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Atmospheric warming induced changes in future rainfall and implications on water and agriculture in India

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ABSTRACT
The projected rainfall change under various scenarios is likely to have both positive and negative implications on agriculture and water supply because in rainfall pattern across the country. Rise in rainfall is seen over all states except Punjab, Rajasthan and Tamil Nadu, which show slight decrease in precipitation in the future scenarios. Marked increase in covering the Western Ghats and northwestern peninsular India including Maharastra and the adjoining parts of Andrapradesh, Madhyapradesh and Karnataka. The annual maximum peak in the sub basin of Mahanadi has exceeded from the present level of about 20000 cumecs under control scenario to a maximum level of 37000 cumecs under Green House Gas (GHG) scenario, such an increase in flood peak may be detrimental to a large number of existing structures on these drainage system. The number of drought weeks has considerably increased during GHG scenario barring about five sub basins out of the 21-sub basins of Krishna.

Keywords: Climate change, India, rainfall, water.

INTRODUCTION

One of the more important questions in rainfall climatology or hydrology is: if the climate warms in the future, will there be an intensification of the water cycle and, if so, the nature of intensification? There is considerable interest in this question because an intensification of the water cycle may lead to changes in water availability, an increase in the frequency and intensity of floods and droughts. There is a general consensus that global average surface air temperature increased during the 20th century, and, although there is great uncertainty about the magnitude of future increases, most assessments indicate that future warming is very likely (Houghton *et al*. 2001). There is also a theoretical expectation that climate warming would result in increase in precipitation and evaporation leading to the hypothesis that of either one of the major consequences will be an intensification or acceleration of the water cycle (Arnell *et al*. 2001). The theoretical basis for this intensification is summarized in the Clausius-Clapeyron relation that implies that specific humidity would increase approximat-ely exponentially with temperature. Recent modeling studies suggest that as a consequence of this relationship, precipitation would increase by about 3.4% per degree Kelvin (Arnellen and Ingram, 2002). It is now well established that surface air tempera-tures and precipitation over land have increased during 20th century. Results from recent simulations using one of about 20 coupled OAL (Ocean-Atmosphere-Land) models based IS92A mid range emission scenario indicated that global mean temperature, precipitation, evaporation, and runoff will increase 2.3ºC, 5.2, 5.2 and 7.3% respectively, by 2050 (Wetherald and Manabe, 20032002).

Indian subcontinent with a geographical area of 329 m ha occupies 2.11% of land area of the world. It receives an annual average rainfall of 1150 mm, which is the highest in the world for a comparable geographical area and second wettest country in the world. Rainfall varies from 100 mm in the northwest to more than 12,000 mm in the northeast. The rainfall is highly variable in its time and space. Orography plays a significant role in the distribution pattern of the rainfall. The southwest monsoon contributes nearly 74% of the annual rainfall between June and September. During October and December the northeast monsoon and depressions in the Bay of Bengal bring rainfall to Tamil Nadu and coastal districts of Andra-pradesh. Jammu and Kashmir also receives good amount of rainfall during northeast monsoon. It is endowed with a network of 2.8 million sq. km of river basins, with an average annual discharge of 1900Billion Cubic Meter (BCM), which accounts for 4.9% of the world's runoff and occupies the fifth position. The runoff is more than that of USA, which has land area about thrice that of India. World's growing population and strained resources, particularly for food production and water supply, the reliable forecast of future rainfall is of utmost importance for India and elsewhere in the world. Human activity since the beginning of the industrial revolution has has led to unprece-dented changes in the chemical composition of the earth's atmosphere. We now have evidence to show that such changes have the potential to influence earth's climate, though it is difficult to clearly delineate the charac-teristics of climate change associated with the natural and anthropogenic forcings due to complex interaction with in the climate system. Although meteorological data compil-ed over the past century suggest that the earth is warming, there are significant differences at regional levels. Climate variations and change, caused by external forcings, may be partly predictable, particularly on the larger (continental and global) spatial scales. Because human activities, such as the emission of greenhouse gases or land–use change, do result external forcing, it is believed that the large-scale aspects of human-induced climate change are also partly predictable. How ever, the ability to actually do so is limited because we cannot accurately predict population change, economic policy, technologic-al developm-ent, and other relevant characteristics of future human activity. In practice, therefore, one has to rely on carefully cons-tructed scenarios of human behaviour and determine climate projections on the basis of such scenarios. The Third Assessment Report (TAR) of the Intergovernmental Panel on Climate Change (IPCC) notes that the current versions of Atmosphere-Ocean Gene-ral Circulation Models (AOGCM) have generally well simulated the features of the present-day climate at the large and continental scale (Houghton *et al*. 2001).

The amount of rainfall received over an area is an important factor in assessing the amount of water available to meet the various demands of agriculture, industry, irrigation, generation of hydroelectric power and other human activities. Ther-efore, the distribution of rainfall in time and space is very important factor in the national economy. Of the rainwater receiv-ed by the country, approximately 35% is lost by evaporation and about 20% goes into soil. Thus 45% of the rain water is available for irrigation, and domestic and industrial purposes; however, at present part of the rain water flows into the Arabian Sea and the Bbay of Bengal. According to Mooley *et al*. (1981) the mean, the standard deviation and the coefficient of variation of the series of annual rainwater volume are 3143 km^3, 300 km^3 and 9.5%, respectively.

The impacts of climate change on water resources have been brought out by TAR of the IPCC. It indicates an intensification of the global hydrological cycle affecting both grou-nd and surface water supply. Changes in total amount of precipitation, its frequency and intensity have also been predicted. Such changes when on the sur-plus side may affect the magnitude and timing of runoff but create drought like situation when these are on the deficit side. The impacts of climate change are also predicted to be dependent on the base line condition of the water supply system and ability of the water resource managers to respond to climate change in addition to pressures due to increase in population, technology, economic, social and legislative conditions. Thus the climate change impacts are going to be very severe in India and the developing world as well, because of their poor capacity to adapt to climate variability. India is coming under this category. The National Communica-tion Project is the first attempt to quantify the impact of the climate change on the water resources of the country. It is generally thought that increasing GHG will cause the global hydrological cycle to intensify, with benefit for water availability, although a possible exacerbation of hydrological extremes may counteract the benefit to some degree. All of the climate models show warming with increasing greenhouse gases and aerosol conce-ntrations, so we can begin to say with some certainty how the hydrological cycle will respond in the future. Therefore this paper discusses the current state of scientific information and knowledge on the future rainfall climatology and its impact on both water resources and availability as well as on agriculture.

Anticipated variation in rainfall intensity based on high-resolution regional climate model (Providing Regional Climate for Impact Studies (PRECIS)

Variation in rainfall characteristics both in space and time are responsible for uneven distribution of precipitation in India. This uneven distribution of the precipitation results in highly uneven distribution of water resources both in space and time, which leads floods and drought affecting agriculture and other water related activities in vast areas of the country. Under A2 scenario (explain this or give a reference) in the 2050s, 57 per cent of the earth's land area has increasing annual precipitation (relative to the climate normal period, 1961-1990). The rest of the places will receive either decreasing precipitation or no change in the trend. For example most part of Italy is going to receive reduced precipitation up to 9% during spring while there is no change in trend in Canada. Even within India, the variability of rainfall under the A2 and B2 scenarios (there is no discussion earlier in the manuscript about these scenarios) is high. Both natural and anthropogenic activities can be attributed to such anomalous behavior. The region wise future rainfall climatology of India under A2 and B2 scenarios is discussed hereunder.

The mean annual cycles of all-India mean precipitation for A2 and B2 scenario indicate a general variation in precipitation, for the country as a whole. A2 and B2 scenarios show similar patterns, with B2 showing slightly reduced magnitudes. Special pattern of rainfall change indicate maximum increase over west coast and northeast India for both A2 and B2 scenarios (Rupakumar *et al.* 2006). PRÉCIS estimates 20% rise in all India summer monsoon rainfall in future scenarios as compared to present. Rise in rainfall is seen over all states except Punjab, Rajasthan and Tamil Nadu, which show slight decrease in precipitation in the future scenarios. This is contrary to the forecast given by Murugan *et al.* (2003), their forecast showed an incr-ease of rainfall in Tamil Nadu at least by 3% during North East monsoon period. The observed rainfall in the last four years and the forecast of these workers for the same years were in good agreement. They have also given forecast for the next fifty-five years based on the information available in the Pre Vedic literature and simulated models (Japanese forecast) (Murugan *et al.* (2003). In terms of extreme precipitation, there is a general increase in both 1 day and 5-day extremes. In particular, there is a marked increase in the severe rainfall activities over an extensive area covering the Western Ghats and northwestern peni-nsular India include-ing Maharastra and the adjoining parts of Andrapradesh, Madyapradesh and Karnataka (Gosain *et al.* 2006). The mean annual precipitation over India as computed by CRU (Climate Research Unit, University of East Anglia, UK) was seen to be about 1094mm. The projected climate (average for 2071-2100) for more moderate B2 scenario is both wetter with an average increase of about 220mm compared to Had RM3 baseline. The corresponding value of increase for more extreme A2 scenario is about 300mm. The mean annual precipitation for the projected values for B2 scenario turns out to be 1314mm. There is considerable geogr-aphical variation in the magnitude of changes for rainfall. Northwestern India is likely to become drier, while northeastern India is likely to become much wetter. Therefore, there are substantial spatial differences expected in the projected rainfall all across the country though the warming is monotonously widespread over the country.

Forests types and changing rainfall intensity as predicted by HadRM3 with BIOME4

Climate change always will be an additional pressure on forest ecosystems because the forest ecosystems in India are already subjected to various pressures leading to forest degradation and loss of biodiversity. In general, under the B2 scenario projections, the mean rainfall in areas under forest cover is somewhat higher than that in the non-forested areas. The increase expected in rainfall under the changed climate is also larger for the forested areas, about 376 mm compared to the over all average of about 235 mm. As expected the changes in climate are not uniform across the different forest types – ranging from a large increase of more than 550 mm for hard wood and bamboo forests to a modest 220 mm for the colder fir/blue pine forest (Ravindranath *et al.* 2006). Such a projected shift or change in rainfall is likely to lead to large-scale forest die back and loss of biodiversity.

Impact of future rainfall climatology on the hydrology of Indian River basins based on the prediction of SWAT-Had RM2 model

The climate change impact assessment on water resources can be best handled through simulation of the hydrological conditions in an area. Such a treatment is essential because of the fact the hydrological response is a complex process governed by large number of variables such as terrain, land use, soil characteristics and the state of the moisture in the soil. The last element warrants a continuous time simulation so as to keep track of the changing moisture conditions. The SWAT (Soil and Water Assessment Tool) water balance model is one such model to carry out the hydrological modeling of the river basins of the country. The SWAT model (Arnold *et al.*, 1990) simulates the hydrologic cycle at daily time steps. SWAT is a distributed, continuous, hydrological model with Arc View GIS interface (AVSWAT). The spatio-temporal water availability is determined without incurporating any manmade changes like dams, diversions, etc. with the assumption that the land use shall not change over time.

A close examination reveals that the increase in rainfall is not resulting always in an increase in the surface run off, as may be general perception. For example, in the case of Cauvery River basin an increase of 2.7% rainfall has been observed but the runoff has in fact reduced by about 2% and actual evapotranspiration has increased by about 7.5%. On the contrary, a reduce-tion in rainfall in Narmada has resulted in increase in the run off, which is again contrary to the usual expectation. It is important to understand that these outcomes have been the result of very elaborate computation of continuous water balance with daily time through the distributed hydrological modeling framework. This has enabled the simulation of the natural processes in a realistic manner so as to represent the socio-temporal variabilities inherent in the natural systems.

Krishna River basin, one of the largest basins in southern India, is expected to receive reduced level of precipitation in the future. Reduction has also been predicted in evapotransiration and water yield of the basin. Annual average rainfall, actual evapotranspiration and water yield as simuated by model over the sub basins for control and GHG scenarios showed variationn in mean annual water balance. A reduction of in precipitation by about 20% of the current value has been predicted in the sub basins of Krishna. The corresponding decrease in water yield over the sub basins is predicted to vary from 30% to 50% . The actual evapotranspiration is also predicted to reduce by about 5% over the basins.

Recently, a soil moisture index has been developed to monitor drought severity using SWAT output. This can be used to focus on the agricultural drought where severity implies cumulative water deficiency. Weekly information has been derived using daily SWAT outputs, which in turn have been used for analysis of drought severity. Number of drought weeks in the sub basins of Krishna (consisting of weeks with SMI of less than or equal to –3.0) considerably increased in the enhanced GHG scenario barring about five sub basins out of the 21-sub basins of Krishna.

In case of the Mahanadi River basin, the impact of the climate change on the dependability of water yield of the river basin has been analysed with respect to four arbitrarily selected levels of 25, 50, 75, and 90%. It was found that the flow for the all the dependable levels has increased GHG scenario over the corresponding control flow magnitude but for the 50% level of dependability, at which the flow has marginally reduced. The worst affected sub basin in Mahanadi has been analysed for flood severity. The annual maximum peak in the sub basin has exceeded from the present level of about 20000 cumecs under control scenario to a maximum level of 37000 cumecs under GHG scenario, such an increase in flood peak may be detrimental to a large number of existing structures on these drainage system.

It has been one of the challenging studies for quantifying the climate change impact wherein the water balance simulation modeling approach has been used to maintain the dynamics of hydrology and thereby make assessments of vulnerability, which are more authentic and reliable. Usefulness of such handling has been proved by the fact that the results of the GHG scenarios have been dictated by temporal variability at daily level as well as spatial state of the land mass in terms of its moisture conditions and land use.

This study has revealed that under GHG scenario the condition may deteriorate in terms of severity of droughts in some parts of the country and enhanced intensity of flood in other parts of the country. However, there is general an overall reduction in the quantity of the available runoff under GHG scenario. Luni with the west flowing rivers Kutch and Saurastra that occupies one fourth of the area Gujrat and 60% area of the Rajasthan shall face acute water scarce conditions (this sentence is not clear, how rivers can occupy large areas? It means river basin not river). River basins of Mahi, Pennar, Sabarmati and Tapi shall also face water scarce conditions. River basins belonging to Cauvery, Ganga, Narmada and Krishna shall experience seasonal or regular water-stressed conditions. River basins belonging to Godavari, Brahmani and Mahanadi shall not have water shortages but are predicted to face sever flood conditions (Mall *et al*. 2006). These predicted climate change impacts may induce additional stresses and shall need various adaptation strategies to be taken up. The strategies may range from change in land use, cropping pattern to water conservation, flood warning systems, etc. and need rigorous integrated analysis before paving way to policy decisions.

Present and expected future status of surface and ground water sources as influenced by rainfall under GHG scenarios

Water is one of the most essential resources for sustaining life and it is likely to become critically scarce in the decades to come due to continuous increase forin its demand by the, rapidly increasing population and expanding economy of the country. There are 70 river basin systems with a network of 2.89 m sq km carrying annual discharge of 1900 BCM. The Indo-Ganga-Bramaputra basins contribute 66% of the surface water resources. However, only about 690BCM could be harnessed through conventional schemes. The total surface water, which could be stored, is 420 BCM and storage built so far is about 180 BCM. The estimated irrigation potential created so far is about 43 m ha.

The estimated annual, replenishable ground water resources of the country are 432 BCM of which utilizable resources is 395.6BCM and 325 BCM is allocated for agriculture. The estimated static sources are about 10,350 BCM. The ultimate irrigation potential is 64 m ha and the irrigation potential created so far is about 46 m ha by developing nearly 160 BCM. Oxygen isotopic studies done on the contribution of rainfall to the recharge of ground water in urban areas showed that rainfall had insignificant influence in urban areas since water penetrability in to the soil is limited by compaction of soil surface (Ramesh and Yadava, 2005). Therefore most of the water comes through the seepage from the nearby agricultural and industrial areas hence the ground water is highly polluted in urban areas. India receives annual precipitation of about 4000 km3, including snowfall. Out of this, monsoon rainfall is of the order of 3000 km3. As per the International norms, the per-capita water availability is less than 1700 m3 per year then the country is categorized as water stressed and if it is less than 1000 m3 per capita per year then the country is classified as water scarce. In India per-capita surface water availability in the years 1991 and 2001 were 2309 and 1902 m3 and these are projected to reduce to 1401 and 1191 m3 by the years 2025 and 2050 respectively.

Contribution of rainfall on the replenishment of ground and surface water resources

The annual potential ground water recharge from rainfall in India is estimated to be 342.42 km3, which is 8.56% of total annual rainfall of the country. The annual potential ground water recharge augmentation from canal irrigation system is about 89.46 km3. Thus the total replenishable ground water resource in the country is assessed as 431.89 km3. The available ground water resource for irrigation is 361 km3 for the country. Provision for domestic and industrial consumption could be around 71 km3. The basin wise per capita water availability varies between 13393 m3 per annum for the Bramaputra–Barak basin to about 300 m3 per annum for the Sabarmathi basin. The total average annual flow in Indian river system estimated to be 1953 km3 of which only 690 km3 is utilizable (CGWB, 1995).

Extensive urbanization induced changes in land use have caused compaction of the top sub soil and significant decrease in exposed land area for direct infiltration of rainfall, resulting in differences in recharge from rainfall has been reported to be 18% in Punjab, 15.5% in Haryana, 2.05% in Western Utterpradesh and 1-14% in Rajasthan. Ground water recharge from rainfall varies widely from region to region and within the parts of the region, depending on the frequency, intensity and distribution of rainfall, soil clay content and land use (Datta, 2006). The per capita annual water resource (AWR) has been used to classify countries with respect to the water scarcity (MWRI, 1999) Countries with an AWR per capita of 1700 cu m and above have been termed as countries where shortage will be rare; those with an AWR per capita of less than 1000 cu m as water stressed countries; and with those AWR per capita of 500 cu m and below as countries where availability of water is a primary constraint to life. In 1985, only seven countries were found to be with water stressed conditions. In 1990 this number rose to 20 and it is expected that by the year 2025 another 10 to 15 countries shall be added to this list including India. It is worth noting that this assessment has been made without taking into account the possible impact due to predicted changes in global climate. Such consideration may aggravate the situation of AWR further.

Scenario based estimation of domestic and irrigation water use

The community consumes 5% of the total water use. About 7 km3 of surface water and 18km3 of ground water are being used for community water supply in urban and rural areas. According to projections, the higher is the economic growth, more the higher would be the urbanization. It is expected that nearly 61% of the population will be living in urban areas by the year 2050 in high growth scenario as against 485 in low growth scenario. According to figure adopted by the NCIWRD (National Commission on Integrated Water Resource Developmentexpand. What is this?) 220 Litres per capita consumptions per day (lpcd) (what is this?) was for the class I (what are Class I ciites?, this term is specific to India and not in use in international journals) cities. For other cities it is 165 lpcd and 220 lpcd respectively for 2025 and 2050. For the rural areas, 70 and 150 lpcd respectively for 2025 and 2050. Based on these norms and projection of population, it is estimated that by 2050, water requirement per year for domestic use will be 90km3 for the low demand scenario and 111km3 for high demand scenario. It is expected that about 70% of urban water requirement and 30% of rural water requirement will be met by surface water sources and remaining from ground water (NCIWRD, 1999).

The irrigated area in the country was only 22.6 m ha in 1951-51. Since the production was much below the requirement of the country, due attention was paid for expansion of irrigation. The ultimate irrigation potential of India has been estimated as 140 m ha. Out of this, 76 m ha would come under surface water and 64m ha under ground water sources. The quantum of water used for irrigation by the last century was of the order of 300 km3 of surface water and 128 km3 of ground water, total 428km3. The estimates indicate that by the year 2025, the water requirements for irrigation would be 561 km3 for low demand scenario. The se requirements are likely to further increase to 628 km3 for low demand scenario and 807 km3 for high demand scenario by 2050 (Kumar *et al*. 2005).

Trend and impact of surface runoff and evaporation as well as evapotr-anspiration on soil water availability

The increases in runoff are consistent with the results of modeling studies that suggest runoff is likely to increase in Indian rivers. Decrease in runoff could occur as a result of increases in evapotranspiration that outweigh increases in precipitation. Some proportion of increase in runoff from major rivers may be attributable to human alterations such as conver-sion from forest to agricultural lands (Alcamo *et al*. 1997; Vorosmarty and Sahagian, 2000) and change in agricultural practices. Worldwide decrease in evaporation has been recorded as the warming accelerated. But many sites in tropical areas particularly in Western Ghats the evaporation had increased by 2.5mm/day in the first pentad (Murugan *et al*. 2006) of the 21st century. The high co-ncentration of aerosols the more is the cloudiness and thereby reduced temp-erature and evaporation in plains, which may not be the same in higher altitudes that is why we get increased evaporation in higher altitudes even though the atmosp-here is thin. This increased evaporation in hill ecosystem will have adverse effect on agricultural and forestry activities through reduced availa-bility of water in summer.

Anticipated water requirement under high and low demand scenarios

Traditionally, India has been an agriculture-based economy. According to National Water Policy, the food grain production has increased from around 50 million tones in the 1950's to about 209.3 million tones in the year 2005-2006. According to the estimates adopted by NCIWRD, by the year 2025, the population is expected to be 1333 million in high growth scenario and 1286 million in low growth scenario (UN, 1998). For the year 2050, high rate of population growth is likely to result in about 1581 million people while the growth of projections place the number at nearly 1346 million. Keeping in view the level of consumption, losses in storage and transport, seed requirement and buffer stock, the projected food grain and feed demand for 2025 would be 320 million tones (high demand scenario) and 308 million tones (low demand scenario). The requirement of food grains for the year 2050 would be 494 million tones (high demand scenario) and 420 million tones (low demand scenario). The availability of water shows wide spatial and temporal variations. Also there are large interannual variations. Hence, the general situation of per capita availability is much more alarming than what is predicted by the average figures (Kumar *et al*. 2005; NCIWRD, 1999).

Concluding remarks

Current information about the climate related water challenges facing much of India, although by no means perfect, is sufficiently robust that major future problem areas can now be defined. The matter takes greater urgency because the model-predicted signals are already being observed. However, some uncertainties exist in estimating the impacts. All of the future climate predictions have uncertain-ties. In some cases, the uncertainties have to do with the models' ability to reproduce today's climate, casting doubt on future climate predictions. Predictions using regional, high-spatial-resolution mode-ls, for regional water studies, are only now starting to come into their own in the greenhouse arena, but they carry a whole set of problems in addition to those associated with the coupled AOGCM (Atmosphere-Ocean-General Circulation Models). For instance, they often have different physics from the CGCMSs there are scale-dependence issues, and new levels of parameterizations are required. However, such regional models will be required for good quantitative estimates of future water problems. Such high-resolution, regional studies have not yet been undertaken in India. One of the greatest uncertainties in future prediction has to do with the models is forcing. Stated more directly, what are implications of omitting forcing that we strongly suspect (know) are important but cannot yet reliably be included in the model physics? Of these the most important is thought to be the incomplete inclusion of aerosols and their impacts, especially on clouds.

There is a need for increasing the availability of water and reducing its demand. For increasing the availability of water resources, there is a need for better management of existing storages and creation of additional storages by constructing small, medium and large dams considering the economical and environmental aspects. The availability of water resources may be further enhanced by rejuvenation of dying lakes, ponds and tanks and increasing the recharge of ground water in states like Tamil Nadu and Karnataka. In addition to these measures, interbasin transfer of water provides one of the options for mitigating the problems of the surplus and deficit basins for e.g. Mahanadhi basin to Krishna basin However, for interbasin transfer of water the studies need to be carried out for establishing its technical and economic feasibility considering the environmental, socio economic and eco-hydrological aspects.

Some results of the studies done at sensitive areas like Himalayan glaciers show that the future water availability is not driven by precipitation but by temperature, and this makes the conclusions robust because all current models predict a warmer future world. In this case the other key factor affecting water availability is the lack of enough reservoir storage to manage a shift in the seasonal cycle of runoff. All of the future climate predictions have uncertainties. Inspite of these uncertainties, the observed trends in most of the variables are consistent with an intensification of the water cycle during part or all of the 20th century at regional to continental scales. The likely warming will increase the intensity of tropical storms and floods in some rivers and less flow in some other rivers in India. The lack of detectable trends in the frequency and intensity of tropical storms during the 20th century should not be taken as evidence that further warming will not lead to such situations in the future, particularly as the rate of warming in the 21st century is expected to be several times greater than in the 20th century (Hansen and Sato, 2004). Therefore at this point of time any absence of evidence of detectable trend on the danger on the future rainfall climate cannot be taken very lightly on the basis of absence of evidence. On balance, the weight of the evidence is consistent with an ongoing and future intensification of the hydrologic cycle and emphasizes the need for improving our capabilities to monitor and predict the consequences of changing hydrologic regimes. Future improveements in spatial resolution and longer periods of data collection, combined with enhanced process-level understanding of complex feedbacks involving water, will reduce our current levels of uncertainty. Primary hydrologic feedbacks include increase in atmospheric water vapour that result in heat trapping, changes in cloudiness and the properties of clouds that can increase or decrease surface warming, changes in snow cover and snow or ice surface melt that influence albedo and therefore radiative force (Huntington, 2006). The forecast of winter rainfall for Tamil Nadu by Murugan *et al.* (2003) was in full agreement with the observed rainfall during the last four years. According to their forecast most of the years during 2015-2025 and 2035-2045 would experience below average rainfall as compared to present climate normal period. Therefore situation on water availability during 2015-2025 and 2035-2045 could be the worst in the first half of the 21st century in Tamil Nadu and surrounding states thus the agricultural production is going to be highly challenged. Similarly some river basins in southern India such as Krishna and Narmada as well as states like Punjab, Haryana and Rajasthan shall experiencegoing to enjoy reduced rainfall in the decades to come thereby affecting all the water related activities which in turn affect the agricultural production in the fertile zone of India. Hence, under high food requirement scenario (approximately 500 MT) in India, where do we go and how do we achieve this target under limited water situation? How are we going to make up for the situation? These are the two main questions we need to answer scientifically taking all other aspects into consideration.

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