Revised Project Proposal
on

IMPACT OF CLIMATE CHANGE ON WATER RESOURCES IN RIVER BASINS FROM TADRI TO KANYAKUMARI

Submitted to

Ministry of Water Resources
(Government of India)

Submitted by

Indian Institute of Technology Bombay Powai, Mumbai -400076

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Note: "As the objectives and methodologies are similar to the other proposal submitted by IIT Bombay for Godavari River basin, there will be some similarities in this proposal with the same, with specific modifications required for Tadri to Kanyakumari".

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4. **Brief bio data of the Investigators:** Enclosed

5. **Project Title:** ***Impacts of Climate Change on Water Resources in River Basins from Tadri to Kanyakumari***

6. **Track Record and Workload Assessment of the PI**

Sponsored Projects only - Schemes completed:

1) 'Development of Numerical Models for the Prediction of Hydrodynamics & Salinity Transport in Branched Estuary Channels', Department of Science & Technology, India, 2002-2005.
2) 'Scope of Integrated Watershed Modeling Using IRS Data & GIS', ISRO Project, 2003-2004.
3) 'Integrated Watershed Modeling Using IRS Data & GIS', ISRO Project, 2004-2008.

- More than 50 major consultancy projects completed for various industries and government agencies in the past 15 years at IIT Bombay.

Sponsored Projects - Schemes ongoing:

a) "Integrated Flood Assessment Modeling for Urban Watershed Suing Finite Element method, GIS and Remote Sensing", **DST Sponsored research project**, (completed; 2009-2014).

b) "Hydraulic Model Investigations for Design of Raft Foundations for Bridges", Ministry of Shipping, Road Transport & Highways, New Delhi. (completed; 2009-2013).

- Presently 6 industrial research projects are ongoing.

7. **If the scheme is sanctioned, in whose name the cheque is to be issued:**

   The Registrar, IIT Bombay. (for IIT Bombay)

8. **Category of R&D Activity (Tick those which are appropriate):**

   a. **Basic Research**
   b. **Applied Research√**
   c. **Action Research**
   d. **Education and Training**
   e. **Mass Awareness Programme**
   f. **Infrastructure Development**
   g. **Creation of Centres of Excellence**

9. Description of the Research Proposal

As is already well known, the hydrologic cycle is inherently linked with climate and changes in the climate system are likely to affect water resources and regional development. Increased evaporation, combined with regional changes in precipitation patterns, can affect mean runoff, frequency and intensity of floods and droughts, soil moisture, and water supplies for irrigation and hydroelectric power generation. Conventional tools for water resources management assume a hydrologic time series to be stationary, however "stationarity is dead because substantial anthropogenic change of Earth's climate is altering the means and extremes of precipitation, evapotranspiration, and rates of discharge of rivers"[1]. General Circulation Models (GCMs) provide three-dimensional simulations of the earth's climate system under increased greenhouse gas emission scenarios. The 'four holes' of climate science, as reported in literature[2] are regional modelling, precipitation, aerosol and tree ring controversies, among which, the first two can directly impact river basin water resources. GCMs operate, and simulate climate variables, at a coarse resolution and their projections for precipitation or other hydrologic variables at finer scales are not reliable. Furthermore coarse scale precipitation simulations do not serve the purpose in India, when, the summer monsoon rainfall is characterized with the increase of spatial variability[3]. This necessitates downscaling, that is, obtaining finer scale hydroclimatic variables from the large-scale GCM simulations for impacts assessment.

Statistically downscaled GCM simulations will be used in the proposed work in conjunction with hydrologic simulations by the Variable Infiltration Capacity (VIC) model[4] (a grid based hydrologic model to simulate hydrologic variables such as, soil moisture, runoff) or SWAT (Soil Water Assessment Tool), which are useful for agricultural water management, drought forecasting etc. The downscaling relationship obtained between the large scale climate variables that are well simulated by the GCMs, and the fine scale rainfall will be applied to GCM projections and the downscaled variables will serve as input to the hydrologic model. The proposed work will also analyse land use land cover changes and their impact on micro climate and hydrologic processes. The hydrologic variables such as runoff or soil moisture or evapotranspiration, simulated with GCM projections, can be further used in specific applications such as understanding behaviour of extremes, water demand analysis, assessment of water quality, etc. All the generated outputs will be made available to the Central Water Commission (CWC) and Ministry of Water Resources (MOWR), which may further be used by end users, such as water resources planners, agricultural managers for adaptation strategies. Additionally, if time permits, some key research questions can be addressed with the proposed work, such as exploring reasons of changes in regional precipitation patterns, or changes in risks associated with extremes under climate change.

The proposed work aims at assessment of impacts of climate change on the water resources of the river basins from Tadri to Kanyakumari. Most of the Rivers in this area are flowing to west joining Arabian Sea. The Rivers are mainly in Kerala, Karnantaka, and Tamilnadu.

9.1 Project Area Details: West flowing Rivers South of Tadri

The basin extends over states of Kerala, Karnataka, Tamil Nadu and Puducherry having an area of about 56,177 Sq.km which is 1.73 % of total geographical area of the country with a maximum length and width of 777 km and 135 km. It spreads between 74°25’ to 77°36’ east longitudes and 8°3’ to 14°24’ north latitudes. The basin is bounded by Sahyadri hills on the north, by the Western Ghats on the east, by Indian Ocean on the south and by the Arabian Sea on the west (**http://india-wris.nrsc.gov.in)**. Large number of River basins are there for the area considered between South of Tadri to Kanyakumari (Fig. 1). The major part of basin is covered with agriculture accounting to 50.82% of the total area while 3.65% is covered by water bodies. Most of the Rivers are in the states of Karnataka and Kerala. Few small River basins are also there in Tamilnadu and Puducherry. The important River basins in the area are listed below.

West flowing Rivers of Karnataka

Major rivers (North to South): 1) Tadri (Agnashini); 2) Saravathi; 3) Chakra; 4) Varahi (Haladi); 5) Netravathi.

There are numerous independent small streams that directly join the Arabian Sea. They can be classified into independent catchment between the main rivers.

a. **Independent catchment between Sharavathi and Chakra river**.

1) Kollur River (Souparnika); 2) Ghantihole ; 3) Venkatapur ; 4) Baindurhole; 5) Shankargundi; 6) Kumbarhole; 7) Yedamavinahole

b. Independent catchment between Varahi and Netravathi river.

1) Seethanadhi; 2) Uppunda; 3) Swarna; 4) Sambhavi; 5) Udyawara; 6) Mulki river ; 7) Pavanje (Nandini); 8) Nadisalu ; 9) Gurpur (Phalguni); 10) Yennehole ; 11) Madisalhole.

West flowing Rivers of Kerala

1. Manjeswar; 2. Uppala; 3. Shiriya; 4. Mogral; 5. Chandragiri; 6. Chittari; 7. Nileswar; 8. Karingode; 9. Kavvayi; 10. Peruvamba; 11. Ramapuram; 12. Kuppam; 13. Valapattanam; 14. Anjarakandy; 15. Tellicherry; 16. Mahe; 17. Kuttiady; 18. Korapuzha; 19. Kallayi; 20. Chaliyar; 21. Kadalundi; 22. Tirur; 23. Bharathapuzha; 24. Keecheri; 25. Puzhakkal; 26. Karuvannur; 27. Chalakkudy; 28. Periyar; 29. Muvattupuzha; 30. Meenachil; 31. Manimala; 32. Pamba; 33. Achencoil; 34. Pallickal; 35. Kallada; 36. Ithikkara; 37. Ayroor; 38. Vamanapuram; 39. Mamom; 40. Karamana; 41. Neyyar

West Flowing Rivers of Tamil Nadu

1. Kodayar ; 2. Pazhayar

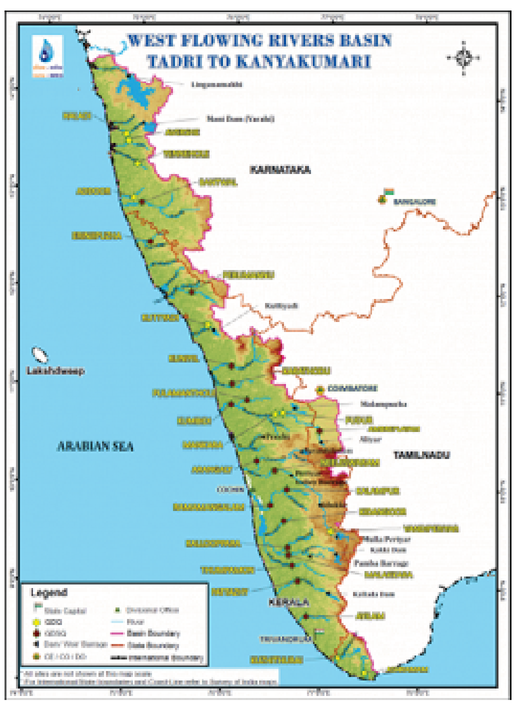

Fig. 1. West Flowing Rivers from Tadri to Kanyakumari (Ref: http://india-wris.nrsc.gov.in/)

9.2 Rainfall, Land Use Land Cover Pattern & Geology

Rainfall

Most of the River basins in the area lies in Wester Ghats which lies in the tropical South Asian monsoon tract characterized by wet summers and dry winters. The principal rain-giving seasons across the Western Ghats are the Southwest Monsoon (June - September) and Northeast Monsoon (October - November). The pre-monsoon months (March - May) account for the major thunderstorm activity in the state and the winter months (December - February) are characterized by minimum clouding and rainfall. The Western Ghats receives heavy annual rainfall ranging from 1500 to 7800 mm in its varied stretches. The total annual rainfall increases from south to north and from west to the east.

Land Use and Land Cover

There are four major forest types in the Western Ghats: evergreen, semi-evergreen, moist deciduous, and dry deciduous. With its high rainfall regime, the western slopes of the Ghats have a natural cover of evergreen forest, which changes to moist and then dry deciduous types as one comes to the eastern slopes Together the forests cover approximately 20 percent of the total area of the Western Ghats. Among the four broad vegetation types, moist deciduous forests occupy the largest area followed by semi evergreen, dry deciduous, and finally evergreen. The majority of the area under moist forest types falls within the southern states of Kerala and Karnataka. Together they account for 80 percent of the evergreen forest and 66 percent of the moist deciduous forests in the Western Ghats (IIRS, 2002).

Geology, Physiography and soil

Geologically the Ghats fall into two sections corresponding to two major categories of rock formation. The Western Ghat segment of relatively fragile rocks and flat hill tops north of the river Tadri corresponds to the basaltic lava flows of the Deccan Trap. The hills do not rise much beyond 1500 m in this tract. South of Tadri is the region of the highly varied Precambrian Archaean crystalline rocks which are much harder. The hills tend to be rounded and rise to 2000 m or more in this segment. The Western Ghats are essentially the Western edge of the Indian peninsular plateau, which is the stable mark of Archaean and Pre-Cambrian formations, where the mountain building has ceased in the Pre-Cambrian times. The Western Ghats presents an almost sheer, abrupt and straight face along its eastern edge to the south of the Palghat gap up to the Shencottah gap. Most of the exposed gneisses of the Western Ghats are 2,500 million years old. The nonmetamorphic sedimentary formations are very rare and found only along the coastal belt (WGEEP, 2011). The Hills of the Western Ghats are generally of elevations between 600 and 1000 m. Peaks over 2000 m are found only in the mountain ranges of Nilgiris, Palanis and Anaimalais. The Western Ghats display an extremely steep western face in contrast with its more gently descending eastern slopes which proceeds to merge with the Deccan Plateau. But far in the south, the east and west slopes are equally steep but with drastically different ecological conditions (Nair, 1991). The soil mainly consists of the derivatives of the ancient metamorphic rocks in India, rich in iron and manganese (Pascal, 1988). There are seven main soil groups found in the region viz. laterites (high and low), red loam, medium black soils, hill soils, red gravelly soils, alluvial soils including coastal alluvium, mixed red and black soils. Soils vary from humus rich peat in the montane areas to laterite in the lower elevation and high rainfall belts. Soils are generally acidic. Along the coastal hills there are exposed lateritic rocks which are barren and mostly unfit for plant growth.

Table 1 gives the salient features of the study area.

Table 1: Salient Features (http://india-wris.nrsc.gov.in)

Basin Extent	
Longitude	74° 25' to 77° 36'E
Latitude	8° 3' to 14° 24' N
Length of River (Km)	Many independent rivers flowing
Catchment Area (Sq.km.)	56177
Average Water Resource Potential (MCM)	113530
Utilizable Surface Water Resource(MCM)	24300
Live Storage Capacity of Completed Projects (MCM)	10236.16
Live Storage Capacity of Projects Under Construction (MCM)	1317.54
Total Live Storage Capacity of Projects (MCM)	11553.70
No. of Hydrological Observation Stations	29
No. of Flood Forecasting Stations	0

References

1. Milly et al. (2008), Stationarity is dead: Whither water management?, *Science*, 319, 573-574.
2. Schiermeier, Q. (2010), The real holes in climate science, *Nature*, 463, 284-287

3. Ghosh et al. (2012), Lack of uniform trends but increasing spatial variability in observed Indian rainfall extremes, *Nature Climate Change*, DOI: doi:10.1038/nclimate1327
4. Liang, X., D. P. Lettenmaier, E. F. Wood, and S. J. Burges (1994), A Simple hydrologically Based Model of Land Surface Water and Energy Fluxes for GSMs, *J. Geophys. Res.*, 99(D7), 14,415-14,428.
5. Nair, S.C.1991. *The Southern Western Ghats; A Biodiversity Conservation Plan*. Studies in Ecology & Sustainable Development V4, Indian National Trust for Art & Cultural Heritage INTACH, New Delhi.
6. Pascal, J.P. 1988. Wet evergreen forests of the Western Ghats of India: Ecology, structure, floristic composition and succession, French Institute of Pondicherry (FIP), Pondicherry, India.
7. WGEEP, 2011. Report of the Western Ghats Ecology Expert Panel, Submitted to the Ministry of Environment and Forests, Government of India, New Delhi.
8. IIRS. 2002. *Biodiversity Characterization at Landscape Level in Western Ghats India using Satellite Remote Sensing and Geographic Information Systems*, Indian Institute of Remote Sensing, Indian Institute of Remote Sensing, Dept. of Space, Govt. of India, Dehradun
9. Daniels, R.J.R. 2001. *National Biodiversity Strategy and Action Plan: Western Ghats Eco-region.* Report submitted to Ministry of Environment and Forests, Government of India, New Delhi

10. Objectives

The proposed work aims to assess the impacts of climate change on the water resources of the river basins on grid basis from Tadri to Kanyakumari. Most of the Rivers in this area are flowing to west joining Arabian Sea. The Rivers are in Kerala, Karnantaka and Tamilnadu. The details of important River basins are given in the earlier sections.

Following are the objectives of the proposed project:

- Preparation of base line data, information and past studies for the concerned River basins
- Parametric/non-parametric tests for trend detection for hydro-meteorological and hydrological variables.

- Preparation of calibrated and validated hydrological model(s) using Variable Infiltration Capacity (VIC)/ Soil and Water Assessment Tool (SWAT) models
- Study of climate change impacts on water availability at various gauging sites within the basin (in terms of change in flow duration curves) using VIC/ SWAT models,
- Study of impacts on irrigation water demands,
- Identification of hydrological extremes based on the base line data
- Study of impacts on meteorological & hydrologic droughts (in terms of change in frequencies of occurrence)
- Analysis of uncertainties in the impacts.
- The impacts and the associated uncertainties must be assessed for near-future (2015-2040) and for distant future (2040-2100), and
- Recommendations for adaptation measures/options
- Organization of Training and National Level Workshops to impart the knowledge generated and disseminate the climate change impact information to various states and central government agencies and Scientists and Engineers.

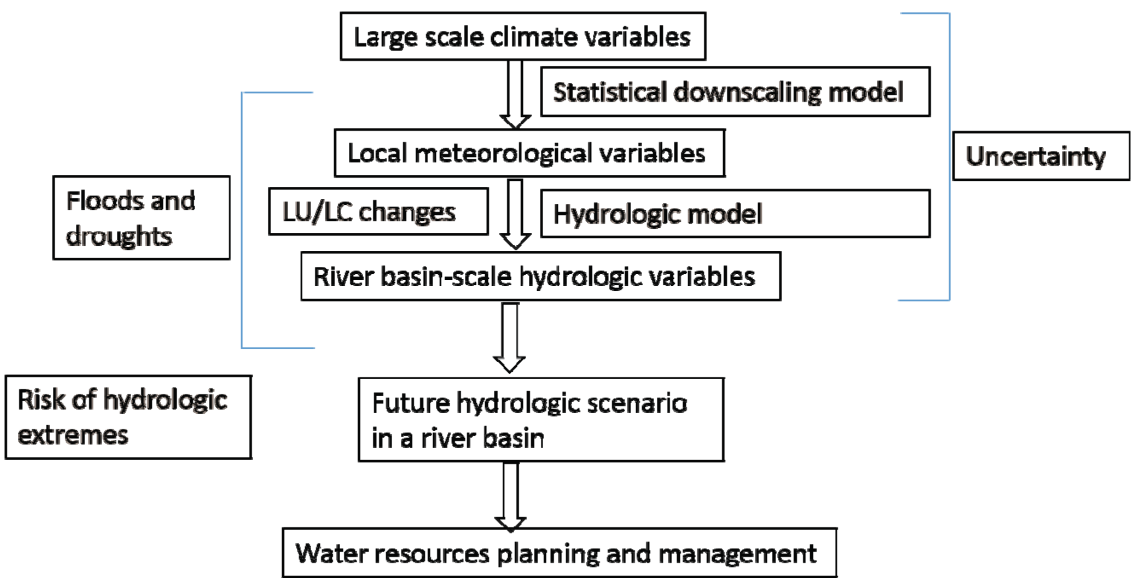

Fig. 2 Research Methodology – an Overview

11. Contribution to Water Resources Development & Management

In many organizations in India, research works have been started in full phase on assessment of impacts of climate change on water resources and on various adaptation and mitigation approaches. However, most of the studies are not comprehensive and disjoint in nature. Applications of end-to-end analyses starting with simulation of climate models to downscaling and further hydrologic modelling are only limited for few River basins in India. Several studies on the other hand consider hypothetical scenarios which may not present a realistic possibility of future, thereby necessitating the use of climate model runs in regional impact assessment studies. Through this project, we will try to achieve the following: development of extensive database for the River basins considered; climate change and impacts for the River basins considered; validation and calibration of hydrological models for future scenarios and climate change impact assessment for the basins considered. Efforts will be made to make available all the outputs and data for water resources communities for further research, impacts analysis and adaptation.

12. Putting the Research to Use

a) Identify the possible end-users for the results of proposed research.

The state and central agencies including the entire water resources community working in the field of water resources management for climate change scenarios will be the end users of the results from the proposed research. From the project output, following studies can be further carried out:

i) Water management for agricultural purposes and crop yield analysis
ii) Studies on drought and its management
iii) Flood management strategies for possible high intense rainfall
iv) Studies on future demands and optimal storage.

b) List the actions that will be necessary to put the results to use.

The research output and analysis (based on climate, meteorological and hydrologic variables) from the study will be huge. MOWR will have to take appropriate measures to keep these data and output for future use by stake holders, researchers and water managers. The internet and web based database may be developed and made available to users.

c) List the difficulties/problems that may be encountered in putting the results to use.

- Availability of accurate data.
- Adaptability of the implementing agencies.
- Facility/ expertise of the Implementing agencies.

d) Are the possible end users being involved in the research? If yes then describe how, if not then explain why not.

Yes: Agency CWRDM, Calicut is agency in the state of Kerala to implement some of the results in Kerala State. The results, they can implement it through state level agencies. For River basins in Karnataka, the details should be given to Karnataka Irrigation Department.

13. Present State of Art

a) *Work at International Level:*

The General Circulation Models (GCMs) provide three-dimensional simulations of climate variables globally, in response to changes in the concentration of greenhouse gases in the atmosphere. GCMs might capture large scale circulation patterns and correctly model smoothly varying fields such as surface pressure, but it is extremely unlikely that these models properly reproduce non-smooth fields such as precipitation. Additionally, there is a scale mismatch between GCM simulations and hydrologic processes as the GCMs operate at very large scales. Therefore, for assessment of hydrologic implications of global climate change, scientists take resort to downscaling techniques. Methodologies to model the hydrologic variables at a smaller scale based on large scale GCM outputs are known as downscaling. The methodologies include dynamic downscaling, which uses complex algorithms at a fine grid-scale describing atmospheric process nested within the GCM outputs (commonly known as Limited Area Models or Regional Climate Models, RCM) and statistical downscaling, that produces future scenarios based on statistical relationship between larger scale climate features and hydrologic variables such as precipitation. The commonly used dynamic downscaling models are REGCM, WRF etc. In India, PRECIS, a dynamic downscaling model coupled with Hadley Climate Centre GCM is widely used. Statistical downscaling, on the other hand, focuses on deriving a statistical relationship between large scale predictors and the target hydrologic variables (predictands). Statistical downscaling techniques can fall into three categories: weather generators, weather typing and transfer functions. Weather generators (Hughes and Guttrop, 1993; Wilks, 1999) are based on complex random number generators, the output of which resembles daily weather data at a particular location. Weather typing approaches, on the other hand, involve grouping of local, meteorological variables in relation to different classes of atmospheric circulation. Future regional climate scenarios are constructed either by re-sampling from the observed variable distribution (conditioned on the circulation pattern produced by a GCM), or by first generating synthetic sequences of weather pattern using Monte Carlo techniques and then re-sampling from the generated data. The most popular approach of downscaling is the use of transfer function (Cannon and Whitefield,

2002) which is a regression based downscaling method that relies on direct quantitative relationship between the local scale climate variable (predictand) and the variables containing the large scale climate information (predictors) through some form of regression. The transfer functions can be either linear (such as multiple linear regression) or non-linear (complex learning techniques such as Artificial Neural Networks and Support Vector Machines) in nature. In statistical downscaling approaches, it is assumed that the relationship between the predictors and the predictand remains unchanged in future. Typically, statistically downscaled large scale climate variables are used as input to hydrologic models which in turn simulate regional hydrologic variables of interest, such as runoff and soil moisture.

b) Work at National Level:

Studies focussing on the Indian region are either mostly limited to using PRECIS output in SWAT (Gosain et al., 2006) or direct single site downscaling (Ghosh and Mujumdar, 2007, 2008; 2009), without any 'end to end' research and development. There are some river basin scale hydrologic models based on Soil and Water Assessment Tool (SWAT), which consider PRECIS output for future projections, but none of them are for near term future (2010-2040) which may be of immediate interest. Moreover, the present generation of climate models are forced with radiative forcings instead of concentrations of carbon-dioxide, thereby necessitating updating of impact analyses.

c) Difference of the Proposed Work from Earlier Works:

Scientific research efforts indeed seem to have increased as far as regional hydrologic impacts of climate change are considered. However, efforts to simulate climate, hydrologic and meteorological variables for near future seem rare and subsequent availability of the research output for follow-on researchers is limited. Furthermore, many scientific questions remain unresolved, such as, identifying the effects of sea surface temperature changes, orography and land use change on rainfall trend, requirements of finer resolution climate models or regional climate models, etc. Earlier efforts pertaining to this topic appear only a routine work of either using dynamic downscaling model output in river basin hydrologic water quality quantity model or development of statistical downscaling relationships with some uncertainty quantification. Extensive research works either on understanding the geophysics using multiple climate run experiments or use of rigorous statistics and data driven models for river basin scale finer resolution climate simulation are lacking. The proposed study aims at addressing these specific research issues and focuses on ensured availability of research outputs available for follow-on works or for direct use by water managers.

d) References:

- Cannon, A.J. and P.H. Whitfield (2002), Downscaling recent streamflow conditions in British Columbia, Canada using ensemble neural network models, J. Hydrol., 259, 136-151.
- Dickinson RE, Errico RM, Giorgi F, Bates GT. 1989. A regional climate model for the western United States. Climate Change 15: 383-422.
- Ghosh, S. and Mujumdar, P. P. (2007), Nonparametric Methods for Modeling GCM and Scenario Uncertainty in Drought Assessment", Water Resources Research, 43, W07405, doi:10.1029/2006WR005351.
- Ghosh, S. and Mujumdar, P. P. (2008), Statistical Downscaling of GCM Simulations to Streamflow using Relevance Vector Machine. Advances in Water Resources, 31(1), pp. 132-146.
- Ghosh, S and P. P. Mujumdar (2009), Climate Change Impact Assessment- Uncertainty Modeling with Imprecise Probability, Journal of Geophysical Research- Atmosphere (AGU), 114, D18113, doi:10.1029/2008JD011648
- Gosain, A. K., Rao, S. and Basuray, D. (2006), Climate Change Impact Assessment on Hydrology of Indian River Basins, Current Science, 90(3), 346-353.
- Hughes, J. P., Lettenmaier, D. P. and Guttorp, P. (1993), A Stochastic Approach for Assessing the Effect of Changes in Synoptic Circulation Patterns on Gauge Precipitation, Water Resources Research, 29(10), 3303-3315
- Mujumdar, P. P., and Ghosh, S (2008), Modeling GCM and scenario uncertainty using a possibilistic approach: Application to the Mahanadi River, India, Water Resources Research, 44, W06407, doi:10.1029/2007WR006137.
- Skamarock WC, Klemp JB, Dudhia J, Gill D, Barker D, Wang W, Powers JG. 2005. A description of the Advanced Research WRF Version 2. NCAR Technical NoteCAR/TN-468+STR

- Wilby, R. L. and T. M. L. Wigley (1997), Downscaling general circulation model output: a review of methods and limitations, Progress in Physical Geography, 21, 530-548.
- Wilks, D. S., (1999), Multisite downscaling of daily precipitation with a stochastic weather generator, Climate Research, 11, 125-136.

14. Methodology

As per the discussion and information given by Ministry of Water Resources, the downscaled data for the considered River basins will be made available through another project. Based on this, the overall methodology to be adopted in the present study is given in Fig. 2. The methodology adopted for the present project has been considered into four parts:

Part A) Database Management - Data collection, Analysis and Database Development
B) Hydrologic Simulation - Modeling, Calibration and Validation
C) Climate Change Assessment o
D) Climate Change Impacts-Analysis and Adaptation

Based on above, a brief overview of all the works with their sub-themes and responsibilities to each participating Institutions are described below:

A) Data Base Management - Data Collections, Analysis and Database Development

A1. Data Collection and Compilation (IITB, NITK & CWRDM):

This part includes collection of hydrologic and meteorologic data (historical) of the river basin and compilation in proper format to make it usable for the participating institutes and different stakeholders in the basins. CWC and MoWR will facilitate collection of all data including hydrological data from IMD, discharge/flow data, LULC data, soil data, and project specific data. NITK will take lead to collect data for the Karnataka region and CWRDM will take lead to collect data from Kerala region. IIT Bombay will coordinate all efforts in data collection.

A2. Data Analysis (IITB, NITK & CWRDM):

This part includes analysis of patterns and trends of the historical data, data driven approaches to understand the geophysical processes associated with changing climate. All relevant baseline data, information and past studies available on the particular river basin will be collated in the project. For the Kerala region, CWRDM will take the lead and for Karnataka region, NITK will take the lead. IITB will collate all information.

A3. Development of Database (IITB, NITK & CWRDM):

From the collected and collated data, Database for the respective River basins will be developed, together by all participating Institutes. Some of the important database include: meteorological data, toposheets, landuse, landcover, hydro-geological data, Digital Elevation Model etc.

B) Hydrologic Simulation – Modeling, Calibration and Validation

B1. LULC change detection and projections (IITB, NITK, CWRDM):

This work will be done either grid wise/ river basin wise. Changes in the Land Use and Land Cover (LULC) have significant impacts on hydrologic scenarios. In the project, the changes in LULC will be assessed over the river basins and their impacts on hydrologic processes. Remote sensing images will be used for change detection. Future land use scenarios will be generated with geo-spatial techniques which will be further used for future hydrologic scenario generation. Efforts will also be made to quantify the impacts of LULC changes on micro-climate.

B2. Hydrologic Modeling with Variable Infiltration Capacity Model (VIC) (IITB):

Variable Infiltration Capacity (VIC) model (Liang et al., 1994; 1996), a grid based model will be used for hydrologic simulation. Depending upon availability of data, we plan to use the model at 0.5/0.25 degree spatial resolution and daily time step. Based on CWC/ MOWR observed stream flow data, the calibration and validation of the VIC model will be carried out at daily/ weekly/ monthly. After calibration, the model will be evaluated at various locations based on the availability of the observed stream flow. Further, this hydrologic modelling framework will be used for the development of hydrologic scenarios under the projected future climate. Hydrologic scenarios for the projected future climate for the River basins will be generated for the three periods: near term (2015-2039); midterm (2040-2069), long term (2070-2099). Based on this, changes in soil moisture, surface and sub-surface runoff, evapotranspiration, and streamflow will be assessed under the projected climate. Further attempt will be done to carry out drought and flood analyses.

B3. Hydrologic Modeling with Soil Water Assessment Tool (SWAT) (NIT K, CWRDM)

Further we will also use Soil Water Assessment Tool (SWAT) for hydrologic modeling, with the climate forcing for generation of hydrologic scenarios. The modeling will involve calibration for model parameters and the uncertainty. The SWAT simulated hydrologic variables will be used for impacts assessment.

C) Climate Change Impact Assessment *(IITB, NITK, and CWRDM):* Using the various scenarios generated based on the hydrological modeling mentioned above, impacts of climate change will be assed. The hydrologic scenarios will be developed for the three periods: near term (2015-2039); midterm (2040-2069), long term (2070-2099). For the projected climate change scenarios, changes in soil moisture, surface runoff, evapotranspiration, and stream flow etc will be assessed. We will also develop scenarios for the frequency and severity of hydrologic extremes (drought and floods).

D) Climate change Impacts - Analysis and Adaptation

D1. Uncertainty Modeling (IITB):

Assessing impacts of climate change on river basin hydrologic processes is characterized by uncertainty at different stages such as:

i) Uncertainty resulting from multiple GCMs
ii) Uncertainty resulting from multiple hydrologic models
iii) Uncertainty resulting from parameter variations of hydrologic models

Assessment of uncertainty will be carried out using appropriate models for all possible scenarios.

D2. Hydroclimatic Extremes and Risk Assessment (IITB, NITK & CWRDM):

An attempt will be made to analyze the changes in hydrologic extremes (droughts and floods). For the drought analysis, we will consider meteorological, hydrological, and agricultural droughts using the standardized precipitation index (SPI) The drought analysis will be mainly done for the monsoon season (JJAS). For the flood analysis, the results obtained from VIC/SWAT will be analyzed.

D3. Water Demand Availability Analysis (IITB, NITK, CWRDM):

For the River basins considered, the future hydrologic scenario will provide the water availability information. The water demand information will be derived from projected demographic information. Detailed water demand availability analysis will provide information for storage requirements and sustainable water management policies.