Proposal for a Research Project

Impact Assessment of Climate Change on Hydro-meteorological processes and Water Resources of Mahanadi River Basin

Prepared for

Ministry of Water Resources (MoWR)

by

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4. **Brief bio data of the Investigators**
   One page bio-data of PI and Co-PIs are attached at the end of the proposal.

5. **Project Title:**
   Impact Assessment of Climate Change on Hydro-meteorological processes and Water Resources of Mahanadi River Basin

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

a) Schemes completed

Project Title	Sponsoring Agency/Client	Duration	Co-Investigators (if any)
Stochastic River Basin Simulation in Climate Change Scenarios	Dept. of Science and Technology (DST), India	April 2004 -April 2006	-
Water Resources Assessment and Management in Malaprabha Reservoir System of the Krishna River basin	International Water Management Institute (IWMI), Colombo through their Hyderabad office	June 2005- June 2006	D. Nagesh Kumar
Future Projections of Precipitation and Temperature for Different Climate Change Scenarios at Sites in Beas River Basin on Daily Time Scale	National Institute of Hydrology, India	October 2011- May 2012	D. Nagesh Kumar

b) Schemes foreclosed with reasons for foreclosure: NIL

c) Schemes ongoing

Project Title	Sponsoring Agency/Client	Duration	Co-Investigators (if any)
Modelling Hydrology of Mahanadi River Basin Considering Changes in Land-Use/Land-Cover	Ministry of Earth Sciences (MoES)	August 2011 -August 2014	Ravi S Nanjundiah

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

   Registrar, Indian Institute of Science, Bangalore

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 Programme
f) Infrastructure Development
g) Creation of Centres of Excellence

9. Description of the Proposal

Recently, there is increase in evidence of impact of climate change on hydro-meteorological processes and water resources in various parts of the world. In this backdrop, Ministry of Water Resources has formulated National Water Mission (NWM) to meet challenges associated with impacts of climate change on water resources of India. The first and the foremost objective of this mission is to conduct basin-wise studies particularly for downscaling plausible future climate scenarios to basin/sub-basin scale and generating the corresponding probable hydrological scenarios to assess stress on water resources in the study areas. Several national institutes have been identified for the intended studies on basins across the country. In this regard, IISc has been identified as the lead institute to conduct study on Mahanadi basin, and IIT Bhubaneswar has been identified as supporting Institute for the activity.

The proposed study is motivated to model hydrological processes in Mahanadi river basin and assess impact of climate change on water resources of the basin. Understanding implications of projected climate change on the vulnerable resources would be useful to devise better strategies for management and conservation of water resources in the basin for coping with projected future droughts, and for assessing risk associated with water resources infrastructure to cope with projected plausible future floods in the river basin.

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

The goal of this study is to model hydrological processes in Mahanadi river basin and assess impact of climate change on water resources of the basin at basin/sub-basin scale.

a) Finding answers to as yet un-answered questions. (List the questions)

(i) Are there any trends in climatic and hydrologic data sets (including extreme rainfall, floods, and droughts) for Mahanadi basin? What can the trends (if evident) be attributed to?

(ii) What are historical relationships between the components of hydrological cycle (i.e., water balance components) in the Mahanadi basin? What are likely changes in those relationships for future climate change scenarios?

(iii) What is the historical scenario of meteorological and hydrological extremes (including extreme rainfall, floods, and droughts) in Mahanadi basin?

(iv) How to effectively arrive at future projections of meteorological and hydrological variables and their extremes in ungauged basins? What are likely impacts of climate change on those extremes?

(v) What are likely scenarios for water availability at critical locations (hot spots) in the basin under climate change?

(vi) What are likely changes in irrigation water demand under climate change?

(vii) Which operating policies could be recommended for the Hirakud reservoir (a major reservoir in the basin) corresponding to the current and climate change scenarios?

(viii) Is there any trend in the annual sediment yield of the Mahanadi river and reservoir capacity of the Hirakud dam?

(ix) What are historical relationships between the suspended and bed sediment transport and the discharge in the Mahanadi river? What are likely changes in those relationships for future climate change scenarios?

(x) What are likely impacts of future plausible sediment load on reservoir capacity of Hirakud dam?

(xi) What measures/options could be recommended to mitigate adverse impacts of climate changes in Mahanadi basin?

11. Contribution to Water Resources Development

The expected outcomes and deliverables of the project contribute to water resources development of the Mahanadi basin. The deliverables include,

(i) Future projections of various components of hydrological cycle (i.e., water balance components) in sub-basins of Mahanadi basin and impacts on water availability at critical gauged as well as ungauged locations (hot spots) in the basin. The knowledge would be useful to devise better strategies for management and conservation of water resources in the sub-basins;

(ii) Future projections of irrigation water demands at Hirakud reservoir for various climate change scenarios, and the corresponding operating policies at Hirakud dam. The results would be useful to agencies focusing on water resources development and management of Hirakud dam .

(iii) Future projections of extreme rainfall, floods, meteorological and hydrological droughts. The knowledge would be useful to devise mitigation strategies to cope with projected future droughts, and for assessing risk associated with water resources infrastructure to cope with projected plausible future floods in the river basin.

(iv) Future projections of sediment load in Mahanadi basin and implications of the same on Hirakud reservoir capacity. The knowledge would be useful to devise strategies to minimize sediment load in the river.

12. Putting the Research to Use

a) Identify the possible end-users for the results of proposed research.
The possible end-users of expected outcomes of the proposed project include central and state government agencies. Those with central government include agencies associated with Ministry of Water Resources (MoWR) such as Central Water Commission (CWC), Central Ground Water Board (CGWB), Central Water and Power Research Station (CWPRS), National Water Development Agency (NWDA), Natural Resource Management Division (NRMD) of Indian Council of Agricultural Research, Climate Change Division of Ministry of Environment and Forests (MoEF), and Department of Land Resources (DoLR) of Ministry of Rural Development. Those associated with state governments include Department of Water Resources of Government of Orissa, and Water Resources Department of Government of Chattisgarh.

b) List the actions that will be necessary to put the results to use.
Capacity building programs could be planned through the co-ordination of Central Water Commission, wherein knowledge gained through the project can be shared with policy makers and engineers associated with the aforementioned end-user agencies to facilitate use of the deliverables.

c) List the difficulties/problems that may be encountered in putting the results to use.
Investigators do not foresee any difficulties/problems in putting the results to use

d) Are the possible end users being involved in the research? if yes then describe how, if not then explain why not.
The possible end users are not directly involved in the research, as they do not have a mandate for research. However, the results will be communicated to the end users.

13. Present State of Art

a) Describe the work that has already been done at International level
The work done at the International level is reviewed under three subheadings:
(i) Literature review on modelling hydrological processes in river basins, and

(ii) Literature review on modelling sediment yield in river basins.
(iii) Literature review on impact assessment of climate change on streamflows

Literature Review on Modelling Hydrological processes in River Basins

The hydrological processes in a river basin, which depict translation of rainfall to streamflow that finally leaves the basin, are many and complex. Modelling the processes is necessary to address a wide spectrum of environmental and water related issues. Challenge in modelling the processes stems from the fact that they vary in both space and time. Rainfall-runoff models are widely used to model the hydrological processes.

There are several rainfall-runoff models currently in use by hydrologists (Singh and Woolhiser, 2002; Singh et al., 2006; Jain et al., 2009). These models have found wide applications in water-supply forecasting, optimal design and/or operation of water storage and drainage networks, groundwater development and protection, planning and design of flood protection projects, and evaluation of floodplain management strategies and water quality issues (Singh and Woolhiser, 2002; Wagener et al., 2008). An inventory of state-of-the-art models can be found at web site of Texas A and M University, United States <http://hydrologicmodels.tamu.edu/models.htm>. The rainfall-runoff models can be classified in terms of the processes represented, the time and space scales used, and the methods of solution to equations (Jain et al., 2009). The main features for distinguishing approaches to rainfall-runoff modeling are: (i) the nature of basic algorithms (empirical, conceptual or process-based), (ii) assumptions concerning nature of the process (e.g., deterministic, stochastic, chaotic), and (iii) spatial representation (lumped, distributed). Extensive review of literature indicates that the MIKE, HEC-HMS and SWAT models have been popular (Jain et al., 2009). **In the proposed study it is envisaged to quantify various components of the land-phase of hydrological/water cycle in the Mahanadi river basin by modeling hydrology of the basin using SWAT, HEC-HMS and/or VIC models**.

Literature Review on Modelling Sediment Yield in River Basins

In the climate change scenario, change in the modes of suspended and bed sediment transport in rivers and streams are to be expected, owing to changes in precipitation and consequent streamflows. The likely increase in sediment load can result in major problems for water resources infrastructure, through reservoir sedimentation and siltation of water diversion and irrigation schemes. Consequently, the efficiency of flood control and irrigation schemes gets affected. In the scenario of increasing population and an associated increase in demand for water for domestic, industrial and agricultural use, as well as for hydropower generation, loss of storage (due to sedimentation) would enhance stress on water resources. This problem needs to be addressed to devise plans for sustainable water resource development in a region. However, there are no meaningful studies in this direction.

Markus and Demissie (2006) studied the way to predict the annual sediment load based on the data collected during the floods. Garbrecht (2011) investigated the impact of climate variations and soil conservation on sedimentation of the Oklahoma reservoir. Suspended sediment rating curves are developed to estimate the average annual watershed sediment yield. Wren et al. (2000) applied various field techniques for the measurement of suspended sediment transport. Yang et al. (1996) modified power formula for the estimation of the sediment load of the Yellow river. Nakato (1990) tested different sediment transport formulae. Significant deviations were observed with the measured data except a few cases. Guo and Wood (1995) derived a simple analytic expression for calculating the fine suspended sediment transport rates, which compared with the field measurements favourably.

(iii) Literature review on impact assessment of climate change on streamflows

The methods that are available for projecting future streamflows under climate change scenarios can be broadly classified into four categories, 1-4. In methods of category 1, GCM simulated streamflows for the present and future climate scenarios are considered as true streamflow projections (e.g., Arora and Boer, 2001). In methods of category 2, hydrological models are driven by GCM simulated meteorological variables such as precipitation and temperature, either directly or after modification for bias, to determine streamflows (e.g., Toth et al., 2006; Maurer, 2007). The GCMs of the current generation produce large errors in simulating dynamics of subgrid-scale processes such as precipitation and streamflows, owing to inadequate and simplistic representation of the hydrologic cycle within the models. Therefore, the methods of categories 1 and 2 are deemed ineffective in arriving at streamflow projections at watershed scale.

In methods of category 3, hydrological models are driven by hypothetical/synthetic, analogue or downscaled scenarios of meteorological variables to determine future projections of streamflow in target watershed (e.g., Akthar et al., 2008; Fujihara et al., 2008; Li et al., 2008). In methods of category 4, large scale atmospheric variables (LSAV) simulated by GCM are directly downscaled to streamflow at river basin scale for the present and future climate scenarios using methods such as nonlinear regression and artificial neural networks. These methods do not take into account dynamics of regional hydrological processes and the mechanisms governing streamflow generation in a watershed. Hence their use may lead to unrealistic simulation of streamflows (e.g., Diaz-Nieto and Wilby, 2005).

b) Describe the work that has already been done at National Level

The work done at the National level is reviewed under two sub-headings:

(i) Literature review on modelling hydrological processes in river basins, and

(ii) Literature review on impact assessment of climate change.

Literature review on modelling hydrological processes in river basins

Previous studies in India have estimated surface water potential in various river basins and country as a whole (e.g., Khosla, 1949; National commission on agriculture, 1976; NCIWRD, 1999) by estimating streamflows. Jain et al. (2009) and Gupta (2008) provide a brief review of relevant literature. While the past studies have served useful purposes, they were based on water balance analysis only and did not use any hydrological model. Moreover, the data considered for those studies were sparse and the variables included mainly precipitation and streamflow, though several other variables are deemed important in modeling hydrology of a river basin. Further quality of data, particularly discharge data, was doubtful in many cases. More importantly computation details on the past studies are unavailable to independently verify those (Jain et al., 2009). Most data used were at-site data and limited or no spatial information was used. In this perspective there is a need to update estimates on streamflows and quantify other components of hydrological cycle in river basins of the country by developing hydrological models. This is presently feasible due to technological and theoretical developments in hydrological sciences, and incorporation of the theoretical knowledge on hydrological processes in software that are readily available.

Literature review on impact assessment of climate change

Both statistical and dynamical downscaling approaches have been considered in India to study the impact of climate change on the hydrology and water resources. Of these, studies that considered dynamical downscaling are very few. Further majority of studies were focused to assess impact of climate change on rainfall.

Impact assessment based on statistical downscaling

Ghosh and Mujumdar (2008) have proposed the use of relevance vector machine (RVM) for statistical downscaling, and demonstrated effectiveness of the method over standard support vector machine (S-SVM) by downscaling Japanese (CCSR/NIES) GCM simulations for B2 scenario to monthly monsoon streamflows at Hirakud dam in Mahanadi basin. Flow data during 1961-1990 were considered for developing the downscaling model. Predictors were chosen as 2 m surface air temperature, MSLP, 500 hPa geopotential height and surface specific humidity. The RVM model projected decrease in future monsoon streamflows and was not able to mimic the extreme streamflows observed in the record (p.143, Ghosh and Mujumdar, 2008). To downscale streamflows, statistical relationship was developed directly between streamflows and GCM simulated climatic variables. As stated in the previous sub-section (a), this method does not take into account dynamics of hydrological processes in sub-basins and hence may lead to unrealistic simulation of streamflows.

Mujumdar and Ghosh (2008) modelled GCM and scenario based uncertainty on downscaled streamflows using a possibilistic approach. Its applicability was demonstrated by downscaling simulations of three GCMs (CCSR/NIES; HadCM3;

CGCM2) for A2 and B2 scenarios to streamflows in Mahanadi River at Hirakud dam. The set of predictors considered was same as that used by Ghosh and Mujumdar (2008). Possibilities were assigned to all the GCMs with scenarios based on their performance in modeling the observed streamflows for the period 1991–2005. They were then used as weights to compute the possibilistic mean of the CDFs projected for three standard time slices 2020s, 2050s, and 2080s. The result indicated reduction in probability of occurrence of extreme high flow events in future. To downscale streamflows, statistical relationship was developed directly between streamflows and GCM simulated climatic variables. Hence the downscaling analysis has similar shortcomings as those for Ghosh and Mujumdar (2008).

Mujumdar (2008) presented an overview of the current water resources scenario in India, and a selected (very brief) review of literature pertaining to India on assessment of the climate change impact on hydrology and water resources.

Anandhi (2008) downscaled CGCM3 simulations to daily values of maximum and minimum temperatures, precipitation, solar radiation, relative humidity, and wind speed in Malaprabha river basin within Karnataka State using least square support vector machine (LS-SVM). The downscaled values were input to SWAT hydrological model to arrive at daily streamflow projections in the study area. Precipitation, maximum and minimum temperature, relative humidity, cloud cover and streamflows were projected to increase in future for A1B, A2 and B1 scenarios, whereas no trend was discerned with the COMMIT scenario. The projected increase in predictands was found to be high for A2 scenario and least for B1 scenario. The wind speed was not projected to change in future for any of the scenarios. The solar radiation was projected to decrease in future for A1B, A2 and B1 scenarios, whereas no trend was discerned with the COMMIT scenario.

A very few attempts were made to establish empirical relationships between sediment yield and discharge in rivers (e.g., NIH, 1998). But there is dearth of efforts to assess impact of climate change on sediment yield and consequent loss in reservoir capacity.

Impact assessment based on dynamical downscaling

There are no India specific developed dynamic downscaling models, as developing such models is perceived as a highly cumbersome exercise. Currently efforts are being made at various Institutes across the country to adapt models developed elsewhere to model climatic condition of the country. Perhaps the first attempt to assess impact of climate change on water resources by directly using weather variables simulated by dynamical downscaling model developed elsewhere was done as part of National Communication (NATCOM) project study by Gosain et al. (2003).

Gosain et al. (2006) and Gosain and Rao (2007) used Hadley Centre Regional Model 2 (HadRM2) generated daily weather data for the control/present (1981-2000) and the GHG (Green House Gas)/future (2041-2060) scenarios as an input to SWAT hydrological model to assess impact of climate change on water resources in twelve major river basins of India (Brahmani, Cauvery, Ganga, Godavari, Krishna, Luni, Mahanadi, Mahi, Narmada, Pennar, Sabarmati, Tapi). Gosain et al. (2006) presented results for Krishna and Mahanadi river basins at sub-basin level, whereas Gosain and Rao (2007) showed the same for Godavari and Tapi river basins. The studies indicated non-uniformity in impacts of climate change across India and overall reduction in the quantity of runoff under GHG scenario. It was inferred that some river basins could experience severe droughts, while some could experience increase in intensity of floods. Luni with the west-flowing rivers Kutch and Saurastra which occupies about one fourth of the area of Gujarat and 60 per cent of the area of Rajasthan were projected to face acute water scarce conditions. River basins of Mahi, Pennar, Sabarmati and Tapi were projected to face water shortage conditions. Cauvery, Ganga, Narmada and Krishna basins were projected to experience seasonal or regular water-stressed conditions. Godavari, Brahmani and Mahanadi river basins were predicted to face severe flood conditions, but no water shortages.

c) Explain how the work proposed to be done by you will be different form the work already done by others at National and International levels.

Literature review revealed that earlier studies did not address the following for the Mahanadi river basin.

(i) Detection of trends in climatic and hydrologic data sets (including extreme rainfall, floods, and droughts) and identification of causal factors.
(ii) Assessment of relationships between various components of hydrological cycle (i.e., water balance components) for the current and future climate change scenarios.
(iii) Implications of climate change on meteorological and hydrological extremes (including extreme rainfall, floods, and droughts) in both gauged and ungauged subbasins.
(iv) Assessment of impact of climate change on sediment yield and storage capacity of Hirakud reservoir.
(v) Assessment of uncertainty in impacts of climate change on streamflows associated with the use of different hydrological models.

In the proposed work, investigations would be done to detect presence of trends in climatic and hydrologic data sets (including extreme rainfall, floods, and droughts) collated for various parts of Mahanadi basin, and to identify the possible cause(s) of trends (if evident).

Appropriate hydrological models such as SWAT (Soil and Water Assessment Tool), HEC-HMS and/or Variable Infiltration Capacity (VIC) will be considered to arrive at estimates of water balance components in the river basin. Further, future projections of water balance components (including surface and ground water) corresponding to various climate change scenarios would be obtained at basin/sub-basin scale by integrating projections of hydro-meteorological variables obtained using downscaling models by other team(s) [at IITB/IITD] with the hydrological models developed in the present study.

Future projections obtained for rainfall and streamflows in the river basin would be analysed to determine implications of climate change on meteorological and hydrological extremes in the basin. It is necessary to arrive at reliable predictions of probable hydrological scenarios and hydrological extremes even in ungauged sub-basins of the study area. To aid in this task an attempt would be made to develop new regionalization methodology. This follows strategies devised in earlier investigations of PI for basins in United States (Rao and Srinivas, 2006 a,b; Srinivas et al., 2008, Rao and Srinivas, 2008) and in India (Satyanarayana and Srinivas, 2008, 2011).

Furthermore, an attempt would be made to predict the suspended and bed load sediment transport in the Mahanadi river under the current and future climate change scenarios. Trend in the annual sediment yield and consequent variation in the reservoir capacity of the Hirakud dam would be assessed for the scenarios.

d) List the references examined by you to reply to a), b) and c) above

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14. Methodology

Mahanadi river has catchment area of about 1,41,134 km^2 that lies in Chhattisgarh (75136 km^2), Orissa (65628 km^2), Maharashtra (238 km^2) and Jharkhand (132 km^2) states (Figure 1). The river originates in Chhattisgarh and traverses a length of about 357 km before entering Orissa state, where it further traverses about 494 km before it confluences with Bay of Bengal. Its tributaries include Ib, Jeera, Ong, Tel, Brutang, Manjore, Karandijore, Hariharjore, and Surubalijore (Source: Department of Water Resources, Government of Orissa).

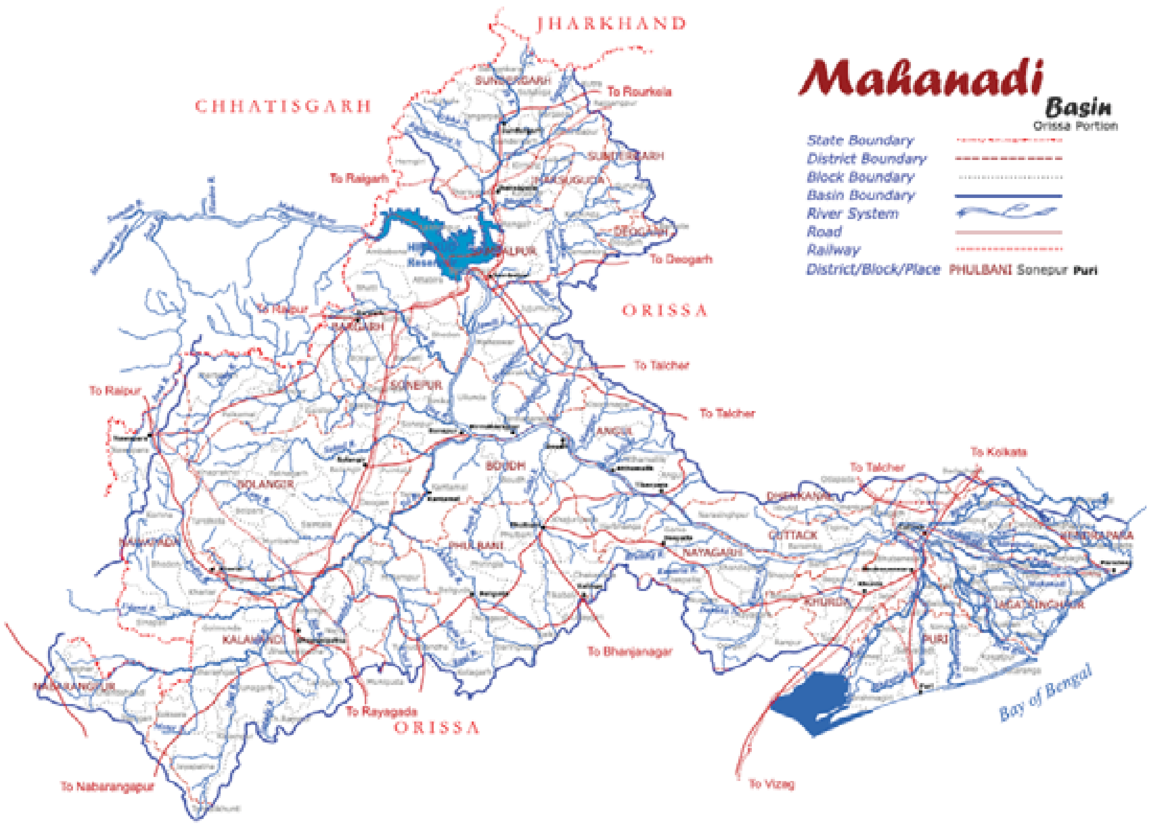

Figure 1: Mahanadi basin (Source: Department of Water Resources, Government of Orissa)

The sediment yield of the Mahanadi catchment is around 200-400 tonnes/km. The catchment area receives significant part its rainfall (about 70%) during the monsoon season. The Hirakud Dam, with a gross storage capacity of 7189 MCM, catchment area of 83,400 km^2 and command area of 2639 km2 is the largest dam constructed across the Mahanadi River.

In this project, IISc Bangalore (Lead Institute) and IIT Bhubaneswar (Partner Institute) propose to study impact of climate change on hydrological processes (including exteremes) and sediment yield in the Mahanadi river basin. The modelling activities in this project are listed below. Among these activities, (i) to (ix) would be undertaken by Investigators at IISc, and activities (x) to (xiii) would be performed by Investigator at IIT Bhubaneswar. Activity (xiv) would be done together by all the investigators.

(i) Trend analysis of the observed meteorological and hydrologic data and exploration of possible causes for trend (if evident).

(ii) Modelling hydrological processes in Mahanadi basin utilizing historical data for baseline period.

(iii) Establishing relationships between components of hydrological cycle (i.e., water balance components) in the basin for the current (historical) scenario using baseline data..

(iv) Identification of hydro-meteorological extremes (including extreme rainfall, floods, and droughts) based on the base line data, and developing equations to estimate their magnitude corresponding to various frequencies at gauged and ungauged target locations (hot spots) in the river basin.

(v) Assessment of changes in relationships between the components of hydrological cycle (i.e., water balance components) in the river basin for future climate change scenarios using downscaled projections on meteorological variables.

(vi) Assessment of impact of climate change on water availability at critical gauged as well as ungauged locations (hot spots) in the basin in terms of change in flow duration curves.

(vii) Assessment of changes in irrigation water demands corresponding to various climate change scenarios.

(viii) Development of operating policies for the Hirakud reservoir corresponding to the current and climate change scenarios.

(ix) Assessment of impact of climate change on magnitude and frequency of meteorological and hydrological extremes in the basin at the identified hot spots.

(x) Trend analysis of the observed sediment data.

(xi) Establishing a relationship between the suspended and bed sediment transport and the discharge in the river utilizing the past data.

(xii) Assessment of trend in the annual sediment yield of the Mahanadi river for future climate change scenarios.

(xiii) Assessment of trend in the variation of the reservoir capacity of the Hirakud dam for the current and future scenarios.

(xiv) Assessment of uncertainties in the impacts associated with the use of various GCMs, climate change scenarios and hydrological models.

(xv) Framing recommendations for adaptation measures/options to mitigate adverse impacts of climate changes in Mahanadi basin.

Data collection

Relevant data for addressing the objectives would be collated by all the investigators.

- Historical/observed data of meteorological and hydrological variables would be procured from various sources and through field survey (wherever necessary). The variables include rainfall, temperature, streamflows, flow velocities, groundwater levels, evaporation/evapotranspiration, wind speed, humidity, soils, soil moisture, and sediment transport.
- Satellite derived landuse/landcover (LULC) information (in raw form) would be collated from NRSC and other sources. The LULC information is necessary for at least four distinct years during the period 1979-2010 to investigate changes in LULC patterns.
- DEM (Digital Elevation Model) would be collated from web resources.
- Digital soil maps and relevant documents of Chhattisgarh, Orissa, Maharashtra and Jharkhand states would be procured from All India Soil & Land Use Survey (AISLUS) or Nagpur regional remote sensing centre. Soil maps would be digitized wherever necessary.
- Data on groundwater levels and soil parameters would be collated from Groundwater Boards.
- Information on water releases at major projects in the river basin would be collected from government organizations.

Proposed Analysis

- Compilation and base line analysis of data on meteorological and hydrological variables would be done.
- Information on water releases at major projects in the river basin (if available) would be used for naturalization of observed streamflows.
- Trend analysis of the observed meteorological, hydrological and sediment data would be done using parametric/non-parametric tests to detect presence of non-stationarities (if any) in the data sets. An attempt would be made to attribute the trends to appropriate causal factor(s).
- Stream network and watersheds of Mahanadi river basin would be delineated in GIS framework using DEM (Digital Elevation Model) and toposheets. Information on various parameters of watersheds in the river basin would be extracted.
- Hydrological models such as SWAT (Soil and Water Assessment Tool), HEC-HMS and/or Variable Infiltration Capacity (VIC) would be considered to arrive at daily estimates of components of hydrological cycle (i.e., water balance components) in the Mahanadi basin for baseline (historical) period. Among these models, SWAT is being widely used internationally for water resources assessment due to its effectiveness in modelling the hydrological processes, landuse and management practices. The model(s) developed would be calibrated and validated following standard procedures.

  LULC information is necessary for use in hydrologic models. ERDAS and IDRISI software would be used for processing LISS - III (23.5 m) (IRS1C/1D/P6) imageries to be procured from NRSC, Hyderabad, for extracting LULC information and investigating changes in LULC patterns. The inferences would be useful to provide meaningful LULC data for hydrological models.

- Mahanadi basin is often affected by floods. In several instances data are unavailable or limited at target locations. Equations to estimate the hydrological extremes corresponding to various frequencies at gauged and ungauged target locations (hot spots) in the river basin would be developed using baseline data by state-of-the-art regionalization techniques. This follows strategies devised in earlier investigations of PI for basins in United States (Rao and Srinivas, 2006 a,b; Srinivas et al., 2008, Rao and Srinivas, 2008) and in India (Satyanarayana and Srinivas, 2008, 2011).
- Future projections of water balance components (including Evapotranspiration, surface and ground water) corresponding to various climate change scenarios would be obtained at basin/sub-basin scale by inputting projections of hydro-meteorological variables (obtained using downscaling models by other team(s) [at IITB/IITD) in the developed hydrological models at daily time scale.

- Impact of climate change on water availability at various gauging sites and critical locations (hot spots) within the basin would be assessed in terms of change in flow duration curves. The curves would be developed using state-of-the-art regionalization techniques at ungauged stations identified as hot spots.

- Changes in irrigation water demands corresponding to various climate change scenarios would be estimated based on downscaled projections of climate variables [obtained from team(s) at IITB/IITD] which influence evapo-transpiration.

- Operating policies for the Hirakud reservoir corresponding to the current and projected future irrigation water demand scenarios would be developed.

- Future projections obtained for rainfall and streamflows in the river basin would be analysed to determine implications of climate change on meteorological and hydrological extremes in the basin in terms of changes in magnitude and frequencies of occurrence for near-future (2015-2040) and for distant future (2040-2100). Standardized precipitation index (SPI), which requires only precipitation as an input, would be used as an index to quantify severity of meteorological droughts. Characteristics of projected future flood hydrographs would be analysed in bi-variate domain for various climate change scenarios and the associated projections of Cumulative Distribution Functions (CDFs) will be compared with bi-variate CDFs based on historical (observed) data at various locations in the river basin to infer possible impacts of climate change on floods. The knowledge would be useful to arrive at mitigation strategies to alleviate adverse consequences of flooding.

- Sediment transport data at various locations in the Mahanadi river (collated on a daily or monthly basis) would be used for establishing a relationship between the suspended and bed sediment transport and the discharge in the river for the baseline period. Annual sediment yield of the Mahanadi river would be estimated using empirical approaches in vogue in literature. Information on future projections of streamflows obtained for various climate change scenarios would be utilized for predicting suspended and bed sediment transport. Also, the erosion rate and the deposition rate would be estimated for different locations in the Mahanadi river. Annual data would be utilized to calculate the annual reservoir capacity and all these past sediment and reservoir capacity data would be utilized to estimate loss in the reservoir capacity. Finally, after analyzing all these data, the implications of future projections of sediment load on Hirakud reservoir capacity would be assessed for various climate change scenarios.

- Climate change impact assessments on hydrological processes at the local scale (e.g., watershed/sub-basin) based on downscaling procedures are subject to large uncertainty. The uncertainty could arise due to differences in reanalysis data, GCMs, runs of a GCM, climate change scenarios, spatial domain considered for downscaling, grid interpolation procedures, predictor variables, downscaling strategies and hydrologic models. Even there are uncertainties associated with the assumption that the empirical relationships developed between predictors and predictand for the current state of climate remains valid in the future. Quantification of the consequent uncertainty on output of hydrological models is necessary to arrive at reliable estimates of water resources and deserves attention. In the proposed project, uncertainty associated with GCMs, climate change scenarios, and hydrologic models would be investigated.

- Recommendations for adaptation measures/options to mitigate adverse impacts of climate changes in Mahanadi basin would be framed.