

## **ASSESSMENT OF ANTICIPATED CLIMATE CHANGE IMPACT ON WATER RESOURCES IN KRISHNA BASIN**

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and  
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### **ABSTRACT**

*The Krishna, one of the longest rivers in southern India with a cultivable area, 77 per cent is experiencing steady changes in atmosphere with erratic rainfall, increased humidity and decreased temperatures. The prime objective is hydrological assessment of future monsoon and its uncertainties for sustainable crop production and irrigation water management practices in a changing climate. The impact of future climate change is assessed using calibrated and validated ArcSWAT modelling tool. The Basin on an average receives 800 mm rainfall in the monsoon period with least of 300mm in the south and a maximum of 2000mm in the west. The basin has surface water potential of 78.1 km<sup>3</sup> and groundwater potential of 26.41 km<sup>3</sup>. The hydrological assessment of the basin based on the IPRC model shows that by mid-century there would be increase in flash floods with prolonged dry spells. The assessment on spatial and temporal distribution of water availability, precipitation, PET and soil water suggests the need for eco-friendly adaptation technologies along with a planned irrigation development to capture in abundance and supply in the deficient period, when the demand is more and a need for efficient crop model to understand and assist the flooding situation.*

**Keywords:** Climate Change, Water Resources, SWAT Model, Krishna Basin.

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## Introduction

The threat of climate change, population, urbanisation and industrial growth on availability of quality water is slowly lurking into a major global problem of the world. The intensity of spatial and temporal variations of water availability is ever changing with climate change. The socio-economic growth of the rural community is dependent on crop production and rearing the livestock which is in turn dependent on water availability. Rice is one of the water-intensive crops and more than 75 per cent of the world's rice is produced in irrigated rice lands, which are predominantly found in Asia (Van der Hoek et al. 2001). Rice grown under traditional practices in the Asian tropics and sub-tropics requires between 700 and 1,500 mm of water for a cropping season depending on soil texture (Bhuiyan 1992). Water demand will grow from 656 km<sup>3</sup> in 2010 to 1069 km<sup>3</sup> by 2050 (Thatte et al. 2009). Hence, India has to gear up to the changing climatic conditions to maintain the production rates to feed the increasing population both at the State, national and global levels. Researchers are looking at the adaptations strategies that could help the farmers to improve the production and income in the context of changing climate and increasing water scarcity. As rice is a high water demanding crop, its production will be riskier in future due to increased frequency of extreme temperatures, droughts and floods. Understanding the fundamental relationship between natural variables namely, soil, climate, terrain parameters and crop management practices is required to cope with climate change for sustaining the

production of rice. This warrants employing a spatially distributed and physically based hydrologic model such as Soil and Water Assessment Tool (SWAT) model, which incorporates each of these interrelated functions. This report describes the hydrologic modelling of Krishna basin to assess the water availability and water demand under current and future climatic conditions. Considering the significant applications of SWAT model world-wide, in the present study, SWAT model was employed for accomplishing the prime objective of assessing the hydrological response to climate change in Krishna basin.

## Methodology

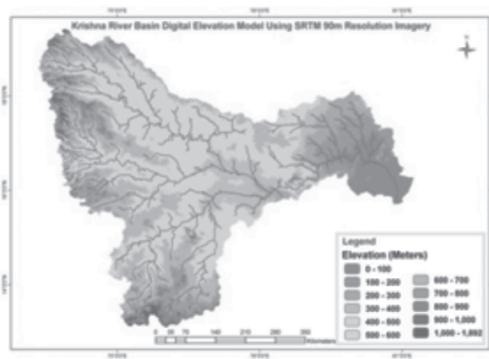
The Krishna basin is a water stressed basin, approaching a closing state, where discharge into the ocean has decreased rapidly from 1960 to 2005 due to irrigation expansion (Biggs et al. 2007). Despite lack of additional water supplies, development of both surface and groundwater continues, primarily for irrigation. Water extractions for agriculture, industrial and domestic uses continue to grow to support one of the fastest developing regions of peninsular India.

The Soil and Water Assessment Tool (SWAT) is a well-known basin-scale model, which is physically based, computationally efficient, and capable of continuous simulation over long time periods. The model simulates hydrologic cycle along with plant-root growth and land management such as irrigation. It is designed to predict the impact of climate and management on water flows, sediment loss, agricultural

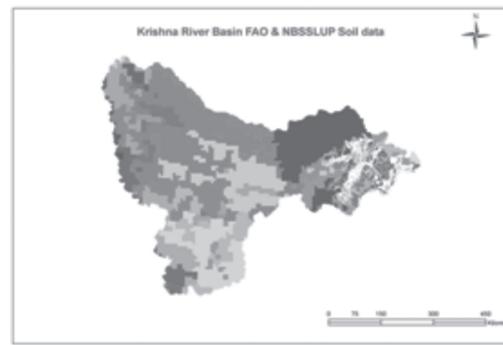
chemical yields and nutrient balances in complex basin (Arnold et al., 1998; Srinivasan et al., 1998). The major advantage of the model is that, unlike other conventional conceptual simulation models, it does not require much calibration. The model can be used for the assessment of existing and anticipated water uses and water shortages (Gosain et al., 2005).

### Input Datasets

The source of the digital elevation model (DEM) is the Shuttle Radar Topographic Mission (SRTM). The data has a resolution of 90m (Source: <http://srtm.csi.cgiar.org/>). The DEM data are the primary and essential input of the model; it provides the topographic information for delineating the stream flow and watershed (Figure 1).



**Figure 1: Digital Elevation Model**

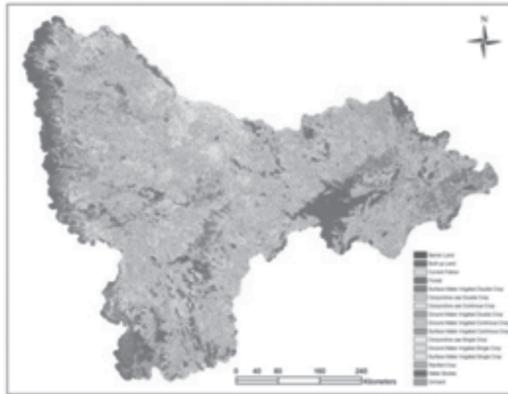


**Figure 2: Soil Map**

A soilmap of erstwhile Andhra Pradesh State at 1: 2,50,000 scales was collected from the National Bureau of Soil Survey and Land Use Planning (Reddy et al., 1996), Nagpur, India. The soil map has the attributes such as soil texture, depth, drain, nutrient, soils, AWC (Available water capacity), Landform and Erosion. A copy of Andhra Pradesh Soils-Profile Characteristics by Water Technology Centre (ANGRAU), was used to collect the soil characteristics wherever it was needed. Detailed soil data at 1:2,50,000 were prepared only for a portion of the Delta region.

For rest of the other portions of Krishna basin, the FAO soil data and the soil pedon data information from National Resources Conservation Service of United States Department of Agriculture were used (<http://ncsslabdatamart.sc.egov.usda.gov/>).

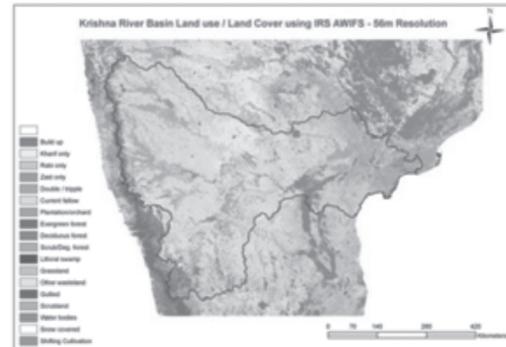
The Land use / land cover data are prepared by merging the IWMI Global Irrigated Area Mapping (GIAM) and *Bhoosampada*, land use / land cover map by National Remote Sensing Centre (NRSC), derived from Advanced Wide Field Sensor (AWiFS), 56m resolution data.



**Figure 3: LULC -GIAM**

IWMI GIAM, was developed by Thenkabail et al., 2009 using a continuous time series satellite imagery of various resolutions and different sensors such as MODIS 250m / MODIS 500m and Landsat ETM+ 30m whenever it is available. This data at 500 meter resolution, primarily indicate if an agricultural area is irrigation or rainfed. The irrigated area is also identified by its source such as surface water, groundwater or conjunctive use. However, information on the season during which a crop is grown is not present in this data.

The land use/land cover data from the National Remote Sensing Centre (NRSC) under the *Bhoosampada* initiative, were obtained for the year 2006-2007. This was developed by NRSC using multi-temporal Resources at-1 AWiFS data acquired during August- May of the year (kharif, rabi, and zaid seasons). This dataset is available at a spatial resolution of 56m., has a much higher spatial resolution and clearly indicates the areas with predominant cropping seasons.



**Figure 4: Soil Map**

### Climate Data and Scenarios

Climatic data is one of the important components that drive the hydrologic model. In this study, the climatic data needed for this study were processed by the Indo-pacific Research Centre (IPRC), Hawaii. Climate simulations made using the Global Circulation Model (GCM) GFDL (Geophysical Fluid Dynamics Laboratory), at a coarse resolution were spatially downscaled using the IPRC – Regional Circulation Model (RegCM) with lateral and boundary conditions taken from GFDL coupled model integrations. The daily meteorological parameters such as precipitation, maximum temperature, minimum temperature, wind speed, solar radiation and relative humidity for grid points with a grid space of 0.250 by 0.250 (~25km x 25km) spatially spread across the entire basin were obtained from IPRC Reg CM. Daily meteorological datasets at 25km resolution were developed for three scenarios:

1. Baseline – 1981-2000
2. Doubling of CO<sub>2</sub> by mid-century itself – Y1B (2031-2050)

3. Doubling of CO<sub>2</sub> by end-century – A1B (2081-2100)

In addition to this, daily observed gridded data of precipitation at 0.50 by 0.50 resolution and maximum and minimum temperature at 10 by 10 resolution obtained from the Indian Meteorological Department (IMD) were also used to verify the hydrologic model and to adjust the model bias in the precipitation data downscaled using IPRC RegCM.

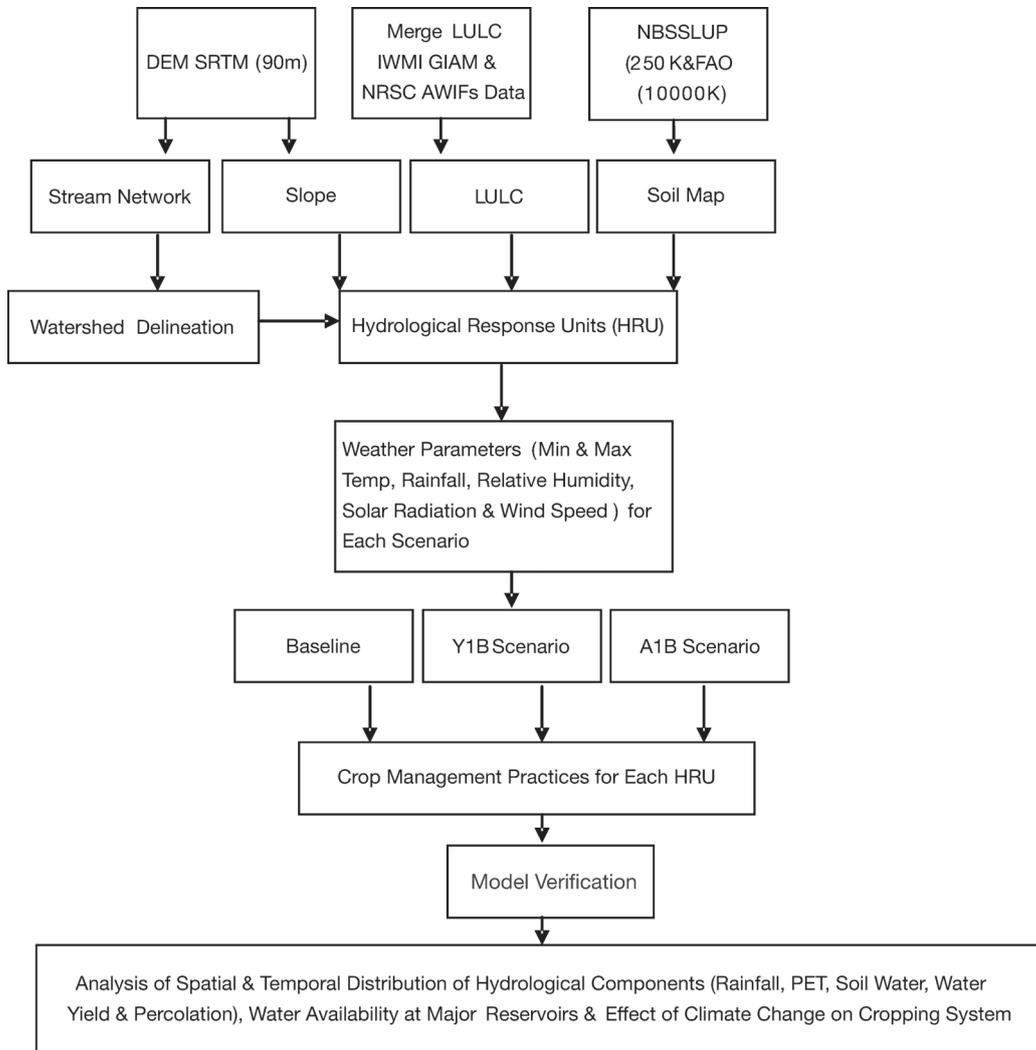
#### **Bias Adjustment of Precipitation Data**

Simulations made by any Regional Circulation Models are prone to systematic errors (Bias) due to uncertainty in the conceptualisation, as the model physics involved in the atmospheric circulation system are quite complicated (Teutschbein and Seibert, 2012). Further, the bias in the estimates could also arise due to the level of discretisation and spatial averaging of parameters within the grid cell. Bias in the estimates of rainfall estimates is quite common due to complexity of cloud physics and the trigger mechanisms for precipitation. Both under-estimation or over-estimation of rainfall would have implications in the amount of water available for irrigation, flood and drought assessment. Hence, bias adjustment of rainfall data is a prerequisite for hydrologic modelling.

#### **Hydrologic Modelling**

SWAT was used in this study to assess the effect of climate change on the water resources. SWAT considers spatial variability of soil, land use, climate and also captures human induced land and water management practices which is particularly important in a large river basin like Krishna. The GIS interface ArcSWAT 2009 (Version 93.7f) for ArcGIS9.3.1 was used in this study for preparing the spatial datasets needed to run SWAT model. Albers equal area projection was used for all the spatial data used in this project. The entire process followed is explained through a flow chart (Figure 5).

SWAT requires three basic files for delineating the HRU's: a Digital Elevation Model (DEM), a soil map, and a land use/land cover (LULC) map. For ease of modelling and handling the data over a large region, the Krishna basin was divided into three major watersheds. Each of these three major basins were further sub-divided into many sub-basins based on topography and each sub-basin into several hydrologic response units (HRU's) based on the unique combination of soil and land use. On the whole, the entire Krishna Basin was divided into 937 sub-basins and 11,901 HRU's.



**Figure 5: Flow Chart of the Hydrologic Modelling Methodology**

### SWAT Model Setup for Estimating Water Availability

For assessing the changes in water availability, strictly due to climate change alone, the river basin was assumed to be in virgin condition without any water storage or diversion structures. Further, the crops within the basin were also assumed to be grown under rainfed

conditions. This was done so because, if the operational aspect of the reservoirs and various diversions and extractions were to be simulated then i) more detailed information would be required and ii) it would be difficult to isolate the effect of climate signals alone on the hydrology of the basin and water availability. Since the objective of this study was to assess the impact

of climate change on water availability, model was executed by keeping all the SWAT input parameters constant except climate variables which were changed according to the period of simulation. The level of CO<sub>2</sub> maintained in the

model was 350ppm for Baseline, 550ppm for Y1B (Mid-century) and 650ppm for A1B (end-century), respectively. The effect of climate change on the water yield, evapotranspiration and soil water was assessed.



**Figure 6: Major Sub-divisions of Krishna River Basin**

### **SWAT Model Setup for Estimating Water Demand**

For assessing the water demand, it is very important that accurate information on the spatial extent of paddy cultivation, the season during which it is grown at a particular place and the length of the growing season, the cropping sequence/rotation and the irrigation source (surface or groundwater) are input in the model. For this, district-wise agricultural information on principal crops grown, cropping patterns, cropping sequence, sowing period, harvest

period and other general information about these crop management practices were collected from agriculture departments of respective State governments, the Bureau of Economics and Statistics, Government of India, Crop production information issued by Acharya N G Ranga Agricultural University and Central Research Institute for Dryland Agriculture ([http://www.crida.in/CP\\_2012/index.html](http://www.crida.in/CP_2012/index.html)). A detailed set of management practices were prepared for typical cropping systems and management operations like tillage, plantation, fertilisation,

irrigation and harvesting were provided as input to the model.

Based on the source of irrigation, the overall irrigation efficiency was assumed as 45 per cent and 55 per cent respectively for irrigation from surface water and groundwater source. The overall conveyance efficiency of the system was assumed as 70 per cent, indicative of long loamy earthen canals. These efficiency values were selected based on the FAO irrigation scheduling manual (Brouwer et al, 1989). As the crop growth could also be affected due to nutrient stress (lack of nutrients), which will have a cascading effect on the crop ET and irrigation water demand, the auto fertiliser option was triggered, so that the crops growth will not be impaired due to nutrients.

### Calibration and Validation

For assessing the performance of the hydrologic model, a model run was made using the IMD gridded rainfall and temperature data. The simulated average monthly stream flows by the model at four locations, Paleru Bridge, Madhira, Halia, and Keesara were compared with the observed average monthly stream flows measured by CWC and other State Government agencies in erstwhile Andhra Pradesh. Although observed stream flows were available for several gaging sites, these four locations were selected because the flow to these locations is not affected by any upstream storage and diversion structures. About 10 years of observed daily stream flow data were available for these four stations from 1988 to 2000.

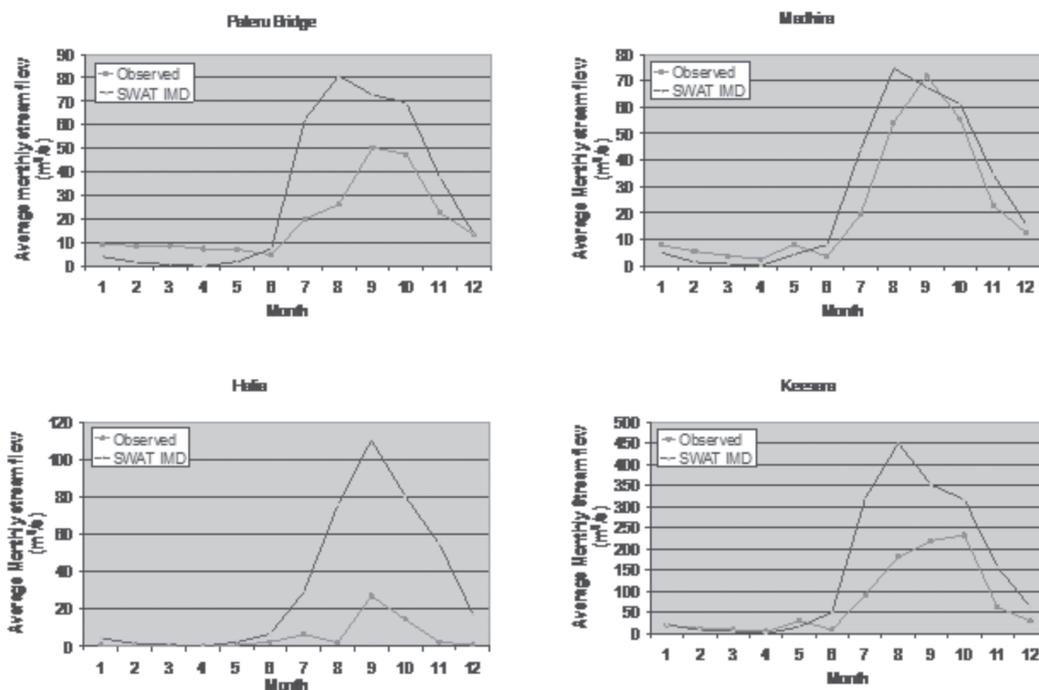


Figure 7: Observed and Simulated Average Monthly Stream Flow Hydrographs

For the next level of hydrologic model verification, the effect of bias correction of downscaled precipitation data on the hydrologic model simulations was studied. For assessing the effect of bias correction, the monthly stream flow hydrographs (Median, min and max) simulated using IMD gridded precipitation data were compared with the simulations made using raw (uncorrected) and bias corrected precipitation data for the baseline period (1981-2000). The comparisons were made at nine

critical control points distributed across the three sub-divisions of Krishna.

**Results and Discussion**

**Hydrological Response To Climate Change:**

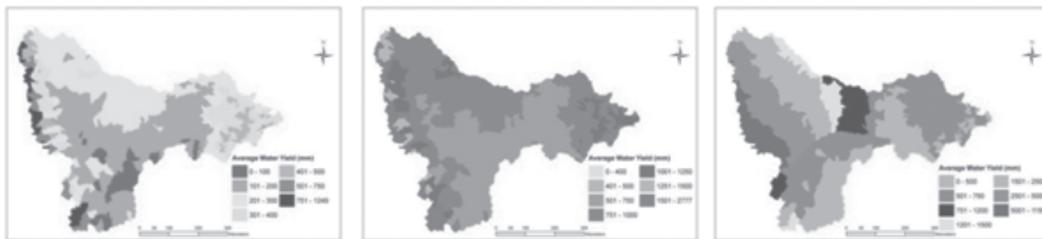
The spatial and temporal distribution of hydrological response to climate change in terms of potential evapotranspiration, soil water content and water yield is estimated and analysed for baseline scenario (current condition), Y1B scenario in mid-century and A1B scenario in end-century.

**Spatial Distribution of Average Annual Water Yield**

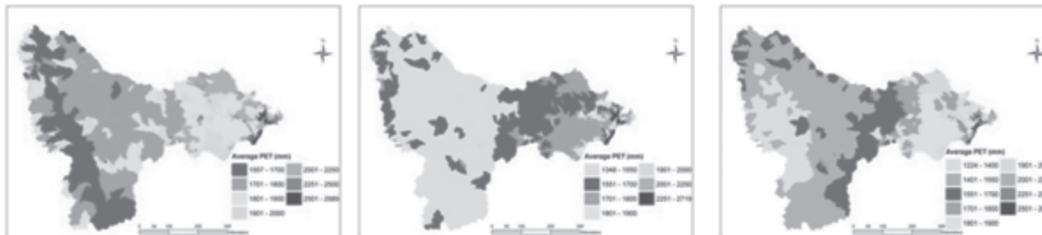
Baseline 1981 - 2000

Y1B Scenario 2021 - 2050

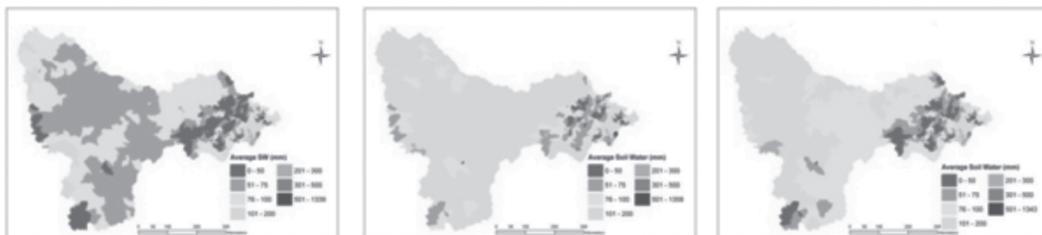
A1B Scenario 2081 - 2100



**Spatial Distribution of Average Annual PET**



**Spatial Distribution of Average Annual Soil Water**

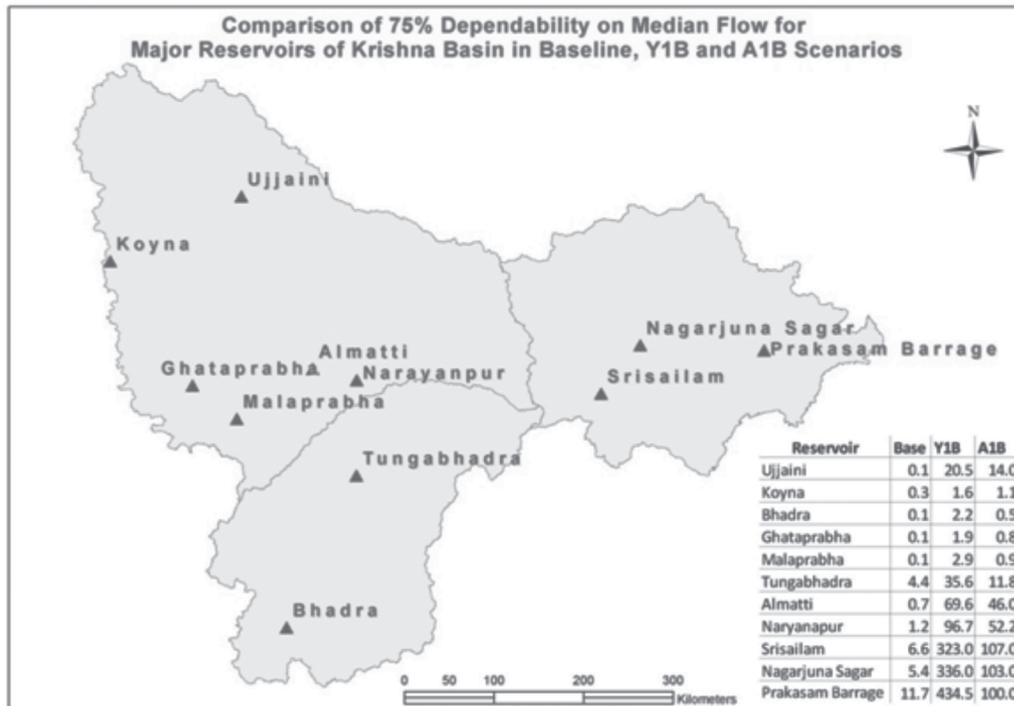


**Figure 8: Spatial Distribution of Parameters Simulated in Different Climate Scenarios**

### Water Availability at Major Reservoirs

The spatial and temporal distribution of water availability at some of the major reservoirs is studied for baseline, Y1B scenario mid-century

and A1B scenario end-century. The water availability was assessed in terms of average flow hydrographs and flow duration curves.



**Figure 9 : 75 Per Cent Dependable Natural Flows at Reservoirs Under Different Climate Scenarios**

### Water Demand

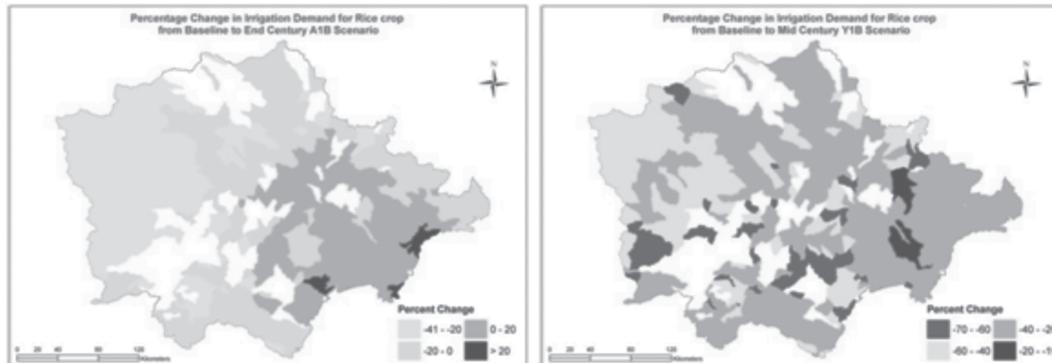
The potential irrigation water demand for paddy was simulated in SWAT by assuming that unlimited supply of water is available to meet the crop consumptive use requirements. The assumption made in this simulation run is that the extent of irrigated area remains the same in current and future climate. This simulation showed that the crop irrigation water demand is expected to reduce in the future. This reduction is due to increased rainfall

and reduced potential evapotranspiration.

Potential evapotranspiration is affected not only by the temperature but also by the CO<sub>2</sub> concentration. It is known that increase in CO<sub>2</sub> would increase plant productivity and decrease the stomatal conductance of the leaves for transpiration. The level of CO<sub>2</sub> maintained in the model was 350ppm for baseline, 550ppm for Y1B (mid-century) and 650ppm for A1B (end-century),

respectively. Although the temperature increase due to global warming would increase the soil evaporation, the increase in CO<sub>2</sub> reduced the

transpiration, thus effectively reducing the potential evapotranspiration and hence the irrigation water requirement in the future climate.



**Figure10: Reduction in Irrigation Water Demand Under A1B And Y1B Scenario**

### Conclusion

In this study, the effect of climate change on the water resources of Krishna river basin was assessed. Hydrographs and flow duration curves at the important discharge stations and reservoir locations were analysed. This information is quite useful for the irrigation engineers to make a decision of when to expect the water and when to release it and how much of it could be stored.

The climate change simulations show that there would be a considerable increase in total

rainfall in the future climate (A1B and Y1B scenarios), however, the number of rainy days may be lesser; thus increasing the probability of flood occurrence. The hydrologic model simulations with SWAT indicate that the flows at the major reservoir locations are expected to be much higher than in the baseline scenario. The flows at 75 per cent dependability level are also expected to be much higher than in the baseline. Due to reduced PET and increased rainfall, the future irrigation water demand is also expected to be lesser than the current level.

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