Climate Change Impacts Studies for Rajasthan

(Areas of Inland Drainage and Mahi Basin)

under

National Water Mission

Proposal

Submitted to

Indian National Committee on Climate Change (INCCC)

NIH, Roorkee

Department of Civil Engineering

Malaviya National Institute of Technology Jaipur

Jaipur - 302017

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Appendix 1 Performa of Application for Research Grants

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4 **Brief Bio-data of the Investigators** *(enclose at the end of the proposal)*

5 Project Title (*keep it as short as possible***)**

Climate Change Impacts Studies for Rajasthan (Areas of Inland Drainage and Mahi Basin)

6 Track Record and Workload Assessment of the PI

Dr. Mahender Choudhary, AssociateProfessor, Dept. of Civil Eng., MNIT Jaipur is working in the field of Water resources management and climate change impact on Water Resources. He has research interest and worked in the field of Arid Hydrology, hydrological modeling, water management; artificial ground water recharging and climate change impact studies. Dr. Choudhary has received training at UNESCO-IHE, Delft, The Netherlands on 'Climate change in Integrated Water resources management' and at Hadley Centre, Met Office, UK on 'Regional Climate Modelling using PRECIS'. Presently one Ph.D. on the impact of Climate Change on Urban Water management is under the supervision of Dr. Mahender Choudhary is in progress. The list of projects completed by Dr. Choudhary is as follows

Title of Project	Status	Duration	Grant (Rs.)	Sponsored by
Proper Management of Flood Water for Rural Development at JNV Paota, Jaipur	Completed	2008 2 Year	6.90 Lac	DST
Quantification survey of pollen proteins in allergen extracts	Completed	2008 2 Year	0.75 Lac	Institution of Engineers
Environmental Assessment & Monitoring of Project	Completed	4 years	40 Lac	DPIP, Govt. of Rajasthan
Checking of the DPR's of Pradhan-mantri Gramin Sadak Yojana (PMGSY)	Completed	Since 2003	3-5 Lac annually	MORD, Govt. of India
Third party quality inspection of water supply and drainage projects	Completed	2003-04	2 Lac	RUIDP, Govt. of Rajasthan
Design & Drawing of RWH structures in Jaipur	Completed	2010	6 Lac	JDA Jaipur

Drawing of RWH structures (for Storm Water) in Jaipur	Completed	2011	5 Lac	JDA Jaipur
Design of Storm Water Harvesting system	Completed	2010	1 Lac	TODAR

There are no foreclosed or ongoing projects with Dr. Mahender Choudhary

7 If the scheme is sanctioned, in whose name the cheque is to be issued. (write precise title of the account)

Registrar MNIT Jaipur

8 Category of R&D Activity (Tick those which are applicable)

a. Basic Research

b. Applied Research

c. Action Research

d. Education & Training

e. Mass Awareness Program

f. Infrastructure Development

g. Creation of Centers of Excellence

9 Description of the Proposal

The impact of Climate Change (CC) is being felt around the globe. In order to study the impact of CC on National Water Resources, Central Water Commission (CWC) has prepared a plan for basin level study under National Water Mission and NAPCC. The Department of Civil Engineering Malaviya National Institute of Technology (MNIT) Jaipur along with IIT Delhi and Central University of Rajasthan, Kishangarh, Ajmer proposes a comprehensive research on the Areas of Inland Drainage in Rajasthan in western part of the state and Mahi Basin in the South Eastern part of the State. The primary objective of the project is to study the impact of Climate Change on various Hydrological parameters of a river basin using high resolution GCM outputs from multi model downscaling experiments. This would include the analysis of extreme weather phenomenon, development of basin specific Hydrological model for quality and quantity of available water and identification of hotspots with respect to hydrological parameters. The outputs of these studies would then be used for planning of Adaptation to the climate change in the form of water distribution for Municipal and Irrigation uses, Reservoir operation, crop cycling and Mitigation strategies for extreme events like flood, drought, heat wave and cold wave etc.

Water resources development is largely seen as a medium for social and economic development. Exploitation of this resource through a formal and a rigorous management paradigm has often put it in direct, and often bruising, competition with society's desire to preserve the integrity of our natural eco-system and its various services that the latter has come to depend upon. Accordingly, therefore, perturbations, both in short as well as in long term, have the potential of causing damage all across the entire spectrum. Presently, global climate change is being attributed to global warming which has been triggered by release of 'greenhouse gases' into the atmosphere at an alarmingly increasing rate. It is widely recognised that climate change is affecting the weather parameters such as rainfall, temperature, evaporation and transpiration. These large scale changes in the Earth's environment are a result of the 'Greenhouse effect', acid rain and the impact of the use of certain industrial and commercial chemicals on the protective ozone layer. It is widely believed that the predicted changes, during the next few decades, could far exceed natural climate variations in historical times and in the context of the foregoing discussion, water supply across the entire spectrum of uses and the quality of derived eco-system services is ultimately linked to climate and, in turn, to the various factors, including greenhouse gases, that determine its character.

Recent experiences do portend towards the intensity and scale of morbidity and the consequent derangements that are likely in river basins across the country. These derangements are not all that rare; nor are the damages likely to be superficial. Such disturbances can be quite cataclysmic in their consequences and this invariably results in a dramatic metamorphosis of the watershed landscape including the associated ecology. This is in line with the widely accepted Principle of Disproportionate Percentages which suggests that even the most trivia affect beyond apparent means. The "Butterfly Effect" in Meteorology is a well-known example of the principle of disproportionate percentages and there is a fair degree of unanimity amongst scientists that increasing carbon dioxide level in the atmosphere will result in changes not just in global and regional climate but also in watershed dynamics and land surface processes. A diagnosis of the past performance of a river basin is essential in case future prognosis of its hydrologic cycle is desired with a degree of objectivity and assurance. The prognosis that is being sought, must consider the influence of climatic as well as anthropogenic factors on the hydrologic cycle. A rational evaluation of the impact of climatic changes on a river basin's water cycle requires that the impact of anthropogenic influences of the branch cycle and those due to climatic factors be amenable to differentiation from each other.

Climate change impact assessment is carried out using General Circulation Models (GCMs), which are the most credible tools for future climate projections. However, since GCMs work at coarse spatial resolutions, impact assessment of hydrologic variables at regional scales demands either dynamic or statistical downscaling. In the present case downscaling of GCM would be done using Statistical and Dynamic downscaling methods. Multiple GCMs will be used for downscaling and confirming to CMIP5 radiation forcing to quantify model uncertainties in the predictions. The output from these multi-model downscaling experiments will be used in basin level hydrological model.

For hydrological modelling of the basin it is proposed to use SWAT (Soil and Water Assessment Tool) model (Arnold et al., 1998). SWAT is a river basin, or watershed, scale model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods of time and it operates on daily time scale. The model is physically based, semi-distributed and computationally efficient, uses readily available inputs, and enables users to study long-term impacts. In SWAT, basins are divided into multiple sub-watersheds which are further subdivided into hydrologic response units, which consist of homogeneous land use, management, and soil characteristics. The overall hydrological balance is simulated for each hydrologic response units (HRU) including precipitation, infiltration, soil water redistribution, evapotranspiration, lateral subsurface flow, and return flow.

Region 1: Area of Inland Drainage in Rajasthan

The proposed project consists of the area of Inland Drainage in Rajasthan and has unique hydrological characteristics. The area has no drainage and mostly occupied by the Thar Desert (Figure 1). It has an Arid Climate and slopes gently towards West – Southwest towards Indus River system. Rainfall varies between 100-400 mm annually and is received mainly during monsoon season. In addition to the monsoon rain which is very erratic and often fails the region receives water from Indira Gandhi canal system from which water is mainly used for drinking purpose and irrigation of Rabi crops. The soil formation consists of a thin veneer of Dune Sand of zero to few meters in thickness underlain by an impervious clay layer. The area is not investigated properly and at a few places subsurface palaeochannel containing fresh water or perched aquifers have been reported. Monsoon often fails in the region and Droughts are a common phenomenon followed by heat wave. In the recent past there have been few instances of flooding due to high rainfall intensity and low percolation rate. In such an environment, climate-change can have a serious impact on the effectiveness of policies as it doesn't only affect the availability of new resources, but also the efficient utilization of the existing resources. Judicious and well-thought adaptation measures will be needed. The outcomes from the studies carried out shall be disseminated through the digital platform that will enable more effective formulation, implementation and evaluation of policies in a dynamic manner.

Figure 1: Area of Inland Drainage in Rajasthan Desert

Region 2: Mahi Basin

The proposed project consists of the area Mahi River Basin. River Mahi originates in Dhar District and joins Gulf of Khambat. The Mahi basin extends over an area of 34,842 km^2 which is nearly 1.1 percent of the total geographical area of the country. It lies between east longitudes 72º 15' to 78º 15' and north latitudes 22º 0' to 22º 40' N respectively (Figure 2). The Mahi River originates in the Mahi Kanta hills in the Vindhyachal range, in the western part of Madhya Pradesh. It is bounded on the north and north-west by the Aravalli hills, on the east by the ridge separating it from the Chambal basin, on the south by the Vindhayas and on the west by the Gulf of Cambay. The basin lies in the States of Rajasthan, Gujarat and Madhya Pradesh. The upper part of the basin in Rajasthan and Madhya Pradesh comprises mostly hills and forests except the lower half in M.P., which is fairly plain. The central part lying in Gujarat consists of developed lands. The lower part of the basin lying in Gujarat is flat and fertile and well developed alluvial tract. Important soil types in the basin are red and black soils. The culturable area of the basin is about 2.21 Mha which is 1.1% of the total culturable area of the country. The principal tributaries of the Mahi River are Som, Jakham, Moran, Anas, and the Bhadar. Major projects on the River Mahi are Jakham Reservoir, Panam Dam, Mahi Bajaj Sagar Project and Kadana Project. As per a previous study by Gosain et al. (2003) the two river basins Sabarmati and Mahi show drastic decreases in precipitation and consequent decrease in total runoff to the tune of two thirds of prevailing runoff. This may lead to severe drought conditions in future in these basins. Therefore, it becomes necessary to undertake a comprehensive study of the Mahi basin for climate change impacts on hydrology of the Basin. The reservoir operation strategy under changed climate would require improved water use efficiency and conjunctive use of ground water under and Integrated water resources management approach. The outcomes from the studies carried out shall be disseminated through the digital platform that will enable more effective formulation, implementation and evaluation of policies in a dynamic manner.

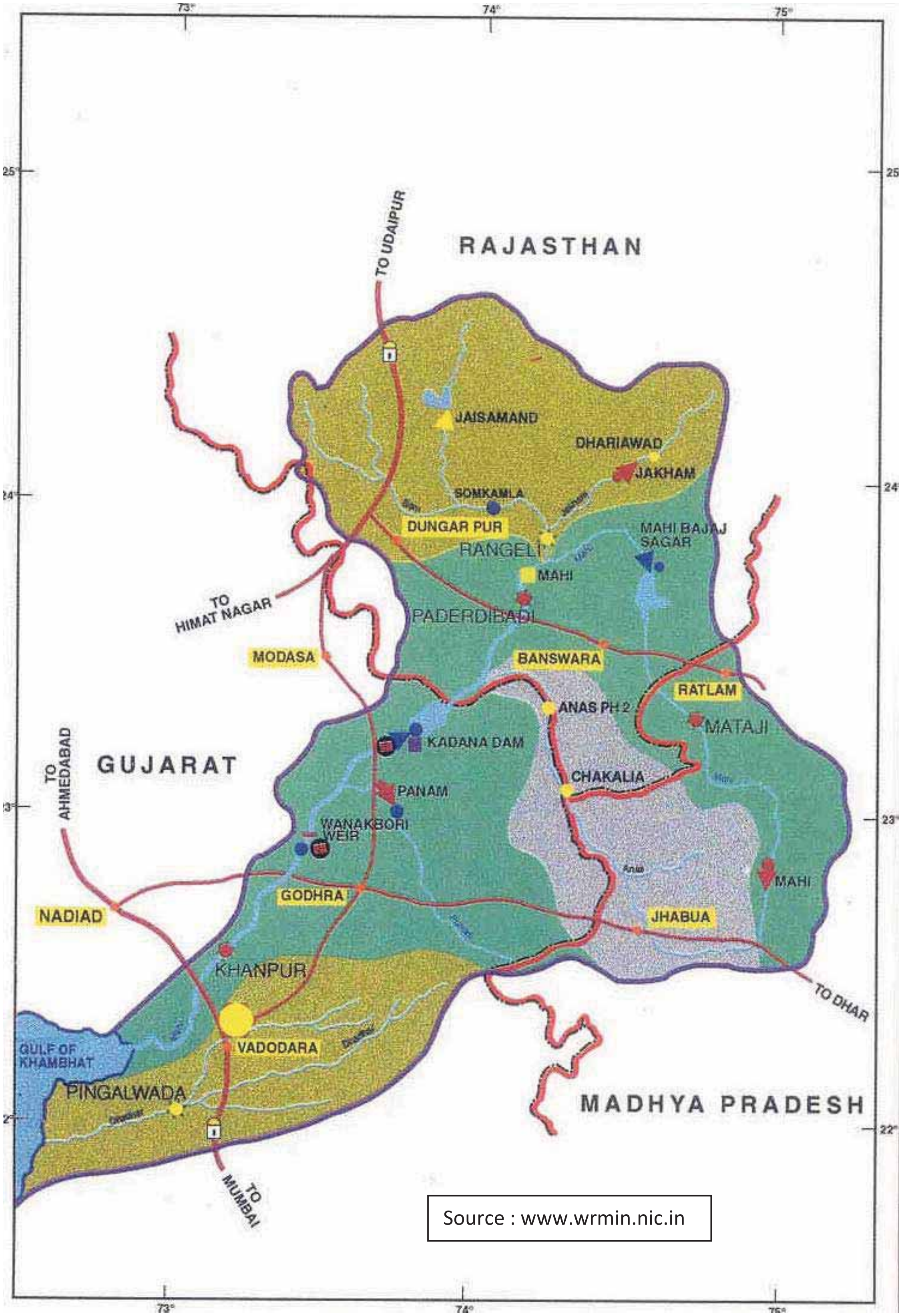

Figure 2: Area of Mahi Basin

10 Objectives. Classify the objectives of proposed research under one or more of following and explain the objectives briefly.

The objective of the proposed project is to study the impact of Climate change on the hydrology of the study area and suggest strategic adaptation and mitigation options. There are four main activities to be performed viz. Surface water modelling (using SWAT), groundwater modelling (using mudflow), crop productivity modelling and reservoir/canal operation modelling. The specific objectives are as follows:

- Literature review : analysis of past studies and literature available to ascertain the present state of the art.
- Data Collection: base line data collection of the study area and analysis.
- Trend analysis of hydrological and meteorological parameters like precipitation, temperature, stream flow, groundwater levels, sediment no. and size of water bodies, evapo-transpiration, land use land cover and extreme climate events like floods and droughts.
- Hydrological modelling of the basin in a GIS environment :
  - Conceptualisation of hydrological model of basin
  - Calibration and validation of hydrological model
- Hydrological responses corresponding to different climate change scenarios obtained from downscaling using different GCM models.
- Development of crop production functions, their calibration and validation.
- Hydrological impact analysis of climate change:
  - Generation of surface water responses i.e., stream flow under climate change scenarios and assessment of water availability
  - Impact of hydro-meteorological changes on crop production under different climate change scenarios
  - Groundwater responses under different climate change scenarios and water availability
  - Soil erosion responses under different climate change scenarios
- Adaptation strategy under Climate Change:
  - Optimal water allocations/use involving different sources and users under different climate change scenarios
  - Optimal reservoir/canal operations under different climate change scenarios

    - Optimum agricultural practices under different climate change scenarios
    - Various water demand management options for different sectors
- Identification of possible mitigation strategies for extreme hydrological events like floods and droughts

11. Contribution to Water Resources Development

The project would be helpful in understanding the impact of CC on the hydrology of Region one and two in the state of Rajasthan. That would mean that it will estimate the possible increase/decrease in availability of water, intensity of drought/floods, extremes of temperature and other parameters related to climate change so that strategic planning for Adaptation and Mitigation may be done. The study would also suggest canal/reservoir operation strategy for optimum water utilisation under CC.

12 Putting the Research to Use

a. The output of the research will be useful for Ministry of Water Resources and CWC for planning National Water Resources and increasing the understanding about impact of CC on regional water resources. It will also be useful to State Govt. Agriculture Dept., Water resources Dept., Forest Dept. etc. who are stake holder in water use.

b. The results will be available in GIS format and can be used by the entire stake holder from web based interface on a National Portal.

c. All the data from different users may not be available in the same format for which uniform reporting guidelines may be prepared in the initial stage itself.

d. The present end user is CWC which has initiated this project.

13 Present State of Art

Climate change is already happening and represents one of the greatest environmental, social and economic threats facing the planet. Environment and ecosystem components are sensitive to climate variability and change. Human health, agriculture, natural ecosystems, coastal areas, and heating and cooling requirements are examples of climate-sensitive systems. Some observed changes include change in regional circulation and monsoon pattern (i.e. hydrological cycle), shrinking of glaciers, later freezing and earlier break-up of ice on rivers and lakes, lengthening of growing seasons, shifts in plant and animal ranges and earlier flowering of trees (IPCC, 2007). The atmospheric temperature are expected to continue to rise as human activities continue to add carbon dioxide, methane, nitrous oxide, and other greenhouse (or heat-trapping) gases and particles to the atmosphere. The extent of climate change effects, and whether these effects prove harmful or beneficial, will vary by region, over time, and with the ability of different societal and environmental systems to adapt to or cope with the change. A brief review on international and national status of these areas is as follows:

International status

Any climate change impact assessment on water resources study requires the down-scaling of the precipitation and other variables such as temperature, relative humidity, solar radiation, wind direction and wind speed from the global scale to the regional scale. Such down-scaling is done by using either analogue or statistical down-scaling procedures.

The future predictions are described in terms of SRES (Special Report on Emissions Scenarios) storyline scenarios (IPCC, 2007). Each scenario has made assumptions that are dependent on demographic, social, economic, technological, and environmental developments. Around the same time there has been a study wherein general projection of the water resource demand for 2050 has been worked out by the Central Water Commission without considering any climate change impact (Thatte, 2000). He has shown that even without considering climate change impact, the total water demand shall surpass the availability by 2050 even under a low consumption scenario.

Sea-level rise could raise a wide range of issues in coastal areas. Studies in the New York City metropolitan area have projected that climate-change impacts associated with expectations that sea level will rise, could reduce the return period of the flood associated with the 100-year storm to 19 to 68 years on average, by the 2050s, and to 4 to 60 years by the 2080s, jeopardizing low-lying buildings and transportation systems. Similar impacts are expected in the eastern Caribbean, Mumbai (India), Rio de Janeiro and Shanghai, where coastal infrastructure, population and economic activities could be vulnerable to sea-level rise.

The causative factors leading to climate change can be due to natural variability within the system, natural external forcings or man-made forcings. Detection and attribution (D&A) studies differentiate the natural variability and trends in the climate system from those induced by anthropogenic activities and assign these variability to specific causative factors.

Differentiating between natural and anthropogenic influences in a quantitative manner is challenging task.

IPCC WGI/WGII expert meeting on detection and attribution related to anthropogenic climate change (Hegerl et al, 2010) has suggested some guidance while conducting any D&A studies. Much of the D&A studies have been conducted on assessing the human influence on possible temperature changes at continental, subcontinental, and even regional scales (Barnett et al, 2001; Christidis et al., 2005; Hasselmann, 1997; Hegerl et al, 1997; Hegerl et al., 2004; Karoly et al. 2003; Karoly and Stott 2006; Stott 2003; Stott et al. 2010; Zwiers and Zhang 2003). A review of techniques being used in climate change detection studies can be found in Zwiers (1999). Most of these studies have either adopted an optimal fingerprinting or extreme values distributions to assess the anthropogenic influence on the variable of interest. Although, evidence of man-made influence are being highlighted, the results are subjected to uncertainties associated with the model-derived climate change signals, model sensitivity, incorrect aerosol forcing and uncertainties in statistics used.

The impact assessment of climate change on hydrology necessitates the quantification of uncertainties originating from several sources. Uncertainties arise from various sources such as (i) GCM uncertainty, (ii) scenario uncertainty, (iii) internal variability and (iv) uncertainty due to various downscaling approaches. These uncertainties accumulate and cascade down with an increase in resolution or regional levels (Wilby, 2005). Quantification of these uncertainties is basically done by determining the spread of the outputs from various GCMs, scenarios and downscaling approaches. Studies have been employing probabilistic, Bayesian and Monte-Carlo approaches to evaluate the uncertainty (New and Hulme, 2000; Raisanen and Palmer,2001; Tebaldi et al., 2004; Wilby and Harris,2006). An ensemble of projections from different GCMs, scenarios, statistical/dynamical downscaling methods is generated to evaluate the effects of climate change on hydrological variables (Prudhomme and Davies, 2009; Kay et al., 2009; Wilby, 2005). Some recent studies have analysed the suitability or skill of GCMs using an index measured with respect to the observed climate (Murphy et al. 2004; Dessai et al., 2007; Wilby and Harris, 2006).

The above mentioned studies have considered different sources of uncertainty such as future greenhouse gas emissions; structure of GCM; downscaling from GCMs; hydrological model structure; hydrological model parameters and the internal variability due to sensitivity of initial conditions. Among these different sources of uncertainty, the largest contribution from the choice of a GCM. Scenario uncertainty and downscaling uncertainty are much smaller than GCM uncertainty and are almost of similar magnitude.

Regional projections can be obtained either by statistical downscaling in which specific relationships are derived between the GCM and the regional variable of interest or by dynamical downscaling with regional climate models. Another approach of most recent origin through which the downscaling uncertainty can be omitted is macroscale modeling. The outputs from GCMs in coarse resolution are utilized by hydrologic model. The areal heterogeneity in topography, land use, land cover, soil, vegetation and hydrological characteristics should be taken into account in macroscale hydrological modelling.

Vicuna (2008) investigated the effect of climate change on the generation of energy from high-elevation hydropower systems by generating scenarios from a macroscale hydrologic model and coupling it with two general circulation models under two greenhouse-gas emissions scenarios. Wenger et al. (2010) studied the effect of stream hydrology on the structure of aquatic communities. The macroscale hydrologic model was found efficient in simulating the hydrologic changes in smaller streams also.

Nijssen et al. (1997) predicted stream flow for continental river basins using a two layer Variable Infiltration Capacity (VIC-2L) model. Global river sensitivity to climate change was attempted by Nijssen et al (2001) by studying nine large river basins to analyze the regional hydrological consequences of climate predictions using Variable Infiltration Capacity (VIC) model.

Adaptation is the process through which adequate measures are taken to reduce or cope with the negative effects of climate change (IPCC, 2007). Adaptation can be done in a reactive or anticipatory way. Last few years have seen a significant increase in the literature on adaptation to climate change. The role of adaptation in impact assessment (Schneider et al., 2000) and also in reducing vulnerability (Yohe, 2000; Mimura an Yakoki, 2004) have been taken up by many studies. However, very few studies have been conducted on decision-making accounting hydrological impacts.

National status

The predictions made on the future scenarios through the region level downscaling are used by researchers to quantify the impacts on water resources. At the national level the NATCOM (NATional COMmunication) project has been the first one in this direction. Gupta and Deshpande (2004) has predicted that the gross per capita water availability in India will decline from about 1,820 m3/yr in 2001 to as low as about 1,140 in 2050. The reduction in per capita availability of water is entirely due to population growth and cannot be attributed to climate change or any other factor. A case study by Roy et al (2003) deals with the impact assessment of climate change on water availability in the DamodarRiver basin. Hydrologic modelling for evaluation of the effect of climate change on the water scenario has been performed. The water availability in the basin under changed climate scenario was evaluated using the projected daily precipitation and mean monthly temperature data for 2041-2060. It was concluded that decreased peak flows would hinder natural flushing of stream channels leading to loss of carrying capacity and production of non-monsoonal crops will be severely affected.

There has been one comprehensive study that has been carried out to quantify the climate change impact on majority of Indian River systems (Gosain et al, 2003). In this study, the SWAT model (Arnold et al, 1990), a distributed, continuous, daily hydrological model with a GIS interface has been used with daily weather generated by the HadRM2 control climate scenario (1981- 2000) and GHG (Green House Gas) climate scenarios (2041 – 2060). They concluded that although there is an increase in precipitation in some of the river systems for the GHG scenario, the corresponding runoff for these basins has not necessarily increased due to increases in evapo-transpiration on account of corresponding increased temperatures. Two river systems which are predicted to be worst affected from floods are Mahanadi and Brahmani. The frequency as well as the magnitude of the floods is predicted to be enhanced under the GHG scenario. They further concluded that decrease in precipitation has been experienced in many other river basins. The two river basins Sabarmati and Mahi show drastic decreases in precipitation and consequent decrease in total runoff to the tune of two thirds of prevailing runoff. This may lead to severe drought conditions in future in these basins. There has been widespread retreat of glaciers worldwide during the current century (IPCC, 2007). If current warming rates are maintained, Himalayan glacier could decay at very rapid rates, shrinking from the present spread of 500,000 km2 to 100,000 km2 by the 2030s. Many rivers draining glaciated regions, particularly in the Hindu Kush-Himalayas and the South-American Andes, are sustained by glacier melt during the summer season (Singh and Kumar, 1997; Mark and Seltzer, 2003; Singh, 2003; Barnett et al., 2005). Higher temperatures generate increased glacier melt. The entire Hindu Kush-Himalaya ice mass has decreased in the last two decades. Hence, water supply in areas fed by glacial melt water from the Hindu Kush and Himalayas, on which hundreds of millions of people in China and India depend, will be negatively affected (Bernett et al., 2005).

India is especially susceptible to increasing salinity of their groundwater as well as surface water resources, especially along the coast, due to increases in sea level as a direct impact of global warming (Han et al., 1999).

Regional Studies

Rajasthan is a unique region with the major part being a sandy desert and some part as mountainous has not been investigated extensively. There are few studies conducted regarding the metrology, groundwater recharge and existence of palaeo drainage basins. But these studies are highly insufficient to properly understand the hydrology of the region. The region encounters extreme weather phenomenon and Dhar and Rakhecha (1979) studied the incidences of heavy rainfall on Indian desert reporting occasional rainfall of 250-500 mmm in a single day. Groundwater recharge studies using Isotope tracers have been carried out to by Sharma and Gupta (1988), Navada et.al. (1993) and Sukhija et.al. (1996) suggesting 3-15% recharge under different geological and meteorological conditions. The existence on palaeo drainage channels was studied by Khilnani (2009) and related the occurrence of water bearing aquifers and salt lakes with the Vedic rivers. Some recent studies related to canal water management and water logging have been done by Sharma (2001) and Arora and Goyal (2012). Studies related to water conservation and harvesting, and agroforestry were done by Narain et. al. (2005) and khan et. al. (2006). There is a need for further investigation of other studies conducted by other investigators regarding the hydrology of this region before starting further work on hydrological modelling of the region.

A brainstorming meeting involving official from Ministry of Water Resources, Central Water Commission, National Institute of Hydrology and many academic institutions suggested the following actions for effective mitigation/ adaptation measures towards climate change.

- Updating the basin wise water availability
- Coping with the variability in the water sector through development and regulation
- Review of hydrological design and planning criteria under the changed scenario
- Study of Water-Energy-Climate change relationships
- Development of databases and associated tool-boxes for Integrated Water Resources Management (IWRM).

c) Importance of the proposed project in the context of current status

Flow in a river at any point reflects the integrated effect of various, mutually interacting, physical and hydro-climatological processes of the hydrologic cycle. This interaction, which takes place in a natural environment, transforms a climatic input in the form of precipitation into surface and subsurface flows which in turn are modified by human activities as much as by changes that occur in natural processes. The literature has revealed that many studies have been done in the developed countries for assessment of Climate Change on local water resources but in Indian context such studies are lacking. The area of Inland Drainage of Rajasthan is even behind the other river water basins in terms of available data and characterisation of basin. In order to estimate the impact of Climate Change on availability of water for effective planning of Adaptation strategy and identifying extreme events of temperature and precipitation for planning Mitigation strategies it is proposed to take up a comprehensive study of the area.

14 Methodology

To achieve the proposed objectives of this proposal following steps will be taken with specific focus on local conditions:

i. Identification of current knowledge gaps and existing issues,
ii. Conducting applied research on CC related issues/problems,

1) *Identification of current knowledge gaps and existing issues.*

Baseline data will be collected and present understanding of the hydro metrology of the area will be developed based on earlier studies. Current knowledge gaps related to scientific, applied, and social science-related information and existing climate change-related issues will be identified using extensive literature review.

2) *Conducting applied research on climate change-related issues/problems*

Applied research projects will be conducted on different climate change-related issues using experimental and mathematical modelling procedures. Issues identified from step 1 will be guiding-posts for selecting high-priority problems areas and conducting applied research. Some of the identified issues/problems related to different aspects of climate change are presented below:

i. Updating the basin wise water availability,
ii. Development of GIS databases and SWAT hydrological model for Integrated Water Resources Management (IWRM),
iii. Development of Groundwater model in mudflow and study the water quality and quantity parameters
iv. Assessment of climate impact on crop water productivity using FAO AQUA crop model
v. Trend analysis and identification of extreme events, hotspots and vulnerability assessment
vi. Reservoir/canal modelling for water management, water allocation strategy for irrigation/Municipal/industrial uses.
vii. Feasibility of linking of climate, social, and ecology data by employing integrated approaches, such as GIS
viii. Quantifying the uncertainties in climate impact modelling
ix. Development of strategies for cost-effective intervention in water and environmental systems and their consequences for alternative scenarios.
x. Macro scale modelling to study basin hydrology and study the effect due to changes in land use/ land cover.
xi. Identify suitable adaptation policies for water use, cropping patterns, calamity management, reservoir operation policies etc.

All efforts will be made to propose sustainable and vulnerability based climate change impact and adaptation strategies. IPCC (2007) defines adaptation as the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities. In the context of both social and natural systems, adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damage, to take advantage of opportunities or to cope with the consequences).Adaptation is critical to enable societies to deal with the impacts of both natural and anthropogenic environmental change, especially in low-income countries. The adaptation strategy for a country, a basin or part thereof, refers to a general plan of action for addressing the impacts of climate change, including climate variability and extremes. It will include a mix of policies and measures with the overarching objective of reducing the country’s vulnerability. Detailed methodology of the proposed research has been presented in Figure 3 below. Also some of the main processes are explained in subsequent sections.

Hydrological Modelling

SWAT:- In recent years, distributed watershed models are increasingly used to implement alternative management strategies in the areas of water resources allocation, flood control, impact of land use change and climate change, and finally environmental pollution control. SWAT is a well-established physically based distributed models for analyzing the impact of land management practices on water, sediment, and agricultural chemical yields in large complex watersheds. SWAT is continuous time, spatially distributed model designed to simulate water, sediment, nutrient and pesticide transport at a catchments scale on a daily time step. It uses hydrologic response units(HRUs) that consist of specific land use, soil and slope characteristics. The HRUs are used to describe spatial heterogeneity in terms of land cover, soil type and slope class within a watershed. The model estimates relevant hydrologic components such as evapotranspiration, surface runoff and peak rate of runoff, groundwater flow and sediment yield for each HRUs unit.Within the SWAT conceptual framework, the representation of the hydrology of a basin is divided into two major parts: (a) the land phase of the hydrological cycle; and (b) the routing of runoff through the river network. The present study concerns the application of a physically based watershed model ArcSWAT to examine the influence of topographic, land use, soil and climatic condition on stream flow. For the land phase water balance, within SWAT evapotranspiration can be calculated using one of three methods: Penman-Monteith, Hargreaves or Priestley-Taylor. For surface runoff calculations, SWAT gives the user two alternatives: (a) the use of the Soil Conservation Service curve number (SCS CN) procedure, and (b) the Green and Ampt infiltration method.The model setup involved five steps: (1) data preparation;(2) sub basin discretization: (3) HRU definition; (4) parameter sensitivity analysis; (5) calibration and uncertainty analysis.

Modflow:- It is a modular three-dimensional finite-difference groundwater model of the U. S. Geological Survey, to the description and prediction of the behaviour of groundwater systems have increased significantly over the last few years. Since the publication of MODFLOW various codes have been developed by numerous investigators. These codes are called packages, models or sometimes simply programs. Modflow will be used to model the groundwater regime in the region and suggesting the adaptation strategy for the basin.

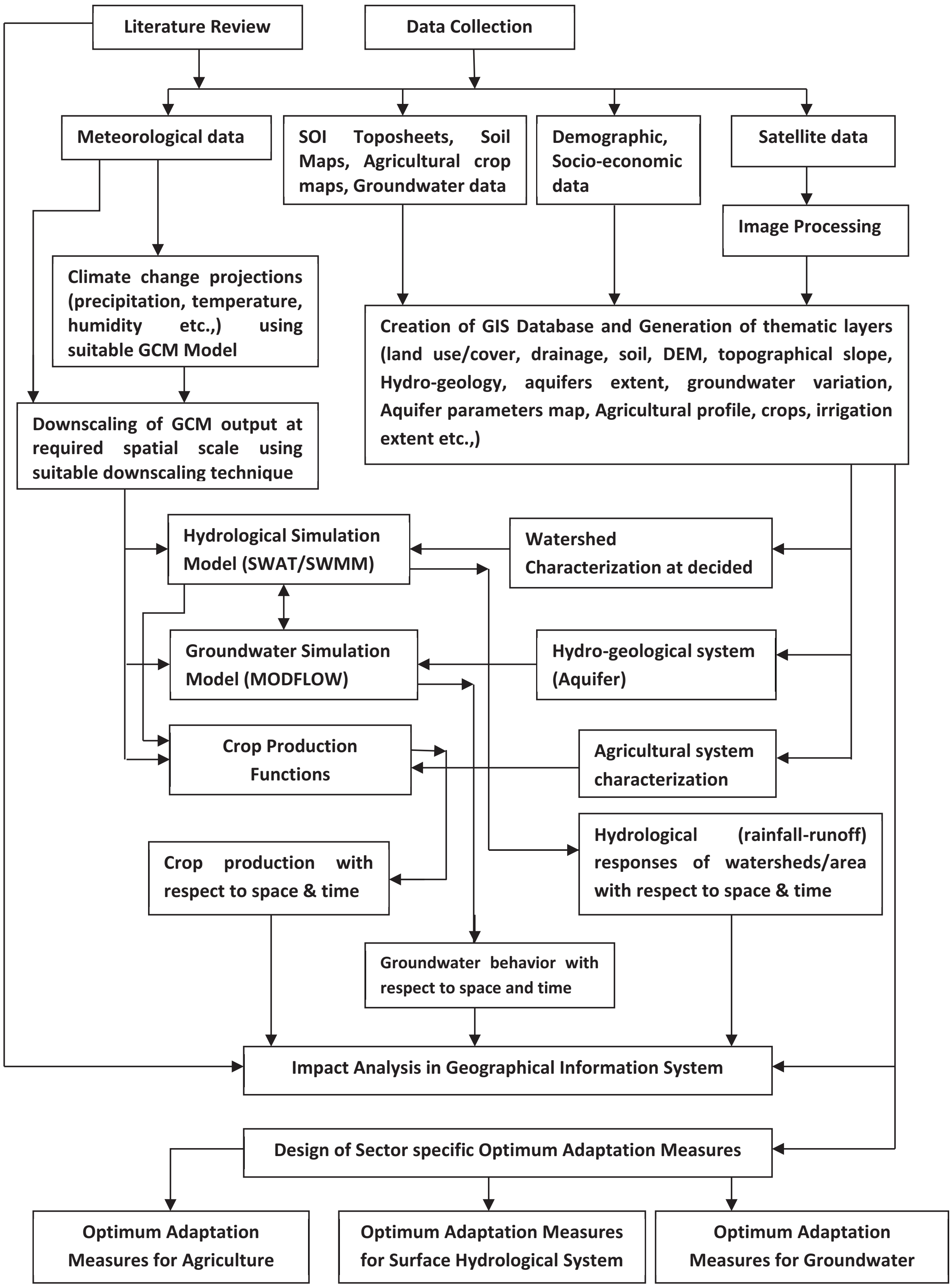

Fig 3: Flow chart of Methodology

Analysis of Trend and Extreme Indices

Extreme weather or climate events have impacts on society, economy and the environment. Analysis of extreme indices is essential as an initial step for climate change impact studies. The climate trend analysis is performed in two parts, i.e., stability of mean and trend in extreme indices.

In the first part, t-test will be applied to check the stability of mean between two subsets of temperature and precipitation time series along with shifts in different normal means. Before developing indices, it is important to check the quality of data and identifies outliers in time series of input data. The outliers are specified as daily values outside a defined range. Kendall's Tau test (non-parametric) will be applied for statistical trend estimation because of its advantage of making no assumption about the statistical distribution (e.g., normality) of the input variables.

In the second part, annual extreme indices related to precipitation and temperature will be calculated on an annual basis for all stations and grid points. Based on the historical datasets and future projection of climatic data, number of extreme indices will be calculated statistically using well defined criterions. This indices will be calculated both on temporal and spatial scale for the river basin. Some of these indicators are Consecutive dry days, consecutive wet days, Cool nights, warm nights, hot days, cool days, very heavy precipitation days, warm spell duration indicators, cold spell duration indicator, etc.

Table 1: List of Extreme Climate Indices

Indicator Code	Units	Indicator name
CDD	Day	Consecutive dry days
CWD	Day	Consecutive wet days
PRCPTOT	mm	Annual total wet-day precipitation
R10	Day	Number of heavy precipitation days
R20	Day	Number of very heavy precipitation days
R40	Day	Number of days above 40 mm
R95p	mm	Very wet days
R99p	mm	Extremely wet days
RX1day	mm	Max 1-day precipitation amount
RX5day	mm	Max 5-day precipitation amount
SDII	mm/day	Simple daily intensity index
TN10p	Day	Cool nights
TN90p	Day	Warm nights
TNn	°C	Minimum T_{min}
TNx	°C	Maximum T_{min}
TX10p	Day	Cool days

TX90p	Day	Warm days
TXn	°C	Minimum T_{max}
TXx	°C	Maximum T_{max}
WSDI	Day	Warm spell duration indicator
CSDI	Day	Cold spell duration indicator

Dataset Requirement: Historical and projected climatic variables (minimum and maximum temperature, rainfall) both on temporal as well as spatial scale

Crop Modelling

Aqua Crop is a crop water productivity model developed by the Land and Water Division of FAO. It simulates yield response to water of herbaceous crops, and is particularly suited to address conditions where water is a key limiting factor in crop production. Aqua Crop attempts to balance accuracy, simplicity, and robustness. It uses a relatively small number of explicit and mostly-intuitive parameters and input variables requiring simple methods for their determination. Initial input data required for the model are Temperature (mean), Rainfall (daily rainfall), Sun radiation (daily) and Regional soil and land properties.

With a daily time step the model simulates successively the following processes:

1. Soil water balance. 2. Crop development. 3. Crop transpiration (Tr). 4. Above ground biomass (B). 5. Partitioning of biomass into yield (Y).

Reservoir and Canal operation

In the western part of Rajasthan there are no major reservoirs but it has the largest canal system in the country. There is an increasing need to model the climate change simulations on operation and water supply response of the canal system. The area has been receiving attention for the presence of palaeo channels containing fresh water. Study by Khilnani (2009) suggest two major palaeo drainage channels exist in the region under study and these provide an opportunity for use of these aquifers as a cyclic storage and supply reservoirs along with the surface sources. An attempt will be made to improve the efficiency of canal system and conjunctive use of ground water wherever possible. The study will focus also calculate the water supply and demand under present and future climate change scenarios. Demand will be estimated for various sectors i.e., agriculture, domestic and industrial. Primary and secondary data both spatial and temporal will be gathered from various state departments. Supply side will be estimated using geospatial database (landuse, soil and even output from hydrological component of the project). Result of this component will be used in identification of vulnerable areas with water scarcity in future climate change scenarios.

Datasets: Climatic variables, RS/GIS datasets (soil, landuse/cover, DEM), soil characteristics, etc.

Deliverables

Successful completion of the project will leads to following deliverables -

- Base line data and information.
- Present status of the study area with reference to hydrology, water availability, water use practices and policies.
- Trend analysis results of hydro-meteorological variables and identification of hydrological extremes.
- Calibrated hydrological model of the study area.
- Quantitative and qualitative impacts of climate change on hydrologic cycle components at selected points for near (2015-2040) and distant future (2040-2100).
- Impacts of climate change on agriculture sector
- Optimum water allocation /use policies for different sectors under different climate change scenarios.
- Impacts of climate change on ground & surface water quality.
- Organisation of a conference/workshop.

Refrences

Arnold, J.G., Williams, J. R., Nicks, A. D. and Sammons, N.B., 1990. SWRRB-A basin scale simulation model for soil and water resources management.TexasA&M Press.College Station, TX. 255 pp.

Arora, A.N. & Goyal, R. (2012): Groundwater model of waterlogged area of Indira Gandhi NaharPariyojna, Stage I, ISH Journal of Hydraulic Engineering, 18:1, 45-53

Barnett, T.P., J.C. Adam and D.P. Lettenmmaier, 2005: Potential impacts of a warming climate on water availability in snow-dominated region. Nature 438, 303-309

Barnett, T.P., Peirce, D.W., and R. Schnur, 2001: Detection of Anthropogenic Climate Change in the World's Oceans, Science 13 April 2001: Vol. 292 no. 5515 pp. 270-274, doi: 10.1126/science.1058304.

Christidis, N., P. A. Stott, S. Brown, G. C. Hegerl, and J. Caesar, 2005: Detection of changes in temperature extremes during the second half of the 20th century. Geophys. Res. Lett., 32, L20716, doi:10.1029/2005GL023885.

Dessai, S., and M. Hulme, 2007: Assessing the robustness of adaptation decisions to climate change uncertainties: A case study on water resources management in the east of England. Global Environ. Change, 17, 59–72.

Dhar, O.N. and Rakhecha, P.R. (1979) 'Incidence of heavy rainfall in the Indian desert region' *The hydrology of areas of low precipitation* (Proceedings of the Canberra Symposium, December 1979; IAHS-AISH Publ. no. 128.

Gillett, N. P., F.W. Zwiers, A. J.Weaver,G. C.Hegerl,M. R.Allen, and P. A. Stott, 2002: Detecting anthropogenic influence with a multi-model ensemble. Geophys. Res. Lett., 29, 1970, doi:10.1029/ 2002GL015836.

Gosain, A. K., Rao, S., and Basuray, D. 2003. Assessment of vulnerability and adaptation for water sector.NATCOM Vulnerability and Adaptation Workshop on Water Resources, Coastal Zones and Human Health, Ministry of Environment, New Delhi.

Gupta, S.K. and Deshpande, R.D. 2004. Water for India in 2050: first order assessment of available options. Current Science, 86: 1216-1224.

Han, M., M.H. Zhao, D.G. Li and X.Y. Cao, 1999: Relationship between ancient channel and seawater intrusion in the south coastal plain of the Laizhou Bay. Journal of Natural Disasters, 8, 73-80.

Hasselmann, K, 1997: Multi-pattern fingerprint method for detection and attribution of climate change, Climate Dynamics, 13 : 601-611

Hawkins, E., and R. Sutton, 2009: The Potential to Narrow Uncertainty in Regional Climate Predictions. *Bull. Amer. Meteor. Soc.*, 90, 1095–1107

Hegerl, G. C., F. W. Zwiers, P. A. Stott, and V. V. Kharin, 2004: Detectability of anthropogenic changes in annual temperature and precipitation extremes. J. Climate, 17, 3683–3700.

Hegerl, G. C., K. Hasselmann, U. Cubasch, J. F. B. Mitchell, E. Roeckner, R. Voss, and J.Waskewitz, 1997:Multi-fingerprint detection and attribution analysis of greenhouse gas, greenhouse gas-plus-aerosol and solar forced climate change. Climate Dyn., 13, 613–634.

Hegerl, G.C., O.Hoegh-Goldberg, G. Casassa, M. P. Hoerling,R. S.Kovats,C. Parmesan, D.W. Pierce, and P. A. Stott, 2010: IPCC expert meeting on detection and attribution related to anthropogenic climate change. T. F. Stocker et al., Eds., IPCC Meeting Rep., 65 pp.

IPCC (Intergovernmental Panel for Climate Change), 2007. Fourth Assessment Report, WMO/UNEP

Karoly, D. J , K. Braganza, P. A. Stott, J. M. Arblaster, and G. A. Meehl, 2003: Detection of a human influence on North America climate. Science, 302, 1200–1203.

Karoly, D. J., and P. A. Stott, 2006: Anthropogenic warming of central England temperature. Atmos. Sci. Lett., 7, 81–85, doi:10.1002/asl.136.

Kay, A. L., Davies, H. N., Bell, V. A., and Jones, R. G. (2009). "Comparison of uncertainty sources for climate change impacts: flood frequency in England." *Climatic Change*, 92(1-2), 41-63.

Khan, M. A., Tewari, J. C., Singh, R.,and Narain, P. (2006): Structure, Production Attributes and Management StrategiesIn A Traditional Extensive Agroforestry System In An Arid RegionWatershed Of India, *Forests, Trees and Livelihoods*, 16:3, 227-246

Khilnani, M., (2009) 'Palaeodrainage and Palaeoclimate of North-West India' *Hydrology Journal* 32(1-2): 21-29

Mark, B.G. and G.O. Seltzer, 2003: Tropical glacier meltwater contribution to stream discharge: a case study in the Cordillera Blanca, Peru.J.Glaciol., 49, 271-281.

Mimura, N. and H. Yakoki, 2004: Sea level changes and vulnerability of the coastal region of East Asia in response to global warming. SCOPE/START Monsoon Asia Rapid Assessment Report.

Murphy, J. M., D. M. H. Sexton, D. N. Barnett, G. S. Jones, M. J. Webb, M. Collins, and D. A. Stainforth, 2004: Quantification of modelling uncertainties in a large ensemble of climate change simulations. Nature, 430, 768–772.

Narain, P, Khan, M.A. and Singh, G., (2005) ' Potential for water Conservation and Harvesting against Drought in Rajasthan, India. Working Paper 104 (Drought Series: Paper 7), Colombo, Sri Lanka: Internationa Water Management Institute(IWMI)

Navada, SV, Nair, AR, Rao, SM, Paliwal, BL, and Doshi, CS (1993) Groundwater recharge using isotope techniques.*J. Arid Environment*, 24, 125 -133

New, M., and Hulme, M. (2000).“Representing uncertainty in climate change scenarios: A Monte Carlo approach.”*Int. Assessment*, 1, 203– 213.

Nijssen, B.N., Lettenmaier, D.P., Liang, X., Wetzel, S.W. and Wood, E.F., 1997.Streamflow simulation for continental-scale river basins. Water Resour. Res, 33(4): 711-724.

Nijssen, B.N., O'Donnell, G.M., Lettenmaier, D.P. and Wood, E.F., 2001. Predicting the discharge of global rivers. J. Clim., 14.

Prudhomme, C., and Davies, H. (2009). Assessing uncertainties in climate change impact analyses on the river flow regimes in the UK. Part 2: future climate." *Climatic Change*, 93(1-2), 197-222.

Raisanen, J., and T. N. Palmer (2001), A probability and decision-model analysis of a multimodel ensemble of climate change simulations, *J. Clim.*, *14*, 3212-3226.

Roy, P. K., Debasri Roy, Asis Mazumdar and Balaram Bose, 2003.Vulnerability Assessment of the Lower Ganga-Brahmaputra-Meghna Basins. NATCOM - V&A Workshop on Water Resources, Coastal Zones and Human Health,IIT Delhi.

Schneider, S. H., Easterling, W. E., and Mearns, L. O. (2000). Adaptation: Sensitivity to natural variability, agent assumptions and dynamic climate changes." *Climatic Change*, 45(1), 203-221.

Sharma, P. and Gupta, S.K. (1987) 'Isotopic investigation of Soil water movement: A case study in the Thar desert, Western Rajasthan' *Hydrological Sciences* 32(4), 469-483

Sharma, K.D. (2001) 'Indira Gandhi Nahar Pariyojana—lessons learntfrom past management practices in the Indian arid zone' *Regional Management of Water Resources* (Proceedings of a symposium held during die Sixth IAHS Scientific Assembly at Maastricht , The Netherlands, July 2001) . IAHS Publ .no. 268, 2001 .

Singh, P. and N. Kumar, 1997: Impact assessment of climate change on the hydrological response of a snow and glacier melt runoff dominated Himalayan River. J. Hydrol., 1993, 316-350.

Singh, P., 2003: Effect of warmer climate on the depletion of snow covered area in the Satluj basin in the western Himalayan region. Hydrol. Sci.J.,48, 413-425.

Stott, P. A, N. P. Gillett, G. C. Hegerl, D. Karoly, D. Stone, X. Zhang, and F. W. Zwiers, 2010: Detection and attribution of climate change: A regional perspective. WIRCC, 192–211, doi:10.1002/ wcc.34.

Stott, P. A., 2003: Attribution of regional-scale temperature changes to anthropogenic and natural causes. Geophys. Res. Lett., 30, 1728, doi:10.1029/2003GL017324.

Sukhija, B.S., Nagabhushanam, P., and Reddy, D.V. (1996), Groundwater Recharge in SemiArid Regions of India: An Overview of Results Obtained Using Tracers, *Hydrogeology Journal* 4(3), 50-71

Tebaldi, C., L. O. Mearns, D. Nychka, and R. L. Smith (2004), Regional probabilities of precipitation change: A Bayesian analysis of multimodel simulations, *Geophys. Res. Lett.*, *31*, L24213, doi:10.1029/ 2004GL021276.

Thatte, C.D., 2000. Green to evergreen revolution through a blue revolution.*Journal of Indian Water Resources Society* 20(2), 63-75

Vicuna, S., Leonardson, R., Hanemann, M.W., Dale, L.L., and J. A. Dracup, 2008: Climate change impacts on high elevation hydropower generation in California's Sierra Nevada: a case study in the Upper American River, Climatic Change, 87 (Suppl 1):S123–S137.

Wenger, S.J., Luce, C.H., Hamlet, A.F., Isaak, D.J., and H.M. Neville, 2010: Macroscale hydrologic modeling of ecologically relevant flow metrics, Water Resources Research, vol. 46, W09513, doi:10.1029/2009WR008839.

Wilby, R. L. (2005). "Uncertainty in water resource model parameters used for climate change impact assessment." *Hydrological Processes*, 19(16), 3201-3219.

Wilby, R. L., and I. Harris (2006), A framework for assessing uncertainties in climate change impacts: Low-°ow scenarios for the River Thames, UK, *Water Resour. Res.*, *42*, W02419, doi:10.1029/2005WR004065.

Yohe, G. (2000). Assessing the role of adaptation in evaluating vulnerability to climate change.*Climatic Change*, 46(3), 371-390.

Zwiers, F. W., 1999: Climate change detection: A review of techniques and applications. Anthropogenic Climate Change, H. von Storch, E. Raschke, and G. Flo¨ ser, Eds., Springer, 161–206.