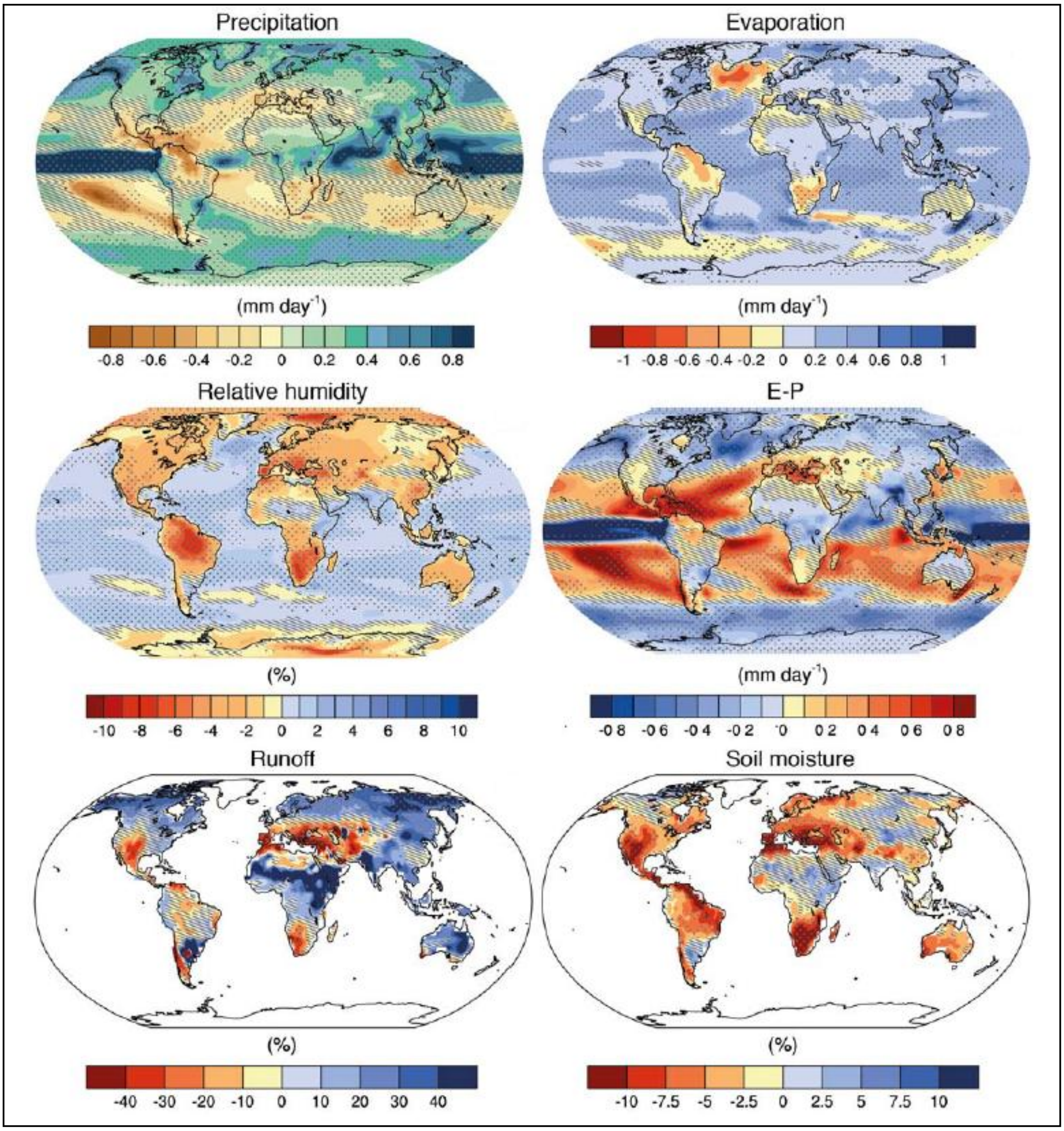

Figure 1: Annual mean changes in hydrological cycle for 2081-2100 relative to 1986-2005 under high representative concentration pathway
(Source: IPCC Fifth Assessment Report)

3. Farming Systems and Food (In) security in South Asia

South Asia is primarily an agrarian economy (Table 1). The region has about 70% rural population, majority of which depend on agriculture as the main livelihood activity. Further, the agriculture sector employs a major proportion of labor force which varies from 33% in Sri Lanka to 70% in Afghanistan. Contribution of agriculture to national GDP varies from 12.8% in Sri Lanka to around 33% in Nepal.

Table 1: Agrarian economy of South Asia

Country	Proportion of area under agriculture (%)	Proportion of rural population (%)	Proportion of labor force employed in agriculture (%)	Agriculture contribution to GDP
Afghanistan	58	77	70	31.6
Bangladesh	65	72	48	18.6
India	55	70	56	19.0
Nepal	30	81	66	32.8
Pakistan	33	64	45	21.2
Sri Lanka	40	85	33	12.8

(Source: IGES and GWP South Asia, 2012)

Agro-ecologically, 20% of the region's land consists of hills and mountains with steep slopes, 19% is humid or moist sub-humid lowland, 29% is dry sub-humid, and 32% is the semi-arid and arid lowland. The humid and moist sub-humid zones with more than 180 crop growing days per annum are located in Bangladesh; northeastern, eastern and southern fringes of India; and centre, west and south of Sri Lanka. With large areas of alluvial soils and a high proportion of the land under intensive rice cultivation, these areas support a particularly dense population. The dry sub-humid areas (with 120 to 179 growing days each year) cover most of the Deccan Plateau in Central India. While, the northwest parts of India, most of Pakistan and Afghanistan are semiarid or arid with less than 120 crop growing days, low population density and large areas under desert (FAO and World Bank, 2001).

Eleven major farming systems have been identified in South Asia (Figure 2). These include: 1] rice farming; 2] coastal artisanal fishing farming; 3] rice-wheat farming; 4] highland mixed[4] farming; 5] rain-fed mixed farming; 6] dry rain-fed farming; 7] pastoral farming; 8] arid farming; 9] mountain farming; 10] tree crop farming; and 11] urban based farming systems (FAO and World Bank, 2001).

4

Mixed farming systems are those where crop cultivation and livestock rearing together form integrated components of a single farming system. The same farm may grow cereal crops, and keep cattle, sheep, pigs or poultry. They can also include the livestock systems of landless smallholders that rely on the crop cultivation of neighboring farms (Source: FAO).

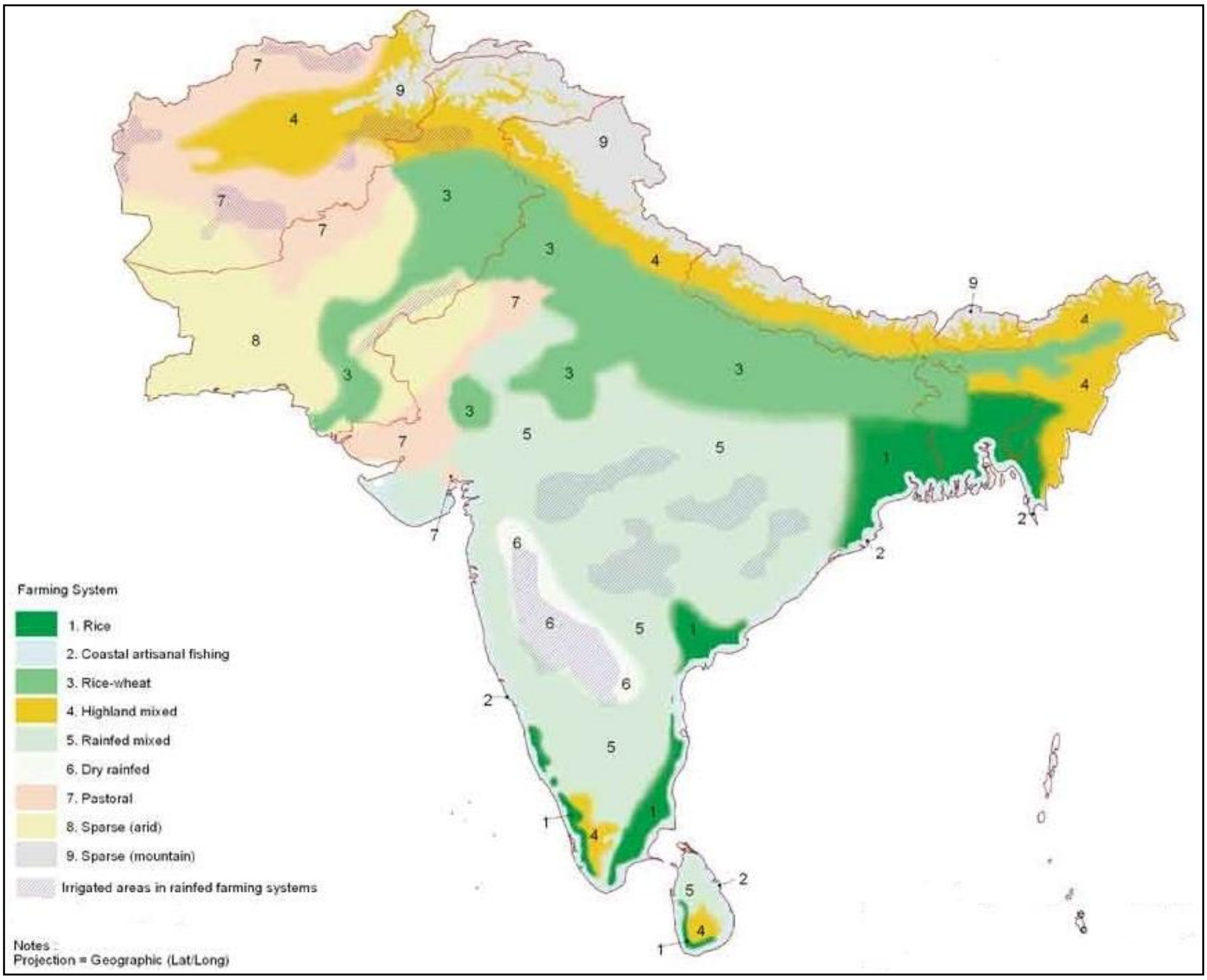

Figure 2: Major farming systems in South Asia
(Source: FAO and World Bank, 2001)

The salient features of these major farming systems are presented in Table 2. It shows that most of the population in South Asia is dependent on rice, rice-wheat and rain-fed mixed farming systems. These are also the farming systems where prevalence of poverty is extensive. Further, significant proportion of total land area was found to be under highland mixed, sparse (arid and mountain) and pastoral farming systems, but agricultural population in this region was found to be quite low.

During 2011-13, average dietary energy supply adequacy (dietary energy supply as a percentage of the average dietary energy requirement) in South Asia was 108 per cent. This indicates that food supplies have kept pace with average dietary energy requirements, resulting in higher levels of energy adequacy in the region. However the quality of food intake has not improved with diet remaining highly imbalanced with heavy dependence on cereals (mainly rice and wheat) and roots and tubers (FAO, IFAD and WFP, 2013).

Table 2: Characteristics of the major farming systems in South Asia

Farming Systems	% Land Area	Agricultural Population (% of region)	Principal Livelihoods	Prevalence of Poverty
Rice	7	17	Wetland rice, vegetables, legumes, off-farm activities	Extensive
Coastal Artisanal Fishing	1	2	Fishing, coconuts, rice, legumes, livestock	Moderate - extensive
Rice-Wheat	19	33	Irrigated rice, wheat, vegetables, livestock including dairy, off-farm activities	Moderate - extensive
Highland Mixed	12	7	Cereals, livestock, horticulture, seasonal migration	Moderate - extensive
Rainfed Mixed	29	30	Cereals, legumes, fodder crops, livestock, off-farm activities	Extensive (severity varies seasonally)
Dry Rainfed	4	4	Coarse cereals, irrigated cereals, legumes, off-farm activities	Moderate
Pastoral	11	3	Livestock, irrigated cropping, migration	Moderate-extensive (especially) Drought induced)
Sparse (Arid)	11	1	Livestock where seasonal moisture permits	Moderate-extensive (especially) drought induced)
Sparse (Mountain)	7	0.4	Summer grazing of livestock	Moderate (especially in remote areas)
Tree Crop	Dispersed	1	Export or agro-industrial crops, cereals, wage labour	Moderate (mainly of agricultural workers)
Urban Based	<1	1	Horticulture, dairying, poultry, other activities	Moderate

(Source: FAO and World Bank, 2001)

Average cereal production in South Asia was 147 million ton in 1980-81 which increased to 239 million ton in 1999-2000. These results were mainly due to productivity enhancement through use of high yielding varieties and improvement in crop management practices (Broca, 2002; Aggarwal et al., 2004; Lal, 2011). Much of this increase in production was within the Indo-Gangetic Plains (IGP) where rice and wheat are grown in rotation on almost 12 million hectares (M. ha) of land covering large areas of Pakistan, India, Nepal and Bangladesh (Aggarwal et al., 2004; Lal, 2011). Though cereal production in South Asia exceeded demand, acute poverty and malnourishment persisted due to low purchasing power (Bruinsma, 2003). As a result the region continues to have a high proportion of undernourished people (Table 3).

Table 3: Extent of undernourishment in South Asia during 2011-13

Countries	Number of undernourished people (million)	Proportion of undernourished in total population
Bangladesh	24.8	16.3
India	213.8	17
Nepal	5.0	16
Pakistan	31.0	17.2
Sri Lanka	4.8	22.8
South Asia	**294.7**	**16.8**

(Source: Compiled from FAO, IFAD and WFP, 2013)

It is projected that by 2020, food grain requirement will be almost 150 per cent of 1999-2000 levels mainly due to population growth in the region. Also, demand for fruits, vegetables, milk, meat, eggs and marine products will almost be doubled (Table 4). Such a large increase in food demand and change in consumption pattern is likely to arise from the improvement in economic conditions of the population, and rising per capita income levels.

Table 4: Projected food demand by 2020 in South Asia

Food Items	Production (Mt) in 1999-2000	Demand (Mt) in 2020
Rice	85.4	122.1
Wheat	71.0	102.8
Coarse Grains	29.9	40.9
Pulses	16.1	27.8
Fruits	41.1	77.0
Vegetables	84.5	149.7
Milk, Meat and Eggs	79.0	142.7
Marine Products	5.7	11.8

(Source: Paroda and Kumar, 2000 as cited in Aggarwal et al., 2004)

The existing production scenario and rising population show that the demand[5] for paddy in Afghanistan, Bangladesh and Nepal will outstrip production by 2020 (Figure 3a). Similarly demand for wheat in Afghanistan, Bangladesh, Pakistan and Sri Lanka will outstrip production by 2020 (Figure 3b). Thus meeting growing food grain demand will be an arduous task for many of the South Asian nations.

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Estimates are based on the trends in agricultural production for the last 47 years (1961– 2007) (Titumir and Basak, 2010).

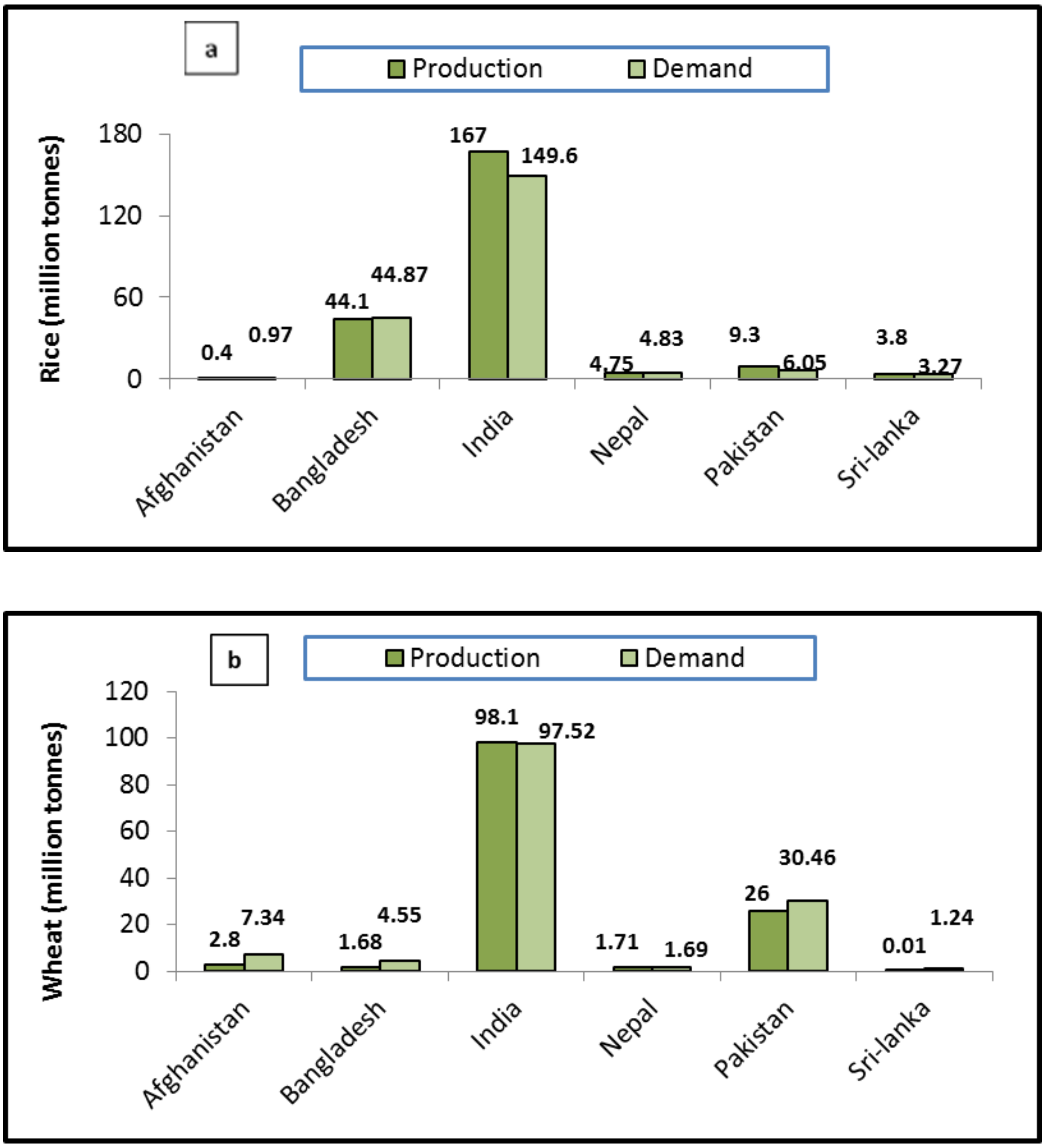

Figure 3: Projected food grain demand by 2020 in South Asia: a) rice and b) wheat
(Source: Author's analysis using information from Titumir and Basak, 2010)

4. Food System Approach to Analyze Food security and it's Interaction with Environmental Changes

Food security debate in South Asia has mainly emphasized on aspects of food production (such as increasing crop yield and production) and access to food, and continues to be the subject of major research investment. However, of late, food systems approach in order to better understand the complex interaction between food security and environmental variability and change has been advocated (Figure 4).

Food systems encompass a number of activities (producing; processing and packaging; retailing and distributing; and consuming food) which give rise to food system outcomes. These outcomes contribute to food security which consists of three components: 1] food availability (production, distribution and exchange); 2] access to food (affordability, allocation and preference); and 3] food utilization (nutritional value, social value and food safety). These food system outcomes also contribute to environmental (stocks of available natural capital, and ecosystem services) and social (income, wealth, and health status) welfare issues (Ericksen et al., 2010). The environmental welfare arises as a result of use of environmental friendly agricultural practices (crop rotation to replace nutrients in soil, use of organic fertilizer, treatment of effluent before discharge by food processing and packaging industries), whereas, the social welfare outcomes arise because many people rely on food systems as sources of livelihoods. Also, there are interactions between the different categories of food system outcomes, for example, between income levels and access to food (Ericksen et al., 2010).

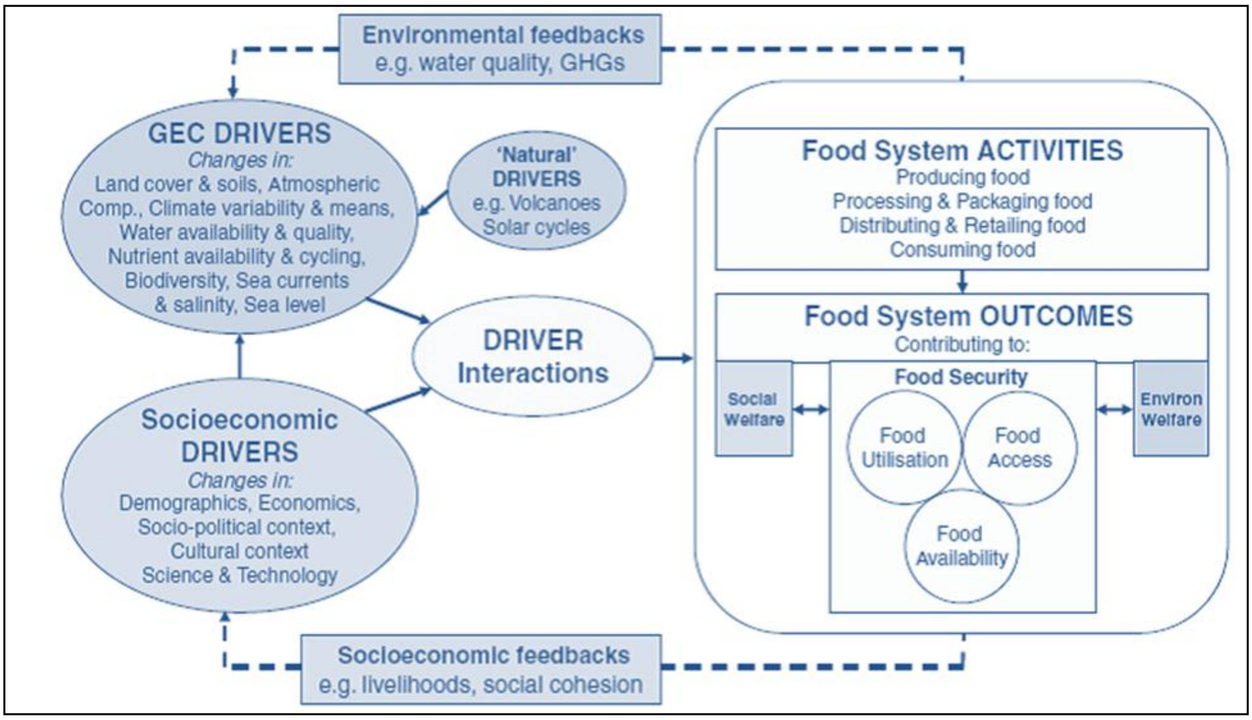

Figure 4: Food system activities, outcomes, drivers and feedbacks
(Source: Ericksen et al., 2010)

Both the food system activities and their outcomes are influenced by the interacting global environmental changes and socio-economic drivers (Ericksen et al., 2010). For instance, in spite of major investment in irrigation infrastructure, excessive ground water abstraction in Indian Punjab (mainly due to the policy of free or subsidized energy supply to farm sector) has led to reduced irrigation supply. The situation is further exacerbated by the variability in rainfall, which affect crop production. This threatens the region's ability to produce food, and hence the supply component of food security. Contrary to this, poor food distribution infrastructure and frequent flooding in Nepal's Terai region has affected the distributing activity and hence the distribution element of food availability component (Ingram, 2011).

Further, food system activities and outcomes affect the environment and socio-economic conditions which in turn influence the food security (Ericksen et al., 2010). For instance, huge amount of effluent (having large amounts of organic materials, suspended solids, high BOD, COD, pathogens and pH) is released into the environment by the food processing and packaging industries (Ingram, 2011). This effluent, which is mostly untreated, can pollute surface water bodies. Farmers using this contaminated water for irrigation would be susceptible to health hazards, and hence affecting food absorption. Similarly, release of Greenhouse Gases (GHG) from agriculture and food transportation affects the environmental change drivers which in turn influence the food system outcomes.

5. Impacts of Climate Variability and Change on Food Security in South Asia

As discussed in the earlier section, in most of the South Asia demand for food grains will outstrip production by 2020. Further, it is expected that increasing climate variability and change will also affect the crop production. This will have a major adverse impact on the millions of poor households who depend on agriculture as their main source of food security and livelihood activity. Following a food system approach, this section will analyze the probable impacts on food production, its distribution, and access to food due to climate variability and change.

5.1. On Food Production

Droughts and floods in South Asia, which are mainly caused by the climate variability in the region, significantly affect the overall food production. For instance, during drought of 2012, food crop production in Gujarat State of India reduced by about 21% in comparison to the previous year (2011-12). Similarly, it reduced by 21% in Baluchistan Province of Pakistan which was hit by severe drought during 1999-2000. On other hand, inundation of arable land due to flooding in Sindh Province, Pakistan during 2011 (0.7 m. ha); in Assam State, India during 2013 (around 6,100 ha); and in Bangladesh during 2012 (more than 1,000 ha) resulted in huge damages to crop. Such events have not only caused huge economic losses but have also resulted in food insecurity due to their adverse effect on agricultural production and employment. Between 1960 and 2013, almost 1.6 million people have died and 2.4 billion have been affected due to lack of food security during disasters in South Asia. Further, the total economic damages have been estimated at US$ 84.8 billion (Table 5).

It is important to mention here that most of the economic losses during droughts result from crop losses and death of livestock, and those during floods result from the combined effect of damage to properties (buildings, telecommunication networks, power generation and distribution networks, transportation infrastructure such as roads and bridges, livestock etc.), and damage to standing crops. These figures do not include the expenditure on relief and rehabilitation of people affected and rehabilitation of civil works. The public expenditure in drought relief operations, for supplying safe drinking water for humans, fodder and drinking water for livestock, and public works for generating employment is often very significant. Similarly, in the case of floods, large amounts of funds are spent on supply of safe drinking water and food to the affected people, and fodder and drinking water for livestock, and building temporary shelters for humans.

Table 5: Extent of damages due to droughts and floods in South Asia

Countries	Droughts (1960-2013)				Floods (1960-2013)			
	No. of events recorded	No. of Lives lost	No. of people affected (million)	Economic damages (million US $)	No. of events recorded	No. of Lives lost	No. of people affected (million)	Economic damages (million US $)
Afghanistan	6	37	7	142	73	4063	1	396
Bangladesh	5	18	25	-	85	52233	318	12038
India	12	1500320	1062	2441	238	65276	817	37146
Iran	2	-	38	3300	66	3643	4	7653
Nepal	6	0	5	10	39	6313	4	1038
Pakistan	1	143	2	247	72	12648	77	19368

Sri Lanka	9	-	8	-	56	1325	13	981

(Source: EM-DAT: The OFDA/CRED International Disaster Database (www.emdat.be), Université catholique de Louvain, Brussels, Belgium.)

Projected changes in climate will further have a significant impact on crop growth, development, water use, and productivity in South Asia (Attri and Rathore, 2003). It will also affect the soil condition through changes in moisture content, runoff and erosion, workability, salinization, biodiversity and organic carbon and nitrogen content (Aggarwal et al., 2004). Already, declining yields in areas of intensive rice and rice-wheat farming systems have been attributed to deteriorating soil physical condition, declining organic matter and unbalanced fertilization (FAO and World Bank, 2012).

In many tropical and subtropical regions, potential yields are expected to decrease under most of the generated scenarios on temperature increase (Houghton et al., 2001). Most of the research on impact of environmental changes on crop productivity in South Asia relates to wheat and paddy which are the two important staple food crops in the region.

It is important to understand how changes in climate affect crop yield. Temperature and CO_2 influence plant growth and development through their effects on stomatal opening and rate of physiological processes. Higher temperatures speed up the biochemical reactions and also increase transpiration losses (Attri and Rathore, 2003). An increase in CO_2 concentration will increase the net primary productivity of plants, especially those with C3 mechanism of photosynthesis such as wheat and rice (Aggarwal, 2008). Further, enhancement of temperature and CO_2 due to climate change may lead to more infrequent opening of stomata, thereby reduction in evapotranspiration and an increase in crop water use efficiency and yield (Attri and Rathore, 2003).

However, positive yield response to rise in temperature will be limited to a particular range of temperature after which the yield will decrease even under the higher CO_2 levels. For instance, it was observed that the beneficial impact of elevated CO_2 levels on wheat yield in north-western India were negated due 3^{o}C or more rise in temperature (Attri and Rathore, 2003). Similar results were obtained for other South Asian Countries too where paddy and wheat yields under irrigated conditions were adversely affected due to combine effect of rise in surface air temperature (3^{o}C or more) and CO_2 concentration (Table 6). Further, under rain-fed conditions, the combined effects of a 2^{o}C rise in surface air temperature and a 20 per cent decline in precipitation will have serious consequences on rice and wheat productivity in South Asia (Lal, 2011). Overall, there could be 4-5 million tonnes of loss in wheat production with every 1^{o}C rise in temperature (Aggarwal, 2008).

Additionally, increased occurrence of weather extremes (such as droughts and floods) will have a major impact on productivity of rice-wheat based cropping system. It has been demonstrated that recent decline in yields of rice and wheat in IGP may have been partly due to changes in weather extremes (Aggarwal et al., 2004). Environmental changes will also bring about increasing incidence of vector borne diseases in both crops and livestock. In fact, increasing occurrence of weeds, insects and diseases along with intensive input use explains the diminishing Total Factor Productivity (TFP) in Indian IGP (Aggarwal et al., 2004). As a result technological change contribution to agricultural growth is gradually diminishing in IGP (Figure 5).

Table 6: Changes in cereal yields in South Asia due to environmental changes

Scenarios	Changes in irrigated cereal crop yields (%)				Changes in rain-fed cereal crop yields (%)			
	Rice yield		Wheat yield		Rice yield		Wheat yield	
	Region 1*	Region 2**	Region 1	Region 2	Region 1	Region 2	Region 1	Region 2
2 X CO_2	+17	+18	+26	+25	+15	+18	+26	+24
2 X CO_2; + 1^{o}C	+5	+3	+23	+23	+4	+6	+21	+22

2 X CO_2; + 2^oC	+1	+1	+12	+9	-1	-1	+11	+7
2 X CO_2; + 3^oC	- 8	-5	+1	-2	-12	-8	+2	-1
2 X CO_2; + 2^oC; +10% rain	-	-	-	-	+2	+3	+16	+9
2 X CO_2; + 2^oC; -10% rain	-	-	-	-	-5	-4	-3	-8
2 X CO_2; + 2^oC; -20% rain	-	-	-	-	-24	-21	-11	-19

*Region 1 includes Pakistan; north, northeast and northwest India; Nepal; and Bangladesh
**Region 2 includes central plains of India, south India and Sri Lanka
(Source: Lal, 2011)

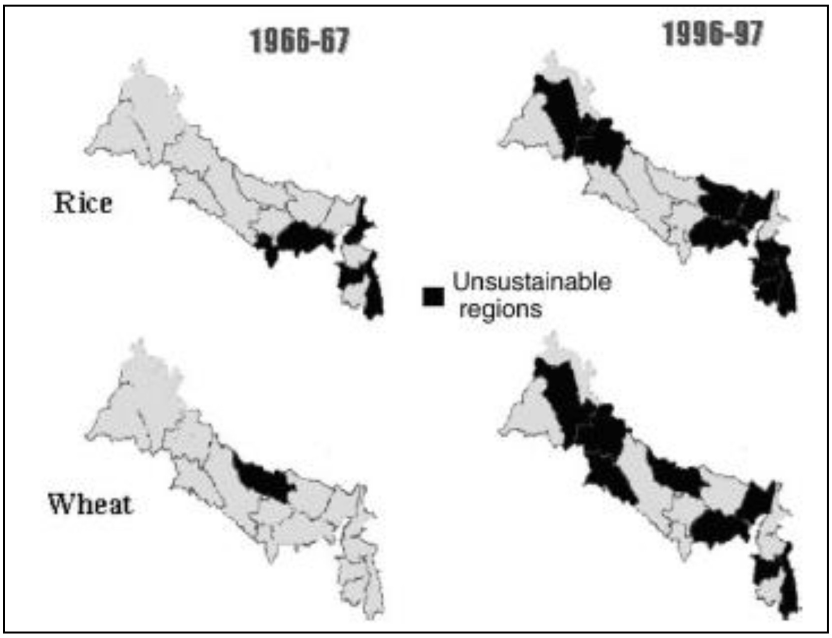

Figure 5: Decline in TFP as represented by increase in unsustainable area of rice and wheat in Indian IGP
(Source: Joshi et al., 2003 as cited in Aggarwal et al., 2004)

Further, changes in precipitation will also affect the availability of irrigation water and hence crop yields. For instance, western semi-arid parts of South Asia comprising mainly Indian and Pakistan Punjab, Haryana, and Gujarat which is the major food producing region will get scantier rainfall. As a result irrigation supplies will be adversely affected which will make food production more vulnerable in this region. The rain-fed mixed and pastoral farming systems will also be constrained by the limited availability of both groundwater and surface water for crop and livestock production (FAO and World Bank, 2001). Conversely, eastern parts of South Asia comprising Bihar, West Bengal and Assam in India, and Bangladesh will get more rainfall. However, land scarcity in this eastern region will make it impossible to increase area under crops and hence would not result in increased crop production (Kumar et al., 2013; 2014). Also, increased precipitation may lead to recurring floods which would result in crop damage and livelihood losses. For instance, during flood of 1974 in Bangladesh, about 0.6 million ton of food crops were damaged and several farm workers lost employment (Douglas, 2009).

5.2. On Food Distribution

Extreme climate events such as floods disrupt existing transport and communication system and thus make movement of food supplies more difficult. As a result delivering food to the people in real need becomes a challenge. For instance, during the floods of 1988 and 1998 in Bangladesh, government managed to balance food demand and supply but failed to ensure food security at the household level as supplied food was not able to reach flood affected people (Douglas, 2009). Similarly, in the Ruhani Basin District of Nepal, where food production is historically low and distribution infrastructure is poor, increased flooding due to environmental changes will disrupts the distribution activity (Ingram, 2011). In such areas, investment in infrastructure and policies for strategic food reserve at local level are required (Dixit, 2003).

5.3. On Access to Food

In the earlier sub-sections it has been discussed how environmental changes will affect the food production and its distribution in South Asia. Fluctuation in crop yields and local food supplies will adversely affect the stability of food supplies especially in semi-arid and sub-humid regions of South Asia (Chatterjee and Khadka, 2011).

In a scenario where adverse impacts on crop production are observed, food prices will go up due to reduced supplies. The price rise could also be triggered by the increase in demand, which will mainly come from the growing size of the population with high income and purchasing power. As a result, food will become un-affordable to millions of poor who inhabit South Asia (about 570 million people in the region live on less than US$1.25/day). Impacts will be visible on households of small and marginal farmers who are more vulnerable to climate related shocks due to limited access to resource and low purchasing power. Further, due to events such as floods which affect the distribution of food, many more people in eastern region of South Asia will not be able to access food due to its reduced supplies and their low affordability to procure it from a distant source. Already about 45% of the population in Bangladesh, 33% in India, 25% in Nepal and 21% in Pakistan live below the national poverty line. Thus poor household are destined to be hit the hardest due to price inflation and natural calamities in the region (Chatterjee and Khadka, 2011).

5.4. On Food Utilisation

Recurring droughts and floods, as experienced in South Asia, has an adverse impact on human health through their effect on nutritional intake by the affected people. Droughts in western India, many parts of central and peninsular India, south-western Pakistan, and Afghanistan (which are all water scarce regions), result in unavailability of safe food and drinking water and hence escalates the malnutrition problems. This is quite concerning as South Asia already has a very high prevalence of undernourishment (about 35% of the world’s undernourished people live in the region).

On another hand, increased flooding in eastern India and Bangladesh, expose people to diarrhoeal and other infectious diseases which lower their capacity to utilize food effectively. For example, after South Asian floods of 2007, around 54 people lost their life and 0.24 million were affected due to an outbreak of cholera in Bangladesh and eastern India (Source: SDMC Database). Thus, extent of food insecurity due to malnutrition and water-borne diseases following natural disasters has been quite high in South Asian countries.

6. Conclusion

South Asia with its diverse agro-ecology is home to about 25% of the world's population. However, it also has the unique distinction of having the highest proportion of world's undernourished people. The reasons are many. Agricultural production in the region is under stress due to land use changes and climate extremes, affecting the poor farmers; population is constantly growing, including rural areas, reducing the size of operational holdings; proportion of the people living below the poverty line, who have limited ability to purchase food, is high; and the size of the middle class population is on the rise, causing high growth in food demand. Further, as the region already exhibits marked spatial and temporal variability in climate parameters, such as solar radiations, temperature, relative humidity and precipitation, any predicted changes in climate will exacerbate the present problem of food insecurity.

Major adverse impacts of the climate variability and change will be felt on the rice-wheat food production systems (mainly in IGP) which accommodate majority of population which depend on agriculture. The rice and wheat yields will be adversely impacted due to combine effect of increase in CO_2 and temperature. Also, food and livelihood security is under threat as the region is expected to experience more frequent droughts in north-western parts and floods in eastern parts. Considering that the demand for food grain is expected to outstrip production by 2020, the region needs promotion of food systems that can meet growing demand and adapt to environmental changes. Further, research related to impact of environmental changes on food security in South Asia should take an integrated approach and focus more on the food system approach rather than only on food production functions.

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Module 4: ***Socio-economic and Health Impacts of Climate Variability, particularly Droughts and Floods in South Asia***

Socio-economic and Health Impacts of climate variability, particularly droughts and floods in South Asia

MVK Sivamohan

1.0 Introduction

Many urban and rural communities and their economies in South Asia are exposed to the grave risks of climate related water stress. These risks relate to flooding due to heavy rainfall and storm surges on one hand and drought on the other. Floods and droughts are two severe resultants of climate variations occurring constantly. By far international organizations like World Bank, ADB, FAO, Inter governmental panel on climate change (PDCC), OECD, ITDG and SAARC,IDRC disasters management's centres, are some of the organizations extensively worked on the aspects of Climate Variability and change and published a fund of information. These are several scholars who researched extensively on these two major types of disasters of world over and particularly on the south Asian region. This paper is an attempt to review the available research and present a state of art account on the two extreme forms of climate variation namely, floods and droughts.

There has been an increased trend in flood disasters occurring over the past three (four) decades in South Asia (Sreshtha, 2008) and a similar increasing bend is also observed in Europe (Hoyois and Guha, 2003) as well as in entire world (Jonkman, 2005) Though this trend has been partially attributed to improved information technology (ICT) is also said to be due the increased socio economic vulnerability and development process. Some of the factors contributing to this phenomenon are the impacts of population, economic growth, rapid urbanization, environmental degradation along with climate change. In this region varying types of floods including flash floods, debris flow, land sides and glacial lake out bursts are of common occurrence.

South Asia harbors largest number (40%) of the world's poorest population. Social and economic indicators in terms of number of persons below the poverty line, rates of illiteracy and high infant mortality are appalling features In spite of the availability of a large working force. Inaccessibility to the basic facilities such as health, nutrition and education inhibit development of the intense potential of the people and keep them aloof from any opportunity to flourish in life. The story is distressing. South Asia is the most vulnerable region on the global map often haunted severely by floods and droughts in addition to other calamities like earthquakes, tidal waves, and many other types of manmade disasters. These calamities, when occur individually or in combination cause great impact on the lives and livelihoods of the population.

The subcontinent covers 32% of land mass of the world and 10 % of Asia with over a population of 1.46 billion accounting for 25% of the world population (CIA 2005). This region is comprised of eight countries viz., Afghanistan, Pakistan, India, Bangladesh, Nepal, Bhutan, Maldives and Srilanka. Imbalances in economic growth, glaring, disparity among classes, castes, and faiths and between genders add to the misery of the poor and those highly vulnerable. The key development indicators as computed from different sources by Sreshtha, (2008) for the region are given in Table 1.

Table1 Key Indicators of development in South Asia

Indicators	Afghanistan	Bangladesh	Bhutan	India	Maldives	Nepal	Pakistan	Sri Lanka
Area(km2)	647,500	144,000	47,000	3,287,590	300	147,181	803,940	65,610
Population(millions)2005	21.9	141.8	0.66	1094	0.33	27.1	155.8	19.6
Annual growth rate (%)*	4.4	1.9	2.4	1.4	2.5	2	2.4	0.8
Infant mortality rate(per 1,000 live births)2004		56	67	62	35	59	80	12
Agriculture land(% of population)2004	58.3	69.8	12.2	60.8	33.3	29.3	32.6	36.5
Access to safe water(% of population)2004	39	74	62	86	83	90	91	79
Access to sanitation(% of population)1995	12	35	69	16		23	39	
Adult literacy rate(% of people 15 & above)2003	51(M): 21(F)	54(M): 32(F)	60(M): 34(F)	70(M): 48(F)	91(M): 97(F)	63(M): 35(F)	62 (M): 35 (F)	95(M): 90(F)
Per capita commercial energy use: annual (Kg of oil equivalent)2003		159		520		336	467	421
Percapita electricity consumption(KWh)2003		128		435		68	408	325
Population below national poverty line (%)	53 in 2003	45 in 2004		25 in 2002		31 in 2004	32.0 in 2000	32
Per capita GNI(US $), 2005	250	470	870	720	2390	270	690	1160

Source: FAO'S Information system on Water and Agriculture, World Fact book, 2005, CIA (http://www.fao.org/ag/agl/aquastat/water res Bhutan census 2005), World Bank Report.
Note: Blank spaces in the Table indicate that there is no data available.

There are different typologies of droughts, viz., meteorological, agricultural, hydrological and socio-economic. Broad definition of a drought is "deficiency in precipitation over an extended period of times usually a season or more which results in a water shortage of some activity, group or environmental sectors" (SAARC, 2010). Historically, drought was among the early efforts in the management in South Asia. Successive droughts and resultant famines killed several millions of people in this region. Effects of the droughts are mainly on agricultural production and on the consumptive use of water for domestic and industrial purposes. Impact of Droughts is slow and has a long lasting imprint on the country's economy drought by itself does not trigger an emergency. Whether it becomes an emergency or not depends on its effect on local people, communities and society and thus in turn depends on their vulnerability to the stress of drought. The impact of climate change on water will affect the poor disproportionately. It impairs quality and reliability affects their health, productivity and livelihoods, thus further adding to their poverty.

2 Floods in South Asia

2.1 Socio Economic Impacts

As pointed out floods in South Asia are caused by unique hydro meteorological and monsoonal topographical interaction and are also accentuated by increased human interventions. South West monsoon plays a pre-dominant role with its spatial and temporal variations in rainfall and temperature in South Asian region. The average annual precipitation of 11,873mm was recorded at Mawsynram in Meghalaya hills of India. From the east to west the average rainfall decreases with some areas having less than 400mm per year. Rivers in the region play a vital role in the socio-economic development positively and also negatively. Indus Ganges, Brahmaputra and Meghna are major rivers in South Asia Kabul river a tributary of Indus originates in Pakistan and traverse through Afghanistan. They are major source of water for drinking, irrigation, hydro power generation, fishers and inland navigation as well as maintenance of wetlands and biodiversity. At the same time they cause different types of floods and seriously hamper the socio-economic development of the region.

Shrestha, (2008) in the paper "Impacts of floods in South Asia" analyzed the data elaborately on floods and their impacts from two different available data sets. The EM-DAT data base recorded a total of 332 flood events during three decades from 1976 to 2005 in South Asia. 20 of them were categorized as flash floods and 3 as valley floods and no consistency or uniformity was noticed in any of the flood events while categorization and analysis of data was not possible. The data on flood disasters was on an increasing trend during this period. Also floods seem to occupy major share (35.2%) in the natural disasters of the region. Floods accounted for 64658 deaths of people with 2154 people killed annually during this period. Annual floods increased by five floods in Asia accounting for 39% during in the three decades. Small scale disasters were not reported and about 30% people killed in disasters in under reported. Further it was reported that about one billion people were adversely affected. The increasing trend showed more in India flowed by Bangladesh. An economic loss of about US$ 32 billion due to floods during this 30 year period was estimated.

It is observed that though there has been a downward trend of major flood events in the years of 2008, the region witnessed two devastating and in precedent floods in the year 2011-2012 in Pakistan effecting 29 million people (Ghatak *et al.,* 2012) floods in their wake bring more negative socio-economic impacts than other disaster to the region some being immediate and some others over a long time. Due to changing river courses and upsurge of sea, sometimes fixed assets are lost permanently.

2.1.1 Loss of Lives and property

Major flood disasters cause immediate impact by loss of human life, livestock, destruction of crops damage or loss of property and infrastructural facilities. Water borne diseases become rampant and impact the health and wellbeing of the flood affected population. Compared to river floods flash floods occur suddenly with very little warning time or in many cases without any warning. The monetary loss due to floods depends on extent, depth and duration of floods and velocity of flows, and winds in the damaged areas. Further it is also dependent on the vulnerabilities of the economic activities and communities. Floods are more costly and economically wide sprawling of all natural hazards Nott, (2006) estimates that India and Bangladesh 300 million live in flood affected areas. The physical damage to property is a tangible loss due to floods. This includes cost of damage to goods and possessions, loss of income or services in the aftermath of floods and cleaning, cleaning and sanitizing costs.

Bangladesh with 80% of flood plains is prone for 1/3rd of its area inundated by floods once in every 10 years. In 1988, 1998, and 2004 more than 60% of the country's area was severely affected by floods (Bronwer *et al.,* 2007). Pakistan in spite of its massive investments in water sector also suffers from severe floods. The major flood disasters in 1950, 1956, 1974, 1976, 1988, and 1992 cost more than 10 thousand lives each. On economic front the loss incurred was 3% of the country's total GDP (Mustafa 2002). Pakistan faced 19 major flood events in the past 60 years with a cumulative flooding over 594700 sq. km area with 166075 villages and loss of life rearing ID 700 numbers. Mostly the Makraln coast and south eastern parts of Sindh bear the brunt of floods (Ghatak et al., 2012) in Srilanka major floods occur in to monsoon seasons. Heavy rainfall in eastern and south western slopes is a principal cause of flood risk coupled with improper drainage system. The eastern slopes getting heavy rainfall occur along with cyclone and storms

Flood damages are difficult to compute as assessments singling out floods is difficult. Other natural calculating distinctive phenomena like cyclones usually accompany floods. Except in rare cases segregation of damages due to flood is difficult. Further, indirect potential losses resulting from un-productivity in several areas like trade, commerce, business, etc. coupled with the economic losses. These cannot be offset by whatever gains are made by economic development.

After Bangladesh, the next flood distressed country in the world is India. Both the countries put together account for $1/5^{th}$ of global deaths due to floods every year. While 40 million ha of land is vulnerable to floods, 8 million ha are affected continuously year after year at one place or the other. India witnessed several flood disasters. Bihar state prone for floods is linked with Koshi River to Nepal. Excessive rainfall in Nepal as a result of global warming is a prime reason for flooding Koshi River and undulating Bihar every year.

Bihar floods in 1987 killed 1400 people and more than 5000 animals. The economic loss was estimated at about 69000 lakhs (INR). River Koshi earned the name of 'Sorrow of Bihar' after these floods. The successive 2008 floods in 2008 affected 2 million people. The floods in Maharashtra and Gujarat states in 2005 took a toll of 5000 and 123 people respectively. Economic loss was estimated to a tune of more than Rs.800 million. The 2007 South Asian floods devastated destroying large zones in India, Pakistan, Nepal, and Bangladesh. It had been termed by UNESCO as worst flooding of South India in living memory lasting for more than 15 days. In 2009 floods caused and killed over 200 people in Karnataka, Orissa, and Kerala, Gujarat, and North-eastern states and destroyed a million homes. This was followed by downpour and floods killing 255 people and resulting in a loss of Rs.133 crore in Leh and other villages of Ladak. Heavy downpour in 2011 flooded rivers in north and eastern India affecting 10 million people and making roads and towns disappear in West Bengal, Bihar, Kerala, and Assam. The chain of events continued in India with 27 people dead and 9 lakh evacuated forcibly during 2012 in Assam. The impacts of floods in India during 1953-2006 are shown in the following Table 2.

Table 2.Impact of Flood in India (1953-2006)

Years in Group	Average Area Affected in '000 hectares	Average Population Affected in Million	Average Human Loss in '000	Average Cattle Loss in '000	Average Economic Loss in Million Rupees
1953-57	6664	16.76	399	33	140
1958-62	6448	11.714	648	31.8	148
1963-67	4342	12.636	347.2	6.4	98
1968-72	7832	34.53	1503.8	98	1162
1973-77	9606	44.956	3022.2	186.2	2542
1978-82	9588	46.518	2379	249	6382
1983-87	9162	55.80	1775.6	105.2	17540
1988-92	8351	37.42	2109	96	14928
1993-97	6821.4	33.66	1992.2	73	16090

1998-2000	5382.5	26.89	2143.25	59.03	16863.3
2003-06	2867.5	23.864	1563.75	34.14	N.A.

Source: Joshi, PC et.al (Delhi University)

In all the cases cited above extensive relief systems strained substantially the public purse. Many state governments spent more on relief and damages due to disasters than and crore rural development programmes. For example in Maharashtra's single drought (2003) and flood (2005) absorbed more of the budget (Rs 175 billion) than the entire planned expenditure (Rs 152 billion) on irrigation, agriculture and rural development from 2002-2007' (World Bank 2008). It is to be noted that India however has emerged as one of the top countries in the world in ably addressing the issues in disaster management in recent years. The economic losses due to the recurrent floods however have heavy talk on public expenditure and private agriculture losses.

2.1.2 Impact on Livelihoods.

Loss of livelihoods is both an immediate and medium term impact in the poor economies of South Asia. The communication networks and infrastructures gets disrupted due to floods, Roads, power plants, transformers, electric poles and wires get destroyed or damaged and all the economic activities come to a grinding halt. This situation generally persists beyond flood time paralyzing the normal life in the area. The direct effect on production assets agriculture, industry and traditional economic activities hinder their regular operations and functioning leading to loss of livelihoods. The indirect effects as spill over of the loss of livelihoods impact business and economic activities in neighbouring non flooded areas also.

Being non-resilient the poorer strata of the societies are worst hit due to lack of food security and loss of daily wages income. Stories of flood disasters in the region are replete with these instances next only to loss of human life. Fishermen who solely dependent on fishing and other engaged in traditional vocations suffer for different durations depending on the intensity of floods and disruptions of opportunities to restore normally for their operations. Small and marginal agricultural families apart from losing their productive assets (crops) are thrown in to situations of food shortage or lack of it.

2.1.3 Decreased purchasing and production capabilities

The above impacts- loss of lives, property and livelihoods drive the affected people to reduced purchasing and production abilities. Instances of damage to infrastructure networks may also cause long term impacts on availability of clean water, electricity, transportation, education and health care. The impact of loss livelihoods triggers reduction in purchasing power in the hands of affected and the land value in flood plains comes down exposing the communities living in the area to increased vulnerabilities. As mentioned earlier the additional costs to the government and others in rehabilitation works, relocation of people and removal of property from flood affected areas diverts the capital required for maintaining production.

2.1.4 Impact on economic growth and development

Frequent floods and their devastation cause high costs for relief and recovery in the region quite often the development investments by the governments in south Asia on infrastructure and welfare are seriously hampered and sometimes abandoned as a sequence. Long term investments by government and private sector may not be forth coming because of frequent floods in the areas. The impact on dwindled on livelihoods along without migration of skilled labour strains the region's economic growth. The chain reactions of the loss of resources thus add to high costs of goods and services putting development programmes in jeopardy.

In comparison with economic loss, while Asia accounts for about 60% of global economic damage, only 16% of this is reported to have caused in South Asia. This low figure may be due to several reasons viz., poor and incomplete reporting, damage assessments remain limited in South Asian countries, and absence of a standardized methodology for reporting further limited resources and economic development in the region categorize these countries as least developed (Sreshtha, 2008).ADB reports that their studies on the economics of climate change have commonly involved in the review of existing climate studies, climate economic modeling and national and sub-regional consultations with experts and policy maker. However, their thematic process from region to region varied "part 1 of the South Asia study assessed and prioritized clean technologies, and mitigation options in the energy and non-energy sectors and developed country specific MAC curves part 2 assesses local level future climate change and its potential physical and economic impacts on agriculture, water resources coastal zones human health energy use and tourism. It also examines potential distributional and cross-sectoral macro-economic impacts and estimates the cost of adapting to future scenarios.

2.1.5 Outmigration

Strong linkages are established between poverty, high social vulnerability to low capacity to cope with water related hazards and disasters (UNESCO 2006) while it is virtually impossible to forecast the [physical impacts of climate change with a great accuracy at the regional scale, given vast uncertainties in input parameters as well as non-linearity in system dynamics these are several added difficulties in fore-casting its social impacts (Byravan and Rajan 2009) In the context of flood management social impacts assessment is somewhat a neglected aspect. MICRODIS a team involved in assessment of social impact with special reference to flood, cyclone and earth quakes in India.

They point the following (Joshi, PC. *et al.,)* Social Impacts of Flood:

- At the conceptual level the social impact deals with the vulnerability and resilience of the group.
- Vulnerability is the attribute the people have and resilience is the behaviour they engage in.
- The vulnerability of the population depends on several social factors like-age, gender, economic status, social cohesion, population density, gender, health status, race/ethnicity, education, residential status, culture etc.
- In India the major breakthrough in the social impact assessment studies came with the UN/ISDR funded landmark work done by CRED and Delhi University on Tsunami flood victims.
- The study reveals a number of vulnerability factors like-age, gender, lack of warning and preparedness and distance from the sea.
- Young children and frail elderly are more vulnerable as they lack developmental capacity or strength to escape the hazardous situation.
- The lack of ability to swim among the women made them more vulnerable during the 2004 Tsunami.
- Areas with lowest socio-economic conditions show higher mortality rates.
- In Indian context another aspect of vulnerability is the caste system in social life.

In majority of the calamities of extreme climatic changes, the out migration of affected people may be more in 'hot spots' where the human settlements are at a relatively high risk for both sudden and slow onslaughts of the events. Some displacements of people may be temporary but their eviction from their home area worsen the existing pressures on infrastructures and services, hamper economic growth, enhance the risk of conflict, and propel the decline of social conditions(ADB, 2011). Migration either temporary or permanent resulting from the floods overcrowded nearby cities as the people migrate for alternate employment and livelihoods these migrants add to the ranks of urban poor and live in marginal lands exposed to other risks and health hazards. Selective out migration of workforce depletes availability of skilled people in the affected areas and sometimes creates complex social problems. Though people always move in search of better opportunities, natural disaster like floods and droughts induced by climate change are expected to trigger waves of human migration. Disruption of ecosystem dependent livelihoods will likely to remain leading drivers of long term migration over next two to three decades. However, out migrants of extreme events like floods require different range of humanitarian and political responses. Estimates of future 'climate migrants' and natural disaster migrants may number around 1 billion by 2050 (Suar, 2013).

2.1.6 Psychological impacts

Flood victims and their families are subjected to lasting psychological impacts for long periods of time and in several instances forever. The loss of loved ones and children impact the victims deeply. Stress is caused to them because of trauma and loss of homes memorable security in the aftermath of floods and in temporary shelters. A review of research in India and other South Asian countries on psychological and mental health impacts of disasters shows that research is related to more concerned with natural disasters as work on manmade disasters is still in its infancy. The stories on health consequences of disasters cover basic psychosocial services, psych-education, relaxation and child focused psychological problems and interventions and psycho behavioural therapies. While in Bangladesh the work in this context is inadequate due to dearth of professionals to deal with the problems in Pakistan, Thailand and Maldives the initiatives started only after Tsunami in 2004. It is seen that the magnitude and pattern of psychological and mental health problems are similar in all these countries of the region and they are stress- related as well as anxiety-depressive disorders, PTSD and associated psycho somatic problems. The impact assessments covered magnitude and pattern of psychological and mental health indicators largely covering adult survivors. Very few studies are available on children and extremely few on the vulnerable groups. Increasingly research trends are growing to gain better appreciation in this area with the accumulation of knowledge to serve as a basis to anticipate the effects on the people families and social systems. However, this aspect of research is of recent origin with 5-10 years history in most of the countries (Satapathy and Subhasis, 2009).

2.1.7 Political implications

Floods have major political implications when not responded to timely and adequately by authorities or governments. With growing discontent among flood affected people they lose trust in the administration. Lack of development in the flood prone areas cause social inequality and even social unrest in the regions.

2.2 Health impacts

The number of inundation deaths due to floods in south Asia (India, Nepal, Bangladesh and Pakistan) due to floods was reported to be around 2,200 in 2007. A wide spread illness reported over a vast number of people. Diseases such as diarrhoea, dysentery, cholera and typhoid threatened the millions affected by the deluge that lacked safe drinking water, medicine and hygienic food. In Bangladesh more than 70,000 people were hospitalized with water borne diseases (Sunday Times 2012).Whenever floods occur in the region the above type of reporting is of common sight in national newspapers urging the need for risk reduction. Changes in temperature and rainfall may also affect the distribution of disease Vectors, viz., those of malaria and dengue and the incidence of diarrhoea.

A review of literature (Alderman *et al.,* 2012) assessed recent epidemiological evidence on impacts of floods on human health. Health outcomes were categorized into short and long term and were found to depend on the flood characteristics and the level of people's vulnerability. An increase in mortality rates to an extent of 50% in the first year of post flood is reported time and again. After floods, It was noticed an increased risk of diseases such as Hepatitis E, gastro intestinal disease and leptospirosis ,particularly in areas with poor hygiene and displaced populations. (Haines *et al*., 2006) reiterate that there are several mechanisms by which climate can affect health. For example experiences of flooding lead to sustained increases in common mental disorders. Climate changes also are likely to affect bio-diversity and the eco-system goods and services that we rely on for human health. There is a web of interactions between ecosystems climate and human societies which influences the occurrence of infections in some cases, floods may mobilize dangerous chemicals from storage or remobilize chemicals already in the environment e.g. Pesticides, heavy metal soil contamination (Haines *et a.,* 2006). The centre for Research on Epidemiology of Disasters estimates the deaths due to diseases in floods during 2002-11 in developing countries compared to high resource regions World Wide to be in the ratio of around 23:1 (EM-DAT, 2011).

The Intergovernmental Panel on climate change asserted that climate change is likely to further affect the health status of millions of people (IPCC, 2007). This can have different Pathways: direct impact may come through changing weather patterns and extreme weather events like floods. The indirect effects may be due to changes in air equality, water, crop yields and agriculture vector ecology and eco systems. However it is important to note that social and environmental conditions may modify the impacts, as with the availability of health systems and infrastructure (Perin, 2008). Drawing from different published articles, Perin *et al*., (2008) developed the disease vector and potential as in the following Table3.

Table 3: Potential impact of climate change on vector –borne diseases

Disease	Vector	Potential
Malaria	Mosquito	Data from the mapping malaria risk in Africa Project suggests a 5-7 per cent increase in Africa by 2100, as a result of malaria becoming more prevalent at higher altitudes. It is estimated that the prolonged transmission season could lead to overall increase in person-months of exposure risk to malaria of 16-28 per cent in Africa by 2100. However, this model does not take non-climatic factors into account. A range of other models project different impacts. A biological model suggests that based on IPCC 2001 specific climate scenarios – there might be a global increase of 260-320 million people living in a potential malarial transmission zone in 2080, representing a 24 per cent increase in number of people at risk from malaria. China and central Asia are likely to see the largest increase in risk
Dengue	Mosquito	Out breaks are usually associated with high rainfall and

		humidity; warmer temperatures also increase the rate of viral replication, increasing the probability of transmission. Hales at al estimate that the number of people likely to be at risk from dengue in 2085 will be 5-6 billion, compared with 3.5 billion without climate change. However, the impact of human factors and increasing travel has not yet been fully incorporated into models.
West Nile Fever	Mosquito	Transmission appears to be associated with drought conditions, although the link is not well understood. The foresight report concluded that the intensity of extreme weather events could facilitate increased transmission, and there was a theoretical possibility of emergence in the UK.
Tick-borne encephalitis, Lyme disease	Ticks	Temperature and humidity are important determinants of tick distribution and there is already evidence that the vector is moving to higher latitudes and higher altitudes in Europe, for example in Sweden. However, socio economic factors and changing agricultural practice may also be involved
Leishmaniasis	Sand flies	Climate change could have a direct impact on sand –fly distributions; changes in land use patterns will also have an impact. Geographical distribution of vectors in parts of Latin America and in South west Asia could increase.
Schistosomiasis	Water -Snails	Regional warming is thought to have contributed to a recent epidemic of Schistosomiasis in china, and there are concerns the infection could expand into the country's northern territories. Increased temperatures shorten the reproductive cycle for both snails and worms, leading to increased numbers of both pathogen and vector.

Source: Nicola Perrin (2008),

In the context of identifying research needs the WHO concluded that "changes in infectious disease transmission patterns are a likely major consequence of climate change". The report went on to recommend there is a "need to learn more about the underlying complex causal relationships, and apply this information to the prediction of future impacts, using more complete, better validated, integrated, models".

Statistical and biological modeling are in vogue to predict the impact of future climates on vector borne diseases the statistical modeling uses empirical approach based on 'current epidemiology present day distributions of vectors are statistical matched to current climate variables this understanding is then applied to future climate scenarios to predict future distribution'. The biological modeling uses 'mechanistic approach aggregating the effect of climate on individual components of the disease transmission cycle (Nicola Perrin, 2008).Water related diseases are water borne which are transmitted by ingestion and water washed which are caused by lack of hygiene. In different ways the burden of both types will be altered by climate change- changes in rain fall surface water availability and water quality (IPCC, 2007)

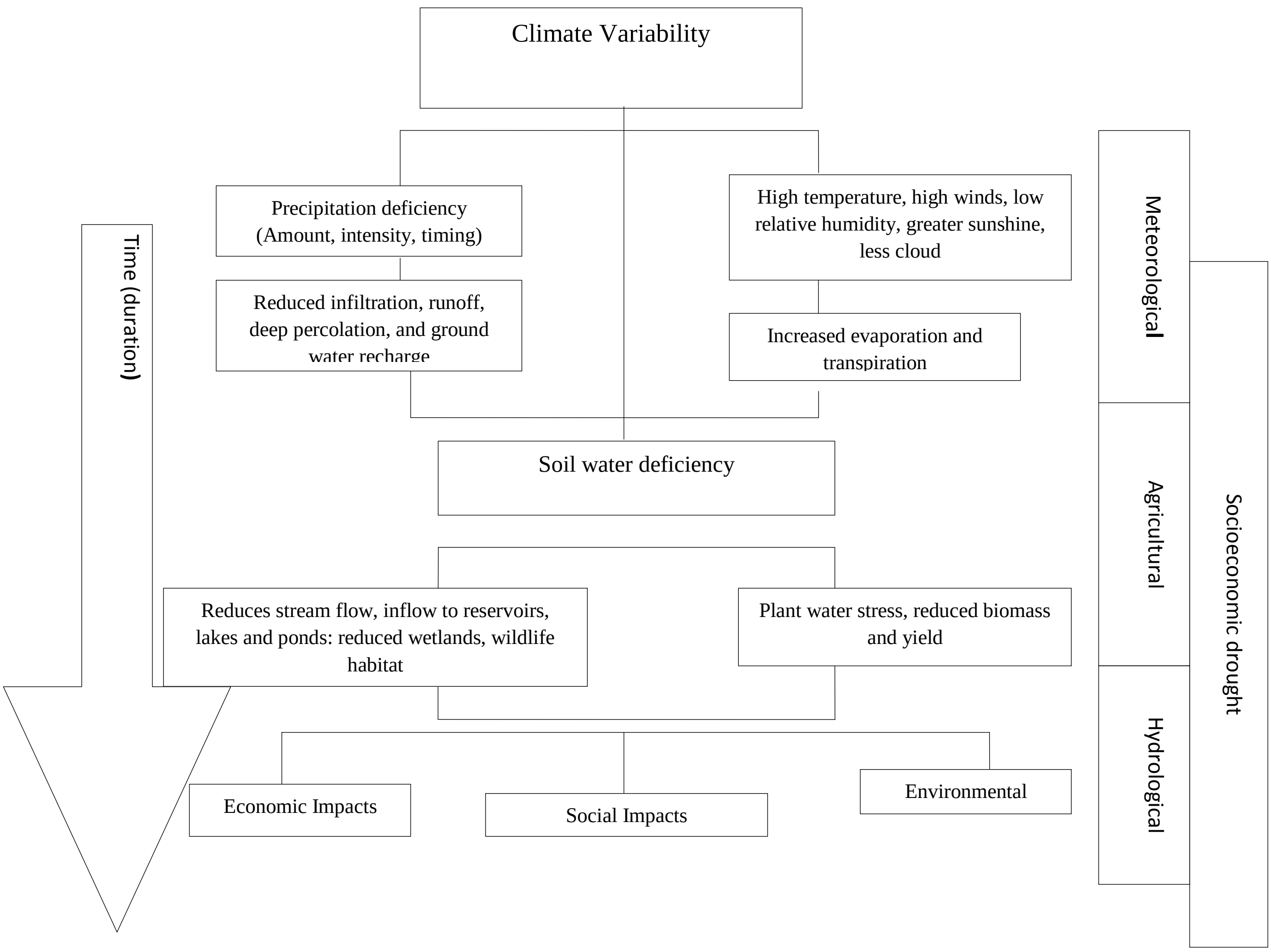
- Higher temperatures could have an effect on the microbiological and chemical contamination of water supplies;
- Extreme rainfall events and flooding could lead to contaminated water supplies and facilitate water borne outbreaks of diseases;
- The incidence of diarrhoeal disease is sensitive to temperature and rainfall.

* (AJ Mc Michael *et al.,* 2003) provides a comprehensive update of balanced evidence not only of the breadth and magnitude of climate change effects but also their distribution across the populations and overtime. It identifies vulnerable populations and measures to adapt to changing conditions. This work also provides quantitative estimates of total health impacts and identifies future research needs.

3.0 Droughts in South Asia

Drought is a natural part of climate, although it may be erroneously taken as a random and rare occurrence. Drought is different from aridity (restricted to low rainfall areas). It can occur in any climatic region. The droughts classified as meteorological, agricultural hydrological and socio economic droughts have relationships as shown in the following Figure 1. And as quoted by SAARC disaster management drought is a most vastly spread centre. Hydro-meteorological syndrome of prolonged period of water scarcity affecting natural resources, environment and there by impact people adversely. Drought by itself does not trigger emergency. Whether it develops into an emergency or nor depends on several factor like the effects on local people, communities, societies and this in turn on the latter's vulnerability to the stress of drought.

Figure 1: Relationship between Meteorological, Agricultural, Hydrological and Socioeconomic Drought



Source: National Drought Mitigation Centre, University of Nebraska, USA (as given in SAARC 2010)

The relationship of different types of droughts is illustrated in the Figure.1 (SAARC, 2010) as follows: Agricultural, hydrological and socio-economic droughts occur less frequently than meteorological droughts. The impacts in these sectors are linked to the availability of surface and sub-surface water supplies it takes considerable time for the rainfall deficiencies to result in soil moisture deficit and cause stress on crops. In the eventuality of supplies through precipitation as a result subsurface water dwindled over a long time. The agricultural hydrological and socio – economic droughts occur producing associated impacts. The short fall in water supplies raises further demand for water resources. Among all the south Asian Countries India is most affected by drought with vast population and areas impacted. Generally the areas affected are with low rainfall (approximately high 750mm) and high evaporation and high variation of precipitation along with the absence of water security. Thus drought is reported to be affecting 16% of the area and 11% of the total populations in the country. The South-west monsoon (June-September) is the main raining season in the country when about 73% of the rainfall in the county occurs. Thus, failure of South West Manson often manifests as drought. In India drought affected areas are classified into two categories' -chronically drought affected and droughts prone. Droughts prone areas are those with 20 % probability of rainfall efficiency or more than 25 % of the normal rainfall. Regions coming under this category are majority of states in the country. In areas with less than 40 % probability of rainfall like Western parts of Rajasthan and Kutch region of Gujarat are classified as chronically drought affected areas. In the recent years past (37 years) 2009 was the major drought year in India. Based on the experience and understanding of impacts of droughts the focus of action for drought management took different approaches as shown in the following Table 4.in the country.

Table 4: Droughts in India focus of action and learning

	Focus	Approach
Pre-1947	Minimizing starvation deaths through "Test relief" and free kitchens	Post-Occurrence of Calamity
1947-65	Addressing negative impact on agriculture(Mitigation) distribution of charitable relief	Providing immediate relief assistance on onset of scarcity to prevent famine
1960-90	Drought management through long term and short term development programmes. livelihoods ensured with relief works at the end of monsoon	Prevention and mitigation approaches. Introduction of PDS for food security
Post -1991	Monitoring and implementations of contingency plans to minimize economic losses through draught	Continuous and coordinated management. Institutional arrangements.

As Shown in the above Table in the pre-independence period the management of drought focused on post occurrence activities of the calamity. More than 25 droughts occurred during the British time and some of them resulted in famines. During the period, 1947-1965, focus was given addressing on the negative impacts for mitigation of adversities primarily and agriculture. Five year plans were initiated and measures for the prevention of destruction from droughts was given priority from mid. 1960 to 1990 focus was on long term and short term development programme with prevention and mitigation objectives. Post 1991 Pre disaster management was given emphasis after 1987 drought in the government efforts and close monitoring and contingency plans are being developed in drought risk management. India in the year 2009 witnessed a major drought with a rainfall deficiency of 22%. Regarding droughts in other south Asian countries (SAARC, 2010) gives some salient features.

Pakistan with its extensive canal network controlled drought effects to an extent. However in some areas drought remains chronic. With an annual rainfall of less than 200mm. about 60% of the total land in Pakistan is classified as arid. The area includes Cholisitan DG Khan, DI Khan, Kohistan, Tharparkar and western Baluchistan. Certain areas experience two or three droughts annually Seasonal aridity plagues Bangladesh and drought he is a temporary, Spatially irregular and non-periodic phenomenon Bogra and Noakhalic areas in Bangladesh have same drought Years.

Nepal does not have an adequate and systematic microclimatic monitoring of information in the different ecological zones. All parts of Terai lag irrigation facilities and western development region because of inadequate monsoon experience induced drought like conditions. Sri Lanka the dry zone constitutes drought- prone area in the country. The country is divided into wet, intermediate and dry zones depending on the quantum of rainfall. Dry zone receives rainfall below 1900 mm.

For assessing drought several parameters like rainfall, temperature, evaporation, Vegetation health, Soil moisture, stream flows are important. Consult assessment through measurements of the above parameters is done by different agencies. This is to map climate change and spatial distribution of drought conditions on global, regional and drainage basin levels. Drought is recognized through economic consequents, yet requires a scientific quantitative index of water shortage. Though several other indices are in vogue, but drought index value is a single number used in decision making. Standard Precipitation Index (SPI) expresses the actual rainfall as standardized departure from rainfall probability distribution function and, hence this index has gained importance (Kumar *et al.*, 2009).

Gupta *et al.* (2011) detail suitable meteorological indices for assessing droughts. They considered the degree of dryness, duration of dry period and specific atmospheric conditions which result in efficiencies. The author's further detail the data analysis methods like probability based methods for drought and regression run based method with notion runs. Drought parameters such as longest duration and larger severity are analyzed through time series of random and Markovian variables. Discrete auto regressive and moving average process model for the variability of wet and dry years and Group theory based methods to show length and duration as groups and clusters. Data-sets are analyzed to develop drought prediction and forecasting utilizing the concept of pattern recognition and neutral network. In the PDSI based methods synthesis of PDSI based time series data is achieved for identification of severity and characteristics of the drought. Remote sensing and geo informatics application is now increasingly used (Gupta *et al*., 2011).

Thus several methodologies are available to assess and as well as fore-cast the effects of drought its duration and depth. However precautions coupled with sound policies to contain drought are important as nothing can't be done after the onset of drought. Drought is however a slow process and to the gestation period ranges from 3 to 4 years to manifest.

3.1 Impacts on agriculture and livestock

The direct impacts of droughts are primarily on agricultural production and the livestock in the region. Drought has a number of short term and long term effects on the eco-system of the affected area. Agricultural production in India, Pakistan, Srilanka and Bangladesh is dependent on rainfall. In India statistics show that rain-fed rice, a major staple food crop occupies primary importance covering 60 % of the agricultural land in the country. Drought reduces the food grain production in the country in certain years by 15-20 per cent of the yield of a normal year. There were ten severe drought years effecting 39.5% of the area in India and 7 phenomenal drought years affecting 47.7% of the area (Kulkshektra, 1997). Those years were 1877, 1899, 1918, 1972, and 2002. Crop losses of different magnitude were reported due to droughts depending on their geographic incidence, intensity and duration. The droughts thus not only adversely impact food supply at farm level but also impact national economy. Following are some estimation of drops in crop productivity in recent past due to droughts.

Table 5 Year of drought and drop in crop and productivity in India

Year	Drop in crop productivity	Location
1987 Drought	Pearl millet -78.74% to 43%	Western
1997	Groundnut and Millet Varying drop rates	Andhra Pradesh
1970-96	Loss of food grain product to a tune of $ 400	Eastern India

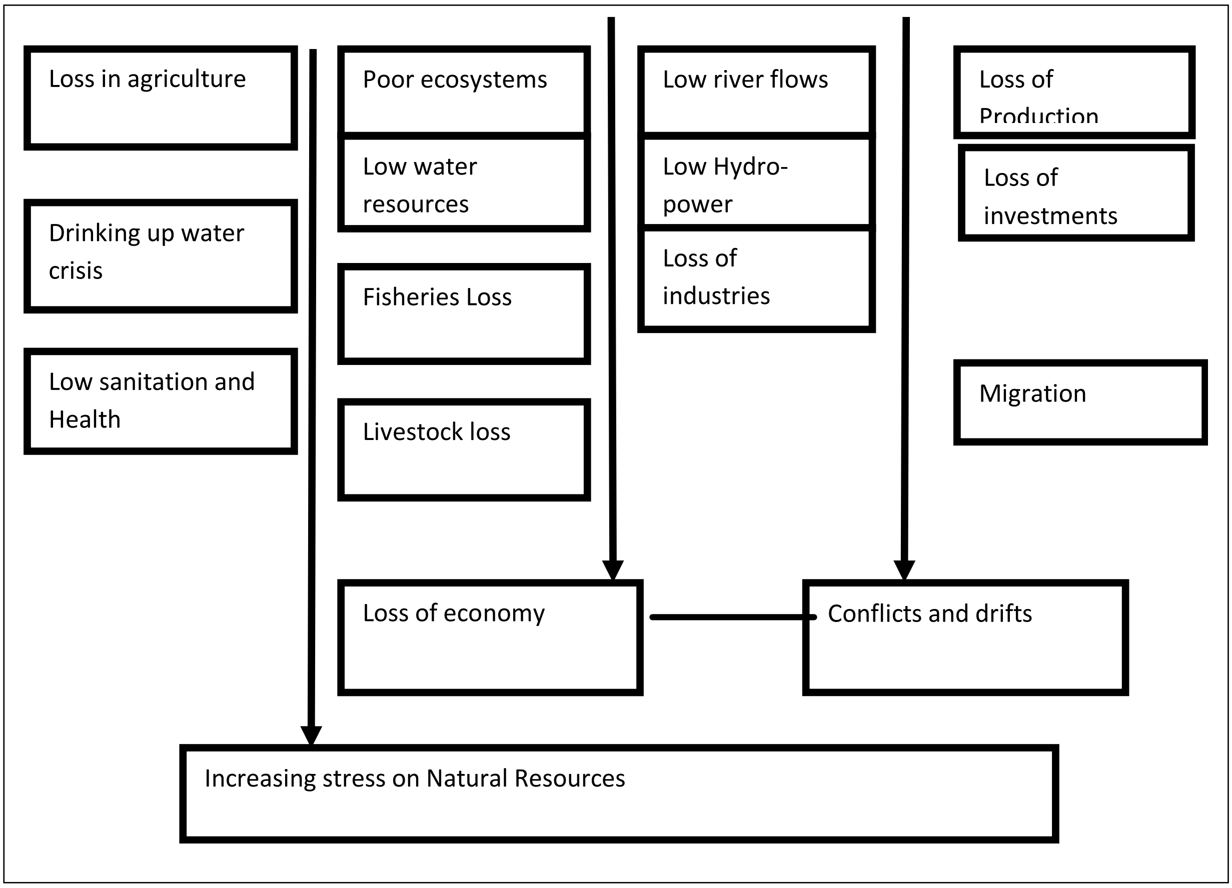
The effect of drought was more on fodder compared with food grains. However better contingency plans helped during 2009 drought though the rainfall departure (shortage) during the year was higher than in 2002 (Venkateswarlu, 2010).The effects of the droughts are clearly seen in the reduced productivity and mortality. The depletion of forage resources during drought along with overgrazing and indiscriminate cutting of vegetation leads to land degradation distress sale cattle and small holdings. Decrease in the size of herd (about 52%) was reported due to frequent droughts in Rajasthan (GoI, 1994).

In Bangladesh 2.7 million ha of land is severely drought prone and the country experiences dry spell during the months from November to May every year. Droughts occurred in Bangladesh 24 times between 1949 and 1991.Very severe droughts were reported in 11 years. (1951, 1957, 1958, 1961,1972,1975,1979,1981,1982,1984 and 1989).The loss in food grain production during 1978-79 drought in the country was said to be more by 50 to 100 per cent than that was lost in great flood of 1974, showing that the effect of drought can be as great as that of a major flood or cyclone food grain supply through ration and relief systems averaged 227 thousand tons per month in June to November 1979 compared to 169 thousand tons per month during the corresponding month in 1974 production of rice , jute and other crops were severely affected although jute suffered most mainly because of lack of water for retching farmers resorted to sell their livestock for distress price for want of fodder. The consecutive droughts of 1978 and 79 directly affected 42% of cultivated land and reduced rice production by estimated 2 million tons. The losses due to drought in 1982 use more than double the losses caused by floods in the same pear. The 1997 drought caused a reduction of around one million tons of food grains (Hasan and Rehman, 2010).

The worst droughts experienced by Pakistan were in the years 1899, 1920 and 1935. The most severe droughts in the recent past occurred in 1999-2000 stretching to 2002 in certain areas of Pakistan. Agricultural growth suffered severe setback during 2000-2001 as a result of drought while major crops like wheat cotton and rice registered a negative growth of 10%, the overall growth of a agriculture recorded a negative growth of 26% though coping mechanisms were developed and well adopted the reduced production of major crops and fodder adversely affected the livestock. (Ahmed, S.*et al.,* 2010) The irrigation for agriculture in the country is mainly through surface irrigation in Nepal. Some parts of the country face the problem of drought due to uneven and irregular monsoon rainfall. The mountainous of region of northern belt is generally dry and it lacks irrigation facilities. The drought in 2008-2009 winters has affected wheat and barley which are winter crops in Nepal. The production fell down to 17% at national level and up to 70% in some parts of the country. Similarly late monsoon in 2009-2010 affected the major crop paddy and the decline was about 11% at national level (Regmi HR, 2010). Once in every 3-4 years Srilanka also experiences severe droughts of regional significance and sometimes these of national significance randomly the prolonged drought caused major decline of rice production in 1988-89 and 2001-02. And necessitated major imports of rice grains and enhanced relief expenditure on drought affected people. The effects of droughts were colossal on livestock in Srilanka. Cattle-rearing is the traditional occupation of the people. However the recent resettlement activities and drying up of small reservoirs are changing the land use patterns. In times of intensive droughts there is loss in production of milk and other dairy products (SAARC, 2010).

Droughts have a number of short term and long term effects on the ecosystem of the affected area. Like floods, the extreme events of droughts could pose significant threats to food security. They use a vicious circle of rising prices distress sales of livestock and fixed properties and impoverishment and malnutrition with attendant diseases. The already existing poverty conditions in the region are accentuated leading to further deterioration of economy and human wellbeing. Several of the severe droughts in the past apart from causing famines had taken a large toll of human and cattle population in South Asian countries. Even today, cases of migration of people from affected areas of drought are not uncommon, despite the advancements in planning and preparedness by the national governments. Thus the impact of droughts caused by climate change can be shown as in the following Figure 3.

Figure 3: Impacts of Droughts



Source Adapted from (Anil K Gupta *et al.,* 2011)

Conclusions

The IPCC 4th assessment reports states that climate change in particular risk of floods and droughts is expected to have severe impact on South Asian countries. Though South Asia has low

GHG emissions, climate change and the frequent disasters of floods and droughts are expected to have already effected severely the economic growth and development of the region. Christensen *et al.,* (2007) and Curz *et al.*, (2007) point the following sector vulnerabilities that are in offing due to climate change and extreme events.

Sectoral Vulnerabilities

Water

- Increasing water stress to over a hundred million people due to decrease of fresh water availability in Central, South, East and Southeast Asia, particularly in large river basins such as changing.
- Increase in the number and severity of glacial melt-related floods, slope destabilization followed by decrease in river flows as glaciers disappear.

Agriculture and food Security

- Decrease in crop yield for many parts of Asia putting many millions of people at risk from hunger.
- Reduced soil moisture and evapotranspiration may increase land degradation and desertification.
- Agriculture may expand in productivity in northern areas.

Health

- Heat stress and changing patterns in the occurrence of disease vectors affecting health.
- Increases in endemic morbidity and mortality due to diarrhoeal disease in south and Southeast Asia.
- Increase in the abundance and /or toxicity of cholera in South Asia.

Terrestrial Ecosystems

- Increased risk of extinction for many species due to the synergistic effects of climate change and habitat fragmentation
- Northward shift in the extent of boreal forest in north Asia, although likely increase in frequency and extent of forest fires could limit forest expansion.

Coastal Zones

- Tens of millions of people in low lying coastal areas of south and Southeast Asia affected by sea level rise and an increase in the intensity of tropical cyclones.
- Coastal inundation is likely to seriously affect the aquaculture industry and infrastructure particularly in heavily populated mega deltas.
- Stability of wetlands, mangroves, and coral reefs increasingly threatened.

As pointed earlier the main impact of the floods and droughts is on the food security of the people who are mostly poor and live in rural areas. Changes in the intensity and spatial occurrence of rainfall, breaks in monsoon cycles, increase in ambient air temperature, and changes in evaporation, precipitation, steam flows and sea level rises lead to second order effects on water resources. This consists of decrease in water supply, increased flooding and drought affecting agricultural production, fisheries, forest composition and consequent land use changes. However these changes are dependent and degree of vulnerability vary because of the local differences in growing seasons of the crop and crop management practices. Yet, low income segment of the population living on traditional agricultural systems or on marginal lands are highly susceptible to these vagaries. The thickly populated mega deltas and the long coast line run a constant risk of floods and cyclones. Sea-level rise is most conspicuous aspect in coastal areas. They get vastly affected because of economic and social disruption caused by the disasters. Instances of increased salinisation loss of wet lands are common in several parts of the region in coastal areas.

Next is the economic instability as the third order effects of the severe forms of climate change. These effects are Instability in food prices, increase in diseases, and increase in electricity prices, trade problems and problems of housing the affected people which become prominent. Another important impact of climate change is the glacier melt in Himalayas which is projected to increase fivefold and affect water resources aggravating the conditions of poor. The most adverse impact of the severe forms of climate change may result from large migrations out of the affected areas which can occur along with increased unemployment and economic loss. All these impacts if not addressed properly may even jeopardize national security of the country involved.

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Module 5: ***Impacts of Droughts and Floods on Women, Poor and Vulnerable Sections of the Community***

Impacts of Droughts and Floods on Women, Poor and Vulnerable Sections in South Asia

M.V.K. Siva Mohan and K Siva Rama Kishan

1. Introduction

Frequent occurrences of natural disasters like floods and droughts and their adverse impacts in south Asia are becoming increasingly alarming. While systematic and standardized data collection and analysis efforts regarding these events in the region are not adequate, gender related data on these disasters informing us on impacts on women and weaker sections is awfully lacking. Systematic understanding of problems connected with these events help early warning systems and to devise appropriate risk reduction strategies in the poor countries of south Asia. The South Asia Disaster Report (SADR, 2008), argued that the benefits of south Asia's high economic growth has accumulated benefits in the hands of a few privileged individuals and had failed to trickle down to the poor. Instead poverty has escalated, resulting in increased vulnerability of peoples and properties to natural hazards. At the same time mal-development has introduced new hazards and risks. Climate change is fast becoming the largest source for mal-development induced disasters. Many studies clearly indicated that poor, marginalized, women, children and the disabled are most vulnerable to the climate change impacts as they have less capacity to cope up with such situations.

This paper aims to get to an understanding of the impact of severe forms of hydro meteorological disaster floods and also droughts on women and vulnerable sections of the societies in South Asia.

2. Women in South Asia and their Vulnerability to Disasters

Vulnerability represents the interface between exposure to the physical threats to human well-being and the capacity of people and communities to cope with those threats. Threats may arise from a combination of social and physical processes. Human vulnerability thus integrates many environmental concerns. Since everyone is vulnerable to environmental threats, in some way, issue cuts across rich and poor, urban and rural, North and South, and may undermine the entire sustainable development process in developing countries. South Asia with a large population base is susceptible to greater disasters in the wake of climate change. More than 750 million people in the region have been affected by at least one natural disaster in the last 2 decades. South Asia has a long and densely populated coastline with low lying islands; the region is highly vulnerable to cyclones, storm surges, tsunamis and sea level rise. Women are often in the frontline in respect to the impacts of a changing climate. Climate induced risks and disasters will contribute to pre-existing poverty, low economic development, and exclusion of communities making them more vulnerable and poor. Risks and disasters will also weaken livelihood assets and further increase their vulnerability.

South Asia recorded 128 natural disaster events between 2006 and 2008. 93% of these were of hydro-meteorological origin. 86 incidences of flooding were reported, with nearly 8000 lives lost. India had by far the highest number of disaster events, but flooding in Bangladesh claimed most lives (South Asia Disaster Report 2008) In recent Global Assessment Report (GAR) the UN International Strategy for Disaster Reduction (UNISDR) published a risk model that assesses a country's exposure to natural disasters in terms of mortality (based on historical data and known vulnerability information) and economic losses. A risk classification of 10 points signifies extreme mortality risk. All South Asian countries are positioned above 5, with Maldives assigned an unknown classification. Bangladesh and India are classified as 9 (major risk) Pakistan and Afghanistan as 8 (very high risk), Nepal and Bhutan as 6 and Sri Lanka as 5 (medium risk). The South Asia Disaster Report (SADR) 2008 argued that the benefits of South Asia's high economic growth have accumulated in the hands of a few privileged individuals and have failed to trickle down to the poor. Instead, poverty has escalated, resulting in increased vulnerability to natural hazards. At the same time mal-development has introduced new hazards and risks. Climate change is fast becoming the biggest source of mal-development induced disasters.

Before discussing the impacts of natural disasters on women it is important to understand the dimensions connected with women as a sector in this region. They differ on several counts with their counterparts in the western hemisphere. South Asia has diverse socio-cultural and ethnic populations, religions faiths, and legal frames, economic and political forces. There a distinct kin, clan relationships and dominant caste considerations all these features impact on the lives of women directly and indirectly. This region has been identified as the most deprived area in the world with dense population, agricultural dependence and severe poverty. South Asia has been termed as 'patriarch belt' (Cald well, 1982), where women are subordinated to men in kin- ordered social structure (Mathema, 1998). Women in this region have no proper property or land rights. The rights devolve to men in the social structures.

Only in certain aspects such as the ratios- education, child mortality, fertility rates etc., data is available in aggregate terms regarding women. On other counts such as work participation, political participation and violence etc., the periodicity of available data is varied in the south Asian countries. Hence averages for the region as a whole for these dimensions is difficult to make. More difficult is the quantitative assessment of impacts of natural hazards on women, children and weaker sections. Ever since 1975, however the south Asian countries increased their efforts to assess the status of women and to move towards equality of genders.

The region which is predominantly agricultural and traditional in character has abundant women participation in economic activities. However, their work being 'intertwined' with household work which is mostly unpaid on one side and the flawed definition of economic activity on the other women's economic participation remains mute statistically. The cultural and traditional barriers here ignore their participation of women in diverse activities generally covered under the definition of economic activities. To overcome the inherit problems Nepal of late, has pioneered in collating satellite data on women's work and India undertook pilot survey. (HDSA, 2000), based on some observations suggest that South Asian Women work for 10 to 12 hours per day which is 2 to 4 hours more than men's work. In recent years women participation is increasing in economic activities as seen in the following Table 1.

Table 1: Sectoral distribution of Labour Force in South Asia

Country	Percentage Labour Force in			Percentage of Female workers
	Agriculture	Industry	Service	
India	62	11	27	32
Pakistan	47	20	33	27
Bangladesh	59	13	28	42
Nepal	93	1	6	40
Srilanka	49	21	30	36

Source: HDSA (1997, 2000)

The Table 1 shows that majority of women in Nepal and Bangladesh and India work in the agricultural sector. In Srilanka, women are involved extensively in the plantation work. Rural women in South Asia are involved in crop farming animal husbandry and a host of off-farm activities. Substantial quantum of women's time in this region goes for looking after livestock, finding and collecting fodder and water, collecting eggs, milking and ensuring the health of animals and poultry (Rustagi, undated).

It is shown in the above study that improvements in life expectancy and reduction of mortality rates from 1975 to 2000 are recorded in south Asian countries. But compared to male child, the female child mortality rates is higher. The ratio is above 1 in four countries viz., Maldives, India, Nepal and Bangladesh. The best performing female child survival index in South Asia is that of Sri Lanka with 0.91 ratios.

Poverty, lack of access to resources and low status putting women subservient to male members in South Asian countries also adversely influence their health priorities. The women's health needs are not often realized or articulated even by women themselves. It can be seen that there is a definite improvement in literacy levels among women in South Asia through there is lot more remains to be done for achieving universal literacy goals bias among these societies though south Asian countries produced eminent women leaders in politics at top level, but down the line of hierarchy of political decision making women representation is lacking.

In the development of any country the welfare of women and children is very essential. The country's future lies with the children. Women play a key role in the household and children are highly vulnerable in society. United Nations has declared Millennium Development Goals (MDGs) and in its transformational promises welfare of women and children got special importance. They were all accepted to be implemented by member states and all international agencies. Four Goals of the MDGs are primary education, gender equality, child survival and maternal health which are important for both women and children.

South Asian countries being very poor tend and characterized by higher total fertility rates higher population growth which translates into decreased standards of living. This relationship has been amply confirmed by several empirical studies (Mankiw *et al.,* 1992; Barro, 1997). It is sufficient to mention here that the 'Son preference' for example as observed in India also increases the fertility rate in the country. There are several other reasons for increased birth rates and child mortality.

Specific social features in south Asia also include seclusion and limited mobility of women and the exclusive nurturing role given to them in the gender division of labour All the aforesaid factors and cultural values in these countries create a total dependency syndrome for women and children on men. Most of the value systems are akin and almost all south Asian countries believe in need for protection of a male for women to carry on life (Anyabandu, 2000).

Thus the interplay of the following social, economic and cultural handicaps makes the women in South Asia a highly vulnerable segment of the population. They are: very high illiteracy; meagre or no ownership of assets, like land and other properties; minimum work opportunities outside home; limited mobility out of their homes and their homes and their own localities; subordinated social status to male members; and, socially constructed dependency on male relatives.

3. Impacts of Disasters on Women

The number of natural disasters which include storms, floods and droughts increased three fold in the past 30 years. Some of these disasters are major catastrophes and many others are of small scale import. However, the cumulative impact of the smaller events could be as devastating as major one. When disasters strike both men and women, rich and poor and elderly are all affected. But the impacts are different on specific groups. Women in south Asia are extremely vulnerable to impacts of disasters due to the above discussed skewed power relations and inequitable cultural and social norms. Studies have found that women shoulder disproportionate burden of the consequences of acute climate variations. A summary of the detailed review of published literature on the topic of impact of climate change and natural disasters on women, poor and vulnerable communities is provided in Annexure 1. The review offers a theoretical discussion on the concept of vulnerability to natural disasters; show using empirical evidence of how women in general and south Asian women in particular are vulnerable to water related natural disasters; and discusses the impacts of climate induced natural disasters on women, using empirical studies. From this review, there are some generalizations we can draw about effects of disasters on women in general and women in south Asia, in particular.

2.1 Loss of life and adverse health effects:

The mortality risk classification due to natural disasters placed south Asia at 5 on a 10 point scale (GAR, 2008) Women are more likely to die and suffer health problems as a result of natural disasters. For example, globally for every one adult male who drowns in a flood, there are 3-4 women who die (Agullar, 2008). This was due to the reason the women /girls don't learn how to swim or climb a tree. It was reported in a study (WHO 2002), that a cyclone in Bangladesh that many women died at home along with their children as the former had to wait for their husbands to return and make the decision to evacuate. Death toll during the natural hazards indicates that ethnic groups, Dalits, women and children account for 70% of the total. Climate change impacts on livelihoods of poor and the vulnerable (CARE, 2009). While the natural disasters trigger diseases common to men and women there are some diseases which affect the women. First the diseases set in because of their reproductive roles. It is said that in developing countries about 1 in 5 women of child bearing age is pregnant. Women have harder time due to the calamities. Studies show adverse reproductive outcomes following disasters including early pregnancy loss, premature delivery, still births, complications and infertility. There can be social taboos around norms of appropriate behaviour which in turn cause health problems in young women. This was illustrated by WHO findings on 1998 floods in Bangladesh Adolescent girls reported rashes and urinary infections because they were not able to wash menstrual linen in private and could not find place to dry them.

It was also reported that 20% of mothers who had been breast feeding their children at the time of the 2005 Pakistan earth quake were not able to do so. These mothers were either nursing or dead or in 10% of cases the supply of milk from mothers is insufficient for their infant children (Ferris, 2010). The effects of Pakistan floods in 2010 show that in cases where women deaths are less in number than men, women suffer more due to family separation and loss of interest in daily life activities. The depression and mental agony among the effected Women made them psychological wrecks.

Climate change is expected to have many consequences on human health. Intense heat experienced over years result in development of allergies and itching problems, particularly in women and children. Women play a dominant role in subsistence agricultural production. The increasing trend of male migration during droughts to earn a living put great pressure on women for subsistence production. Many women and children in the affected countries live in camps and other temporary shelters which lack adequate sanitation, clean water, health services and security. Government compensations promised to the affected people do not reach them or not adequate to restore their livelihoods women right to food is violated in several ways.

3.2 Adverse effects on household economies and children

Poor women are also wage earners along with men to run the households the rural areas and also in urban vicinities. The household economy is severely affected. In many households after the disasters set in. When men loose life in a disaster the women are left to take care of themselves and children. Often this situation leads to ghastly suicides and destitution among women. In some cases the women are thrown into a pathetic situation of indulging in prostitution to keep their children and themselves alive. Agriculture is being the main resource for income generation and the impact of disasters like floods and droughts effect agriculture adversely leaving the women without any wage earning opportunity and sometimes when the land properties were lost force them to migrate along with attendant consequences on the women and children and their psychological dispositions. In South Asia majority of the children suffer with malnutrition there are a few facts and myths reported (Mendelson, 1996), regarding child malnutrition in India they are:

- 47 per cent of India's children below the age of 3 years under weigh due to nutritional deficiency the World Bank puts the number – probably conservatively at 40 million. This is out of global estimate total of 146 million
- 47 per cent of Indian children under the age of 5 years are moderately or severely affected by malnutrition.
- South Asia has the highest rate of malnutrition among children in the world
- According to 2008 CIA fact book, 32 babies out of every 1000 born alive die before their first birth day
- Women and children are 14 times more likely to die during natural disasters[6]. At least half of the infant death in India are due to malnutrition associated with infectious diseases
- Malnutrition impedes motor, sensory, cognitive and social development. Children affected are less likely to benefit from schooling and consequent loss of income as adults. In India, women born during an extreme event in the 1970's were less likely to the primary schools[7]
- The most damaging effects of under nutrition occur during pregnancy and below two years of child life.

It has been shown that the response to rising food prices is first, to attempt to replace money with labour, and second, a cut in portion size of consumption. Rates of child malnutrition rise as food prices rise, leading to the Trans generational transfer of poverty (IFAD, 2008). Lot of

[6] http:/www.wedo.org/category/learn
[7] http:/www.europe.solidaire.org/spip? Article 27968

carbon is increasingly getting emitted it's full burden will be felt in the next generation, by the children who will not have benefited from the things the carbon emissions were used to produce.

"The Social Enigma" (Ramalingaswami *et al.,* 1996) point insufficient prior research and no clear consensus on the underlying causes of malnutrition after considering various theories the researchers placed the blame on the extremely low social status of women relative to men in south Asia (compared even, to Sub-Saharan Africa). The link between women's status and child malnutrition took however along time to clearly establish the factors empirically as responsible. However organizations like IFRI sought to fill this gap with a research study with data from 36 developing countries in 2003.

Children being totally dependent on mothers are severely affected due to several security losses resulting from disasters. The implications come from water nutritional, health, and environmental insecurities and climate induced migration due to climate change.

In the event of a natural disaster distribution of consequences is defined by several factors, ranging from individual and community level characteristics to the macro level infrastructure. The importance of risk in a hazard may be explained by an equation: Vulnerability +hazard= effect (cash, R.A *et al.,* 2013), vulnerability in this context is defined as "the differential capacity of groups and individuals to deal with hazards based on their positions with in physical and social worlds". Women, elderly people and children are most likely to die in natural disasters. Low income households are also at risk because their dwelling places provide least protection.

3.3 Violations of Women's Human rights

Apart from other vulnerabilities disasters showed the occurrence of sexual violence against women when lost their husband in disaster or were away to earn livelihood or while the women staying in recue camps or while fetching drinking water from far of places. Such atrocities were abundantly reported in case of poor and lower caste women in India. In Pakistan inheritance laws were biased and helped men to grab property in the times of calamities. Thus as opposed to the dominant paradigm in disaster management research which places major focus on disaster agent and the individual response, the vulnerability paradigm focuses on differential vulnerability. The contextualization of disasters with in everyday vulnerabilities recognizes the role of interlocking systems of vulnerability in both physical and social space that is, the construction of overlapping ' geographies of vulnerability' (Fordham, 1999).

The Asia Pacific Forum on Women articulated on why are women more vulnerable during disasters in the context of Tsunami aftermath. It showed that thousands of women and children in the affected countries still live in campus and other temporary facilities. Their right to food is violated. Women suffer from increased domestic violence in relief camps and shelters in India, Srilanka and Thailand as a sequel to increased alcohol consumption by the aggressors on women. The protection provided is meager and the perception of violence against women is simply a 'personal matter'. The temporary and permanent housing facilities are of substandard design and construction. Safety measures and trauma counseling are inadequate. Some of the worst violations of women's rights, involving sexual abuse, seem to have taken place in Srilanka. There had been reports of rape, gang rape, molestation and physical abuse of women and girls in the course of unsupervised rescue operations (APWLD, 2010). In another example the Sri Lankan Government gave funding to families affected by 2004 tsunami, but in the eastern coastal area of Batticalova, authorities picked up male-headed households only ignoring others where male head died in disaster.

3.4 Silver lining in the impacts

While the disasters leave grief, agony depression, and financial stress on women; Women had shown great resilience in facing the ordeal to keep their families together and to keep them safe and healthy. They responded staying at the ‘front line’ in the moments of crisis. They are also long –term caregivers to disaster effected family members. Members disabled in the calamities are looked after by women for a long time. Often they provide succor on emotional plane than their male family members, even though women like men also go through trauma and fear. When disaster occur traditional gender roles can change. Women take up non-traditional jobs like clearing roads, organizing relief works at community level and working side by side with men folk in the rural settings. They often display ingenuity and creativity in coming up with livelihood strategies.

‘Living within victimizing relationships, women in south Asia display enormous strength and capacity throughout the entire cycle of disasters; in preparation to face hazards, managing once the disaster strikes and rebuilding the damaged livelihoods (Anyabandu, 2000). The groups organized by women themselves catered to drinking water and water security issues in south east of Sri Lanka in the adverse times of floods. Likewise women’s group which operated in Banaskantha in the state of Gujarat in India initiatives for fodder security of cattle took when severe a drought struck.

4. Conclusions

The socio- economic, cultural and religious values in south Asia make women, children and the aged people highly vulnerable to disasters. A vicious circle develops from which these sections of population find it difficult to wriggle out. Death rate of women, children and aged was found to be high in disasters like that of the morbidity. Women are likely to experience violence more than men during disasters and resultant law out - breaks. The gender inequities haunt women not only on economic health, legal and psychological counts but also due to depression and gloomy thoughts regarding their future.

However, women showed more resilience in the moments of calamities. Preparedness and planning either in coping with floods or managing food and water for children and other members of the family during prolonged droughts are handled by women deftly. While men tend to see reconstruction phase of disaster in terms of physical infrastructure provision, women tend to focus on the family, community and social capital. Detailed research is needed further in clearly getting the issues informed and also management alternatives with women at the centre of stage in disaster management.

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Annexure 1: Summary of Literature Review on Climate Change, Vulnerability and Impact on Women
Christian Nellemann, Ritu Verma, Lawrence Hislop (2011) "Women at the Frontline of Climate change: Gender Risks and Hopes", UNEP, ICIMOD and CICERO
Findings:
1. Patterns of development and settlements put the poor and the vulnerable at increased risk with many forced to settle on the only land available at the time. 2. Women are often in the frontline in respect to the impacts of a changing climate. Globally the world is seeing increasingly frequent droughts and floods which are having economic but also profound social consequences. The women and people of Asia are currently greatest risk with over 100 million people affected in this region annually. 3. Women are more vulnerable to human trafficking during natural calamities due to displacement of communities. 4. The impacts on food security will become more important with increasing climate change. Adaptation will become very crucial where women are primary source for it through experience, strength and responsibilities. Sustainable adaptation must focus on gender and the role of women if it is to become successful. 5. Women's voices, responsibilities and knowledge on the environment and the challenges they face will need to be a central part the adaptive response to a rapidly changing

climate.

6. Women in the South Asia are particularly vulnerable to the impacts of disasters due to skewed power relations and inequitable cultural and social norms. At the same time, women are essential for developing sustainable adaptation options due to their knowledge, multiple and simultaneous responsibilities and as well as roles in productive areas. These include all sectors from agriculture, rangelands, biodiversity and forests, to households, income generation, livelihoods and other socio-cultural and political-economic institutions and relations.
7. Several dynamics put women at distinct disadvantage, and few programs include or focus on them for adaptation. They do not have important role in political context at any level. Moreover women are prone to adverse impacts like sexual harassment, rape and organized trafficking during drought, floods and other climate-related disasters due to breakdown of normal social controls and protections. They often discouraged from learning coping strategies and lifesaving skills.
8. Women experience acute and differential impacts given the accelerated pace of climate change. Women also provide vital hope for successful adaptation through their knowledge, experience, agency and unique role in agriculture and participation in a variety of institutions.

Recommendation:

1. Designing adaptation programs responsive to the different and multiple roles women and men play in various spheres of natural resource management.
2. Ensuring women's access, control and ownership of natural resources and institutions.
3. Invest in gender sensitive and culturally appropriate labor-saving technology which is suitable for within the communities.
4. Conduct a systematic analysis of climate change from environmental, development and gender equity perspectives to fill urgent gaps in research, knowledge and data.
5. Ensure an enabling environment for the increased participation and substantive inputs of women in decision and policy-making at different levels.
6. Ensure that education, training, awareness raising and information programs address the vulnerability and risk of gender-based violence.
7. Coordination between different government and non-government institutions must be created.

UN Women Watch (2009) "Women, Gender Equality and Climate Change", Fact sheet www.un.org/women watch/feature/Climate change

1. Women and men in rural areas in developing countries are especially vulnerable when they are highly dependent on local natural resources for their livelihood. Those charged with the responsibility to secure water, food and fuel for cooking and heating face the greatest challenges.
2. Secondly, when coupled with unequal access to resources and to decision-making process, limited mobility places women in rural areas in a position where they are disproportionately affected by climate change. It is thus important to identify gender-sensitive strategies to respond to the environmental and humanitarian crises caused by climate change.
3. It is important to remember, however, that women are not only vulnerable to climate change but they are also effective actors or agents of change in relation to both mitigation and adaptation. Women often have a strong body of knowledge and expertise that can be used in climate change mitigation, disaster reduction and adaptation strategies.

4. Furthermore, women's responsibilities in households and communities, as stewards of natural and household resources, positions them well to contribute to livelihood strategies adapted to changing environmental realities. 5. Biodiversity also comes in the form of the wealth of knowledge on the environment that indigenous people and communities possess. Indigenous knowledge comprises: an understanding of wild ancestors of food, medicinal plants and domestications with ecosystems; an awareness of the structure of ecosystems and the functionality of specific species; as well as the geographic ranges of said species. In order to further preserve biodiversity and limit its degradation, indigenous people can and should play a leading role in the global response to climate change. 6. Studies show that global warming and extreme weather conditions may have calamitous human rights consequences for millions of people. Global warming is one of the leading causes and greatest contributors to world hunger, malnutrition, exposure to disease, and declining access to water. Moreover it poses limitations to adequate housing, spurring the loss of livelihoods as a result of permanent displacement. Climate change affects the economic and social rights of countless individuals; this includes their rights to food, health and shelter. 7. Mitigation, adaptation, technology transfer and financing are critical building blocks in response to climate change.
Atiq Rehman & others (2009) Policy study on "The probable impacts of climate on poverty and economic growth and the options of coping with adverse effect on climate change in Bangladesh", Bangladesh Centre for Advanced Studies, Published by Support to Monitoring PRS & MDGs in Bangladesh, General Economics Division, Planning Commission, Government of People's Republic of Bangladesh & UNDP Bangladesh.
1. The UNDP study in Bangladesh made an attempt to assess adverse effects of climate change, variability and extremes on poverty and economic growth related to crop agriculture. 2. 50% reduction of crop production would increase poverty at the same percentage. Assessment of impacts on economic growth is difficult to find but it appears that it could reduce 12% of GDP contribution for that particular time. Effects of cyclone are more severe than flood. The experts agreed that 60% damage of crop by a cyclone increases poverty at the same percentage affecting their resources and livelihoods, and decreases economic growth by 15% for the perspective period. Thus, MDG 1 (poverty eradication and hunger) is badly affected and pushed backward. 3. Flood and river bank erosion and cyclone and storm surge have severe impacts on fisheries. These impacts affect poverty and economic growth moderately. The experts explained that these shocks damage aquaculture infrastructure and cause fish loss. This leads to loss of livelihoods of the poor fishermen and decrease nutrition status of the rural poor. Moreover, frequent warnings of cyclone lead the fishermen to stay at home for longer periods and thus their income decreased which increased poverty level. 4. Livestock rearing is an important source of income and livelihood options for the rural poor of the country. Pertinently, the impact of climate change on livestock affects the livelihood of the rural poor. It reduces livelihood opportunities, income and employment opportunities of the poor villagers. Drought, salinity intrusion and heat wave affect the sector moderately and consequently, both poverty and economic growth are moderately affected. Thus, the impacts of climate change on livestock affect poverty reduction activities and in attaining the MDGs.
SAGUN Program in Collaboration with LIBIRD (2009) "Climate Change Impacts on Livelihoods of Poor and Vulnerable Communities and Biodiversity Conservation", A case study in Banke, Bardia, Dhading and Rasuwa Districts of Nepal, CARE Nepal.

1. Climate change is expected to have many consequences for human health. Communities experienced intense heat since the last 10 years that resulted in development of allergies and itching problems, particularly in women and children. The time-lines show that communities' perception of intense heat also coincides with the spread of mosquitoes and outbreak of diseases like Japanese encephalitis and malaria.
2. Climate induced risks and disasters will contribute to pre-existing poverty, low economic development, and exclusion of communities making them more vulnerable and poor. Risks and disasters will also weaken livelihood assets and further increase their vulnerability.
3. Community members in study clearly indicated that poor, marginalized, women, children and the disabled are most vulnerable to climate change impacts as they have less capacity to cope up with such unavoidable situations.
4. Due to drought, farm labor input is increasing and poor people must input hard labor to produce enough to feed their family. Similarly, death toll from landslides, flooding and other disasters indicate that ethnic groups, Dalit's, women and children account for 70% of the total.
5. There are examples where land and livestock of poor are totally lost during flooding, and due to lack of available cultivated land and livestock their lives became miserable. There are even landless communities in Rajpur village of Bardia district in Nepal who have to rely on wage labor for their survival due to loss of their limited parcel of land.
6. Studies have found that women have to bear a disproportionate burden of climate change consequences. Women play a dominant role in subsistence agricultural production. The increasing trend of male migration for exploring employment opportunities creates pressure on women for subsistence production in addition to household chores. Moreover, climate change and its consequences increase the unpredictability and scarcity of food sources. Around 90% of female respondents reported that they were facing problems from climate change, particularly increased temperature and unpredictable rainfall that exposed them to loss of harvest, often their sole source of food and income.
7. Climate change increase household activities, burden of care giving and burden due to damage of infrastructure.

Muhammad Naseem Baig and Razia Sharif (2013), "Gender Perspective Considerations in Disasters like Earthquakes and Floods of Pakistan", World Academy of Science, Engineering and Technology 78-2013

1. In rural and in urban settings in any disaster like earthquake or flood, elements like gender perspective, their age, physical health, demographic issues contribute towards vulnerability.
2. Females are the most vulnerable and are more at risk during disasters. Females experience high rate of mortality, morbidity and dependence on others for basic needs. There are certain underlying factors which exacerbate vulnerability of female which includes cultural norms, lack of access to resources, lack of initiative ability, in most cases deprived of education and even on basic health and other needs.
3. Male and female vary in needs, priorities, capacities in setting of disaster and their resilience also varies. The most obvious examples are Pakistan flood 2010 and Kashmir 2005 earthquake. If women deaths are less than men, women suffer more in cases like family separation. Women completely rely on husband resulting in financial and moral crises.
4. From the study of 2005 earthquake and 2010 floods in Pakistan the most palpable ways in which women suffered includes following:
   Women loss interest in daily life activities if her close family member died.

- Lack of legal rights particularly for illiterate women.
- Girls if become orphan than in most cases she becomes more vulnerable economically.
- Emotionally unstable if her close one died in disaster.
- Lack of privacy in shelter camps which enhance sense of insecurity.
- Increased sense of responsibility which sometimes makes it difficult to even fulfils basic needs.

Recommendations:

- Social context differ from country to country and even culture to culture so need is to investigate it locally.
- Both men and women should be involved in prevention, preparation (emergency plans, education) and in recovery phase.
- Disaster management assessment teams should include gender specialists as well.
- Gender audit assessment must be carried out which ensures collection of complete gender related data.
- Particular attention should be given to women workload.
- There is a need to develop gender based training programs, Case based training exercises and training courses should also be developed.
- Since disasters also provide opportunity so need is to respect and develop the capacities of women.
- Implementation of gender integration in all tiers to be ensured which will enhance the achievement of MDG's.

Sara Ahmed (2004), "**The Gendered Context of Vulnerability: Coping / Adapting to Floods in Eastern India" as part of the Adaptive Strategies project, funded by USAID through ISET (USA/Nepal)**

According to Cannon (1994): "there are no really generalized opportunities and risks in nature, but instead there are sets of unequal access to opportunities and unequal exposure to risks which are a consequence of the socio-economic (and increasingly, political) system….It is more important to discern how human systems themselves place people in relation to each other and to the environment than it is to interpret natural systems," (cited in Morrow 1999: 2). That is, vulnerability is linked to complex sets of interacting conditions, some related to geography and location (for example, where do the poor reside in flood-prone villages) others with the nature of the dwelling (Kachcha or pucca houses) and access to physical infrastructure (potable water supply systems), and some with everyday patterns of social interaction and organization (social networks, community institutions). Thus, the contextualization of disasters within everyday vulnerabilities recognizes the role of interlocking systems of vulnerability in both physical and social space that is, the construction of overlapping 'geographies of vulnerability' (Fordham 1999: 19).

1. Asia as continent is particularly vulnerable to disaster. Between 1991 and 2000, the continent accounted for 83% of the population affected by disasters globally. India accounted for 24% of disaster deaths in Asia during this period, mostly due to floods and cyclones. Nearly 4 crore hectares of land area in the country are flood prone, while 68% of the net sown area is vulnerable to drought.
2. During disaster moments that the intersection of gendered identities with other cultural identities for example, of caste, community or tribe become critical, either providing a means of social support or at worse, denying access to basic rights-for example, a Dalit

women in the drought prone districts of northern Gujarat may have to walk further to collect water than say a Koli patel women if she is not allowed access to the village 'common' well or tank. In such conditions, sexual exploitation by upper caste men is not uncommon, particularly when familial men are not around (migrated) to 'protect' their wives/daughters/sisters, though in many cases the vulnerability of the poor is so critical that protection becomes a meaningless concept for women.

3. Household level analysis provides us with a means of looking at certain critical types of gendered inequality it cannot be separated from wider social norms shaped by patriarchy, class and caste which define or prescribe women's movements, behavior and attitude (sex role stereotypes) or larger economic policies (globalization, structural reforms) and demographic trends (often sharply contrasting, e.g. longevity of life and a declining sex ratio). This does not mean that women only remain as victims of embedded social, economic and political processes even though they are 'victimized' during disasters.

APWLD (2005), "Why are women more vulnerable during disasters? "-Violations of Women's Human Rights in the Tsunami Aftermath, Asia Pacific Forum on Women, Law and Development.

1. Thousands of women and children in the affected countries still live in camps and other temporary facilities which lack adequate sanitation, clean water, health services and security. Government compensations have not reached them or are insufficient to restore their livelihoods.
2. Women's right to food is violated: People are on the verge of starvation getting one meal a day. The food rations provided are of very low quality. This affects health of children and pregnant, breast feeding and elderly women.
3. Women suffer from increased domestic violence in relief camps and temporary shelters, especially in India, Sri Lanka and Thailand as a result of increased alcohol consumption. Protection provided by the police and camp administration is inadequate because of the general perception of violence against women being "a personal matter".
4. Both temporary and permanent housing facilities are of low standards in design and construction and climatic conditions have not been taken into account.
5. The tsunami exacerbated women's access to land. Women in Aceh and India do not have ownership rights to land registered to their husband and father's names as women are not recognized as head of household.
6. In India, entire communities of? Dalit (so-called untouchables) and *Irula* (indigenous people) have been left out of relief and rehabilitation efforts. They have not been receiving any assistance from the Indian Government as they are not seen as directly affected by the tsunami although they have lost their livelihood sources.
7. Experiences of women from all communities affected by the tsunami continue to point to the fact that more women have moved into the public arena and are developing their leadership capacities as well as making practical interventions at every level, locally and nationally. However, the patriarchal nature of the different government and non-governmental institutions and agencies that are engaged in making decisions and designing policies and programs results in the almost complete exclusion of women from these higher levels of engagement.
8. Post-tsunami process becomes more focused on permanent resettlement and livelihoods, the need to keep a gender-sensitive approach and focus becomes all the more imperative. In particular, a gender-sensitive approach the focuses on men and

	on male responsibility in all sphere of life would be critical if the post-tsunami phase is to facilitate the advancement of women. 9. Issues of equal rights for women in land allocation and housing and other grants and benefits still must remain a priority on the agenda because the categories of women slip through the fault lines in the system-widows, female heads of household, single women, disable and elderly women-are large and varied. 10. Some of the worst violations of women's rights, involving sexual abuse, seem to have taken place in Sri Lanka. There have been reports of incidents of rape, gang rape, molestation and physical abuse of women and girls in the course of unsupervised rescue operations and while resident in temporary shelters. 11. Special needs of women like health and reproductive care and privacy needs have been ignored during tsunami relief programs. The camp committees have been dominated by male. Women are too shy to request sanitary towels and contraceptives from male leaders of the camp. 12. Safety must be guaranteed to women and girls in IDP camps. Adequate measures must be taken to prevent violence against women and children. 13. Trauma counseling must be provided for women and children-survivors of the tsunami. Revolving funds for women must be established to facilitate income generation. Vocational training for women should be provided. Special support for women, especially heads of the household, must be provided e.g. education support for their children. The affected communities, including women, must be able to participate in the rehabilitation management, including environmental and coastal resources management.
	Tharuka Dissanaike (2008), "A South Asian perspective on Climate Change and increased Disaster Risk", South Asia Disaster Report Special Copenhagen Issue, Practical Action.
	1. South Asia recorded 128 natural disaster events between 2006 and 2008. 93% of these were of hydro-meteorological origin. 86 incidences of flooding were reported, with nearly 8000 lives lost. India had by far the highest number of disaster events, but flooding in Bangladesh claimed most lives (South Asia Disaster Report 2008) 2. In recent Global Assessment Report (GAR) the UN International Strategy for Disaster Reduction (UNISDR) published a risk model that assesses a country's exposure to natural disasters in terms of mortality (based on historical data and known vulnerability information) and economic losses. A risk classification of 10 points signifies extreme mortality risk. All South Asian countries are positioned above 5, with Maldives assigned an unknown classification. Bangladesh and India are classified as 9 (major risk) Pakistan and Afghanistan as 8 (very high risk), Nepal and Bhutan as 6 and Sri Lanka as 5 (medium risk). 3. The South Asia Disaster Report (SADR) 2008 argued that the benefits of South Asia's high economic growth have accumulated in the hands of a few privileged individuals and have failed to trickle down to the poor. Instead, poverty has escalated, resulting in increased vulnerability to natural hazards. At the same time mal-development has introduced new hazards and risks. Climate change is fast becoming the biggest source of mal-development induced disasters.

Module 6: ***Technological Strategies for Adaptive Water Management within the framework of IWRM for mitigating the Impacts of Climate Variability***

Drought Proofing: Groundwater Management in Semi-Arid and Arid Regions of South Asia

M. Dinesh Kumar[8]

1. INTRODUCTION

Groundwater plays an important role in many dry regions of the world because of the large size of the stocks and reliability of supply, as compared to unreliable surface water supplies (Schiffler, 1998), which has high inter-annual and inter-seasonal variability. In irrigation, wells seem to have inherent advantages over surface systems. A study for the Andalusian region in Southern Spain shows that each cubic meter of groundwater used for irrigation provides five times more money and almost four times more jobs than a cubic meter of surface water used also for irrigation (Hernández-Mora, N., Llamas, M.R. and Martínez, L. (1999).

South Asia has some of the most intensive users of groundwater in the World. India, which is the largest of all South Asian countries in terms of population and crop land, annually draws nearly 243 billion cubic metre of water from wells, making it the largest consumer of groundwater in the World. Groundwater use for irrigation is intensive in the Indus basin area of Pakistan. Bangladesh has million shallow tube wells and hand-pumps, mainly for irrigation and domestic use, respectively.

Agriculture is the largest user of groundwater in South Asia, and well irrigation accounts for a significant chunk of the irrigated area in these countries--from 64% in India to 79% in Bangladesh to 64% in Pakistan (2/3rd of it from conjunctive use) to around 20% in Nepal, which is confined to the Tarai region. As per some estimates, well irrigation accounts for nearly 9% of India's GDP. The percentage is much higher for Pakistan, Afghanistan, Bangladesh, which are more agrarian than India. Groundwater also meets a major portion of the domestic water needs in urban as well as rural areas in all South Asian countries, except Sri Lanka. South Asia's groundwater is characterized by great heterogeneity in the physical factors affecting resource availability such as geology, geo-hydrology, rainfall and climate, and physical and socio-economic factors affecting it use such as climate, and degree of intensification of farming, rural electrification and market access.

Problems of groundwater over-draft are growing in semi-arid and arid regions of South Asia, with annual abstraction far exceeding recharge. In the alluvial areas of Punjab, north Gujarat and western Rajasthan in India, and Punjab and Baluchistan provinces of Pakistan, this has resulted in sleep decline in water levels, increasing the cost of pumping groundwater. Whereas in hard rock areas, which have limited groundwater potential, well failures, drying wells and reducing well yields are a common phenomenon. While there has been an exponential increase in number of wells in these regions, the total area irrigated by wells has stagnated. Salinization of groundwater is a major problem in the coastal areas of many states affecting safe water supply for drinking. A large proportion of the rural water supply schemes in the hard rock regions, are dependent on groundwater sources, on which agriculture is a major claimant. Their sustainability is threatened by un-controlled withdrawal for irrigated crop production. Yet, much less attention

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is being paid to addressing depletion problems in hard rock areas. Part of the reason is the resource assessment methodologies. They are yet not perfected for hard rock areas, and thus fail to quantify the magnitude of the problems.

Soil salinization due to use of poor quality groundwater for irrigation has become a major problem in the command area of Indus basin irrigation system in Pakistan, affecting around 4.5 m. ha of crop land in that region.

Groundwater depletion, water quality deterioration and widespread well failures in the country-side put the advancements in social development and livelihoods of agricultural communities of the rural areas in jeopardy. Depletion also has a major adverse impact on the viability of power sector as groundwater irrigation is sustained by huge subsidies for electricity in the farm sector. It touches nearly US $ 5 billion per annum in India alone. Yet, the development discourse and programme interventions on groundwater management have so far focused on implementing schemes for artificial recharge of aquifers, watershed management and community regulation of groundwater pumping to arrest depletion, top-down regulations focusing on electricity supply restrictions, denial of electricity connections and ban on drilling of new wells, with least attention being paid to the physical, socio-economic and environmental contexts. But, the available research points that such approaches are not only ineffective, but often counter-productive. However, this is not fully recognized at various levels.

Strikingly, there seems to be very little appreciation of the need to focus on demand side approaches to managing groundwater and the various institutional and policy interventions required to make them work. Micro irrigation has been projected as the panacea for reducing groundwater draft in agriculture. But, there is inadequate understanding of the conditions under which they become best bet technologies. This note discusses the various supply and demand side options for groundwater management in the context of semi-arid and arid parts of India, and their scope and limitations.

2. PHYSICAL APPROACHES FOR GROUNDWATER MANAGEMENT

There are three different types of benefits that could accrue to the society from a management intervention. They are: economic benefits; ecological/environmental benefits; and livelihood benefits. Hence, the societal point of view, a management decision would be sound, only if the aggregate of these benefits exceed the costs of the proposed interventions. The aggregate benefits are a sum of the economic benefits and all the positive externalities on the society associated with the environmental/ecological and livelihood benefits. They depend on the economy also. In developed economies, the prices which society is willing to pay for environmental services would be high. Here, the costs can be economic, social and environmental.

Supply Side Approaches

Several of the negative consequences associated with groundwater over-exploitation are a result of net groundwater outflows exceeding the net inflows into the groundwater system. Whereas the negative consequences associated with under-utilization of groundwater, are groundwater inflows exceeding out-flows.

The outflows could include: groundwater draft; evapo-transpiration of groundwater from shallow aquifers (both anthropogenic); groundwater outflows into streams and natural drainage and sinks; and regional (lateral) groundwater flows. The inflows include: natural recharge from precipitation (rainfall and snow); regional (lateral) groundwater inflows; recharge from natural water bodies such as lakes, ponds, tanks and river flows; and recharge from irrigation (both conveyance systems and irrigation water application in the field) (Todd, 1997).

The negative consequences associated with over-exploitation could be in the form of secular decline in water levels; seasonal drops in water levels; intrusion of sea water in coastal aquifers, resulting in salinity of the fresh groundwater; land subsidence occurring due to mining of deeper confined aquifers; and deterioration of natural quality of groundwater due to leakages from saline aquifers as a result of hydraulic gradients, and geo-hydro chemical processes; and reduction in stream flows. The negative consequences of under-utilization could be in the form of water-logging and salinity.

The interventions to manage groundwater should attempt: at changing the outflows that are the results of anthropogenic activities, which can be managed through human actions; ii] changing the components of inflows that can be manipulated by human actions. However, here we would only deal with the issues of over-exploitation. So, approaches that are being discussed here would cover those to augment the inflows and cut down groundwater outflows due to human interventions.

Water Harvesting and Local Recharge

While water harvesting has a long tradition in many south Asian countries, modern water harvesting systems, that are being used to recharge depleted aquifers in many arid and semi-arid regions, are in vogue only during the past couple of decades. Some of the technologies which are being tried out in different parts of India and elsewhere are: a] check dams; b] percolation tanks; c] percolation tanks with recharge tube wells; d] spreading basins; e] induced recharge[9]; f] sub-surface dykes; and g] injection method. India has vast experience in undertaking local recharge schemes, based on check dams across streams and rivers (Saurashtra, Madhya Pradesh; Rajasthan); percolation ponds (hard rock areas of peninsular India) and percolation ponds with recharge tube wells (north Gujarat and Kachchh); and sub-surface dykes (Kachchh region, and Bharathapuzha river in Kerala). Injection method of recharging is resorted to when the required hydraulic head between the surface stream and the water table in the aquifer to be recharged is not available.

But, the physical viability of local artificial recharge scheme depends on many factors: 1] the magnitude and pattern of rainfall in the locality; 2] inter-annual variability in rainfall; 3] the magnitude, pattern and inter-annual variability in runoff[10]; 4] the potential evaporation; 5] infiltration characteristics of the soils; 6] the characteristics of the aquifers to be recharged (storage potential and hydraulic diffusivity). Low and erratic rainfall and high aridity reduces the hydrological opportunities for recharge. High inter-annual variability in rainfall reduces the dependability of water supplies from recharge schemes. These are characteristic of many arid and semi-arid regions which experience groundwater over-draft problems; be it peninsular and western India or Indus basin parts of India. Poor infiltration capacity of soils and poor storage potential of aquifers further reduce the efficacy of recharge.

For a given area, the overall economic viability of recharge schemes depends on the runoff characteristics, the inter-annual variability in runoff, and the geo-hydrological environment. The economic viability of recharge would be less if flash floods are characteristic of the locality and more if runoff occurrence is even. High inter-annual variability in runoff would reduce the cost effectiveness of recharge schemes. In regions underlain by hard rock formations, the physical efficacy of recharge systems would be generally low due to the formation of a recharge mount below the structure, which prevents further percolation of the water in the

[9] Water is pumped from the shallow aquifer, which is hydraulically linked to a natural water course, to increase the hydraulic gradient between groundwater and surface water. This helps increase the natural recharge from river channels to shallow aquifers.

[10] This is the function of the magnitude, intensity and pattern of rainfall.

structure (Muralidharan and Athavale, 1998). The cost of artificial recharge through four different types of recharge systems in Rs/m^3 of water are presented in Table 1 below.

But, in basins with high degrees of water development, the economic viability of artificial recharge interventions cannot be performed for individual schemes, but should be done at the basin level, taking incremental hydrological benefit against the incremental costs. The reason is that the recharge schemes in one area could reduce the committed flows in other water impounding/diverting systems downstream[11]. In "closed basins", though local water harvesting might augment the local water resources, it would divide the renewable water resources in the basin, rather than augmenting it. In many water-scarce regions of the world, which also experience groundwater over-exploitation problems, basins are either "closed" or are on the verge of "closure". Some examples are river basins in Peninsular and western India; Yellow river basin in north China; and, Indus basin in India and Pakistan.

Table 1: Estimated Unit Cost of Artificial Recharge Structures Built under Pilot Scheme of CGWB

Type of Recharge Structure (Life in years)	Expected Active Life of the System	Estimated Recharge Benefit (TCM)	Capital Cost of the Structure (in Lac Rs.)	Cost of the Structure per m^3 of water (Rs/m^3)	Annualized Cost* (Rs/m^3)
Percolation Tank	10	2.0-225.0	1.55-71.00	20.0-193.0	2.00-19.30
Check Dam	5	1.0-2100.0	1.50-1050.0	73.0-290.0	14.60-58.0
Recharge Trench/Shaft/	3	1.0-1550.0	1.00-15.00	2.50-80.0	0.83-26.33
Sub-surface Dyke	5	2.0-11.5	7.30-17.70	158-455.0	31.60-91.00

Source: GOI, 2007, Table 7: pp14

*Estimated by dividing the capital cost by the life of the system

A recent analysis looking at the hydrological opportunities and economic viability of artificial recharge programmes for India brought out the following issues. 1. It lacks emphasis on potential local supplies and the demand it has to cater to. While local supply potential is low in most water scarce regions, compounded by poor reliability, demand far exceeds the supply potential. 2. There are complexities involved in economic evaluation of RWH, due to paucity of scientific data on inflows, runoff collection and storage efficiency, beneficiaries, value of the incremental benefits generated and scale considerations. With higher degrees of basin development, the marginal benefit from water harvesting at the basin level reduces, while marginal cost increases. 2. In many basins, there is a strong "trade off" between maximizing hydrological benefits and improving cost effectiveness. 4. Many water-scarce basins are characterized by wide disparity in demand between upper catchments and lower catchments, due to which there is a trade off in maximizing benefits of upstream water harvesting with optimizing basin-wide benefits. 5. In many water-scarce basins, local water harvesting only divides the hydrological benefits rather than augmenting. 6. Lack of integration between surface water system and groundwater system reduces the potential of artificial recharging in hard rocks which also coincide with water-scarce regions (Kumar *et al*., 2006).

Groundwater Banking

11 See Kumar *et al*. (2006), Kumar et al. (2008) and Ray and Bijarnia (2006) for detailed discussions

In semi-arid and arid regions, the scope for obtaining excess endogenous water for recharging is often limited to a great extent. Hence, recharging aquifers in such regions would require import of surplus water from water-rich regions. Since the regions which experiences high variability in rainfall coincide with the regions which experience groundwater over-draft in peninsular India and western India and north western India, they offer ideal environment for storing surplus runoff from water-rich regions. During droughts, the aquifers in these regions have large space to store incoming flows. But, such schemes can work under the following conditions. The value of the direct economic, social and environmental benefits accrued from recharge in the importing region exceeds the foregone benefits in the donor basin/region due to water export. This essentially means that scale of water transfer for recharge should be such that the marginal social benefits should exceed the marginal social costs.

Australia used groundwater banking as a means to store excess runoff during wet years and use in years of drought. Groundwater banking is done to prevent evaporation from surface storages, promote efficient use of water and to make water available at the points of demand. It was estimated that Australia loses around 8,000 MCM of water per year through evaporation from surface reservoirs, and of which 3000 MCM was from the Murray Darling basin alone. Groundwater banking project is regularly done in three regions of Australia, viz., Adelaide, Northern Territory and Burdekin Delta of Queensland (Hostetler, undated).

The United States had used recharge using spreading basin method on a large-scale in California using water imported from the Central Valley Project in Colorado basin. It is to be noted here that a major constraint in using techniques such as spreading basin in semi-arid regions of India is the scarcity of land, which can be spared for undertaking such schemes. In many water-scarce regions of India, the option of importing water for improving groundwater condition can be explored, as availability of local surface water for recharging is extremely limited; its dependability is poor; and the basins in these regions are already fully developed. But, such schemes should meet the social benefit-cost criteria. A study by Ranade and Kumar (20004) analyzed the physical feasibility and economic viability of recharging the shallow alluvial aquifers of north Gujarat in western India using water imported from Narmada Main Canal of Sardar Sarovar project. The study found that recharging the aquifers in the canal command area using water transferred through gravity would be economically viable.

Recharge of Treated Wastewater

Wastewater is going to become an important source of water for meeting future water needs in many regions in India and Pakistan. If treated to desirable levels, which would require tertiary treatment in most cases, wastewater can be used for drinking purpose as well. The advantage with wastewater is that the flows are often more stable and uniform than the natural stream flows. This increases the cost effectiveness of the recharge scheme. Israel is one country which undertakes large-scale artificial recharge of groundwater using treated wastewater. Wastewater from 10 cities (DAN region) in the country is diverted for treatment and recharge. The water is subject to secondary treatment using stabilization ponds and soil aquifer treatment (SAT). This water is pumped out before the recharge mount diffuses and recharge water mixes with the natural storage in the aquifer. This prevents contamination of natural quality water. The pumped water is used for irrigation purpose. In Israel, the untreated wastewater is used for SAT, whereas in the United States, secondary treated wastewater was used for SAT.

In SAT, the quality of raw water which is used for recharging the aquifer changes significantly. Maximum amelioration takes place for BOD/COD. Good nitrogen removal is generally achieved by nitrification-denitrification, ammonia adsorption and particulate N filtration. Phosphorus removal is excellent by chemical precipitation and adsorption. Reduction in infiltration capacity of the recharge basin can significantly affect the efficiency of removal of organic and inorganic pollutants. This is due to the formation of predominantly anaerobic conditions in the soil-aquifer system. Therefore, it is important to ensure sufficient drying periods for oxygen penetration into the soil. Also, the top soil needs to be scrapped to remove the organic matter and the chemical precipitates. The pollutant removal efficiency of SAT for different types of pollutants is given in Table 2.

Table 2: Pollutant Removal Efficiency in SAT

Name of the Pollutant	Concentration Before SAT	Concentration After SAT	Efficiency of Removal
SS	10-80	0.0	100
BOD	5-40	0.50	98
COD	40-160	10-20	85
CODf	40-80	10-20	75
DOC	15-20	3-6	74
UV Absorption	150-400	30-80	80
Detergent	0.40-1.0	0.05-0.20	82
Total N	5-30	5-10	57
Total P	3-10	0.01-0.03	99

Source: Idelovitch, 2003

The pre-treatment requirements for SAT vary depending on the purpose of groundwater recharge, sources of reclaimed water, recharge methods, and location. Some may only need primary treatment or treatment in a stabilization pond. However, pre-treatment processes should be avoided if they leave high algae concentrations in the recharge water. Algae can severely clog the soil of the infiltration basin. While the water recovered from the SAT system has better water quality than the influent, it could still be of lower quality than the native groundwater. Particularly, the concentration of nitrate in the recharge water would be high (see Table 2). Therefore, the system should be designed and managed to avoid intrusion into the native groundwater and use only a portion of the aquifer. The distance between infiltration basins and wells or drains should be as large as possible, usually at least 45 to 106 m to allow for adequate soil-aquifer treatment (Metcalf, 2002).

The detailed economics of SAT is provided in Table 3 below.

Table 3: Economics of SAT: The Israel Experience

Sr. No	Source of Water	**US $/100m^3**
1	Conventional Water Sources	25-30
2	Wastewater Reuse	
	a. Secondary biological treatment	5-15
	b. Tertiary chemical treatment	10
	c. Deep reservoir treatment	7-15
	d. Soil aquifer treatment	17
	e. Total DRT (a+b)	12-30
	f. Total SAT (a+ d or a+ b+ d)	22-42
3	Desalination of brackish water	40-60
4	Desalination of sea water	60-100
5	Dan Region Project	
6	Treatment prior to SAT (a or a + b)	15
7	SAT (d)	17
8	Conveyance and Distribution after SAT	13
	Total Dan Region Project at point of use	45

Source: Idelovitch, 2003

Note: Cost of SAT (item d) includes that of recharge, monitoring and pumping

Demand Management Options

Demand management has received a great deal of attention in the groundwater management discourses in the recent decades, especially due to the limitations of supply-side options. The regions, where groundwater over-draft problems are mainly occurring, are also regions where agriculture accounts for a larger share of the total consumptive water use. Hence, most of the discussions on water demand management had looked at the scope of managing the demand for irrigation water. Improving water productivity in agriculture is a pre-requisite for water demand management (Molden *et al*., 2001) though may not necessarily result in reduction in demand for water in the sector. We would deal with this issue in the later part of this section. Some of the physical approaches to demand management are: i] use of efficient irrigation technologies; ii] improving the reliability and control of irrigation water application; iii] changing water allocation including deficit irrigation; iv] plastic mulching; and, v] introduction of water efficient crops, which give greater income return per unit of water consumed.

Water Efficient Irrigation Technologies

Table 4 gives a list of water efficient irrigation technologies, the names of crops to which the technology is amenable, and the nature of water saving possible.

Table 4: Nature of Water Saving for Different Crops under Different Types of Efficient Irrigation Devices

Name of water-saving and yield enhancing micro irrigation technology	Names of crops for which the technology can be used ideally	Nature of Saving in Applied Water
Pressurized drip systems (inline and on-line drippers, drip tape)	All fruit crops; cotton; castor; fennel; maize; coconut; aracnut; chilly; cauliflower; cabbage; ladies finger; tomatoes; eggplant; gourds; mulberry; sugarcane; water melon; flowers	1. Reduces non-beneficial evaporation (E) from the area not covered by canopy 2. Reduces deep percolation 3. Water saving also comes from reduction in evaporation from fallow after harvest 4. Extent of water saving is higher during initial stages of plant growth 5. Significant yield and quality improvement.
Overhead (movable) sprinklers (including rain guns)	Wheat; pearl millet; sorghum; cumin; mustard; cow pea; chick pea, grasslands and pastures, tea estates	1.Reduces the losses in conveyance 2. Improves the distribution efficiency marginally 3. Reduces deep percolation 3. Yield growth is marginal
Micro sprinklers	Potato; ground nut; alfalfa; garlic and onion, herbs and ornamentals	1. Reduces the seepage and evaporation losses in conveyance.2. Reduces deep percolation over furrow irrigation and small border irrigation 3. Yield growth and quality improvement is significant
Plastic mulching	Potato; ground nut; cotton;	1. Completely checks the evaporation

	castor; fennel; brinjal; chilly; cauliflower; cabbage; ladies finger; flowers; maize	component of ET 2. Stops non-beneficial evaporation (E), kills weeds and pests 3. Extent of water saving is higher over drip irrigation 4. Faster germination and significant yield growth
Green houses	All vegetables, high valued fruits such as strawberry; and exotic flowers, nurseries, vegetative propagation	1. Controls the ambient temperature and humidity, 2. Checks the wind, thereby reducing transpirative demand of plant. 3. The water-saving is highest as compared to other technologies 4. There is substantial yield growth, quality improvement and nutrient savings.
Micro tube drips	All horticultural and plantation crops	1.Reduces non-beneficial evaporation 2. Distributional uniformity is poor and depends on number of micro tubes on a lateral

Source: Kumar *et al*. (2008a)

Field Level Impact of Water Efficient Irrigation Technologies on Real Water Saving[12]

The overall impact of water saving at the field level on basin level WP improvements and water saving had been thoroughly discussed by several scholars, starting from the work of Seckler (1996). They challenge the conventional ways of looking at irrigation efficiencies at the system level that compared the water consumed by the crop against the water delivered. Subsequently, many researchers highlighted the economic surplus created from this “wastage” generated from irrigation (Allen *et al*., 1998; Howell, 2001; Lankford, 2012; van Halsema and Vincent, 2012). Allen *et al*. (1998) provided several interesting examples of how the water which returns from irrigated fields in technically inefficient irrigation systems creates downstream economic benefits such as reduced cost of groundwater pumping, river fisheries, and hydropower production during low-flow seasons. Van Halsema and Vincent (2012) noted that irrigation efficiency is best suited in analyzing performance of irrigation schemes, and ‘water productivity’ is best suited to basin level analysis.

While it is clear that increased irrigation efficiencies to increase the percentage of consumed fraction (CF) in the water supplied might increase the net surplus in the command area or elsewhere through reallocation of the saved water, it is also clear that such interventions would reduce the downstream economic benefits (Molle *et al*., 2004). Hence, the saving from such efforts is treated as “dry water saving”. But there are no empirical studies which examined whether this trade-off is comparable, using real life examples.

Nevertheless, the possibility of enhancing WP (Kg/m^3) through efficient irrigation technologies combined with improved crop varieties and agronomic practices has been widely acknowledged. Such routes to enhance water productivity also lead to “wet water savings” (Howell, 2001). While there is sufficient evidence on the direct relationship between ET and yield (Rockström *et al*., 2002), it has made at least a few scholars argue that reduction in “water depleted’ and therefore “wet water saving” at the field scale is not possible through such technologies without reducing yield unless we use better crop varieties or agronomic practices. But, this argument ignores the fact that a good percentage of the water applied to the crop under

[12] This entire section is drawn from Kumar and van Dam (2013).

traditional method of irrigation, such as flooding or border irrigation, is lost in evaporation from the surface of the soil which is not covered by canopy during the growing stages. Other losses are the moisture gain of the fallow soil after the crop harvest and percolated water to deeper soil layers. In other words, they fail to distinguish between ET and total water consumed. The water balance formula, given in Eq. 1, explains this:

$$\mathrm{I} + Q_{\mathrm{SOIL}} = ET_{\mathrm{BEN}} + E_{\mathrm{NON-BEN}} + DP_{\mathrm{NON-REC}} + DP_{\mathrm{REC}} \text{---- (1)}$$

Here, consumed fraction (CF) as defined by Allen *et al*. (1998) would be:

$$([ET_{\mathrm{BEN}} + E_{\mathrm{NON-BEN}} + DP_{\mathrm{NON-REC}}] | [I + Q\_SOIL]) \text{ .... (2)}$$

Where $I$is irrigation; Q_{SOIL} is the water used up by the crop from the soil profile, which includes the amount of precipitation during the growing season; ET_{BEN} is beneficial evapo-transpiration; $E_{\mathrm{NON-BEN}}$ is the non-beneficial evaporation from the soil surface; $DP_{\mathrm{NON-REC}}$ is non-recoverable, deep percolation; DP_{REC} is recharge to groundwater or runoff, which can be captured downstream.

Kumar *et al*. (2008c) discussed five major factors that determine real water saving through the use of micro-irrigation (MI) technologies. These are: 1] type of crop, particularly the spacing between plants; 2] type of MI technology; 3] soil type, whether light or heavy textured soils; 4] climate, arid and semi-arid or humid; and 5] geo-hydrology, particularly the depth to groundwater table. These are also drivers of crop water productivity improvement. The potential for 'wet water' saving through the use of MI technology increases with increase in distance between plants, more drip irrigation, more sandy soils, more arid climate and larger depth to groundwater. Looking at the water accounting formula given in Equation 2, it is clear that these technologies might be able to reduce the consumptive use, without reducing the beneficial ET and the yield thereby leading to "wet water saving" not only for row crops but also for some field crops with closely spaced plants. This is through reduction in evaporation from the excessively wet soil ($E_{\mathrm{NON-BEN}}$) or reduction in non-reusable deep percolation or flow into saline water bodies ($DP_{\mathrm{NON-REC}}$) resulting from water application in excess of the soil moisture deficit in the root zone. But, as noted by Howell (2001), this is highly dependent on the location.

However, the distinction between ET_{BEN} and CF is often not made by scholars in analysing the impact of depleted water on yields. Hence, an automatic conclusion is that real water saving at the basin level is not possible without changing ET (C. Perry in Frederiksen *et al*., 2012: p.197), or affecting other uses in water-scarce basins (Molle *et al*., 2004). In the context of alluvial plains of north Gujarat, with semi-arid climate and deep groundwater table, real reduction in depleted water would be possible through the use of water efficient irrigation technologies. This will be through reduction in non-recoverable deep percolation. It is quite likely that reduced dosage of irrigation had led to reduced recharge, but the empirical evidence seems to suggest that it also led to reduction in $E_{\mathrm{NON-BEN}}$ and$DP_{\mathrm{NON-REC}}$, without affecting transpiration.

The real water saving that can be achieved through MI system would be high under semi-arid and arid climatic conditions. This is because the non-beneficial depletion of moisture from the exposed soil would be high under such situation due to high temperature, wind speed and low humidity. Such losses would be significant during initial stages of crop growth when canopy cover is small[13].

[13] For instance, direct dry seeded rice in wet season and direct wet seeded rice in dry season were found to be effective ways of saving water in rice irrigation over transplanted rice (Tabbal *et al*., 2002). Similarly, large amount of research in India has demonstrated the benefits of applying irrigation after 2-3

The real water saving would be more for row crops, including orchards, cotton, fennel, castor, and many vegetables, where the spacing between plants is large. The reason is the area exposed to solar radiation and wind between plants would be large, and as a result the non-beneficial evaporation would be a major component of the total water depleted, under traditional method of irrigation. With drip irrigation, water could be directly applied to plants, preventing this loss. Such row crops are widely grown with drips and sprinklers in arid and semi-arid regions of India. Hence, the reduction in non-beneficial evaporation from soils and non-recoverable deep percolation, and hence actual water saving through micro irrigation could be in the range of 10-25 per cent depending on the type of crops and the natural environment, determined by soil conditions, climate and geo-hydrology.

Aggregate Impact of Water Saving Technologies on Water Use in Agriculture

There is debate about the extent of water saving at system and basin level due to the widespread adoption of MI systems. This concerns 1] whether there is a real water saving at the first place, and 2] what users do with the saved water. We have addressed the first question in the earlier section. As regards the second question, many scholars believe that the aggregate impact of drips on water use would be similar to what it makes on water use in unit area of land. While several others believe that with reduction in water applied per unit area of land, the farmers would divert the saved water for expanding the area under irrigation, subject to favourable conditions with respect to water and equipment availability, and power supplies for pumping water (Kumar, 2002).[14], and therefore the net effect of adoption of micro irrigation systems such as drips and sprinklers on water use could be nil or insignificant at the system level. At the same time, there are others who believe that with adoption of WSTs, there is a greater threat of depletion of water resources, as in the long run, the return flows from irrigated fields would decline, while area under irrigation would increase under WSTs.

These arguments have, however, missed certain critical variables that influence farmers' decision making with regard to area to be put under irrigated production, and the aggregate water used for irrigation. They are: groundwater availability vis-à-vis power supply availability; crops chosen; and amount of land and finances available for intensifying cultivation. The most important of these factors is the overall availability of groundwater in an area; and the power supply situation vis-à-vis water availability in the wells.

If power supply restrictions limit pumping of groundwater by farmers, then it is very unlikely that as a result of adoption of conventional WSTs, farmers would expand the area under irrigation. Let us see how this happens. In the states of Punjab, Gujarat, Karnataka and Madhya Pradesh, power supply to agriculture sector is only for limited hours (GOI, 2002). It acts as a constraint in expanding the irrigated area, or increasing irrigation intensity, in those areas where groundwater availability and demand is more than what the restricted power supply can pump.

Since the available power supply is fully utilized during winter and summer seasons, farmers will be able to just irrigate the existing command with MI system. This is because the well

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days of disappearance of applied and ponded water. Field studies conducted on System of Rice Intensification (SRI) also showed significant reduction in applied water use owing to reduction in the duration for which the field remains under submerged conditions (Satyanarayana, 2004; Tiyagarajan, 2005). Majority of this reduction could have possibly come from reduction in deep percolation of water from the paddy field.

[14] If power supply is more than what is required to pump the available water from wells, then water saving can lead to expansion in irrigated area. Whereas, if power supply is less than what is required to pump the available water from wells, then water saving per unit area cannot result in area expansion (Kumar, 2002).

discharge would drop when the sprinkler and drip systems connected to the well outlet start running, owing to increase in pressure developed in the system (please see equation below). In other words, the energy required to pump out and deliver a unit volume of groundwater increases with the introduction of MI system. The only way to overcome this is to install a booster pump for running the MI system. As electricity charges are based on connected load, farmers have least incentive to do this.

$$Q = \frac{\beta * 100 * \eta}{H}$$

Where, "BHP" is pump power in kilowatt/sec, "H" is the total head, "Q" is the discharge. η = combined electrical and hydraulic efficiency of pump set.

Such outcomes are expected in the alluvial areas of north Gujarat and Punjab. In this area, even in situations of availability of extra land, it won't be possible for farmers to expand the area under irrigated crops due to restrictions on power supply.

The analysis of data collected from north Gujarat recently reemphasizes this point. A survey of data collected from 114 adopters of MI systems showed that while the water use per unit area reduced after adoption of MI system for some crops, the aggregate level water use at the farm level also reduced as a result of changes in the cropping pattern and the aggregate reduction in the gross cropped area. The gross cropped area reduced from 3.96 ha to 3.25 ha per farmer. The aggregate farm level water use reduced from 34,870 m^3 to 24,842 m^3 per farmer (Kumar, 2009).

The other factor is the lack of availability of extra arable land for cultivation. This is applicable to areas land use and irrigation intensity is already high. Example is central Punjab. But, farmer might still adopt water-saving technologies for cash crops to raise yields or for newly introduced high-valued crops to increase their profitability. So, in such situations, adoption would result in reduction in aggregate water demand.

On the other hand, if the availability of water in wells is less than what the available power supply can abstract, it is very likely that with adoption of micro irrigation systems, the farmers would expand the area under irrigation. This is the situation in most of the hard rock areas of peninsular India, central India and Saurashtra. Due to limited groundwater potential and over-exploitation, well water is very scarce in these areas. The available power supply is more than what is needed to abstract the water in the wells. Hence, farmers have strong economic incentive to go for MI systems other than yield enhancement. The reason is that the saved water could be used to expand the irrigated area and improve the economics of irrigated farming. In Michael region of central India, for instance, farmers use low cost drips to give pre sowing irrigations to cotton, before monsoon, when there is extreme scarcity of groundwater. This helps them grow cotton in larger area as water availability improves after the monsoon (Verma *et al.*, 2005), and hence there is no water saving at the aquifer level. The third factor is the crops chosen. Often MI technologies follow a set cropping pattern. All the areas/pockets in the country where adoption of drip irrigation systems has undergone a "scale", orchard crops are the most preferred crops (Dhawan, 2000; Narayanamoorthy, 2004b). Therefore, while farmers adopt MI systems, the crops also change, normally from field crops to fruits.

Farmers bring about significant changes in the cropping systems of farmers with the adoption of drips. When drips are adopted for orchards, farmers are found to abandon cultivation of traditional crops such as paddy and wheat permanently. A most recent example is Nalgonda district in Andhra. Farmers generally start with small areas under orchards and install drips. After recovering the initial costs, the general tendency of farmers is to bring the entire cultivated land under orchards, and put them under drip irrigation. This is because orchards require special care and attention and putting the entire land under orchards makes farm-management decisions easier. In the case of cotton, it is difficult for farmers to take up any crop that can be irrigated with drips after the harvest in the end of winter. This is due to the lack of flexibility in the design of the conventional MI systems. Due to the high capital cost, it is best suited to permanent plantings or crops having roughly the same planting space as frequent removal and rolling back can cause damage to online drips. Exceptions are porous pipes used for sub-surface irrigation. In the cotton growing areas, farmers normally roll back the system and cultivate the traditional crops in summer only if water is available. But, early sowing of cotton is found to be common among farmers who have installed drip irrigation, as they are able to manage their pre-sowing irrigation with very little water available from wells (Verma *et al*., 2004). With improved planting patterns (paired rows, pit system) farmers install almost permanent drip systems for sugarcane crop.

While for many fruit crops, the gestation period is very large extending from 3-10 years (for instance, citrus, orange and mango), for many others like grapes, pomegranate and banana, it is quite short extending from one to two years. Also, farmers can go for intercropping of some vegetables and watermelon, which reduces their financial burden of establishing the orchards. This flexibility enables small and marginal farmers also to adopt MI systems, as found in north Gujarat and Jalgaon and Nasik districts of Maharashtra. Access to credit and subsidy further increases MI adoption among small and marginal farmers. The irrigation water requirement of the cropping system consisting of field crops such as paddy, wheat, pearl millet/sorghum combinations is much higher than that of fruit crops such as pomegranate, gooseberry, sapota and lemon. Therefore, even with expansion in cropped area, the aggregate water use would drop. Only in rare situations, the system design for one crop is adaptable for another crop. For example: the micro sprinklers that are used for winter potato, can also be used to irrigate summer ground nut and hence farmers opt for that crop.

The countries which have large-scale adoption of MI systems are Jordan and Israel. While Israel has nearly 80% of its cultivated area under drips[15], Jordan has 100% area under drip systems (HDR, 2006). The availability of water being supplied under pressure through pipe systems enables easy adoption of drip systems in Israel. Australia, in spite of being a water-short country, and with having highly developed agriculture, has only 20% of its irrigated area under MI systems. A large area under groundwater- irrigated cotton in the north China plains are under plastic mulching. Entire sugarcane farming in Mauritius is through drip irrigation. In India, a total of 3.88 m. ha of cropped area is under MI systems, including drips and sprinklers. As Table 5 shows, Maharashtra is the front runner in adoption of drip irrigation systems. Rajasthan stands first in adoption of sprinkler systems, most of which is in the IGNP command area.

Table 5: Adoption of MI Systems in Indian States

Name of States	Area under		Total Area (ha)
	Drip	Sprinkler	
Rajasthan	17002	706813	723815
Maharashtra	482341	214674	697015
Haryana	7136	518367	525502
Andhra Pradesh	363073	200950	564023
Karnataka	177326	228621	405947
Gujarat	169689	136284	305973
Tamil Nadu	131335	27186	158521
West Bengal	146	150031	150177
Madhya Pradesh	20432	117685	138117

15 Personal Communication, Prof. Saul Arlosoroff, Chairman, Economics and Finance, Mekorot, Tel Aviv.

Chhattisgarh	3648	59270	62919
Orissa	3629	23466	27095
Uttar Pradesh	10675	10589	21264
Punjab	11730	10511	22241
Kerala	14119	2516	16635
Sikkim	80	10030	10110
Nagaland	NA	3962	3962
Goa	762	332	1094
Himachal Pradesh	116	581	696
Arunachal Pradesh	613	NA	613
Jharkhand	133	365	498
Bihar	163	206	369
Others	15000	30000	45000
India Total	1429404	2452680	3882084

Source: Ministry of Agriculture, GOI, as on August 31, 2008

For India, the current estimates of area that can be brought under MI systems; and the water saving that is possible through it, are at best over-estimates. A recent study shows that the total area that can be brought under drip systems would be somewhere near 5.84 m ha, with a total reduction in water requirement of 44.8 BCM (Kumar *et al*., 2008a).

That said, in many Asian countries such as India and Pakistan, the incentive for adoption of water-efficient irrigation devices is very low due to the unique way of pricing electricity for groundwater pumping, and the lack of prices and taxes for groundwater. In many Indian states, which are agriculturally prosperous, and which depend heavily on groundwater for irrigation, electricity pricing for groundwater is based on connected load. But, unlike India and Pakistan, in China farmers would show greater motivation to go for MI systems, as they have to pay for electricity and groundwater on the basis of consumption.

Nevertheless, the available evidence from different locations India show that micro irrigation systems are economically viable in terms of private costs and benefits, though the B-C ratios depend on the type of crop and the type of technology (Narayanamoorthy, 2004a; Kumar, Singh and Singh, 2002). Generally, the incremental private benefits exceed the increased costs remarkably for orchards and high valued crops. This is due to the fact that the increase in crop yields (Dhawan, 2000; Kumar, Singh and Singh, 2002) and the benefits of advanced harvest possible with drip irrigation (Dhawan, 2000) normally obtained get converted into large income benefits for these high valued crops (Dhawan, 2000; Kumar, Singh, Singh and Shiyani, 2002).

Improving Reliability and Control over Irrigation

Reliability of irrigation and water delivery control can drive crop water productivity improvement and lead to real water saving. Reliability and degree of control over field-level water allocation are by and large very poor in public surface irrigation systems in India (Brewer *et al*., 1999), leading to poor technical efficiencies (GOI, 1999). Reliable and adequate water supply will maximize the beneficial use part of the CF (and reduce the non-reusable fraction and non-beneficial part of the consumptive use). On the other hand, unreliable and uncontrolled/ excessive water delivery will increase the non-beneficial part of consumptive as well as non-consumptive use. The overall effect will be that in the first case, the consumed fraction would be lower as compared to the second case, for the same ET; or the ET would be more for the same CF. Moreover, with controlled water delivery, the efficiency of utilization of fertilizers will be higher. Hence, with improved reliability and water delivery control, water productivity (Rs/m^3) will increase. Since, there are no extra capital investments this will also lead to higher productivity in economic terms (Kumar and van Dam, 2013).

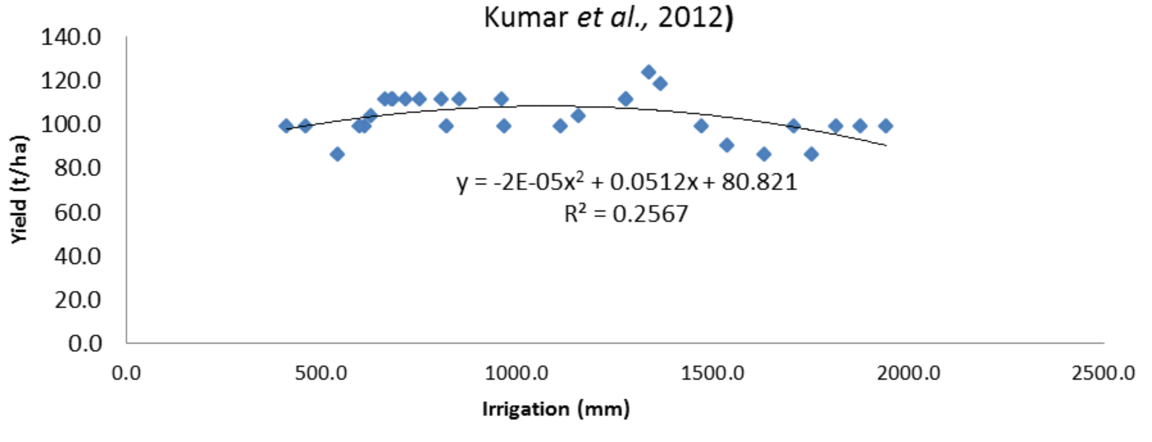
It is a truism that generally, groundwater-based irrigation is more reliable than some of the best managed canal irrigation systems. Also, under the former system, farmers have greater control over flow rates and water delivery in the field. This would increase the efficiency of use of fertilizer. Greater reliability of irrigation water supplies and greater control over flow rates and water delivery would also encourage farmers to take up some of the high valued crops such as vegetables and fruits that are water sensitive, but give higher returns per unit volume of water consumed, in addition to reducing non-beneficial water uses and increasing CF. Thus, in groundwater based irrigation systems, the WP in economic terms would be higher than that of gravity systems. Therefore, if the characteristics of well irrigation, which provides it differential reliability and water control, are introduced in surface irrigation, this can result in improved water productivity in economic terms (Kumar and van Dam, 2013).

Changing Water Allocation

Changing water allocation strategies at the field level, particularly deficit irrigation, has a major role in enhancing WP (Zhang, 2003). The reason is that irrigation dosage and the crop water requirement corresponding to the maximum yield do not correspond to the maximum WP (Rs/m^3) (Molden *et al*., 2003). Water productivity (Kg/m^3) would start levelling off and decline much before the yield starts levelling off (Source: based on Figure 1.2 in Molden *et al*., 2003). Ideally, WP in economic terms (Rs/m^3) should start levelling off or decline even before physical productivity of water (kg/m^3) starts showing that trend. When water is scarce, there is a need to optimize water allocation to maximize WP (Rs/m^3), though it may be at the cost of reduced yield and net return per unit of land (Kumar and van Dam, 2013).

Analysis involving data on irrigation dosage and yield and irrigation dosage and water productivity for sugarcane for straight furrow, serpentine furrow and drip method of irrigation in

Figure 1: Yield response to irrigation: Serpentine furrow (Source: Kumar *et al*., 2012)

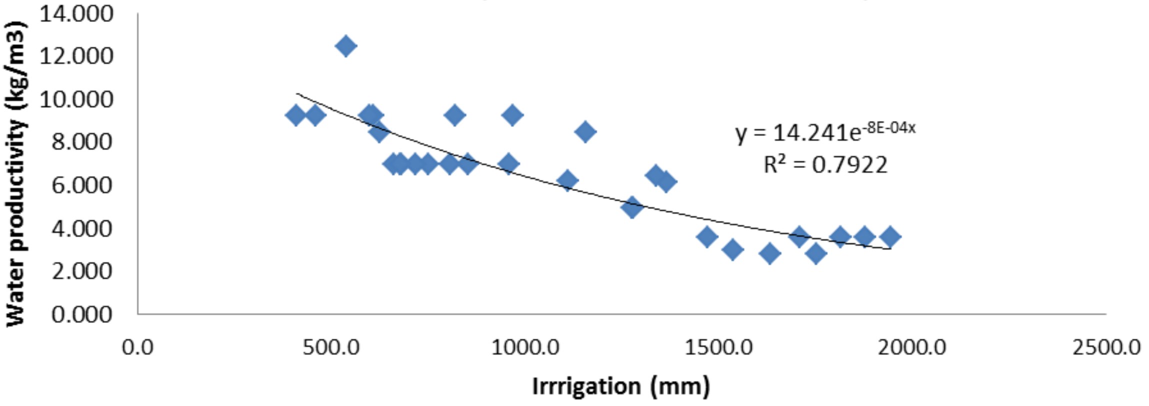


the Godavari basin in India showed interesting trends (Kumar *et al*., 2012). In none of the three cases, WP trends in response to irrigation did coincide with the trends in yield-response to irrigation for the entire range of irrigation dosage. The shape of the WP response curve was different from the yield response curve. Knowing at what segment of the WP response curve a farmer's irrigation dosage corresponds helps understand how changing water allocation would change the crop yield and WP.

As Figure 1 shows, irrigation corresponds to the ascending part of the yield response curve at low dosages of irrigation, but descending part of the yield response curve for medium and high dosage. But, as Figure 2 shows, the marginal WP in Sugarcane with extra dosage of irrigation is negative. Then limiting irrigation dosage might give higher net return/m^3 of water as well as yield/m^3 of water. But, only those farmers whose irrigation corresponds to the descending part of the 'yield response curve' would be interested in this. For others, WP improvement would be obtained only if they compromise on the yield and net return.

Even when the return from the land does not improve, the strategy of limiting irrigation can work only under three situations: 1] the amount of water farmers can access is really limited either by the natural environment; 2] there is a high marginal cost of using water due to high prices for water or electricity used for pumping water which is much closer to the WP (Rs/m^3) values at the highest levels of irrigation; and, 3] water supply is rationed. But, in all these situations, the farmers should have extra land for using the water saved.

Figure 2: Water productivity vs irrigation dozage: serpentine furrow (Source: Kumar *et al.*, 2012)



However, the presence of extra land, the factor which creates incentives for raising WP, would force the small holders of countries like India to re-distribute the saved water for expanding irrigated area so as to sustain or enhance their farm income. The reason is that the amount of water being handled is so small that they would tend to use the same amount of water as done previously since the WP differences would be just marginal (Kumar and van Dam, 2009). Though there would be no 'real' water saving, there would be significant increase in 'basin water use efficiency' and economic output from farming at the basin level. In the case of a large farmer in US or Australia, who might use 100 to 500 times more water than an average farmer in India, enhanced return is possible, even if he decides to reduce the volume of irrigation water (V), as 'V' is very large. Hence, the impact would be greater economic outputs for the same quantum of water.

Thus, it may appear that to affect demand reductions, it is important to ration water allocation in canals along with better education of the farmers about crop management. Proper regional and sectoral water allocation can become an incentive for improving WP. Experiences from the Murray-Darling basin (Haisman, 2003) and Chile (Thobani, 1997) show significant improvements in WUE and value of water realized, respectively, in irrigated production after introduction of volumetric rationing enforced through properly instituted water rights. Nevertheless, marginal water productivity analysis of the kind presented above can help decide on allocation and delivery strategies for canal water.

Plastic Mulching for Reducing Field Evaporation from Crop Land

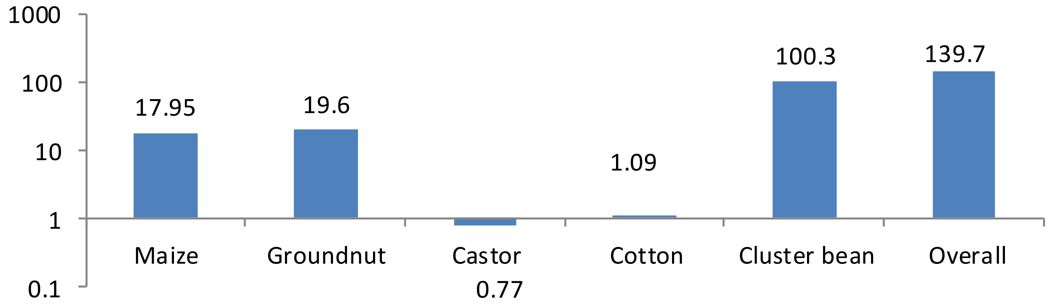
One way to reduce the groundwater imbalance is to affect reduction in kharif groundwater draft. The most effective intervention to manage water for crops would be to use plastic mulches. Mulch can reduce the evaporation of the moisture available in the soil from the limited rains. It can also reduce the evaporation from the crop land, and all the water available in the soil profile would be available for transpiration.

Perforations are made in the plastic sheet in rows at equal spacing determined by the distance between plant rows and spacing between plants, respectively. The plastic sheets are laid in the field prior to the sowing of seeds, and seeds are buried in the soil at the perforations. Experiments in north western China with plastic mulching in rain-fed wheat shows that mulching can reduce soil evaporation significantly and increase transpiration to affect major increase in yield and water use efficiency (Xie *et al*., 2005).

While long duration crops sown during the rainy season would require supplementary irrigation for crop survival (like hybrid castor and cotton), a study carried out in Luni river basin of western Rajasthan showed that many short duration crops grown in the rainy season are also irrigated. This is because of poor management of rainwater in the crop land. Our analysis shows that plastic mulching for rainy season crops could save substantial amount of both irrigation water and the rainwater in the soil profile (Table 5). For purely rain-fed crops, during droughts, the impact of mulching would be in the form of reduced pumping in kharif season. In normal years, the impact could be in the form of enhanced crop output or increased availability of residual soil moisture for winter crop, which can result in reduced irrigation dosage for winter crops. We have assumed a total reduction in irrigation water application of 50mm. The total water saving was estimated to be 139.7 MCM per annum (Figure 3).

Water saving can also be achieved for irrigated kharif crops. For the only irrigated kharif

Figure 3: Total estimated water saving through mulching in rainy season crops in Luni River Basin (MCM)



crop grown in the rainy season, which is amenable to mulching (i.e., groundnut), the total water that can be saved through mulching was estimated to be 26.1 MCM, from an area of around 17370 ha.

Controlling Twin Problems of Waterlogging & Salinity and Groundwater Depletion

The Indus Basin Irrigation System (IBIS) command area in Pakistan poses one of the greater environmental challenges. While many parts of the IBIS, particularly in Punjab experience problems of excessive groundwater draft, there are many areas in Sindh province, where secondary salinization of soils had emerged in a bid way (Qureshi *et al*., 2009). This is because in Punjab, the groundwater is relatively good, with only 23% of the area affected by poor quality groundwater. Whereas in Sindh province, the area in the IBIS command, which is affected by poor quality groundwater, is as high as 78% (Haider, 2000). The former is in areas where groundwater is of good quality and the latter in areas where groundwater is saline. Problems of waterlogging are encountered in the head reaches of canals, where water release from canals is uncontrolled and conjunctive use of surface water and groundwater is not managed properly.

The government of Pakistan had launched many programmes in the past to deal with the problems of groundwater mining, soil salinization and waterlogging, besides the construction of new irrigation canals, reservoirs and inter-river link canals, Pakistan implemented several salinity control and reclamation projects (SCARPS) of vertical and horizontal drainage for lowering water table and controlling salinity in the waterlogged areas (Hussain *et al.*, 2001). The massive projects of National Drainage Program (NDP), Left (LBOD) and Right (RBOD) bank outfall drains are recent efforts for providing the essential drainage to the irrigated lands.

The on-farm Water Management (OFWM) program for partial lining of the tertiary irrigation canals has been going on since the mid 1970's for controlling seepage and improving water delivery to the lower reaches. Water conservation technologies like bed-furrow, raised beds, zero-tillage, laser land levelling and dry-seeding of rice have been introduced but are going at a very limited scale. But, in such complex hydrological environments, a lot of caution needs to be exercised before making such interventions. For instance, before going for lining of tertiary canals, it is important to make sure that the water which seeps is non-recoverable. If the seeping water contributes to groundwater recharge, which would be the case for shallow water table areas, the intervention would be a waste. Hence, it should be taken up only if water table is very deep or the phreatic aquifer is saline.

Promotion of Water-efficient crops

<u>Farm Level Water productivity and Water Saving</u>

Farmers try to maximize water productivity at the farm level if water is a constraint to farming. There is trade-off between maximizing WP at the field level and that at the farm level, though farm level WP is dependent on the processes that govern WP at the individual fields (Kumar and van Dam, 2013).

It is evident that the current scope for improving field water productivity (of more crop per drop) is extremely limited in developing economies like India and Pakistan given the social, economic, institutional, and policy environment. Limitations are more when the strategy of field WP improvement is used as a driver for reducing water demand. Therefore, WP enhancement should focus on crops that are inherently more water efficient in economic terms, but also have high return per unit of land.

In spite of severe problem of groundwater depletion, wheat and paddy continue to dominate the cropping system in Indian Punjab (Kumar and van Dam, 2013). In the IBIS command in Pakistan, wheat, cotton, rice and sugarcane are the major crops, and the area under these crops have been expanding[16]. The extent of adoption of conservation technologies such as bed and furrow irrigation, zero tillage and laser levelling is extremely limited, due to lack of financial resources for initial investment and skilled manpower (Khan *et al*., 2005).

Many fruit crops have higher WP (Rs/m^3) than wheat and paddy in arid areas. For instance, pomegranate grown in north Gujarat gives a net return of nearly USD 1875/ha of land against USD 375/ha for wheat. The WP is approximately US \$ 1.8/$m^3$for pomegranate against US S \$ 0.08 /$m^3$for wheat. Also, there are crops such as potato, tomatoes, cumin, cotton and groundnut which are more water efficient than rice, wheat and sugarcane, which can be grown extensively in the alluvial areas of Indian Punjab and in the IBIS command of Pakistan. As a result

16 Out of the 14.96 m. ha of irrigated area in the Indus basin, 8.06 m. ha was under wheat, 2.76 m. ha under cotton, 2.1 m. ha under rice and 0.93 m. ha under sugarcane during 1990-95.

of growing water scarcity, in semi-arid and arid regions, well irrigators have already started allocating more water for growing highly water-efficient cash crops (Kumar and van Dam, 2009) and applying water in the fields efficiently.

But, there are limits to the number of farmers who can take up such crops due to the production risk, market risk and loss of farming system resilience (Kumar and van Dam, 2009). In South Asia, farmers raise crops and undertake dairy farming together (Baltenweek *et al*., 2003). These crop livestock interactions were seen in the crop residues being used for animal feeding. The extent of use of farm land for fodder was found to be highest for irrigated land under semi-arid conditions (Baltenweek *et al*., 2003: p 44).

Therefore, the extent to which farmers can allocate water to economically efficient crops often would be limited by the need to manage fodder, which comes from by-products of cereals. It may also get limited by the poor market support for economic efficient crops such as fruits. Even globally, scientific data on water use efficiency and water productivity in dairy farming that take into account actual water depleted is extremely limited. Even when they are available, the conditions are different from that in countries in South Asia (Kumar and van Dam, 2013). Studies from northern Victoria and Southern New South Wales analyzed water use efficiency in dairy farms that are irrigated (Armstrong *et al*., 2000) and dairy farming is not integrated with crop production in this region. Green fodder produced in irrigated grass lands is used to feed the cattle in Australia and United States.

Recent analyses from western Punjab for groundwater irrigated area seem to suggest that the overall net water productivity in economic terms gets enhanced when the by-products of cereal crops viz., wheat and paddy are used for milk production. While water productivity values for paddy and wheat were Rs. 7.75/m^3 and Rs. 8.05/m^3, respectively, that for milk production was Rs. 13.06/m^3 (Kumar *et al*., 2008b).

Reduced area under cereal crops such as paddy and wheat in Indian and Pakistan Punjab would mean reduction in availability of fodder. Farmers may have to grow special crops that give green fodder, and in that case, they might in turn be increasing the water use intensity. In a similar semi-arid situation in north Gujarat, it was found that dairy production, which used irrigated alfalfa, was highly water-inefficient, both physically and economically (Singh, 2004). As an alternative to growing fodder, farmers may procure dry fodder from outside, which would involve more labour. Hence, there could be a "trade off" between maximizing crop water productivity and farming system productivity. Otherwise, farming system resilience considerations might limit the opportunities for enhancing farm level water productivity through introduction of new crops (Kumar and van Dam, 2013).

Improving Regional Level Water Productivity and Water Saving

Policy makers are concerned with maximizing water productivity at the regional level. But, there is a clear trade-off between WP improvement at farm level and that at the regional level. The options available to maximize regional water productivity are much less than those for an individual farm. More importantly, the policy maker looks for approaches that would not only enhance the economic returns, but also increase the social welfare as they are more often driven by social and political considerations (Perry, 2001). Many of the decisions relating to public investment in irrigation systems are driven by societal concerns of producing more food, employment generation and poverty alleviation (Kumar and van Dam, 2009).

At the regional level, enhancing water productivity through either shift to water efficient crops or with crop-dairy based farming system might face several socio-economic challenges such as food security, generating sufficient farm employment, and stable price for fruits and vegetables in the wake of large-scale production. Hence, they become drivers of changes in regional water productivity as they can influence regional cropping pattern. For instance, paddy is labour intensive and in fact a large chunk of the migrant labourers from Bihar work in the paddy fields of Punjab. Replacing paddy by cash crops would mean reduction in farm employment opportunities (Kumar and van Dam, 2013).

Water productivity cannot be merely assessed in relation to pure agronomic and economic objectives. Social considerations such as employment generation, poverty reduction and food security are very important as these are in-built goals in large-scale subsidies in irrigation, which enable poor farmers to intensify cropping. One can argue that with more reliable irrigation, with quality infrastructure, farmers can produce more food or generate more employment. But, irrigation has to be affordable to poor farmers. The inability on the part of the government to bear a larger subsidy burden reduces its capacity to invest in high quality infrastructure, which is essential to improve the quality of irrigation (Kumar and van Dam, 2013).

But, it is not the domestic food security concerns which force farmers to adopt paddy, but the unreliable canal water supplies. The stable and high procurement prices offered by the Food Corporation of India for cereals such as rice and wheat allow farmers to stick to this cropping system. But there are major macro-economic imperatives of trying to meet these social objectives. The intensive paddy-wheat cultivation in Punjab is associated with intensive use of electricity for pumping groundwater. Irrigating one ha of winter wheat requires 74 KWhr to 295 KWhr of electricity, and costs US $ 6.9 to US $ 27.3 to the economy (Kumar and van Dam, 2009). The region is already facing power crisis. Enhancing productivity of well irrigation also means enhancing energy productivity and reducing the revenue losses of the government.

If well irrigators are able to get higher return per unit volume of water, that should be a starting point for irrigation bureaucracies to start charging high prices for irrigation water on volumetric basis, with the support of good infrastructure to ensure higher quality and reliability. As empirical evidence from well irrigation suggests (Kumar, 2005), if this is supported by volumetric rationing of water, higher water productivity could be secured. Perhaps, what is required is higher assured prices for cereal crops, along with some incentives for farmers who grow such crops to reflect their social value (Kumar and van Dam, 2009).

3 SUMMARY

Some approaches for augmenting groundwater in over-exploited areas are discussed above. They include: groundwater recharge using local runoff; recharge using imported water; and, recharge using treated wastewater. We have shown that in many arid and semi-arid regions, which experience groundwater over-draft problems, the hydrological opportunities, the reliability and economic viability of artificial recharge using local runoff would be generally very low. The other two options viz., recharge using imported surface water and recharging of treated wastewater, are practiced in developed countries. The financial resources for such schemes are available in plenty, and the environmental benefits due to improved groundwater environment are well recognized in these countries. Among the two options, recharge using imported surface water offers tremendous potential in Indian condition given the fact that the groundwater over-exploited regions coincide with the regions which experience high variability in rainfall and frequent droughts, and there are perennially water-surplus regions in the country from where water can be transferred.

Another major approach discussed here was water-efficient irrigation, to raise crop water productivity. They cover: water-efficient micro irrigation devices; improving the reliability of irrigation and water control; changing water allocation, including deficit irrigation; and, mulching. While the field level real water saving due to water-efficient irrigation devices depends on the crop type, climate, soils and geo-hydrological environment, the water-saving at the aggregate level would depend on a variety of socio-economic conditions including availability of extra land for cultivation; the availability of power supply vis-à-vis the amount of groundwater that can be abstracted etc.

The ability to shift to water-efficient crops and enhance agricultural water productivity at the regional level would be determined by a variety of socio-economic conditions such as the contribution of the existing cropping system to regional food security, the employment generation in rural areas, and the presence of market infrastructure for high valued crops. But, in any case, the outcomes of water productivity improvement through crop shifts in terms of reduction in groundwater draft would also depend on the opportunities for farmers to expand the area under irrigation. We have also demonstrated that in some regions, opportunities might exist for enhancing water productivity by taking climatic advantages.

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Module 7: ***Institutional alternatives and economic/fiscal instruments for adaptive water management for water, energy and food security in South Asian region***

Sustaining Agricultural Productivity with Reduced Groundwater and Energy Use and Carbon Emissions:
Market Instruments and Technologies

M. Dinesh Kumar

1 INTRODUCTION

For countries in the semi-arid and arid tropics, sustainability of agricultural production is largely dependent on irrigation water security (Grey & Sadoff, 2007; Shah and Kumar, 2008). Many such regions are primarily dependent on groundwater for irrigation (Schiffler, 1998). Developing countries, with a disproportionate share of the world's semi-arid and arid tropical regions, face problems of groundwater overdraft due to excessive irrigation withdrawals, which threatens the sustainability of agricultural production and livelihoods of millions of rural families depending on it. India, China, Mexico, Oman, Iran, Pakistan, and Morocco are just some among them trying to tackle groundwater overdraft through a variety of approaches (Garduño & Foster, 2010; Giordano & Villholth, 2007; Kumar, 2007; Kumar, Scott & Singh, 2011; Scott, 2011; Scott & Shah, 2004). In such regions, energy and water security are inextricably linked.

There can't be a better example of this linkage than Indian agriculture. In 2003-04, around 12.8 million electric pumps with a total of 51.84 giga-watts (GW) of connected load consumed nearly 87.09 billion kilowatt-hours of electricity (kWh, also referred to as "units" in India) (source: www.indiastat.com). The consumption went up to 107.77 billion units in 2008-09. The situation in Pakistan is no different. The average annual electricity consumption in Pakistan agriculture was estimated to be 22.02 billion units in 2001-02 to 2005-06 (Source: based on Khan *et al*., und), which in per capita terms is much higher than that of India. As irrigation becomes increasingly energy intensive, energy security is critical for ensuring agricultural water security. Whereas our ability to provide reliable and adequate energy supplies for other sectors of the economy is heavily dependent on how efficiently water for crop production is managed. Improving energy use efficiency in agriculture is also important for reducing carbon emission, as most of energy produced in India is through burning of fossil fuel. Unmanaged water demand for irrigated agriculture, which accounts for 21 per cent of total electricity consumption, can pose serious challenge to energy security in India, which is the World's fourth largest energy consumer (www.eia.gov/EMEU/cab/India/pdf.pdf).

2 IMPACT OF CLIMATE ON GROUNDWATER AND ENERGY BALANCE IN AGRICULTURE

In tropical regions, the demand for groundwater in irrigated agriculture in a particular year would be a function of the climate. In drought years, the irrigation water demand per unit cropped area will be higher as compared to a normal rainfall year due to lower precipitation, higher temperature and intensity of solar radiation and lower humidity. In semi-arid and arid areas, this would increase groundwater demand for irrigation. Electricity demand in farm sector can also goes up in such years proportionately. Simultaneously, monsoon failure would result in reduced recharge and lowering of water table. This would increase the electricity requirement for pumping a unit volume of groundwater, causing a double impact on the energy demand for irrigated agriculture.

Nevertheless, the way droughts affect groundwater use and energy consumption in a region or locality for agriculture would depend heavily on the geo-hydrological environment. In deep aquifer systems (like in the Indo Gangetic plain or Cambay basin), the increased demand of groundwater for crop production could be met from withdrawal from the deep confined aquifers, with a resultant increase in electricity consumption. Whereas in areas with shallow hard rock aquifers (like in peninsular and central India) the amount of renewable groundwater available for crop production would be much less in drought years, and therefore the actual electricity consumption in farm sector can drop.

A region could experience positive groundwater balance in a wet year, owing to increase in groundwater recharge from precipitation and reduced withdrawal as a result of availability of soil moisture for prolonged time periods to meet crop water requirements. But, as mentioned earlier, the groundwater balance could turn highly negative in a drought year, as just the opposite happens with regard to recharge and abstraction. For managing groundwater and electricity use in agriculture on sustainable basis, reducing consumptive use of groundwater during drought years is therefore extremely crucial, be it an alluvial area or a hard rock area.

3 ENERGY AND CARBON FOOTPRINT OF IRRIGATED AGRICULTURE IN INDIA

India is one of the largest consumers of electricity in agriculture sector. The largest user of electricity in agriculture sector is groundwater irrigation, the other being pumping of water from canals and rivers and ponds/tanks. The electricity consumption in agriculture has been steadily going up due to rapid increase in groundwater abstraction for irrigation and gradual decline in water table in areas where energized pump sets largely exist. However, the increase has been exponential since 1985-86 and this growth continued till 1998-99, when it peaked. Since then, it has shown some decline till 2001-02, and then gradually picked up to become 107.77 billion units in 2008-09. But, in percentage terms, the agricultural electricity consumption has begun to decline sharply and consistently since 1998-99 from a highest of around 31.4 per cent of the total consumption in various electricity consuming sectors in the country. The reason for this is the exponential rise in power consumption in the manufacturing sector, which grew at a rate of 7.4 per cent since 1992-93, coinciding with the year of economic liberalization.

Though declining in percentage terms, agriculture continues to be a major source of India's energy footprint and its contribution in aggregate terms is on the rise, with the total electricity consumption in that sector going up. This poses a huge environmental challenge. We have estimated the total carbon emission for fossil fuel based electricity generation be 28 million metric ton per annum[17]. While efficiency improvements in electric pump sets, which is quite low at present, can reduce this footprint, one reason why this does not happen is that farmers do not pay for consumption of electricity on the basis of consumption. But, if the farmers have to pay for electricity on pro rata basis, then they would have incentive to use both electricity and water efficiently. What is important to note is that water use efficiency improvements in irrigation can reduce electricity consumption significantly. Whereas pump efficiency improvements through technical interventions will not guarantee water use efficiency improvements, and on the contrary farmers would be tempted to pump more water. Hence, from the point of view of reducing carbon emissions, efficient pricing of electricity in the farm sector is important.

4 CO-MANAGEMENT OF GROUNDWATER AND ELECTRICITY

One of the key approaches debated and often tried in different parts of the world for co-management of groundwater and electricity revolves around managing the groundwater-

[17] This is based on the formula that producing one unit of electricity through fossil fuel burning would emit 0.26 kg of carbon or 0.96 kilogram of CO_2 (Nelson and Robertson, 2008).

electricity nexus, with the use of metering and *pro rata* pricing of electricity used for pumping groundwater (Kumar et al., 2011 for India; Scott & Shah, 2004 for Mexico; Shah, Giordano & Wang, 2004a for China; Zekri, 2008 for Oman), energy rationing to farm sector using pre-paid meters (Shah et al., 2004a for China; Zekri, 2008 for Oman;), electricity supply rationing (Shah, Scott, Kishore & Sharma, 2004b) and denial of electricity connections in regions which experience groundwater over-draft problems, (Kumar, 2007; Malik, 2007), and tube well permits (Shah et al., 2004b for China and Mexico) and management of groundwater quotas (Madani & Dinar, 2011; Scott & Shah, 2004 for Mexico).

Particularly in the Indian context, electricity used for agriculture is heavily subsidized in India under both *pro rata* and flat rate tariff regimes (Kumar et al., 2011; Scott & Sharma, 2009). Many are of the view that energy subsidies are essential for small holders to sustain irrigated crop production, which is becoming less profitable due to rising cost of inputs including irrigation. This idea, therefore, has high political currency (Kondepati, 2011). Such views are stronger now than ever before in the wake of the gradual removal of fertilizer subsidies, and increasing private cost of well irrigation resulting from declining water levels. But, the long-term impacts of heavy energy subsidies on economic cost of groundwater abstraction and agricultural productivity are not appreciated (Gulati, 2011).

Some, however, do believe that heavily subsidized or free power offered to well irrigators leads to uncontrolled abstraction of groundwater and its inefficient use resulting in over-draft and aquifer mining with the undesirable consequence of agriculture's rising energy footprint (Asad & Dinar, 2006; Madani & Dinar, 2011; Narayanamoorthy, 1997; Saleth, 1997; Scott & Shah, 2004). The reality is that the energy subsidies in groundwater-dependent and agriculturally prosperous states of India have been rising over the years (GOI, 2002; Kumar et al., 2011). This has had a series of cascading, negative effects on the quality of power supply in the farm sector and overall power sector viability. On the other hand, problems of groundwater mining are becoming more rampant. This is leading to serious erosion of both water and energy economies. A World Bank study in the state of Haryana pointed out that even farmers believe that the ability of the governments to offer improved power supply in the farm sector is heavily dependent on higher tariff and metering (World Bank, 2001). Further, as noted by Birner and Sharma (2011) in the context of Andhra Pradesh and Tamil Nadu, electricity subsidies in the farm sector were never introduced in response to demand from farmers' associations for concessions, but were part of a larger "populist welfare policy" of the ruling parties. It is clear that the key to managing India's groundwater economy and power sector efficiently lies in managing the political economy of power subsidies.

5 IMPACT OF SUBSIDIZED ELECTRICITY ON GROUNDWATER USE AND FARM PRODUCTIVITY

Studies have empirically shown the negative impact of subsidized electricity on resource use efficiency (Kumar et al., 2011). Since the marginal cost of using irrigation water is zero under the flat rate tariff regime, theoretically, farmers keep applying water to the crops until the yield maximizes, which correspond to the maximum gross (private) return. The net return also will be highest at this point. Or in other words, farmers will keep applying water until the net marginal return becomes zero. This is under ideal circumstances where the farmer is well informed about the irrigation application corresponding to the maximum yield. But in practice, zero marginal cost tends to lead to excessive irrigation and may even result in yield losses. Nevertheless, in either case, irrigation does not correspond to the economically optimal level, as society incurs a huge cost for the energy used for crop production. The net marginal "economic" return thus becomes negative much before the net marginal (private) return approaches zero. Water use therefore would become highly inefficient (Kumar, 2007).

Yet another consequence of flat rate pricing is that farmers get tempted to grow crops with high water demand, if these help maximize the return per unit of land. The reason is that there are no restrictions on the volume of water that farmers can pump from the aquifer underlying their piece of land (Kumar & Singh, 2001). The preference of well irrigators for high water demand crops like sugarcane in semi-arid areas of Maharashtra, or paddy (rice) in semi-arid and arid areas of Andhra Pradesh, is a result of heavy electricity subsidies for groundwater pumping.

6 A MODEL FOR ANALYZING FARMER BEHAVIOUR IN RESPONSE TO DIFFERENT PRICING AND ALLOCATION REGIMES

Figure 1 provides the model for analyzing farmer behaviour in response to different pricing regimes. The model essentially provides a framework for analysing the differential impact of market-based instruments such as the unit pricing of electricity and volumetric water use rights on energy use efficiencies and physical and economic efficiencies of water use in agriculture, as against that of the flat rate system of pricing and absence of property rights regimes in water. The model suggests that the lowest water use efficiency--both physical and economic--is obtained under the flat rate system of pricing, wherein farmers continue to apply irrigation until the net marginal productivity (equal to gross marginal productivity in this case due to zero marginal cost of electricity and irrigation) becomes zero. The net marginal productivity curve will be AX_2. The selling price of water is expected to be lowest in such a situation, due to the presence of competitive markets.

When changed to unit pricing, farmers might make some improvements in pump efficiency and physical efficiency of water use in irrigation. With price shifts, the selling price of water is also expected to rise slightly. Even though water markets exist, farmers may not be confronted with real opportunity cost of using water due to couple of reasons: [1] mismatch between demand for water and the ability of farmers to supply water; and [2] the average net economic return from irrigated crops might be still higher than the price at which water is sold (Kumar and Singh 2001).

Hence, farmers would continue to grow water intensive crops as water and energy are not limiting factors. Without any efficiency improvements, the net marginal productivity curve would take a dip to A_2X_4 as net marginal return would become zero at much lower level of irrigation itself (X_4 instead of X_2) due to the induced marginal cost of electricity and water. The attempt, therefore, would be to either reduce electricity use per unit of water pumped through improvements in pump efficiency, and maximize the level of irrigation (in which case the curve would be pushed to A_1X_3 from A_2X_4) or to use water for efficiently in which case the curve would be tilted to a new position BY_2. In these two cases, the water productivity would be slightly higher than in the first case.

But, if water is allocated on volumetric basis with rationing, farmers' preference would shift to crops that give higher returns per unit of water consumed, reason being that the price at which water would be traded would be highest as water becomes a limiting factor for generating wealth out of agriculture. Since price would represent the opportunity cost of using water, theoretically it should induce farmers to take those crops which give same or higher return per unit volume of water. The net marginal productivity curve would take a new position of CZ_2, with the average net productivity being higher than the price of water. Economic efficiency of water use will eventually rise. This model however needs hard empirical data to quantify the impact of market-based mechanisms on demand rates for water and electricity. Purpose of the present study is to validate the model through analysis of empirical data on irrigation water application and water productivity.

7 IMPACT OF ELECTRICITY PRICING ON ENERGY AND GROUNDWATER DEMAND IN AGRICULTURE IN INDIA: FINDINGS FROM TWO STUDIES

Theoretically, the shift from flat rate to *pro rata* tariff would encourage farmers to use energy and groundwater efficiently as it induces positive marginal cost of using electricity and groundwater (Asad & Dinar, 2006; Muñoz-Piña et al., n. d.; Narayanamoorthy, 1997). Higher water use efficiency or water productivity would indicate higher energy use efficiency. But, vice versa is not true. One of the responses for higher energy tariff would be for farmers to improve the efficiency of water abstraction devices, including pump sets and the suction pipes, if possibility exists. But, beyond a point, this cannot help reduce the cost of irrigation, and therefore the subsequent response will be to make water use more efficient with two aims. One is by reducing the cost of irrigation input and the other is by increasing the gross return. This can be done through three major steps, i.e., improving technical efficiency of water use by optimizing irrigation water application; through improving agronomic efficiency in water use (kg/m^3 of water) by optimizing agronomic inputs to crops; and through shifting to crops with higher water productivity in economic terms (Rs/m^3) (Kumar, 2007).

Empirical studies, which show the differential impacts of various energy pricing regimes on agricultural groundwater use and land and water productivity in irrigated agriculture, were absent in India and elsewhere until recently. We present here the findings of a recent empirical study to illustrate the impact of energy pricing on groundwater demand for crop production, the socio-economic viability of farming, and sustainability and equity in groundwater use. The study compared the farming enterprises of electric well owners who pay for electricity on the basis of connected load (flat rate tariff), diesel well owners who pay for energy on the basis of consumption, and buyers of water from electric well owners and diesel well owners in eastern UP and South Bihar; plus farmers who pay for electricity on *pro rata* basis in north Gujarat. Here, the buyers of water from diesel well owners incur higher water charges as compared to the buyers of water from electric well owners. But, three categories of farmers, i.e., diesel well owners who irrigate their own farms; and buyers of water from electric and diesel well owners are proxy for *pro rata* electricity pricing, along with the farmers in north Gujarat whose power consumption is metered.

Study 1:

- The study in north Gujarat offers several findings that have major implications for supply and pricing of electricity for groundwater pumping.

- The physical productivity of water improves with positive marginal cost of irrigation water. Further, farmers try to achieve highest physical and agronomic efficiencies when water is priced on volumetric basis and allocation is rationed.

- Farmers try to achieve highest water productivity in economic terms when water is priced on volumetric basis and allocation is rationed, reflected in highest values of overall net water productivity (Rs. 4.18/m^3) obtained by shareholders. Thus the model is validated.

- Higher water productivity is achieved by water buyers through efficiency improvements in water use, and marginally through cropping pattern adjustments. Whereas further enhancement in water productivity is achieved by shareholders through crop shifts as well as efficiency improvements.

- The net return from crop production is less elastic to the cost of irrigation than the reliability of irrigation. This is reflected in higher net water productivity (exclusive of irrigation cost) obtained for shareholders as compared to water buyers, where in the difference between the two cases is in terms of water allocation norms and reliability of water supply.

Study 2:

- Farmers who have metered power connection not only pay positive marginal cost of using well water, but also pay higher cost for every unit of irrigation water (Rs/m^3) as compared to their counterparts having flat rate connections. Similarly, farmers who are buyers of water from electric pump owners and diesel well owners in eastern UP and south Bihar also pay positive marginal cost of using irrigation water pay higher unit costs of irrigation water compared to water selling counterparts.

- Minor differences are found in the cropping pattern of well owners and water buyers in electric and diesel well commands; and between farmers with metered electricity connections and farmers with flat rate connections. The water buyers (in eastern UP and south Bihar) and farmers who have metered electricity connections allocate some amount of land for highly water-efficient crops, which are also less water consuming.

- Water buyers in diesel and electric well commands, and the farmers who have metered power connections in agriculture pay for water on volumetric basis. Our analysis suggests that they secure higher water productivity in physical terms (kg/m^3) for most crops as compared to water selling well owners through: careful use of irrigation water (as reflected in lower water application rates) and agronomic practices (as reflected in higher yield rates). This means that when confronted with positive marginal cost of irrigation water, farmers are encouraged to use water more efficiently.

- Water buyers in diesel and electric well commands, and farmers who have metered electricity connections secure higher water productivity in economic terms for many crops as compared to water selling well owners through: careful use of irrigation water, optimizing costly inputs and obtaining higher yield rates through farm management. This means that when confronted with positive marginal cost of irrigation water, farmers would be encouraged to improve economic efficiency of water use.

- The estimated values of net water productivity in economic terms for dairy animals in case of water buyers in diesel and electric well commands, and the farmers who have metered power connections in agriculture are not higher than that of water selling well owners. This could be because the cost of production of animal inputs are higher in the case of water buyers due to the higher cost of production of inputs in lieu of the higher cost of irrigation water. However, the water productivity in dairying is much lower than that of many crops grown by both well owners and water buyers in all the locations.

- Water buyers in diesel and electric well commands, and the farmers who have metered power connections secure higher water productivity at the farm level as compared to water selling well owners through: careful use of irrigation water; agronomic inputs; optimizing costly inputs for crops; and through judicious selection of crops, cropping pattern and livestock composition, which give higher return from every unit of water consumed. The diesel well owners also secure higher water productivity at the farm level as compared to electric well owners, as shown by data from south Bihar. These results have two major implications for policy: 1] when confronted with positive marginal cost of irrigation water, farmers are encouraged to use water more efficiently over the entire farm from economic point of view; and 2] when confronted with higher cost of irrigation water, the farmers venture into adopting farming system and optimizing use of inputs to secure higher returns from every unit of water to offset the increase in costs of irrigation.

- Higher net water productivity in economic terms (Rs/m^3) which farmers obtain even at high cost of irrigation water is indicative of the fact that it is possible to keep irrigation costs high enough to induce improved efficiency in water use in both physical and economic terms without compromising on farming prospects.

- Comparison of water prices charged to water buyers in diesel and electric well commands against the cost of production of water clearly show that the monopoly price charged by well owners is not a function of the mode of energy pricing. The farmers who are confronted with zero marginal cost of using energy charge even higher monopoly rates for water as compared to diesel well owners. On the other hand, the flat rate pricing puts large well owners in a very advantageous position as they could bring down their implicit unit cost of pumping groundwater. The major policy implication of this analysis is that pro rata pricing of electricity would promote equity in groundwater use, if many farmers from within the same area have access to electricity connections.

- The water buyers in diesel and electric well commands are using much less water for every unit of net cultivated area as compared to the farmers who are well owners. In addition, the farmers who are using metered power connections are using less amount of water per unit of cultivated land. Such reduction in groundwater pumping, with a disproportionately lower reduction in net return from unit of land in the case of farmers with metered connections in north Gujarat, and no reduction in net returns in the case of eastern UP and south Bihar plains, is possible through water productivity improvement in economic terms. This indicates that introducing marginal cost for water and electricity not only promotes efficient use of water, as manifested by higher farm-level water productivity, but also more sustainable use of water.

- In eastern UP, the monopoly price ratio for water sellers was higher in the case of electric well commands than that in diesel well commands. The price charged by electric pump owners was 3.6 times more than their cost of pumping. But, the price charged by diesel pump owners was only 1.8 times higher than their cost of pumping. In South Bihar, the trend was the opposite. The average price charged by electric well owners was lower than the implicit cost of pumping water (Rs 0.70/m^3 against Rs 0.77/m^3). Whereas the average price charged by diesel well owners (Rs 2.15/m^3) was higher than the cost they incur for pumping groundwater (Rs 1.87/m^3). However, a look at the cost and price figures for individual wells brings out a different picture. A few electric well owners incur very high implicit pumping costs, making it higher than the average selling price. The monopoly price ratio for many others was higher than even the average MPR of diesel well owners (1.15) and much higher than that of many individual diesel well owners who incur very high production costs. More importantly, the MPR for some diesel well owners was less than 1.0.

- The selling price of water is more or less same across the farmers, though the unit cost of pumping water varies across farmers. The selling price is decided by the market conditions irrespective of the cost farmers incur for pumping water (Kumar et al., 2011). Fewer numbers of potential sellers against a large number of potential buyers would increase the monopoly power of well owners. Perhaps this is what is happening in the village with electric pumps in eastern UP. On the other hand, presence of large number of sellers against a few buyers would reduce the monopoly power of well owners. They would be forced to sell water at prices conditioned by the market (Kumar, 2007). Perhaps this is what is happening in the village with electric pumps in South Bihar.

Summary

Pro rata pricing for electricity does promote efficiency and sustainability in the use of groundwater. But, more importantly, the price level at which the irrigation demand starts responding to tariff hikes is socio-economically viable. Pro rata pricing is unlikely to create negative impacts on access equity in groundwater as selling prices for irrigation water are determined by the monopoly power of the well owners. The mode of pricing of electricity does not influence the monopoly power of well owners in the market. But, the flat rate pricing puts large well owners in a very advantageous position as they could bring down their implicit unit cost of pumping groundwater. Hence, *pro rata* pricing of electricity would promote equity in access to groundwater, if many farmers from within the same area have access to electricity connections. The positive efficiency impact of *pro rata* pricing is evident from the lower application of irrigation that farmers apply for crops, and higher physical productivity of water in crop production. The sustainability impact is evident from the lower volume of groundwater used per unit of cropped area. The socio-economic viability is evident from the higher economic productivity of water at the farm level and the higher net return per unit area of irrigated land.

But, the impact of rise in energy tariff will not be uniform across the Board. In Pakistan, for instance, rise in power tariff led to farmers shifting to diesel engines for groundwater pumping as water tables were shallow (Qureshi *et al*., 2009). Nevertheless, it is also important that the option of shifting to diesel engines would not be available to farmers, as diesel prices have gone up sharply in South Asian countries in the recent past and with increase in depth to water table, the cost of pumping groundwater would be higher. More importantly, the farmers, who are using diesel engines for groundwater abstraction, pay for every unit of water they pump out, and hence would try and use groundwater efficiently.

8 CLIMATE IMPACTS OF ENERGY CONSERVATION IN AGRICULTURE

The potential impacts of introducing pro rata power tariff on reducing carbon emissions and their associated social benefits are remarkable. As per estimates provided by David and Herzog (undated), the cost of capturing one kilogram of CO_2 emission from thermal power generation is US \$ 0.049 or INR 0.49 (ppp adjusted), and one kilowatt hour of power generation produces 0.26 kilogram of carbon or 0.96 kilogram of CO_2. If we assume that the all the electricity produced for supplying to the agriculture sector comes from a thermal power (coal based or gas based) plant, the economic cost of capturing carbon emissions from generating one kilowatt hour (unit) of thermal power can be treated as the opportunity (social) cost of using one unit of thermal power in agriculture. Hence, the same can be treated as the benefit of saving one unit of power consumed in agriculture through pricing mechanism.

Hence, the social benefit associated with preventing carbon emission by saving one kilowatt hour of electricity would be equal to Rs. 0.47. The total electricity consumption in Indian agriculture sector was estimated to be 107.77 billion units per annum in 2008-09. If we assume that there would be 20% energy-saving obtained from water productivity improvement in irrigated farm production alone due to efficient pricing[18], the total social benefit would be to the tune of 709 crore rupees per annum, for a total electricity saving of 2156 crore (21.56 billion) units. Here we assumed that only 70% of the total electricity consumed in the country comes from thermal power, and the rest comes from clean energy sources such as nuclear power and hydropower.

9 TECHNOLOGICAL ADVANCEMENTS TO REDUCE TRANSACTION COST OF METERING

Loss of electricity in transmission and distribution systems in India was as high as 31.2 per cent of the total electricity available for supply to consumers in 2004-05 (source: Central Electricity Authority, 2006), and is alleged that a large part (30-35 per cent) of such losses is un-accounted, due to pilferage (Tiwari & Shah, 2003). Metering and *pro rata* tariff fixation are crucial for reducing the unaccounted for losses in electricity distribution, improving the financial working of the state electricity boards (SEBs) and reducing the overall power deficits, while ensuring equity, efficiency and sustainability in groundwater use. Today, technologies exist for metering and also for controlling electricity consumption by farmers (Kumar & Amarasinghe, 2009; Kumar et al., 2011; Zekri, 2008). The pre-paid electronic meters, which are operated through scratch cards and can work on satellite and internet technology, are ideal for remote areas to monitor energy use and control groundwater use online from a centralized station (Zekri, 2008). Over the past few years, there has been a remarkable improvement in the quality of services provided by internet and mobile (satellite) phone services, especially in the rural areas, with a phenomenal increase in the number of consumers (Kumar et al., 2011). Such technologies are particularly important when there are large numbers of consumers, and the transaction cost of visiting wells and taking meter reading is likely to be very high. It is inevitable that they will be adopted in rural India (Kumar et al., 2011; Tiwari & Shah, 2003; Zekri, 2008).

Pre-paid meters prevent electricity pilferage (Kumar et al., 2011; Zekri, 2008). They can be operated through tokens, scratch cards, magnetic cards or recharged digitally through internet and SMS. They are extensively used for metering electricity consumption by agricultural wells in north China plains (Shah et al., 2004a) and general electricity consumers in South Africa (Tiwari & Shah, 2003). It helps electricity company restricts the use of electricity. The company can decide on the "energy quota" for each farmer on the basis of reported connected load and total hours of power supply, or sustainable abstraction levels per unit of irrigated land (Zekri, 2008).

Kumar et al. (2011) analyzed five policy options for regulating groundwater use in agriculture weighing their potential benefits in terms of groundwater and energy demand management against the practical problems each one pose in implementation. Four of these five options take the advantages of these pre-paid electronic meters. They are: 1] *pro rata* pricing and energy rationing based on groundwater sustainability considerations; 2] *pro rata* pricing, and energy rationing based on connected load (in horsepower) and supply hours; 3] fixing energy quota based on supply hours and connected load, and energy pricing based on connected load; 4] *pro rata* pricing and unrestricted use of electricity; and 5] connected load based tariff with fixed supply hours (Figure 2).

[18] Energy saving can also come from improvement in pump efficiencies, occurring as a result of pro rata pricing of electricity. However, we have not considered this.

Figure 1: Farmers Response to Changing Price Structure and Water Allocation Regimes

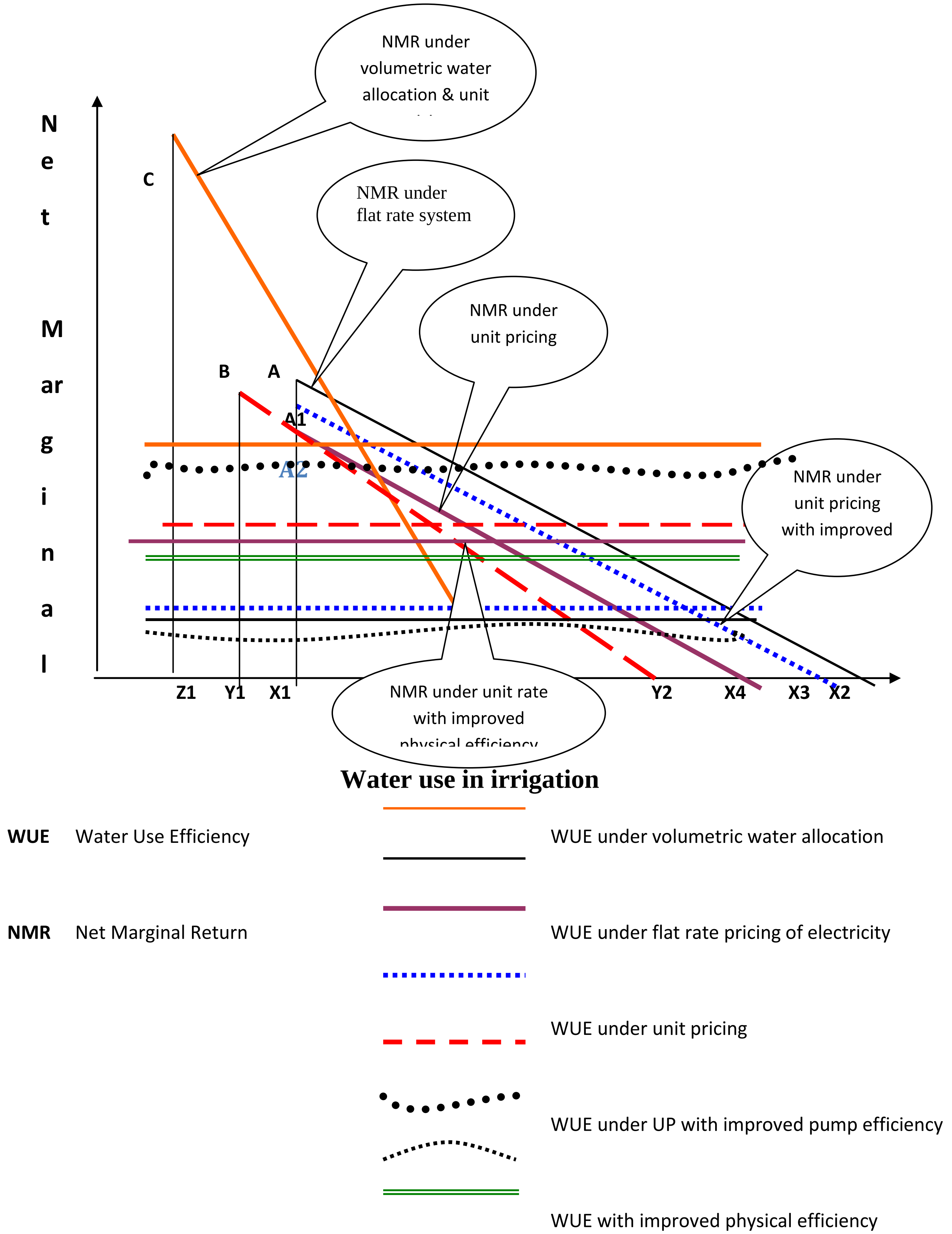
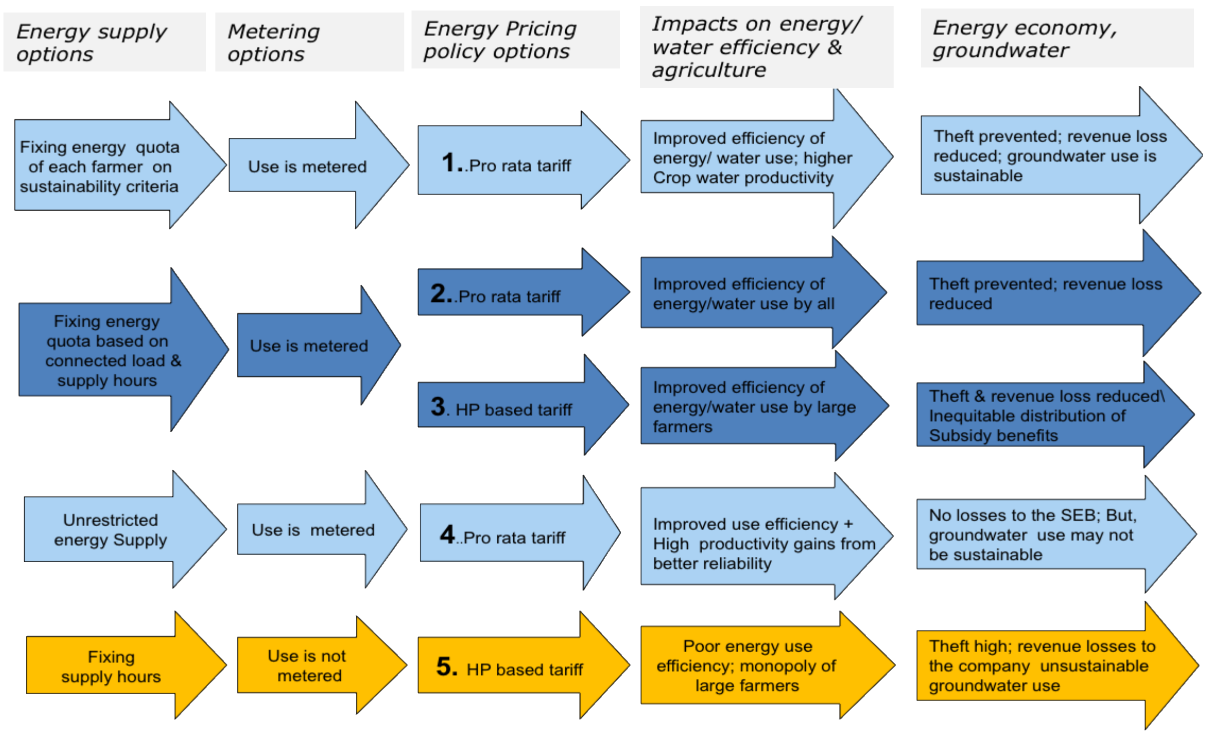


Figure 2: Different modes of pricing & expected outcomes under different energy supply regimes



While Option 3 is easily implementable to manage the groundwater-energy nexus in agriculture, those who have large capacity pump sets would be entitled for large quantum of electricity. Here, again, only farmers with large holding will have incentive to use groundwater efficiently. This is because there is no marginal cost of using water, and the incentive to conserve electricity and groundwater has to come from the opportunity costs of not being able to irrigate the entire land, which will be less for farmers with small holdings and large pump sets. Further, as farmers having large capacity pump sets would corner lion's share of the subsidy benefits, equity in access to groundwater could still be an issue. Also, water use efficiency in small farms could be low. One way to overcome this issue is to fix higher charges per HP of connected load for farmers who enjoy large quotas. Option 2 is slightly difficult as it would involve introducing consumption-based pricing along with energy rationing, but would conserve both groundwater and electricity by all categories of farmers, as in this case, farmers' access to groundwater in volumetric terms would be defined by the connected load and supply hours.

As is evident, option 1 is best for co-management of groundwater and electricity. As it is possible to limit the total abstraction of groundwater from a regional aquifer using sustainability considerations (like long term sustainable yield of the aquifer), and then ration volumetric abstraction by individual well owners, on considerations of their land holdings etc., it would address the issues of equity, efficiency and sustainability. In years of acute groundwater scarcity, stricter rationing of energy as compared to a normal year would be required, as annual groundwater replenishment would be lower. But, implementing this requires great political will as traditionally farmers were enjoying unrestricted rights to use groundwater and these rights would be challenged by this policy intervention. Keeping in view the social benefits of reducing electricity consumption and conserving groundwater, government can offer subsidies for meters if farmers are willing to go for option 1 and 2. Further, the extent of subsidy could be higher in drought years. For implementing any of these options it is necessary that SEBs setup computerized database of all agro wells, comprising their latitude & longitude, physical characteristics and land use details.

10 CONCLUSIONS

We have shown that power tariff reform with *pro rata* pricing and higher unit rates for electricity would not only promote equity, efficiency and sustainability in groundwater use, but also would be socio-economically viable for the small holders. As power generation in India is mainly from fossil fuel, it can also reduce carbon emissions thereby preventing adverse impacts on climate. But, managing the political economy for electricity tariff reforms would require three important steps. *First*: informing the political class and bureaucracy that free power and heavily subsidized power for farm sector not only makes little sense economically, but it also has high political costs when compared to metered pricing provided power supply reliability is ensured. *Second*: convincing farmers that good quality, unrestricted power supply at higher unit cost would enhance their ability to maximize their revenue from irrigation and transform farming through higher land and water productivity as well as efficiency and flexibility in managing farming. *Third*: demonstrating to the state electricity bureaucracies that it would be possible to introduce metering with acceptable costs through the use of information technology (Gulati, 2011) and satellite technology. It is possible to introduce electricity tariff reforms in agriculture to reduce the power demand and increase agricultural productivity, while simultaneously permitting the State Electricity Boards to meet rapidly increased non-farm demand for power. In semi-arid and arid regions, such steps along with energy rationing would be required more in drought years, when the groundwater balance takes a serious negative turn.

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Institutional Responses to the Effects of Climate Variability

Arjun Surendra and Neena Rao

1 Introduction

In India 72 per cent of the population live in rural areas. It is estimated that 42 per cent of the rural population lives below the poverty line, compared to 26 per cent of those living in urban areas (IFAD 2011). This shows an urban-rural divide, with reference to poverty. Efforts have been made to alleviate poverty for many years. These have paid off to a limited extent, though the rate of poverty incidence has declined from around 55 per cent in 1973-74 to 27.5 per cent in 2004-05, the number of poor has remained largely unchanged going from 320 million in 1993-94 to 302 million in 2004-05 (Planning Commission 2009), due to the growth in populations (Kabeer 2002). In addition to poverty, there exists a closely-linked term, vulnerability.

Vulnerability can be seen as the risk that a "system" would undergo a negative change due to a "perturbation". In the context of poverty it can be defined as the diminished capacity to foresee, cope with, resist and recover from the impact of a natural or man-made hazard. Poverty and vulnerability are closely related. The poor are often vulnerable to severe and chronic deprivation, especially in developing countries. Vulnerability can also arise when people are "isolated, insecure and defenceless" when subject to risks, shocks and seasonalities (Naude et al. 2008).
Vulnerability is compounded by general uncertainty with respect to livelihood and life. Due to the risks many poor households face, they are often subject to shocks causing variability in their incomes. The poor are the worst hit by fluctuations in levels of income, consumption and well-being (Kabeer 2002), due to lack of sufficient assets, insurance or capital, shocks and seasonalities may lead to losses such as distress sale of assets, reduced food intake, interruption of schooling - which reduces human capital, or even migration which often reduces social capital.

As mentioned above, there is a distinct geographical dimension to vulnerability. Firstly, it is strongly rural and severe in regions of physical remoteness. It also varies with agro-climatic factors, seeing higher incidence in areas prone to floods, drought and areas difficult to irrigate. Variability of rainfall and temperatures contribute to variability in agricultural production and food insecurity –affecting current and future vulnerability thus directly and indirectly impacting livelihoods, both current and future. In order to attempt to address these issues, governments world over have launched programmes to attempt to reduce vulnerability. The government of India is no different; the following section examines three major institutional attempts to alleviate poverty and vulnerability.

"Fundamentally, poverty is a denial of choices and opportunities, a violation of human dignity. It means lack of basic capacity to participate effectively in society. It means not having enough to feed and clothe a family, not having a school or clinic to go to, not having the land on which to grow one's food or a job to earn one's living, not having access to credit. It means insecurity, powerlessness and exclusion of individuals, households and communities. It means susceptibility to violence, and it often implies living on marginal or fragile environments, without access to clean water or sanitation".

2 Major Institutional Programmes addressing vulnerability

2.1 Public Distribution System

India grows a large quantity of food with a food stock of approximately 50 million tonnes projected in 2009. There has also been a doubling of its GDP since 1991, However, it is still home to around 25% of the world's hungry poor (Kattumuri 2011).

The Public Distribution System in India refers to the distribution of essential commodities, (including, but not limited to rice, wheat and kerosene) by the government at subsidized rates through ration or "fair-price shops" (Jha *et al.* 2011)

The Public Distribution System (PDS) in India as it stands today, has evolved gradually since the late 1930s and today stands as an essential part of the government's strategy to ensure food security (Mooij 1998). The PDS has undergone a number of changes in the intervening years. It started from an urban focus prior to the 1960s and gradually moved towards covering the entire nation, reaching tribal block and areas of high poverty incidence in the 1970s and 80s and especially the 1990s with the launch of the Revamped Public Distribution System (RPDS) in 1992. Till the 1990s the PDS was more or less universal in nature, this changed with the launching of the Targeted PDS in 1997, which aimed to provide subsidized food grains to those families identified as being below the poverty line (POE 2005). This was at a national level, as some states already had existing food subsidy schemes for the poor, such as Andhra Pradesh's subsidized rice scheme, that was in effect from 1983 (Mooij 2002). The scheme is jointly managed by both Central and State Governments, with the centre procuring, storing, transporting and allocating the essential food items. State governments are responsible for identification of beneficiaries and distribution through fair price shops (Kattumuri 2011). Thus, each state has different entitlements under the scheme, apart from supply of rice at Rs. 1 a kilogramme; other entitlements under the PDS in the state of Andhra Pradesh as of 2014 are given in Table 1. Thus it can be seen that there is an effort, in theory, to improve food security in India.

Sr. No	Commodities	Quantity per Card	Consumer Price(Rs.)	Open Market Price (Rs.)	Cardholder benefit (Rs.)
1	Red Gram Dal	1 kg	50/-	73/-	23/-
2	Palm Oil	1 ltr	40/-	58/-	18/-
3	Whole meal *atta*	1 kg	16.50	25/-	8.50
4	Wheat	1 kg	7/-	18/-	11/-
5	Sugar	½ kg	6.75	17/-	10.25
6	Salt (Iodized)	1 kg	5/-	14/-	9/-
7	Chilli powder	¼ kg	20/-	35/-	15/-
8	Tamarind	½ kg	30/-	40/-	10/-
9	Turmeric powder	100gm	10/-	12/-	2/-
	Total		185/-	292/-	107/-
NB: Rice is also provided as per existing schemes mentioned earlier					

Additional schemes under the PDS include:

Antodaya Anna Yojana: Under this scheme, 10 million of the poorest BPL households are identified and 25 kg of food grains are given to each eligible family at a highly subsidized rate of Rs 2 kg of wheat and Rs 3 per kg of rice (Jha et al. 2011)

Annapurna Scheme: Beneficiaries under this scheme are those who are above 65 years of age and are not benefiting from the National Old Age pension scheme.

However, across India, there are various issues reported with the implementation of the programme. Some of the major issues with this scheme are outlined in Table 2.

Such problems have an adverse impact on the goals of the PDS to alleviate food insecurity, if the benefits of the scheme do not properly reach the intended beneficiaries.

Such gaps in implementations are seen in field surveys too. In surveys across four villages in Prakasam and Mahbubnagar districts in Andhra Pradesh, it was seen that there were complaints of inadequate stock, bad quality of food stuffs supplied through the FPS, delayed supply and lack of accountability of FPS and other PDS staff. Thus, the impact that the PDS would have had on ensuring food security is diluted due to these leakages and mis-targeting.

The problems in the current system of PDS have been recognized by the institutional mechanism, and studies being carried out on leakages by the Planning Commission and the Comptroller and Auditor general of India; both organizations have also identified these issues. In order to address these issues a new Food Security Bill was passed in Parliament in 2013, in order to address these issues. This bill has not yet been implemented, thus it remains to be seen how exactly mechanisms would be created to address the issues of leakages and mis-targeting

Table 2 : Some issues related to PDS in India

<table>
<tr><th>Issues</th><th>Source</th></tr>
<tr><td>Illegal diversion of food grains from PDS to open market</td><td>Khera 2011</td></tr>
<tr><td>About 57% of subsidized grains do not reach the target group, of which a little over 36% is siphoned off the supply chain.</td><td>POE 2005</td></tr>
<tr><td>No survey for identification of BPL families under TPDS undertaken in 18 out of 31 States and Union Territories. In States that had completed the identification survey ration cards have not been provided to many BPL households</td><td rowspan="3">Mane 2006</td></tr>
<tr><td>18 per cent of BPL households did not have ration cards</td></tr>
<tr><td>The performance of TPDS was poor in states with larger BPL population</td></tr>
<tr><td>Ghost Cards : Cards exist on fake names etc.</td><td>POE 2005</td></tr>
<tr><td>Irregular delivery of stock to FPS</td><td>POE 2005</td></tr>
<tr><td>FPS Viability: Only 23% of FPSs sampled by POE were found to be viable.</td><td>POE 2005</td></tr>
</table>

2.2 Self Help Groups

There exists a strong gender dimension to vulnerability, especially to climate change as elaborated on in module 5 of this document. This subsection, speaks about empowerment of the poor, especially of women, through financial means, in order to reduce this vulnerability. Self Help Groups are often a mechanism through which vulnerability could be alleviated.

A Self Help Group (SHG) is a small group of persons who come together to work towards a common purpose for issues that could range from medical issues to livelihood generation or watershed management. Often, the route to empowerment is often through financial means. It is seen that the poor were economically and socially marginalized by existing formal credit institutions (Nalini et al 2013), including cooperatives leading to dependence on informal credit providers such as money lenders, who lend money at high interest rates, thereby increasing the financial burdens on the already vulnerable. Thus, in Andhra Pradesh, the groups work largely like a conduit through which micro credit is routed to the poor assuming that it will serve as a catalyst helping them pull out of poverty.

The members of Self Help Groups are usually linked by a common bond like caste, sub-caste, blood, community, place of origin or activity. These natural groups are commonly called "affinity groups". Even when group members are engaged in a similar traditional activity, like basket weaving, the basis of the group's affinity is a common caste or origin"(MYRADA, 2000).[19]
National and state government initiatives, as well as NGO efforts, have used SHGs to implement poverty alleviation programs in Andhra Pradesh since 1979. Following on successes in earlier programs, which were modified from time to time to make them more meaningful, the state has scaled up SHGs in number and its structure significantly by basically using a social mobilization approach (Thomas, 2012).

Capacity building is an important component in the scaling up of Andhra Pradesh's these poverty alleviation initiatives. Trainings include participatory training methods, SHG formation and strengthening, book keeping and financial management and also helps members and leaders develop linkages with banks and other institutions. The primary aim of the SHG-Bank linkage program is to integrate informal savings and credit groups with mainstream banking by providing them with credit to enhance their fund base. (Deshmukh- Randeeve, 2004).

Today, these SHGs are being increasingly used as a vehicle for implementation for many of the government programmes in rural areas in various ways. The process uses social mobilization as an institutional mechanism to help the poor interact with government machinery so that public resources and services are better accessed. The participatory methodology adopted for identification and inclusion of the poor has proved to be very effective. This has helped create a transparent and inclusive methodology for community based targeting for programs.
Besides group mobilization, the programs focus on expanding the assets of the poor and creating economic opportunities connected with people's livelihoods. To reduce, mitigate and manage risks 'Velugu'[20] the AP State Government project supports the Community Investment Fund. This in turn supports investments in sub-projects for the poor and the Comprehensive Insurance Package which seeks to develop a community-based delivery of life and health insurance services.

According to Deshmukh- Randeeve (2004), there is absolutely no doubt that SHGs have led to an expansion in the economic spaces of their members. However the composition of the members reveals that the coverage of the poorest-of- the-poor was still low at the time of this study, while the coverage of non-poor was considerable. This evaluation report states that the financial status of households and savings capacities has improved due to improvement in access to formal credit institutions, since SHGs are linked with banks. Access to credit has enabled women to undertake economic activities, which tend to be an expansion or strengthening of existing traditional activities. A smaller proportion of women have taken up new occupations. This leads towards

[19]Myrada was started in 1968. Myrada at present is directly managing 18 projects in 20 backward and drought prone Districts of Karnataka, Tamil Nadu and Andhra Pradesh. There are other States where it has collaborated with Government, Bilateral and Multilateral Programs, by contributing to program design and supporting implementation through regular training, exposure and deputation of staff.

[20] The Velugu Project was introduced by Andhra Pradesh Rural Development Agency for the development of Poorest of the Poor and Poor. Mainly this project is intended for Poor so as to encourage their inherited skills and strengthen their livelihoods by all means. The execution of this project is done by Society for Elimination of Rural Poverty (SERP),Govt. of AP, India.

financial security, independence, better health care and child care. Social inclusion and participation in the political process are also impacted by SHGs (Badatya *et al*., 2006).

The fact that SHGs have indeed been helpful in reducing vulnerability is also borne out from field evidence. In a survey conducted in four villages of Andhra Pradesh it was noted in interviews and in focus groups that that self help groups have indeed helped in reducing poverty and vulnerability. It was noted that micro loans through SHGs were preferred over other sources as, the loans were at comparatively low interest rates between 7% -15% per annum, as opposed to money lenders, who often charged up to 50% interest per annum. The loans were reportedly used for livelihood generation, investments as well as for tiding over tough times, for food necessities, when daily wage work was hard to come by. People also used loans from SHGs for debt swapping, where they would pay off high interest loans by taking loans with low interest rates from SHGs, thus, and decreasing indebtedness in the household.

Self Help Groups seem to be one of the institutional mechanisms that are working as planned, and have had an impact on reducing vulnerability.

2.3 Rural Employment Guarantee

A large proportion of the rural poor in India are completely dependent on daily wages earned through unskilled labour, especially in agriculture. They are vulnerable to shocks and seasonalities, such as inadequate labour demand, health issues, climate variability or natural disasters which adversely impact their livelihood and food security. In order to address this, wage employment programmes provide people with short term employment on public works that are beneficial to the community or the environment, such as building or water resources development, soil erosion prevention, building infrastructure like village roads or schools. This wage employment is usually provided in the non-agricultural seasons, for a short period of few months each year in order to provide additional income during a period of no agricultural work.
Wage employment schemes were initially instituted on a small scale trial basis in the 1960s, with programmes such as Rural Manpower Programme, (RMP) [1960-61], Rural work Programme (RWP)[1972],Small Farmers Development Agency (SFDA), Marginal Farmers & Agricultural Labour Scheme (MF&AL) etc. Learning from these smaller projects led the government to enact the Food for Work programme in 1977. Other programmes that followed in the 1980's such as the National Rural Employment Programme (NREP) and Rural Landless Employment Guarantee Programme (RLEGP). Both NREP and RLEGP were merged into the Jawahar Rozgar Yojana (JRY1993-94). In 1999, the Jawahar Rozgar Yojana (JRY) was merged with Jawahar Gram Samridhi Yojana (JGSY).

The programme was merged with Sampoorna Grameen Rozgar Yojana during the year 2001-02 and National Food for Work (NFFWP, 2005) (Ministry of Rural Development, 2013). Additionally at the state level, there existed programmes such as the Maharashtra Employment Guarantee Scheme launched in a comprehensive manner in 1977, after small scale trials since 1965.

It is with this context that the Government of India passed The National Rural Employment Guarantee Act (NREGA), also known as the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA) was notified on September 7th 2005 (Gazette of India 2005).

The National Rural Employment Guarantee Act (NREGA), Act mandates that a **minimum** of 100 days of guaranteed wage employment in a financial year to every rural household whose **adult** members volunteer to do unskilled manual work.

According to the Ministry of Rural Development (2012), the objectives of the programme are as follows: To ensure social protection for the most vulnerable people living in rural India through providing employment opportunities; to create durable assets, improved water security, soil conservation and higher land productivity, to ensure livelihood security for the poor and reduce vulnerability; to carry out work that help mitigate the effects of drought and natural disasters, such as floods, in rural India; to aid the empowerment of the marginalized communities, including women, Scheduled Castes (SCs) and Scheduled Tribes (STs), through the processes of a rights-based legislation; to strengthen decentralized, participatory planning through convergence of various anti-poverty and livelihoods initiatives; to strengthening local grass root governance such as the Panchayati Raj Institutions (PRIs); to effect greater transparency and accountability in governance.

As can be seen in the above list, attempting to alleviate the impacts of climate variability, by constructing durable assets, and providing alternate sources of wage employment is one of the aims of the scheme.

Shortcomings of NREGA

As can be seen from Table 3, there is a large expenditure that is made by the government on the MGNREGS annually. From the government reported figures it can be seen that a huge number of person days of wage labour is generated across India.

It was found that there was a large demand from the rural poor for working all 100 days in NREGA, in 6 states of north India that were surveyed, namely Uttar Pradesh, Bihar, Jharkhand, Madhya Pradesh, Rajasthan and Chattisgarh. Thus, there is huge potential for MGNREGS to providing wage employment to the poor in India's most poverty afflicted states. However, despite the demand, it was seen that most people could not get 100 days of work. The percentage of workers that received 100 days of work, ranged from a minimum of 1% in Chattisgarh to a maximum of 35% in Rajasthan. There are said to be "leakages" that are not captured in the official data (Dreze and Khera 2009), apart from issues such as delayed wage payments, under-spending of allotted funds, lack of adequate monitoring and oversight, poor planning, selection of work (Raabe et al 2010).Despite its aims to be gender sensitive, it was seen that there were many barriers, mostly social, that prevented women in UP and Bihar from taking part in NREGA work (Khera and Nayak, 2009).

Picture 1: Removal of P. juliflora in Mahbubnagar

With respect to the impact of MGNREGA on Environment, not many studies have been carried out, one of the major studies, that was carried out by Tiwari et al (2012) that showed that there were positive impacts of MGNREGA work in selected villages in Chitradurga district. The study found that the vulnerability of agricultural production, water resources and livelihoods to uncertain rainfall, water scarcity and poor soil fertility were reduced due to assets created due to MGNREGS. However, it can be seen that these impacts are not seen all over the county. For instance,

In field studies carried out in 4 villages in Andhra Pradesh, from focus group discussions it was noted that water resource availability for irrigation was the major factor affecting the villages. However, respondents in 2 villages in Mahbubnagar district stated that MGNREGA work focused mainly on the clearing of *Prosopis juliflora.* The aim of this work is to convert land rendered uncultivable due to *juliflora* growth, into usable land. However, often, due to lack of water resources, it is seen that the fields are not cultivated, and *P. juliflora*, grows back, only to be cut again the next year under the MGNREGA scheme. In the same villages, de-silting of tanks and land application of silt does occur, however, this has not had an effect on water availability in bore wells. Creating of field bunds and repairing of field channels also occur, which prevents soil erosion during rainfall. However, the main issue of water scarcity sometimes seems to remain unaddressed, during the decision of work. Another issue is the poor quality of assets that have been created. For instance, roads laid in the village under this scheme were of bad quality. Delay of payments or non-payment is a big issue in all the villages. It was reported that people receive less wages than what they were expected to be paid in some cases. In two of the villages one in Prakasam district has been suspended due to alleged financial irregularities. Thus, as in the case of PDS system, there seems to be leakages with the MGNREGA scheme as well.

Employment Provided	Number of HHs provided employment (In Lakhs)			**498.17**
	Number of Person days generated (In Lakhs)			**22987.81**
	% of	SC	Person days	**22**
	% of	ST	Person days	**18**
	% of	Women	Person days	**51**
	Average	No. of	Days	**46.14**
100 Days & Less than 15 days	% of HHs who have completed 100 Days			**10**
	% of HHs who have completed less than 15 Days			**23**
Labour Budget	Approved LB Person days (In Lakhs)			**27870.58**
	% Achieved			**82**
Expenditure	OB in Lakhs (as of April)			**1092144**
	Total amount released (as of)			**2990954**
	Total Expenditure (as per MIS)			**3973552**
	% Expenditure of total fund availability			**87**
	Number of GPs where Expenditure is more than Rs. 1 Crore			**3366**
	Number of GPs where billed Expenditure more than Rs. 50 lakh in a day			**237**
	% of wage expenditure			**68**
	% of Administrative Expenditure			**6**
Works	Total works taken up in current year (new + spill over)			**10636835**
	% of category IV works taken up in the current year			**11**
	% of water related works(WC,WH,FC,IC,DP) taken up			**46**
	Number of works that have remained incomplete for more than 18 months			**3512563**
Wage	Notified Wage Rate (Rs.)			**125.97**
	Average Wage Per Day (Rs.) As Per MB			**121.4**
	No. of GPs where average wage is less than Rs. 60			**406**

Delayed Payment More Than 30 Days	Amount delayed (In Rs. Lakhs)	**706750.3**
	% amount delayed for more than 30 Days	**26**
Bank & Post Office Accounts	% of Individual Bank Accounts	**45**
	% of Joint Bank Account	**9**
	% of Post Office Account	**47**

3 Discussions

There is no doubt some serious issues with the existing institutional schemes. Some of these issues are outlined below.

Leakages: It can be seen from above that in both the Public Distribution System and the MGNREGS there are leakages, where often the benefits were not reaching the intended beneficiaries. It is to be noted, that both these schemes are administered and monitored by the government. However, such irregularities were not reported by beneficiaries of Self Help Groups, where there is self-regulation of finances amongst a group of people who already know each other. Thus this illustrates that an alternative method of management when compared to existing institutional methods could prove to be more effective in reaching the goals of reducing vulnerability and poverty, especially in the context of climate variability.

Difference in implementation: These institutional mechanisms are not uniformly bad. Some states implement some programmes well, whereas others do not. Sometimes even within the same state, there is difference in the implementation of programmes, as it often depends on the efficiency of local administration.

Difference in ability to access benefits from government schemes: Sometimes, within the same village, there may be difference in access to benefits between individuals. To illustrate this let us study a case of two households in a village in Mahbubnagar district in Andhra Pradesh, India. Household A, consists of 5 members, with land ownership of 3.5 acres of irrigated land. The household head also leases 1.5 acres of irrigated land, and owns 10 buffaloes. His primary income source is agriculture, and secondary source is from milk production. Household grew three crops in 2012 viz. rice, cotton and castor. Total earnings would be over Rupees 1.2 lakhs per annum. Additionally, his wife and son work on occasion as labour, including as labour in MGNREGS. This is an example of diversified income source. However, their financial condition was not always this good. In the last 15 years, the family has leveraged various government schemes. Earlier, they had no livestock, and lived in a dilapidated house and were reportedly much poorer than they are now and depended only on agriculture. They had earlier had a few buffaloes, but due to financial distress and drought had to sell them off. However, from the late 1990s onwards, the household has availed of loans from banks and from Self Help Groups to buy livestock and slowly grow their herd of milch buffaloes, to such an extent that milk production has become a large income source to them. Additionally, they have taken loans from agricultural cooperative societies for farming and they are able to repay loans quickly, and are relatively free from long term debt. They have built a pucca house, with a toilet using a government scheme called INDIRAMMA, which provides financial assistance to poor families to build houses. They rent a portion of this house out to other to further augment their income. The wife and a son work during the summer under MGREGA, and have earned over Rs 6000 in 2012, at an average daily wage rate of around Rs. 105. With this increased income in recent years, all three children in the household are educated, with one having finished his undergraduate degree, while the other two are still pursuing theirs. This is an example of how a poor family with awareness of schemes have been able to overcome poverty and distress, to emerge more successful than before. This is in sharp contrast to the next household.

Household B is a woman headed household, headed by a single woman of around 60 years of age. She lost her husband at a very early age and has brought up her children by herself. Her only source of livelihood is daily wage labour. She has no educations, and neither do her children. Her son and daughter in law live with her, though they are not employed. Apart from the pucca house she lives in that belonged to her late husband, she has no assets, such as land or livestock and is in debt, as she is getting older, she is finding it more difficult to engage in labour. She has worked under MGNREGA but states that she gets very low wages, often between Rs. 25–Rs 50 a day, much less than reported in other households. She is unable to tell us the reason for this disparity. She is not aware of many government schemes, and thus unable to benefit from them. She is however a SHG member, but is unable to create livelihood improvement opportunities from the micro credit she gets from it. She states that money from loans usually goes into daily expenses in times where regular work is hard to come by.

Thus it can be seen that those who are really poor and completely lack assets may find it difficult to leverage government schemes in order to reduce vulnerability. When this happens this sets in motion a vicious cycle of poverty, which is extremely difficult to break.

4 Conclusions

There seem to be many reported deficiencies in some of the institutional social protection programmes, thus they are only partially successful in reaching their intended beneficiaries. There are problems of a) leakage of resources towards the non-targeted groups; b) the targeted poor not getting the benefits; and c) the most vulnerable among the poor not benefiting. This is especially true in government monitored schemes such as PDS and MGNREGA. In the case of SHGs, where monitoring is localized and done by the stakeholders themselves, there are reportedly lesser problems. Thus in order to truly alleviate vulnerability, there is a need to look beyond the traditional institutional mechanisms, with alternatives that would seek to supplement institutional mechanisms.

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Institutions and Policies for Integrated Water Resources Management

M. Dinesh Kumar

1.0 INTRODUCTION

There are no easy, quick-fix, soft or readymade solutions to water problems. The solutions are hard, and the answers are not likely to come from one discipline. While there are several solutions which natural sciences offer, such as enhancing productivity of water in crops, transferring water from one crop to another, or transferring water to regions where its economic value would be high, to affect these solutions, solutions from human sciences need to be sought. Such solutions should be capable of changing the behaviour of the users of water for them to be tuned with the interests of the society at large.

There is an increasing recognition that water crisis are mainly governance and management crises (Jønch-Clausen, 2001). Several researchers have highlighted the institutional inadequacy and governance ineffectiveness in India's water sector (Narain, 2000; Kumar, 2001). Kumar *et al*. (2001) had highlighted four major institutional issues in water management. They are: 1] sectoral., segmented nature of institutions and their supply side focus; 2] multiplicity of functions of different line agencies; 3] poor water resource monitoring; and, 4] centralized planning. With the growing scarcity of water, and water resources management, researchers have argued about the need for investing in institutions for water allocation rather than interventions for augmenting its supplies (Saleth and Dinar, 1999). They further argue that in developing countries, the opportunity cost of not investing in institutional reforms would be much higher than the transaction cost involved.

The recent past had seen widespread and heated debates on the theoretical frameworks for managing water in South Asian countries. While some had advocated the use of IWRM (integrated water resources management) principles in managing water, and setting up of river basin organizations (RBOs) (James, 2005; Kumar, 2006) some had strongly criticized the general IWRM prescriptions, which were widely used in the west, as totally unfit for Indian kind of situations (Shah, Sakthivadivel and Makin, 2003; Shah and Koppen, 2006). Some had advocated major institutional reforms in the water sector such as water rights (Kumar and Singh, 2001; Rosegrant and Gazmuri, 1997; Saleth, 1997); community management (Shah *et al*., 1997); cooperative property rights and management (Singh, 1995); and strong top-down legal and regulatory frameworks (Sharma, 1995); and enabling legal frameworks (Moench, 1995). Most of it has been in the context of groundwater, and less on the administrative structures.

After Shah and Koppen (2006), the major arguments against IWRM are: 1] water supply systems in India are highly decentralized due to the dominant role of groundwater in its water supply landscape, and therefore the conventional institutional models for implementing IWRM, which are centralized and regulatory in nature and which work effectively under situations where water supplied by public agencies is a significant part of the total water used up, are not likely to work; 2] very high density of population in the country's river basins, with millions of water users who are scattered all over the basin, making it difficult to register them and bring them under a formal administrative structure; 3] water economy in developing economies like India is still very informal and IWRM approaches would success in situations where water economies are more formalized, which comes only at certain levels of economic progress; 4] weak legal and institutional frameworks for enforcing water management decisions.

They used the relationship between economic growth (per capita GDP) and water environment index (WEI) to make the point that water resource management strategies of a country has to do with the position of a country in the evolutionary process of economic development. But, such an analysis misses some vital aspects of the linkage between water and economic growth. 1. Water environment is just one of the many determinants of the water scenario of a country, the others being water access; water use and capacity building in water sector. 2. The natural water environment gets affected due to increased economic activities in the initial phase of the growth trajectory due to increased water diversion from rivers and aquifers for intensified farming, urban uses and industrial production, and increased use of natural water bodies for disposal of urban sewage and trade effluents. Water access, water use and institutional capacities in the water sector are the factors that drive this growth. However, contrary to the hypothesis postulated by Shah and van Koppen (2006), there are more recent evidences to suggest that the poor economic growth performance is directly linked to water access, as illustrated by a strong correlation between per capita GDP growth and rainfall in Sub-Saharan Africa with poor irrigation infrastructure (Barrios *et al*., 2004), and lower incidence of rural poverty found in irrigation command areas in South Asian countries viz., India, Sri Lanka, Vietnam and Thailand (Hussain, 2005).

The proponents of IWRM very well recognize that IWRM should not be pushed as a universal blueprint to for water resources management (see for instance, Jønch-Clausen and Fugl, 2001:pp509). It had also been acknowledged that IWRM processes will differ from countries to countries and there is no "one size fits all". The role of IWRM will vary depending on the stage of development of the country, whether developed economy, economy in transition or developing economy (see for instance Jønch-Clausen, 2004:pp9). That said, in the Indian context, the decentralized nature of water supply systems force state agencies to look for alternative institutional models for enforcing water allocation norms, they themselves are not sufficient a reason to reject such conceptual frameworks. Secondly, the very assumption that how formal is a water economy in a country is decided by its economic progress, is a misconception.

As a matter of fact, whether water economy is formal or informal depends very much on the situation with regard to the nature of resource--whether groundwater or surface water, the kind of technological/engineering interventions sought after for meeting water demands[21], the nature of access (direct access or water markets) and the institutional regimes governing water use that are in operation. The fact that many countries having highly formalized water economies is not a result of economic progress. For instance, Chile had adopted water rights reforms when its economy was poor (Thobani, 1997). As Beneditto Braga argues, countries have systematically invested in building water infrastructures and formalizing their water economies to attain certain level of human development, which in turn brings in economic progress (Braga, 2005).

In certain situations, no such correlation exists between degree of economic development of a state and the nature of water economy. In situations, communities run out of water, or are not able to manage its water needs, the state agencies are found to be investing in infrastructure and formal institutions for allocating and supplying water. India's water economy used to be much more formal in the early stages of water resources and irrigation development with greater role of public irrigation works in India's irrigation landscape, than it is today, while its economy was one of the poorest in the world.

Finally, the ability of a country in sustaining its economic growth would depend on the investments it makes in water sector (Braga, 2005; Briscoe, 2005), and a significant share of the future investment in the water sector will have to go to setting up institutions for water allocation and water resources management. To that effect, the analyses presented in the previous chapters

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[21] In water rich regions, water economy is likely to be less formal, than in a region facing natural scarcity of water. Water scarce regions of Gujarat such as Saurashtra and Kachchh are served by formal water supply systems of the government, whereas the economically prosperous regions such as central and South Gujarat manage their domestic water supplies through decentralized and often private sources (Kumar, 2010).

also show that the kind of interventions that India's water sector would need are such that local institutions alone would have extremely limited role in water governance and management. The very fact that water is becoming scarce in many regions, and competition and conflicts over sharing of water between administrative, political, hydrological and human boundaries, is growing in such regions, call for institutional mechanisms for water resources management, and water allocation that has influence beyond the boundaries of villages and watersheds. What is needed is development of appropriate institutions at appropriate levels.

In the absence of formal institutional frameworks that can coordinate various actions at the level of river basins, many local water management initiatives such as decentralized water harvesting by communities, NGOs and governments alike lead to over-appropriation and over-allocation of water. In these situations, the local institutions have been very strong and active. Particularly, NGO involvement is strongly being advocated as a catalyst for foresting community participation. The underlying assumption is that NGOs represent the voice of the poor and could be used to deliver the services, which governments fail to provide (Tortajada, 2001: pp360).

While in certain other situations, a greater role for Local Governance Institutions (LGIs)[22] in water management is mooted. The general argument here is that their social and physical distance from the water users concerned is much less than that of centralized water bureaucracies, improving the effectiveness of the institutions. But, in South Asian countries, the local self-governing institutions generally lack technological, organizational and managerial capabilities to deal with water problems (PRIA, 2011), though there are a few notable exceptions[23].

Over and above, these institutions cannot individually act on the interests of the basin communities at large and instead would try and maximize the local hydrological and socio-economic benefits. As the meeting of the Club of Tokyo noted, "Not a single institution, be it government, private sector or NGO, is unlikely to see beyond its own interests, agendas and priorities, every time over the long term. Exclusive dependence on one institution can marginalize the opinions and participation of other sectors" (Tortajada, 2001:pp361). There are limits and trade-offs to modifying watersheds due to complex hydrological and social systems' interactions (Calder, 2005). This is partly because watershed development interventions modify land use impacts on water resources, which in turn may alter downstream water access, while augmenting upstream water supplies (Batchelor *et al*., 2003; Gosain *et al*., 2006). Over and above, there are several negative externalities in local water management initiatives that reduce their effectiveness at the local level, as identified by Kumar, Mudrakartha and Bhalani (1998); Kumar (2000); and Kumar *et al*., (2006). Thus, absence of such coordinating institutional mechanisms at higher levels leads to some form of anarchy in the water sector.

In the next section, we try to illustrate the linkage between sustainable water and economic growth using data available for 147 countries. This draws heavily from the analysis presented in Kumar (2010). Then we try and examine the economic instruments and institutional mechanisms for affecting the solutions that are identified for meeting the future water management challenges. Water use efficiency and water productivity improvements, water allocation--across sectors and regions--, integration of natural water system (with surface water and groundwater and land use and water resource system (blue water and green water), that are major goals to be realized through IWRM, appear to be the key options for water management.

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22 The Panchayats are the local governance institutions in India and Nepal. A three-tier system of local governance exists in India from Zilla panchayat to Tehsil Panchayat to Gram Panchayat. In Pakistan, the local governance institutions are known as "Local Councils". In Bangladesh, they are known as "Union Parishads".

23 Kerala is one such exception. This to an extent can be attributed to the high human development index of the state, and unique geographical distribution of population. To an extent, the Panchayati Raj Institutions in West Bengal and Karnataka are also found to be quite effective.

2.0 SUSTAINABLE WATER USE, HUMAN DEVELOPMENT AND ECONOMIC GROWTH

The debate on the linkage between water and economic development is characterized by diametrically opposite views. While the general view of international scholars, who support large water resource projects, is that increased investment in water projects such as irrigation, hydropower and water supply and sanitation acts as engines of growth in the economy (for instance see Braga *et al*., 1998; Briscoe, 2005) the counterview suggests that countries would be able to tackle their water scarcity and other problems relating to water environment at advanced stages of economic development (Shah and Koppen, 2006). Whereas the proponents of sustainable development believe that the ability of a country to sustain its economic growth depends on the extent to which natural resources, including water, are put to efficient use through technologies and institutions, thereby reducing the stresses on environmental resources (Pearce and Warford, 1993).

An analysis was done by Kumar (2010) using global data on sustainability of water use in different countries, expressed in terms of an index named, sustainable water use index, and the data on human development and economic conditions. The sustainable water use index is built up of four sub-indices, viz., water access index, water use index, water environment and institutional capabilities in water sector. The analyses illustrate how governance and institutions are important in ensuring progress in human development and economic growth in countries. It reinforces the fact that investment in water institutions pay in the long run, though the transaction cost of building institutions for water management could be high in many of the developing countries.

3.0 INSTITUTIONAL CHANGES FOR DEMAND MANAGEMENT IN WATER

Both technologies and institutions are required for demand management (Molle and Turral, 2004; Perry, 2001). But, the behavioural changes required to facilitate adoption of technologies can be affected only through institutional changes. Therefore, institutional mechanisms and market-based (economic) instruments will be the fountainhead of the water management strategy for future.

3.1 Institutional Interventions for Transfer of Water from Low to High Valued Uses

Within agriculture itself, major differences exist in the productivity of applied water across irrigated crops in economic terms within the same region (Kumar, 2010, Kumar and van Dam, 2013). Therefore, opportunities exist for reducing the demand for water in agriculture, without compromising on the economic prospects of farming by shifting from crops having low water productivity to those having higher water productivity in rupee terms.

The growing competition and concomitant conflicts between different sectors are major issues that need to be addressed in water allocation. Allocation of water for high valued uses holds the key to addressing them. The fundamental issue to be tackled is the diversion of water for uses that have low economic efficiency. Inequity in access to water from canals and groundwater is another major concern.

Markets and regulations can be sought as instruments for water allocation (Frederick, 1992; Howe *et al*., 1986; Rosegrant and Gazmuri, 1994). Howe and co-authors (1986) suggest six criteria for comparing alternative institutional arrangements to allocate water: (a) flexibility in allocating supplies in response to both short-term and long-term changes; (b) security of tenure to encourage investment in and maintenance of water-using system while allowing for users to respond voluntarily to incentives to reallocate supplies; (c) whether the user is confronted with the real opportunity costs of the resource; (d) predictability of the outcome of the transfer; (e) equity impacts; and (f) whether public values are adequately reflected in the process. Frederick (1992) lists low-transaction costs of moving water from one use to another to this list.

Both markets and regulatory approaches are likely to fall short of satisfying all these criteria. Let us take the case of maintaining in-stream flows in natural watercourses and rivers, which is an important demand management objective to be achieved through water transfers. This being a public good, the users of in-stream flows have no incentive to pay for the services it provides. As a result, markets are likely to fail in this sector. The enormous geographic and temporal diversity in water supply and demand situations suggest that no single institutional arrangement is likely to be preferred in all instances (Frederick, 1992). Howe and co-authors (1986) argue that markets meet their six criteria better than any likely alternative in many situations.

This argument, by and large, is valid in the Indian context. The spatial and temporal variation in water availability is very high in India, caused by heterogeneity in hydrology and geo-hydrology and high inter-annual variability in rainfall. For instance, 62% of India's water resources are concentrated in the Indo-Gangetic basin (page 21: GOI, 1999). So is the variability in demand situation. In socially and economically regions such as Bihar and Eastern Uttar Pradesh, irrigation demand is very low, though water resources are abundant, and problems of water logging due to rising groundwater levels caused by flooding and excessive irrigation from canals are encountered (Shah, 2000). The demand for water for industrial and urban uses also remains very low in these regions. Demand management challenge here is to create increased demand for groundwater through market institutions, as investment in public tube wells has not been very effective.

On the other hand, demand for water is extremely high in arid and semi-arid regions where water resources are very scarce, and groundwater is the major source of water for all purposes. Pumping regulations in areas facing over-development problems through groundwater legislation, control of institutional financing for well development and restrictions on power connections for pumps has been by and large ineffective in these regions (Kumar, 2000; Janakarajan, 2002). Further, large distances involved in conveyance of water between regions of abundance and shortage reduces the ability of the government to invest in public water systems for supply of water in bulk as it has serious financial and environmental imperatives.

But, the absence of well-defined private property rights regimes can be a major source of uncertainty about the negative environmental impacts of resource use, leading to sustainability use (Pearce and Warford, 1993; Kay *et al*., 1997). The other issue is of efficiency. Since there are no restrictions on the amount of water that can be pumped by a farmer even in regions where water markets are extensive, the well owners are not confronted with the real opportunity costs of using water. This is because of the reason that the price at which water is sold to irrigators is still less than the net economic return from irrigating the crops. In north Gujarat, which is one of the most water scarce regions in India, the price tube well owners charge for water is in the range of Rs.1-1.5/m^3, while the net return from irrigated crops is in close to Rs.5/m^3 (Kumar and Singh, 2001). Also, the lack of opportunity to transfer water to more demanding uses such as industry and urban drinking is an issue in many regions. So the well owners would prefer to pump extra water and sell than using water his/he fields more efficiently and use the saved water for selling.

Lack of well-defined private property rights regimes also lead to the resource rich and the powerful over-using the resource and depleting it. This can significantly reduce the ability of the poor to access groundwater, perpetuating negative impacts on access equity. Analysis of water markets in Kolar, Karnataka and Mehsana in north Gujarat shows that the lack of well-defined groundwater rights increases monopoly power of rich well owners, and causes negative impacts on water buyers, due to monopolistic water prices (Kumar, 2007). Therefore, establishing privately owned property rights is critical to establishing conditions under which, markets and prices provide individuals with opportunities and incentives to develop, transfer and use the resource (Frederick, 1992). This will address the issue of social equity in access to water.

Water rights system in the context of groundwater refers to the rights to abstract and to use groundwater, which generally lies in public ownership, by public agencies, private corporations and farmers or a community under certain terms or conditions. Such rights are generally allocated by water resource authorities of a country or a state within the country or by the Court of Law. These are not absolute ownership rights, and are also known as usufruct rights by lawyers. A water rights system should have the following key attributes: 1] requirement for effective and beneficial use of water; 2] security of water use tenure; and 3] flexibility to reallocate water to more beneficial social, economic or ecological uses after periodic reviews or other mechanisms (Garduño *et al*., undated). Chile had one of the oldest systems of water rights in both surface and groundwater, which also clearly recognized customary rights (Rosegrant and Gazmuri, 1994; Thobani, 1997).

Many researchers in the recent past have suggested establishment of property rights as a means to build institutional capability to ensure equity in allocation and efficiency in use of water across sectors (Singh, 1995; Kumar, 1997a; Saleth 1996; Kumar, 2000; Kumar, 2007). But, again if the rights are allocated only to use water, it can create incentives to use it even when there is no good use of it (Frederick, 1992). Therefore, water rights have to be tradable (IRMA/UNICEF 2001; Kumar and Singh 2001; Saleth, 1996: pp246). According to Mexican Water Law, "tradable water rights" are water rights that can be transferred fully or partly between individual rights holders, or between an individual rights holder and a group, or between two groups, or between two sectors, or between agencies across two river basins, or that are transferred along with the land on certain terms (Rosegrant and Schleyer, 1996: pp272).

The argument is that when tradable property rights are enforced, efficient water markets would develop[24]. The reason being, with tradability, the prices would start reflecting the scarcity value of water (Saleth, 1996: pp246). The price at which water is traded will then reflect the opportunity cost for using water[25]. Such transfers can promote access equity and efficiency in use (Kumar, 2000).

The volumetric use right of different use sectors and individual users can be defined and established by the agency concerned by using a variety of physical, social and economic parameters. River basin organizations (RBOs) can be a viable institutional arrangement to evolve norms regarding water rights of different use sectors and individual users, and allocate the rights and enforce them. A user who needs more water than the actual entitlement can purchase the water rights from another user, by paying prices that are determined by the supply–demand interactions.

Empirical evidences collected on the functioning of groundwater irrigation institutions in north Gujarat show that under a system of fixed volumetric water use rights, farmers prefer to grow mustard, which is less water intensive, in larger area as compared to wheat, though the earlier one has much lower land use productivity than wheat, but getting same water use productivity (see Kumar 2000 for details). Further, Kumar (2005) found that with volumetric pricing of water and its rationing as found in the shareholders of tube-well partnerships, farmers allocate their entitlements for growing crops that give higher economic returns from every unit of water used for crop production (Kumar, 2005).

Tradable private property rights are suggested for groundwater and water supplied from public reservoirs for irrigation and domestic uses. In the case of groundwater, as individuals enjoy access to the resource, private property rights for individual users are envisioned. Also, in the case of canal water supplied for irrigation, private individual property rights are suggested. But,

[24] Water markets are important institutional mechanisms for transfer/allocation of water to alternative uses which are more economically efficient (Frederick, 1992; Howe *et al*., 1986).

[25] The markets and market determined prices could induce incentives among users to shift to alternative uses that provide higher or same economic returns as the price of water, or continue the existing uses with more efficient practices or resort to selling (Frederick, 1992).

in the case of municipal water supplies, the rights of the water utilities over the water from public systems can be recognised (Kumar, 2010).

Frederick (1992) suggests that for markets to function efficiently, the full benefits and costs of transfer should be borne by the seller and buyer. Generally, this is not possible due to the third party effects of water transfer. "Water resources may also produce public goods that are affected either positively or negatively by a water transfer. Non-paying individuals cannot be excluded from enjoying the benefits of public goods. As a result, the users of such goods have an incentive to free ride, and producers have an incentive to under-invest in these goods from a social perspective" (Frederick 1993). Allowing the user to transfer only the consumptive portion of the water he/she uses can reduce the third party effects of water markets. Government will have to play a great role in reducing the third party effects of water transfers, apart from defining and establishing the individual property rights. Similarly, government has to invest in protecting or retaining the public goods that are affected by water transfers.

Efficient water markets are likely to come up more in groundwater irrigated areas due to the following reasons: extensive use of conduits for water conveyance increases the transferability of water and reduces the third party effects; ability to measure the rights purchased; and, relatively low distance of water transfer, which reduces the transaction cost (Kumar, 2007).

Within the same basin, the allocation of water rights in different sectors cannot be in the same proportion over the years and could change significantly depending on the changing priorities. In years of drought, urban areas might face severe water stress. Since the basic survival needs of water cannot wait, a greater share of the available resources will have to be allocated from agriculture to municipal and industrial uses in urban areas. Since the use value would be higher in urban areas, the farmers might be willing to transfer their rights, partly or fully to urban uses, provided they are adequately compensated[26].

In order to meet the ecological and environmental needs such as maintaining in stream flows in rivers, that are public goods, the river basin organization can allocate sufficient water from the basin in volumetric terms. Thus, if water market for competitive uses operates under well-defined tradable private property rights enforced by institutions such as RBOs, some regulations to provide water for environmental needs and reduce third party effects of water transfers can bring about demand management. The cost of providing water for environment to be borne by the RBO can come from the pollution tax that is levied from users of water in streams and rivers for assimilating the pollutant load.

3.2 Economic Instruments for Water Saving

Water conservation has three distinct components: a) conservation by preventing the loss of stored water; b) conservation by preventing the loss of water from the system during conveyance from supply source to the point of usage; and, c) conservation of water at the user level by adopting efficient water use technologies, so as to enable the user maintain the same service. First of all, we will analyze the scope of each of these options in increasing the effective water availability by examining the current efficiency levels in use.

In irrigation, storage losses are very high for surface reservoirs. The potential for saving this water is very high. Again, the conveyance or the network losses are very high for the surface irrigation systems in the country. It is believed to be in the order of 45-55% for many of the large surface irrigation systems with extensive distribution network consisting of several hundred kilometers of unlined channels.

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[26] The willingness might come from the fact that the total amount of water that the allocation will be far less than sufficient to grow crops in a way that gives optimum yields.

The farm level efficiencies in surface irrigation systems in India and the Indus Basin Irrigation System (IBIS) in Pakistan are very poor due to very high field evaporation, percolation, and runoff losses due to flood irrigation and poor on-farm water management practices being adopted by farmers. There is enough empirical evidence to substantiate this (Source: based on Kumar, 2010; GOP, 2012).

But, water saving is often a misunderstood concept (Keller and Keller, 1996). Many of the losses that take place in traditional irrigation methods like flooding are not real "losses". Hence, reduction in these losses may not result in real water saving. For instance, deep percolation of a portion of the applied water in the field is available as return flows to groundwater system, which can be recovered for further use in irrigation in the same basin downstream. Hence, reduction in deep percolation losses means lower irrigation water requirement for the farmer at the field level. This is called "dry water-saving". But, this field level water saving may not result in water saving at the system or basin level in the same proportion. At the same time, reduction in field evaporation would actually result in actual water saving as the consumptive use of water is reduced. This is known as "wet water-saving" (Keller and Keller, 1996; Seckler, 1996).

There are no storage losses in groundwater irrigation. The network losses are also very low due to the generally short conveyance systems used for water conveyance from the source to the fields (Xie *et al*., 1993). The field efficiencies are also generally higher due to greater control over water and manageable discharges. But, ideally, if the quality of power supply is good, under flat rate pricing, farmers use irrigation water excessively, resulting in economic efficiencies that are sub-optimal as the marginal cost of pumping water is zero. However, the quality of power supply in rural areas is very poor. Uncertainties about time and duration of power supply create incentive among farmers to apply excess water when supply is available. This not only leads to inefficient use, and but also low levels of return (Kumar and Singh 2001).

In urban water supplies, distribution losses comprising technical losses due to leakage and breakage and non-technical losses due to pilferage are very high. The percentage of unaccounted for water to the total water supplied in the four cities, namely, Mumbai, Kolkata, Bangalore and Nashik are 14%, 35%, 45% and 59%, respectively (ADB, 2007). The technical losses are huge, where the distribution systems are very old. Pilferage is huge where water is transported over long distances, unprotected. In rural water supply sector, the potential for water saving exists only in regional water supply schemes, as distribution losses are high. In village level water supply schemes, the distribution losses are potentially low.

The levels of production technologies in use in Indian industries are that of other third world countries and therefore potentials for efficient use of water in production systems in water intensive industries such as cement, ceramics, petrochemical and chemical industries, paper industries, thermal power stations etc. are great. The potential for conserving the water used for pollution assimilation through reductions in the pollution load (biological, chemical) of industrial waste is tremendous. The following section will examine what kind of measures will work for bringing about conservation at various levels.

3.2.1 Pricing of Water

The fact that water is a scarce economic input should be a major decisive factor in determining the price of water (Kay *et al*. 1997; Perry, 2001). As a general principle, price of water for competitive use sectors such as irrigation and water intensive, means pricing of water should be fixed in such a way that it discourages uses that are economically inefficient (Kay *et al*., 1997; Pearce and Warford, 1993; Perry, 2001).

Pricing of Irrigation Water from Canals

In India, irrigation water is heavily subsidised. The annual irrigation subsidies are estimated to be around 5400 crore rupees (Wolf and Hubener, 1999). In Pakistan, the price for canal water for irrigation is a mere 24% of the O & M cost, and the annual irrigation subsidy amounts to 5.4 billion rupees. Interestingly, the cost of irrigation for tube well owns is 15-20 times higher than that of canal irrigators in their vicinity in Punjab province (GOP, 2012).

In India, after independence, the governments saw irrigation as welfare means, and were reluctant to raise irrigation fee charged to poor farmers. As irrigation services declined and agencies weakened, farmers became reluctant to pay the water charges (Brewer *et al*., 1999). Also, the charges are paid on acreage basis and are not reflective of the volume of water used. The situation is similar in Pakistan. In Pakistan, the acreage charge for sugarcane is same as that of maize, though the former requires twice the water which the latter requires (GOP, 2012). The lack of linkages between volumetric water use and water charges, and lack of agency capability to recover water charges and penalise free riders create incentive for overuse or wasteful practices (Kumar, 2010).

In spite of the recommendations of the second irrigation commission, state irrigation bureaucracies have failed to hike water charges that make economic sense due to the potential social and political ramifications such measures can create. The failure has its roots in the absence of institutional capability to improve the quality of irrigation services and correctly monitor the water use, lack of institutional arrangements at the lowest level to recover water charges from individual farmers, and enforce penalties on free riders. A few successes have been seen in areas where PIM programme is implemented, where farmers have shown the willingness to pay more for the irrigation services to the Water User Associations.

The recent past has shown significant debates over the usefulness of irrigation water pricing as a way to regulate water demand, with some arguing for (Malla and Gopalakrishnan, 1995; Tsur and Dinar, 1995; Johansson, 2000); and some others arguing against pointing out shortcoming at both theoretical and practical levels (Bosworth *et al*., 2002; Perry, 2001; Hellegers, per. com). There are three major, and important contentions of those who argue against pricing: 1] they question the logic in the proposition that “if the marginal costs are nil, farmers would be encouraged to use large quantities of water before its marginal productivity becomes zero, consuming much more than the accepted standards and needs” (source: Molle and Turral, 2004); 2] the demand for irrigation water is inelastic to low prices, and the tariff levels at which the demand becomes elastic to price changes would be so high that it becomes socially and politically unviable to introduce (de Fraiture and Perry, 2002; Perry, 2001); 3] there are no reasons for farmers to use too much water, which can cause over-irrigation (Molle and Turral, 2004).

Such arguments suffer from many weaknesses (see Kumar, 2010 for a detailed discussion on this). But, what is most important issue is in linking irrigation charges and demand for water (see Perry, 2001; De Fraiture and Perry, 2002). Merely raising water tariff without improving the quality and reliability of irrigation will not only make little economic sense but also would find few takers. As returns from irrigated crops are more elastic to quality of irrigation than its price (Kumar and Singh, 2001), poor quality of irrigation increases farmers’ resistance to pay for irrigation services they receive. Therefore, the “water diverted” by farmers in their fields does not reflect the actual demand for water in a true economic sense, so long as they do not pay for it. In other words, the impact of tariff changes on irrigation water demand can be analyzed only when the water use is monitored and farmers are made to pay for the water on volumetric basis.

The above arguments also lead us to the conclusion that the rates for canal water can be increased to substantially higher levels, provided the quality of irrigation water is enhanced. But, water pricing for irrigation can impact poor farmers adversely, if pitched at higher levels (Frederick, 1992). One of the ways to reduce the negative impacts on access equity is to introduce progressive pricing system. An appropriate pricing structure for water followed by a clearly recognized private property rights and good quality irrigation service could help achieve the desired effect of pricing changes on demand management.

It also means that if positive marginal prices are followed by improved quality, the actual demand for irrigation water might actually go up depending on the availability of land and alternative crops that give higher return per unit of land. This is because the tendency of the farmers would be to increase the volume of water used to maintain or raise the net income (Kumar and Singh, 2001). Hence, water rationing is important to affect demand regulations in most situations (Perry, 2001; Hugh Turral, per.com; Petra Hellegers, per.com).

Impact of pricing on water saving could be through limiting the amount of water applied. When the farmer is confronted with marginal cost of using water, the water application regime should ideally correspond to a point where the net return per unit of land is highest. Though this level of irrigation may not correspond to the point of maximum water productivity for that crop, it would result in higher water productivity in economic terms (Rs/m^3) as compared to a scenario of zero marginal cost of water. But, again, increased efficiency may not lead to reduction in aggregate water use, as farmers might tend to increase the area under irrigation. If the farmer is using an efficient irrigation technology, then the dosage of irrigation required to achieve the optimum yield would be smaller, as greater percentage of the applied water would be converted into beneficial use as compared to traditional irrigation. This means, the compromise farmers make on yield while limiting irrigation would be less under micro irrigation systems, if the water application regime corresponds to ascending part of the yield curve.

Pricing of Urban Water Supplies

As urban areas are likely to emerge as the second largest user of water in South Asia in the near future, promoting efficient use in urban water sector will have a strong leverage in managing the overall demand of water to match the supplies in the region. For this, we would examine the institutional factors that influence domestic water use in cities.

The first institutional factor is subsidy. Domestic water supply is highly subsidised in many cities in South Asia, with the exception of Sri Lanka (Biswas and Tortajada, 2003). Though in many Indian cities, the average water tariff is higher than the cost of production & supply of water, the high average is because of high tariff levied from industries and commercial connections, and domestic supply is actually heavily subsidized (source: ADB, 2007). The second factor is water supply administration. Domestic water supply is not fully metered even in large cities. In more than 50% of the cities falling under Class I and Class II category, household connections are our partially metered or un-metered (source: based on data presented in NIUA, 2005). The third factor is the way water tariff is administered. Many large cities viz., Kolkata, Jabalpur, Jamshedpur, Mathura, Rajkot, Varanasi, Bhopal and Indore meter only less than 1% of the connections, whereas cities such as Ahmedabad, Vijayawada, Amritsar, Chennai, Surat and Visakhapatnam meter 1-10% of the connections (ADB, 2007: pp 22).

Table 1: Cost of Production of Water and Water Tariff in 20 Indian Cities

Name of the City	Average Water Tariff (Rs/m^3)	Average Cost of Production of Water (Rs/m^3)
Bhopal	0.6125	3
Mathura	0.612	2.2
Kolkata	1.25	3.5
Ahmedabad	1.5	1.5
Jabalpur	1.6	1.8
Surat	1.7	2.1
Vijayawada	2.5	2.25
Indore	3	13.2

Varanasi	3.12	2.25
Coimbatore	3.75	1.5
Nashik	4.2	2.15
Jamshedpur	4.32	2.5
Mumbai	4.4	3.75
Chandigarh	5.05	4
Rajkot	5.05	2.85
Nagpur	6.5	2.15
Vishakhapatnam	8.5	4.9
Amritsar	9.32	4.5
Chennai	10.8	6.05
Bangalore	20.5	10.2

Source: derived from charts in ADB, 2007

Often the use of block rates in urban water pricing causes the poor people to pay more for water creating negative impacts on access equity (UNDP, 2006:pp). The factors that make the poor pay more for water needs to be understood. One of the problems facing urban water utilities is the poor infrastructure, with low percentage coverage of individual water supply connections. The people living in city slums, who account for a major chunk of the population, access water from public systems through common stand-posts and taps. Due to the limited amount of water that is accessible through common taps, they have to manage their water supplies from a myriad of sources such as water tankers; private water vendors; and fetching water from long distance sources, spending substantial amount of time and labour. It is also important to note that water supply from public systems is the cheapest, and the costliest being the water supplied by vendors (UNDP, 2006).

A study carried out for the *White Paper on Water in Gujarat* among urban populations showed great inequity in access to water supplies between different classes. In Bhuj town, the Municipality supplies water to the town's population through the piped water supply with individual tap connections in housing societies, commercial establishments and other government and private establishments. Stand posts are maintained for water supply to slum areas. In Bhuj town, the average domestic water use was 14 lpcd in the slums, while it was 79 lpcd in middle class housing societies and 109litre in upper class societies. Since the water charge is not levied on volumetric basis, and instead is linked to property tax, the supply costs the poor slum dwellers much more than what it costs for the economically rich people enjoying independent tap connections in urban areas. In Rajkot city, while the Municipality supplied water through tankers to housing stocks during drought years, a large section of the city's residents was dependent on private water tankers paying high prices**.** The slum dwellers were using 18 lpcd of water a day on an average, against 63 lpcd by middle class societies and 83 lpcd by upper class societies (IRMA/UNICEF, 2001).

While incremental block rates are advocated for urban water supplies for bringing in equity in access to water, efficiency in water use, and improve affordability, they are not widely practiced. One major reason is the poor coverage of public systems vis-à-vis individual connections. As studies from Bangalore, Kathmandu, Bogotá and Chile show, if the private connection charges are low, incremental block rates can produce undesirable equity consequences with a disproportionately larger share of the water subsidy benefits going to the richest and the middle income groups (Komives *et al*., 2005 as cited in UNDP, 2006: pp99). The ability of resource rich urban dwellers to access water from private sources such as wells is another issue in proper pricing.

Hence, the issue is also about building adequate water supply infrastructure and creating sufficient incentive structures, apart from administering water supply, and introducing an efficient tariff policy to address efficiency, affordability and equity concerns and administering it.

3.2.2 Creating Incentives for Pollution Control

Although the existing pollution control norms are stringent, the legal powers to enforce them are lacking with the pollution control agencies. Industries and municipal authorities often get away with flouting the pollution control norms (Kumar and Shah, 2004). The fact that the agency that monitors "pollution" is the same as the agency that enforces the "norms", which is against the institutional design principle for sound water management (Frederiksen, 1998), further weakens the agency. Over and above, the polluting industries and municipal authorities are not confronted with the opportunity costs of pollution as the penalty paid for pollution is much lower than the investment in effluent treatment facilities to avoid or mitigate pollution.

To reverse the trend, pollution taxes that reflect the volume of effluent discharged and the level of toxicity of the effluents need to be introduced. Incremental block rates can be introduced along with creation of two separate institutions, one for monitoring pollution, and the other for levying pollution taxes and carrying out corrective measures against pollution. In doing so, the industries and municipalities will have strong economic incentives to minimize the use by investing in low water consuming technologies, water treatment and recycling.

The effectiveness of economic instruments in affecting pollution control, to a great extent, would depend on the water quality monitoring (WQM) systems established by official agencies. Water quality monitoring in India is very poor and there are several technical issues associated with water quality monitoring (Kumar and Ballabh, 2000 on the basis of Moench and Metzger, 1992; Moench, 1995a; Biswas, 1996). They need to be adequately addressed.

3.2.3 Creating River Basin Organizations

Technological and institutional changes alone will not be sufficient to bring about the desired changes in the demand situation. New institutions such as RBOs will also have to be created by the agencies for enforcing rules and norms relating to volumetric water rights, water prices etc. As Jønch-Clausen (2001) notes, allocating certain resource management functions to river basin entities is a very useful way to ensure that IWRM issues are considered. Kumar (2006) provided a framework for design of river basin organizations (RBOs) for water resources management and water allocation for Sabarmati River Basin. The institutional design principles were as follows:

First, the operational boundaries of the governance units created for effective management should match with the hydrological system boundaries. Second, the institution that is responsible for enforcing norm and regulations on water use (including pollution) should be responsible for investment in water quantity and quality management. Third: the institutions responsible for water quality monitoring and the institutions enforcing pollution control norms will have to be different. Fourth: the governance/management structure will integrate local water management interventions with larger basin management actions and promote involvement of user groups/ communities in the governance and management. The proposed management structure is a vertically integrated hierarchy of organizations from watershed to sub-basins/river catchments to river basins.

Apart from allocating and enforcing tradable water rights among different sectors and users in the river basin, RBOs can provide a coordination structure for: 1] the agencies looking after the water-related services; and 2] water resource management functions such as soil and water conservation, water harvesting, catchment protection and pollution control for sustainable basin management. Currently, these agencies are working in isolation and in a sectoral way as found in Gujarat (Kumar *et al*., 2000; Kumar, 2002).

Some of the countries where RBOs were created for varying purposes from water resources management to water quality management to water allocation are: France, Canada, Brazil, Australia, Indonesia, Spain and Poland (Source: based on Ladel, 2003; Kemper *et al*., 2005). In Spain and Poland, the RBOs have moved towards achieving IWRM objectives, such as water quality protection and water pricing (Kemper *et al*., 2005). The Murray-Darling Basin Ministerial Council of Australia, which is concerned with natural resources (land, water and environmental resources) management, which was encompasses parts of four sovereign states of the country. The role of the Council is to set policy and define broad directions for the management of natural resources in the basin. It is supported by the Murray-Darling Basin Commission to execute its policies. It is charged with efficiently and equitably managing and distributing the water resources of River Murray. It also advices the Council to achieve sustainable, long term water utilization (World Bank/GOI, 1998).

Australia has a long history of organizing water administration around hydrological boundaries such as catchments and river basins[27]. The Murray-Darling Basin Ministerial Council, which is concerned with natural resources (land, water and environmental resources) management, encompasses parts of four sovereign states of the country. The role of the Council is to set policy and define broad directions for the management of natural resources in the basin. It is supported by the Murray-Darling Basin Commission to execute its policies. It is charged with efficiently and equitably managing and distributing the water resources of River Murray. It also advices the Council to achieve sustainable, long term water utilization.

The technical responsibilities of the Commission, which has two commissioners from each one of the participating states, are: River Murray Management; water quality, land resources, nature conservation, and community involvement. The environmental responsibilities include: coordinating action to preserve the native fish and riverine environment, and coordinating the management of wetlands on the River Murray floodplains. The communication team of the Commission produces materials to raise public awareness of the Murray-Darling Basin and the management of its natural resources, and for this they coordinate with the education department, government agencies, community resource centres and the media (World Bank/GOI, 1998). The MDB Commission was reconstituted as MDB Authority in 2010 under the Commonwealth Water Act of 2007.

In France, the river basin organizations were created for allocation of water rights among different sectors of use and users within sectors, as well as for performing water resource management functions within the basin area. From 1970 to 1992, France had six river basin organizations. The water tax rates were decided on the basis of the type of use, and the tax paid by the users is used for implementing basin management activities (Buller, 1996). Many Asian countries are in the process of creating RBOs as institutional tools/mechanisms for allocation of water resources across sectors and regions. Many countries have organized their water

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[27] Attempts to coordinate the management and development of the Murray-Darling Basin's water resources started as early as 1863 during a period of prosperous river trade as steamers plied the Murray. In the 1880's, with the first large-scale diversions from Murray River for irrigation, it became clear that cross-border measures for management of water resources were needed. The new demands for water supplies provoked conflicts between irrigation and navigation interests on the river. Under the River Murray agreement signed in January 1917, the River Murray Commission was formed consisting of Commissioners from New South Wales, South Australia, Victoria and the Commonwealth. It was responsible for building and operating storages, weirs and locks for development, allocation and economic use of basin's resources. In 1982, the focus of the Commission got broadened to cover water quality aspects in recognition of the emergence of water quality problems resulting from development in the upper basin areas. This eventually led to the replacement of Murray River Commission with Murray-Darling Basin Ministerial Council (World Bank/GOI, 1998).

management at the basin level years ago (the Spanish river basin management structures were created in the late 1920's; Mekong River Basin structures were established in the 1950s (Jønch-Clausen, 2004:pp18).

The institutional arrangement for water management, as suggested by Kumar (2006) for Sabarmati river basin, is presented in Figure 4. The institutional arrangements were worked out on the basis of rigorous analysis of: 1] institutional and policy framework governing the water development and use in Gujarat in general and Sabarmati basin in particular, and their impact on basin's water environment (see Kumar and Nagar, 2001); and institutional issues in integrated water management (see Kumar, 2001). The institutional arrangement had their basis in the physical options identified for water management (both supply and demand side) through a basin-wide water balance studies. In other words, if the physical options for basin-wide water management are different, then the institutional arrangements will also have to change.

In order to affect reductions in the demand for water, the institutional regimes governing water use need to be changed. The overall governance of the RBO shall be provided by a G*overning Council*, which will be drawn from the individuals and civil society organizations concerned about the water-related problems and issues in the region. The *Governing Council* will take the major policy decisions such as: [1] the extent of utilization of the basin's water resources for various beneficial uses for the present and future generations and water imports; [2] definition of beneficial use rights, [3] fixing of water taxes; and [4] overall resource management objectives. In Australia, the newly constituted Murray Darling Basin Authority implements a Basin Plan, which is a statutory document, and which provides a new management framework for a trans-boundary, river catchment level management of water resources in the basin, encompassing four states. The Basin Plan is legally enforceable and defines sustainable limits for groundwater and surface water; basin-wide environmental objectives; roles for a basin-wide water trading system; requirement of sub-plans for each one of the four states to implement the Basin Plan objectives; measures to improve the security of water entitlement holders (Cornell, 2012).

A Stakeholder Forum can assist SBO through periodic interactions with the Governing Council**.** The management unit of RBO will implement the policy decision taken by the governance unit. This is parallel to the Water Agencies in French RBOs. It has to perform the following tasks: [1] planning of various water resource management, activities to tackle specific resource degradation problems; [2] water balance studies and water budgeting; [3] water allocation; [4] recovery of water taxes; and, [5] monitoring of basin's water resource availability and its quality. In the governance system proposed, the water resource management functions and functions relating to management of water-related services are to be separated and are to be performed by different agencies. There would be clear "clarity of role" between SBO and the water service agencies.

Under the institutional framework suggested, water allocation was envisaged through well-defined and properly instituted tradable water rights and water markets which emerge due to that. Water rights would ensure social equity in access to water, due to groundwater depletion and over-appropriation of surface water, and which is one of the basic goals in integrated water resources management.

The positive effects of instituting tradable property rights in water and formal water markets on water use efficiency, agricultural growth and welfare of the poor farmers are well-documented in case of Chile (Thobani, 1997: pp170). Water trading has been progressively introduced in the southern MDB since the early 1990s as a mechanism that facilitates the reallocation of scarce water resources to higher valued uses, which provides economic benefits to individual buyers and sellers and to society as a whole. National Water Commission (2010) of Australia provided a comprehensive assessment of the economic, social and environmental impacts of water trading in the Southern MDB over the period from 1998–99 to 2008–09, which covered a period of severe and prolonged drought.

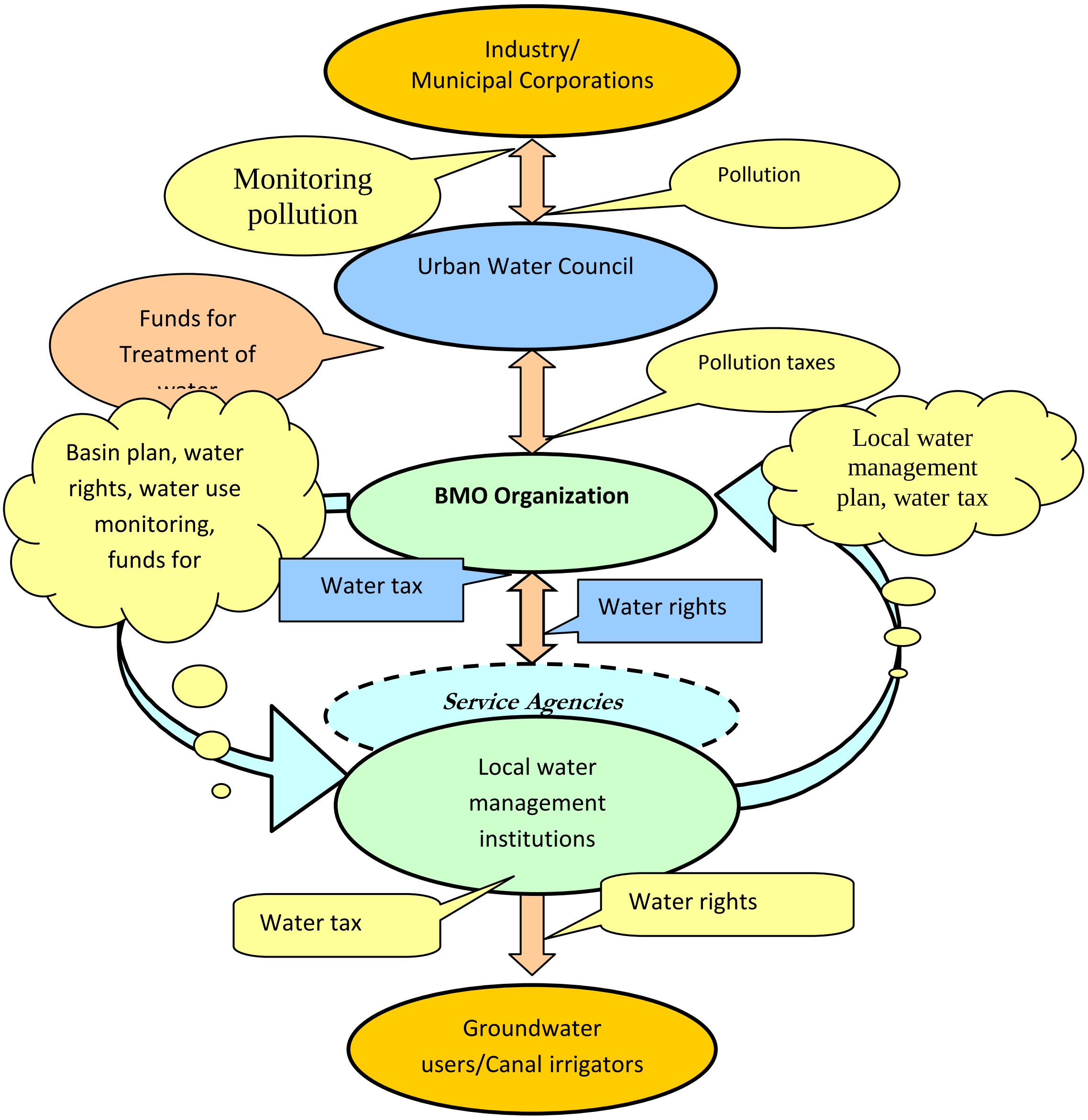
The separation of water entitlements from land making water rights tradeable has unlocked the value of water and given individuals and firms more flexibility in their water-use and production decisions. The option to trade water helps individual irrigators increased their net worth and manage debt and risk. Consultations with irrigators indicated that individual irrigators are becoming increasingly sophisticated in the way they use water trading. Economic modelling using observed data and consultation across the Southern MDB found that these benefits to individuals led to aggregate benefits at the national and South MDB levels to the tune of AUD 220 million in a year (NWC, 2010).

With a participatory institutional format suggested for RBO, the local institutional arms of the RBO such as watershed institutions and sub-basin organization can be made responsible for carrying out local resource management functions, and enforcing water use rights among local groundwater users. The higher order institutions would be responsible for evolving broader water resource management plan, in line with the Basin Plan of MDB Authority, evolving inter and intra sectoral water allocation norms and water taxes, and monitoring the bulk use by different service agencies.

For generating resources to cover their own management cost and the cost of implementing various resource management actions at the local and basin level, the RBOs can levy water tax from the users on the basis of volumetric consumption (Kumar, 2006). In groundwater irrigated areas, the water tax could be linked to the volumetric energy use--if the one knows the energy requirement to abstract unit volume of groundwater. Thus the local management institutions could monitor the electricity use by individual farmers, and charge for water, accordingly.

The water tax in a way should be the charged as the “resource cost”. This can change from year to year depending on the available water resources in the basin that can be safely allocated. In relatively water-scarce basins, the value of water would be eventually higher than that in relatively water-rich basins. Ideally, the “resource cost” also will be higher in water scarce basins. The differential use value and resource cost would encourage users to transfer water from water-rich basins to water-scarce basins, as users there would be willing to pay higher price. The local institutional arms of the RBO can recover the water tax from users based on proper monitoring of the uses.

Figure 1: Institutional Arrangements for Water Management in River Basins



As per the suggested framework for the RBOs, the line agencies in water-related services viz., irrigation, rural and urban water supplies and industrial water supply, are different from the agency concerned with water resources management functions and water allocation at the basin level. Further, the agency concerned which is responsible for setting up of water treatment systems in urban areas would be different from the one which is concerned with water quality monitoring. Therefore, theoretically, RBOs should be able to overcome the common problems facing the water sector such as sectoral and segmented approach to water resource development; sectoral bias in water allocation; inadequate water resource monitoring; the same agency performing a multiplicity of line functions; and lack of user group involvement in planning.

In the case of trans-boundary (here inter-state) river basins, there are two extra challenges in water allocation. They are hydro-institutional in nature and are caused by several socio-economic changes occurring in the basin. The outcomes of these socio-economic changes are land use changes in the upper basin areas with greater use of green water, change in water use patterns with increased diversion and use of blue water, and increasing groundwater draft in the upper basin areas causing reduction in inflows into the surface streams. Understanding the changes in water use hydrology, and surface water groundwater interactions would require intensive monitoring of land use, water use, and trends in stream flows and groundwater level fluctuations in the basin. Such an exercise has to be carried out by an independent agency such as an RBO.

Institutional Innovations for Improving Water Services

In public irrigation systems, wherever exists, monitoring of water use is only at the outlet level. The farmers do not pay for the water lost in the large distribution systems and hence do not have incentives to conserve it. Un-authorized withdrawal of water from canals is also rampant. Technological approach alone will not be sufficient to solve these problems (Kumar, 2010). If water is delivered to the farmers' organizations at higher levels in the hydraulic system instead of minor outlets, and charged on volumetric basis, it will create incentives among the distributary level associations to conserve it and protect it from illegal diversions. On the other hand, if allocation of water has to be done on the basis of previously negotiated volumetric rights, it would increase accountability on the part of irrigation bureaucracy (Kumar, 2010; Kumar and Bassi, 2011).

The farmers' organizations at the distributary and outlet levels can, in turn, charge for water on the basis of volumetric delivery to the outlets and individual fields, respectively. Such institutional arrangements can ensure efficient distribution, proper measurement of water delivery, increase recovery and prevent unaccounted losses in transmission (Kumar, 2010; Kumar and Bassi, 2011). Since the irrigation agency will have to pay for the water it has been allocated, based on consumed volume, it will have incentive to introduce changes in water allocation and pricing policies, and work towards institutional innovations to affect the same (Shah *et al*., 2004).

Since measurement of water delivery at the field level is a difficult task, pricing based on crop water requirement can be an alternative to crop-area based pricing to start with. In China, the provincial irrigation bureaucracies provide irrigation services to the farmers through irrigation entrepreneurs. They charge the entrepreneur on the basis of volume of water delivered, while at the same time, the entrepreneur charges the farmers on the basis of the area irrigated. As measurement of water is difficult, the entrepreneur provides sprinkler sets to the farmers, to bring down their water use per unit area. By doing this, the dual objective of financial viability and efficiency are achieved (Shah *et al*., 2004).

Similarly, in urban water supplies, the technical losses in the distribution system can be prevented by investment in leakage detection and leakage reduction measures. But, the non-technical losses can be prevented only through creating user group organization, along with complete metering of user connections (Arghyam/IRAP, 2010). Also, in regional water supply schemes supplying water to a large number of villages, proper institutional arrangements have to be made at the system and village level for protecting the water systems and maintenance and repair, ensuring equitable water distribution at the village level and recovery of water charges. Gujarat has seen emergence of such institutions in rural water supply sector.

Water Supply and Sanitation Management Organization (WASMO) had been created to facilitate community participation in managing drinking water supplies at the village level. Village Water Committees are created through the involvement of NGOs for taking care of operation and maintenance of the water supply infrastructure in the villages, and recovering water charges from the users. Whereas Gujarat Water Supply and Sewerage Board (GWSSB) is concerned with bulk water supply through large network of pipelines involving regional water transfer from south Gujarat to Saurashtra and Kachchh. The Gujarat Infrastructure Company is responsible for buying water in bulk from the Narmada Water Resources and Water Supply Department of the government of Gujarat, which in turn would supply water to GWSSB. Such institutional set up creates accountability at various levels, as there is clear cut division of roles and responsibilities amongst these agencies in the overall task of drinking water supply management.

4.0 LEGAL AND POLICY FRAMEWORKS

To achieve sustainable water use, the approach to water development should be based on river basins. This would help realistically assess the total water availability and the sustainable levels of extraction; and analysis of various socioeconomic systems affecting demand and use and their inter-dependencies (Mitchell, 1990; Jønch-Clausen and Fugl, 2001). Taking river basin as the unit for planning helps identify various supply and demand side interventions to manage the basin's water resources. It also helps integrate the variety of concerns in water development such as economic growth, social advancement, environment, and ecosystem management and minimize the conflicts between different sectors of water use (Jønch-Clausen and Fugl, 2001; Jønch-Clausen, 2004). Adopting river basin as the unit for water resource planning and water development calls for policy change at the state and central level. Also, the economic and policy instruments that are found to be vital to achieving water management goals in India can result in outcomes that are key goals of IWRM. Hence, there is strong rational for countries like India to pursue the concept of IWRM.

The policy changes should also facilitate a paradigm shift from designing strategies for increasing supplies to altering the socioeconomic systems affecting water use to manage the demand of water. For this, policy changes are also required in the allied sectors. They include irrigation, agriculture, rural water supplies, urban water supplies and industry. Some of the highlights of the policy changes suggested are: [1] involvement of farmer organisations and their representatives in irrigation management beyond the outlet level has to be made mandatory for farmers in the command to claim irrigation water; and, [2] involvement of village water users' groups to be made mandatory in operation and maintenance of water supply schemes and institutions of higher order in the management of large water supply schemes, especially their distribution systems.

Establishment of tradable private property rights is the major institutional change suggested in the water sector. For instituting property right regimes in water and enforcing them, it is essential to have proper laws. Such laws should define the rights of the state and every potential user over water resources in all its natural forms. The laws should also explicitly state the different types of rights such as rights for basic human survival, rights to drinking water, rights to in-stream uses, riparian rights, etc. It should also clearly indicate the circumstances under which the rights can be said as "violated", the penalty for offenders, and how the users should be compensated for the loss of the said rights. The legal framework should also provide for communities to establish their own norms, rules and regulations with regard to water use and management, to protect and manage their water resources and water supply infrastructure.

5.0 SUMMARY AND CONCLUDING REMARKS

The solution to growing water crisis lies in institutional changes that are capable of altering the socio-economic systems for water demand management. The institutional changes suggested for this are: 1) establishing tradable private property rights in groundwater and canal water to enable to promote economically efficient uses; 2) appropriate pricing of water to encourage efficient use of water from public water supply systems including canals and urban water supply systems including industries; 3) unit pricing of electricity used for groundwater pumping to promote efficient use of water in irrigation; and, 4) taxing industrial and urban wastewater on the basis of volumetric effluents and pollution levels to encourage conservation of water. These interventions can bring about improvements in water use efficiency and water productivity, social equity, and environmental and ecological sustainability.

Drawing upon the analysis, the role of economic instruments in tackling water scarcity and mitigating conflicts over water use will be quite prominent. Multiple hierarchies of organizations are suggested in surface irrigation for increasing system efficiency as well water use efficiency at the farm level. Major changes are required in the existing legal framework to provide for creation of RBOs, enable enforcement of tradable private property rights in water.

One of the arguments against creating river basin organizations, and implementing the concepts of IWRM is that the transaction costs exceed the pay offs primarily due to the informal nature of water economy existing in countries like India (see Shah and van Koppen, 2006). But, a cross-country analysis of water institutions and their performance suggests the opportunity cost of not implementing institutional reforms is much higher than the transaction costs (Saleth and Dinar, 2004). The demonstrated strong relationship between sustainable water use index and economic growth provides the empirical basis for investment in water institutions, to improve the access to and use of water and water environment. While the very assumption underlying the "high transaction cost" argument that water economies are very informal itself is questionable. Again, the contribution of many millions of privately-owned wells and pump sets to India's irrigation is shown to make the point.

In most Indian situations, with increasing water scarcity and groundwater depletion, water economy becomes more formal, comes within the ambit of government regulations and policy. The dependence of farmers in regions such as north Gujarat, almost the entire peninsular India and the entire alluvial Punjab for electricity supplied by state power utilities for groundwater pumping is of extremely high degree. To a great extent, the water economies in these regions were also informal when water table was shallow and farmers used animal power and later on diesel engines to abstract water. The ability of farmers to pump groundwater is dependent on when the Electricity Boards in the States supply power and how (Kumar, 2010).

Often, the large number of wells and pump sets owned by small and marginal farmers and the wide prevalence of pump irrigation market has been used to emphasize a point that groundwater economy is pro-poor and there is high degree of access equity in groundwater (Mukherji, 2005). But recent analysis suggests that groundwater economy is largely controlled by large and medium farmers who have very high level of ownership of wells and pump sets (Kumar, 2007; Qureshi *et al*., 2009); the pricing policies give monopoly power to well owners; and that the terms of the trade could be changed only through efficient electricity pricing and instituting water rights, especially in naturally water scarce regions (Kumar, 2007).

Setting up of RBOs should not be viewed as the ultimate answer to all problems facing the water sector. Whether RBOs would be able to make a difference in water management depends on: 1] the legitimacy and institutional capabilities of these organizations; 2] their power relations with the line agencies in the water sector and also with the different levels within the institutional hierarchy, i.e., sub-basin organizations, watershed/village level institutions; 3] the human resource capabilities available with these organizations; 4] the fund flows; and, 5] the degree of maturity. These points are further elaborated in the subsequent paragraphs.

First of all, the RBOs should have the legitimate powers to allocate water rights, and institutional/administrative capacities to enforce them. Appropriate legal framework is therefore important. Rights to use water from the basin will have to be negotiated at least with the line agencies in volumetric terms, and could be very time consuming. The institutional capabilities depend on its coordination with the lower level units in the institutional hierarchy, and the technological and resource edge they have over the line agencies.

Secondly, the RBOs' relationship with line agencies can be tricky. Since RBOs would have the power to allocate water for different sectoral agencies, they can emerge more powerful than irrigation department, water supply board and the groundwater department that are active within the basin. The power relationship of RBO with the irrigation department (ID) would be much more crucial as it is the latter one which had been historically appropriating most of the water in river basins. Since the irrigation department might have already invested large sums towards building infrastructure for storing and diverting water, negotiations over the right to use water would take time. In most situations, the irrigation department may have to forgo some of its volumetric water rights in order to increase the allocation for environmental flows. Hence, it will have to be adequately compensated.

The third issue is more important. Some Indian states viz., West Bengal, UP and Kerala, had already passed legislations to create RBOs. The Maharashtra Water Resources Regulatory Authority Act (2005) provides for setting up of RBOs, and fixing water entitlements for various sectors and individual users within each sector (Source: The Maharashtra Water Resources Regulatory Authority Act, 2005). But, nothing seems to have changed since then on the ground. The ID is reconstituted as water resources department in Maharashtra. The approach to water development and management continues to be sectoral. The different administrative units of irrigation department are reconstituted as river basin organizations. This beats the very purpose for which they are created. The reason is that the very function of RBO is to allocate water among various socio-economic and ecological needs within the basin, whereas the ID would try to protect its own interest, and maximize own benefits. The agency is loaded with civil and construction engineers, and does not have adequate technical capabilities in areas such as water resources management, ecology, environmental hydrology and water economics, to deal with river basin management issues. Capabilities to do water balance studies, water accounting and basin water resource planning that are crucial for the success of RBOs are limited with irrigation department. India has very few training institutions that provide training in topics, viz., river basin planning; and IWRM.

Fourth: financial position of the RBO would depend on how effectively the institution is able to recover water taxes from the line agencies, and the user groups and individual users. Finally, the effectiveness of RBOs would depend on the degree of maturity. As Torkil (2004) notes, IWRM is a process, and not a blueprint which can be implemented once and for all. The institutional maturity of RBOs in implementing some of the basic elements of IWRM will have to be evolved. Building human resource capabilities in various fields relating to basin management, improving negotiating skills, and building organizational skills towards local institutional development would be the key to the success of RBOs.

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