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Integration with Remote sensing and GIS Catchment Scale Hydrological Modeling in Middle Reach of Mahanadi River Basin using Simplified Coefficient Model

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Abstract: *The surface water and groundwater resources in India play a major role in agriculture, hydropower generation, livestock production, industrial activities, forestry, fisheries, navigation, recreational activities, etc. Potential impact of global climate change on water resources include enhanced evaporation due to warming, geographical changes in precipitation intensity, duration and frequency, together affecting the hydrological parameters such as, Runoff, Soil moisture, etc. Due to un– sufficient data available by the different agency Pilot scale calculation is too much difficult. The limited field data like rain fall, slope, land use , land cover pattern, inflow and out flow of river stream is very much difficulty to get it on river basin like Ganga, Godabari, Narmada , Mahanadi and other large river basin. This study emphasizes on quantifying Mahanadi river basin scale water wealth by transformation from presently adapted basin terminal gauge site runoff aggregation to meteorological based water budgeting exercise through hydrological modeling approach integration with remote sensing and GIS approach. Here all the data set is prepared by using Arc–GIS and AREDAS IMAGINE tool and the WEAP Simplified coefficient (rainfall runoff) model is prepared to calibrate and validate using field data and model data. The results of the study exhibit the potential of Integration of Remote–sensing GIS tool with WEAP hydrological model for water resource management and assessment of future resource development in the basin. The calibrated and validated model can be applied for runoff simulations in other basins with similar hydro–meteorological conditions.*

Keywords: *Water resources; Mahanadi river basin; Water demand; IWRM; rainfall–runoff.*

INTRODUCTION

The need for water is universal and without water, life, as we know it, will simply cease to exist. Water is the most precious and replenishable resource. So quantifying water in space to space is very much important to lead the water supply among all demand side. Earth's water is constantly in motion, passing from one state to another and from one location to another, which makes its rational planning and management a very complex and difficult task under the best of circumstances (Turner *et al.*, 2004). The availability and use of water is therefore mainly constrained by its spatial quantity and quality distribution. So, its development and management is of prime concern for any country or region.

With the fast growing economic scenario, change in life styles, industrialization, urbanization and for other requirements such as ecology, the competing demand for water has increased many fold. But it is a tiresome task to volumetric measurement of water resource by depending upon the field data or physical data collection method in a hefty area like river basin. So to hoard the proper knowledge of water quantity regarding the basin can feasible to persuade the different demand of the

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basin.

Orissa is one of the states endowed with ample surface and groundwater resources in its river systems, and the Mahanadi river basin contributes a large share of it. Water resources planning, once an exercise based primarily on engineering considerations, increasingly occurs as part of a complex, multi–disciplinary investigation that bring together a wide array of individuals and organizations with varied interests, technical expertise, and priorities. In this multi–disciplinary setting, successful planning requires effective IWRM models that can clarify the complex issues that can arise (Loucks, 1995). IWRM is viewed as a systematic process for the sustainable development, allocation and monitoring of water resources use in the context of social, economic and environmental objective. The decision problems regarding water resources such as water use and allocation, development, conservation, sustainability and sustenance of fragile ecosystems can be confusing and a DSS tool may bring about clarity.

So to overcome the multiple problem of water resources in the basin , the crucial and elementary work is to fabricate data which can exploit the proper knowledge of water resource regarding the river basin to lead the decipher of quandary like demand and supply.

WEAP21 introduces major advances including a modern Graphic User Interface (GUI), a robust solution algorithm to solve the water allocation problem, and the integration of hydrologic sub–modules that include a conceptual rainfall runoff, an alluvial groundwater model, and a stream water quality model (Rosenzweiga *et al.,* 2004). Water Allocation Models are being widely used in order to assess the impacts of future development trends, water management strategies, climate change, etc on the availability of water resources (Wurbs, 2005). WEAP21 model attempts to address the gap between water management and watershed hydrology and the requirements that an effective IWMR be useful, easy to–use, affordable, and readily available to the broad water resource community (Yates, 2005). This model was used in Ghana to simulate the impact of small reservoirs in the Upper Volta (Hagan, 2007). The model performed well. Arranz and McCartney (2007) have also applied the model to the Olifants catchment in South Africa. In their analysis, the model performed well in doing quick analysis of current and future water demands. Other investigators (Alfarra, 2004; Levite *et al.*, 2003), have applied the model to various catchments around the Globe with success. It is a priority driven software, that employs priority based optimization algorithm as an alternative to hierarchal rule based logic that uses a concept of Equity Group to allocate water in time of inefficient supply (Mounir *et.al.*, 2011).

In this study, Water Evaluation and Planning Version 21 model was applied for rainfall–runoff simulation in middle reach of Mahanadi river basin. The model is preferred to others because of its robustness and ease of use depending on data availability (Mugatsia, 2010). The model with integration with AREDAS and Arc GIS interface can perform both lumped to distributed catchment hydrological simulation. It can handle aggregated to disaggregated water management demands of various sectors.

STUDY AREA

The Mahanadi river basin is divided into three parts. Upper drainage basin of the Mahanadi which is centered on the Chhattisgarh Plain, middle reach which is started from Hirakud to Munduli and the delta region, the lower part of basin where floods may damage the crops. The study area to carry out present research work is middle reach region of Mahanadi river basin. The Mahanadi River flows to the Bay of Bengal in east–central India; it drains an area of 141,589 km^2 and has a length of 851 km. The average elevation of the drainage basin is 426 m with a maximum of 877 m and a minimum of 193 m. About 53% of the basin is in the state of Chhatisgarh, about 46% is in the coastal state of Orissa, and the remainder of the basin is in the states of Jharkhand and Maharashtra. Numerous dams, irrigation projects, and barrages are present in the Mahanadi River basin (Figure 1), the most prominent of which is Hirakud Dam. Approximately 65% of the basin is upstream from the dam. The average annual discharge is 1,895 m^3/s, with a maximum of 6,352 m^3/s during the summer monsoon. Minimum discharge is 759 m^3/s and occurs during the months October through June. Near the city of Cuttack and approximately 114 km from the Bay of Bengal, the Mahanadi River splits into at least six major distributaries and numerous smaller channels. Almost all of the distributaries are channeled in embankments designed to contain a discharge of about 25,500 m^3/s. The river passes through tropical zone and is subjected to cyclonic storms and seasonal rainfall. In the winter the mean daily minimum temperature varies from 4°C to 12°C. The month of May is the hottest month, in which the mean daily maximum temperature varies from 42°C to 45.5°C.

DATA PREPARATION AND METHODOLOGY

Total basin is divided with sixteen sub catchment depending upon the sixteen river reaches. Rainfall data and temperature data was obtained from the India Meteorological Department (IMD) Bhubaneswar, which is interpolated across the hole basin by Arc GIS. Satellite images of the study area were downloaded from the GLCF site (www.glcf.umd.edu) and ASTER DEM (30 m × 30 m) from Earth Remote Sensing Data Analysis Center (ERSDAC) site (www.gdem.aster.ersdac.or.jp). Stream network was delineated from downloaded DEM. The catchment was delineated into sixteen sub–catchments in ArcGIS 9.3 using DEM. There was a fair distribution of rainfall stations in the whole catchment. The daily data for all stations was obtained for the period of study from IMD Bhubaneswar. Runoff data for all six gauging stations were collected from Central Water Commission (CWC) Bhubaneswar. Soil map of study area was digitized to get different soil groups. Land use land cover map was prepared by supervised classification of downloaded satellite images in ERDAS 9.1. The maps are given below in Figure 1, 2, 3, 4, 5, 6, 7, 8. The crop co efficient (kc) values were used from previous studies carried out by Tyagi *et. al.*, (2000) and Mohan *et. al.*, (1994).

Different evapotranspiration methods were examined and it was calculated by DSS–ET software using Hargreave method. The effective precipitation was determined using Smith (1992) effective rainfall method (equation 1).

$$P_{eff} = P\frac{(125 - 0.2P)}{125} \text{ for } P \leq 250 \text{ mm/m}$$

$$P_{eff} = 125 + 0.1P \text{ for } P > 250 \text{ mm/m} \qquad (1)$$

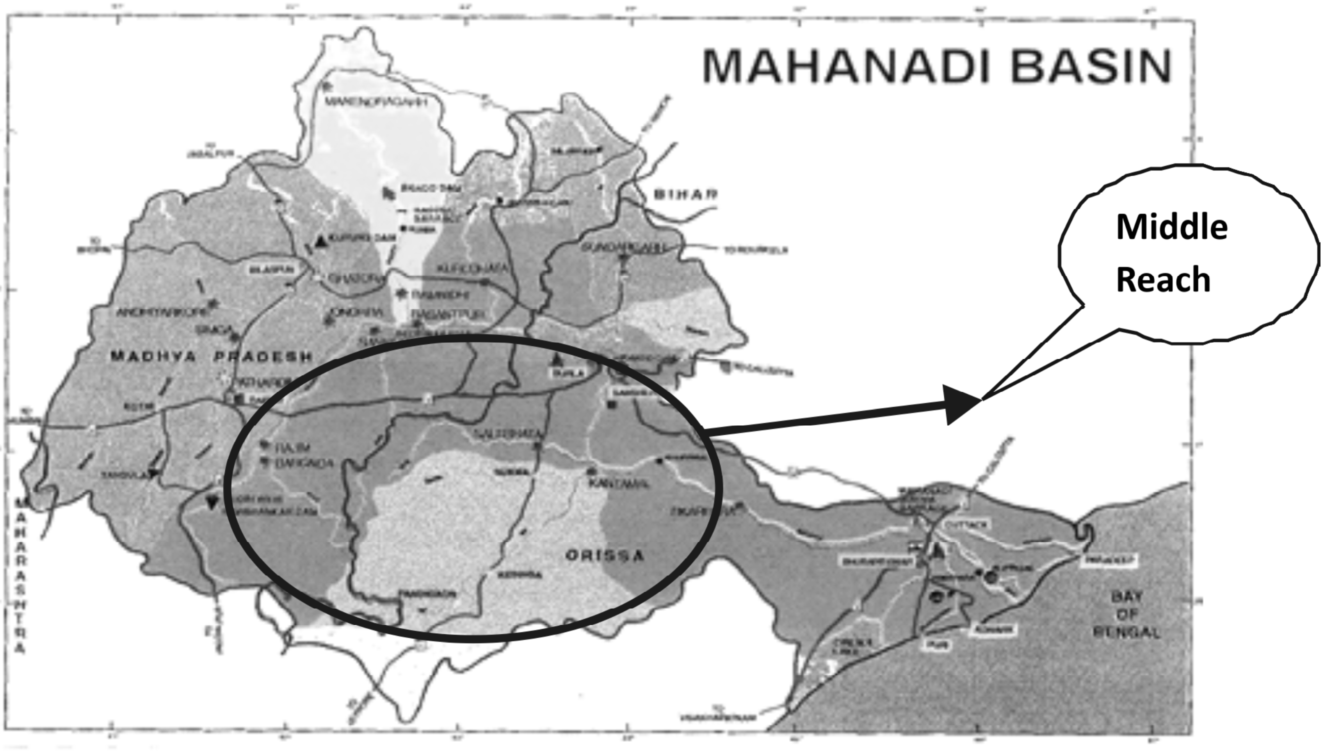


Figure 1: Mahanadi river basin

For this WEAP Rainfall run off model Crop requirements are calculated assuming a demand site with simplified hydrological and agro–hydrological processes such as precipitation, evapo–transpiration, and crop growth emphasizing irrigated and rainfall agriculture. Non–agricultural land classes can be included as well. For this WEAP Rainfall run off model Crop requirements are calculated assuming a demand site with simplified hydrological and agro–hydrological processes such as precipitation, evapotranspiration, and crop growth emphasizing irrigated and rainfall agriculture. Non–agricultural land classes can be included as well.

The following equations were used to implement this approach, in equation 2, 3, 4 and 5.

Precipitation available for

$$ET_{LC} = \text{Precip}_{HU} * \text{Area}_{LC} * 10^{-5} * \text{Precip Effective}_{LC} \qquad (2)$$

$$\text{ET potential}_{LC} = \text{ET reference}_{HU} * \text{Crop-coefficient}_{LC} * \text{Area}_{LC} * 10^{-5} \qquad (3)$$

$$\text{Runoff}_{LC} = \text{Max}\ (0, \text{Precipitation available for } ET_{LC} - \text{ET potential}_{LC}) + (\text{Precipitation}_{LC} * (1 - \text{Precipitation Effective}_{LC})) + (1 - \text{Irrigation Frac}_{LC,\ I}) * \text{Supply}_{LC,\ I} \qquad (4)$$

$$\text{Runoff to Surface Water}_{HU} = \Sigma_{LC}\ (\text{Runoff}_{LC} * (1 - \text{Runoff to GW Fraction}_{LC})) \qquad (5)$$

where subscripts are land cover = LC, hydro–unit =HU, time–step = TS, irrigated =I, and non–irrigated= NI

The first two equations are used to determine the additional amount of water (above the available precipitation) needed to supply the evapo–transpiration demand of the land cover (and total hydro unit) while taking into account irrigation efficiencies.

In the Rainfall Runoff method, runoff to both groundwater and surface water can be calculated with the equations 4&5.

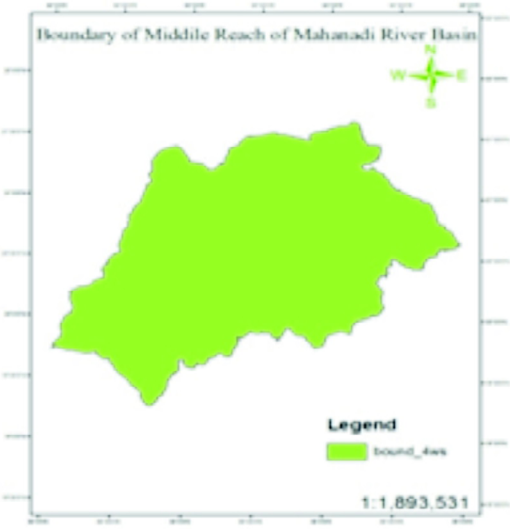
WEAP21 Model

The WEAP model was developed by the Stockholm Environment Institute (SEI) in 1988. The first major application of WEAP was in the Aral Sea region in 1989 with the sponsorship of the newly formed Stockholm Environment Institute (SEI). WEAP was conceived by Paul Raskin, President of Tellus Institute, and developed under his supervision until 2001. This new version of WEAP is called as WEAP21. WEAP21 operates on the basic principle of a water balance and can be applied to agricultural systems in a single watershed or complex transboundary river basin systems.

WEAP21 is a general multi-purpose, multi-reservoir simulation program which determines the optimal allocation of water for each time–step according to demand priorities and supply preference. It operates at a monthly time step on the basic principle of water balance accounting. The model can represent any water resource system incorporating natural inflows, precipitation, evaporation, and evapotranspiration as input data. Operational features that can be represented include storage and release of water by reservoirs, physical discharge controls at reservoirs outlets, water flow in channels, consumptive demands and hydropower releases. These operational features can be specified as steady-state or time-varying. In addition, WEAP21 allows users to develop their own set of variables and equations to further refine and adapt the analysis to local constraints and conditions with possible data exchange with other software such as excel (SEI, 2005).

In the current study, the primary objective was to test WEAP's ability to simulate the rainfall-runoff process of the basin. Therefore the Simplified Coefficient Model was selected for this study. The schematic of WEAP rainfall-runoff component is shown in Figure 9. Hydrological processes occurring in the catchment were modelled and stream flow, simulated on a monthly time-step, was compared to the measured flow series available six catchments. This was done because in this catchment, measured flow records from gauging stations are affected by human water abstractions and do not represent the flow originally from the rainfall-runoff process. The model was calibrated for year 2007 using two parameters at different steps *i.e.*, crop coefficient (Kc) and effective precipitation .

It was consider the initial value of Kc range was 0-1.59 with the step of ± 5 % where as effective precipitation initial value 100% with step of ± 1%.


Boundary of Middile Reach of Mahanadi River Basin
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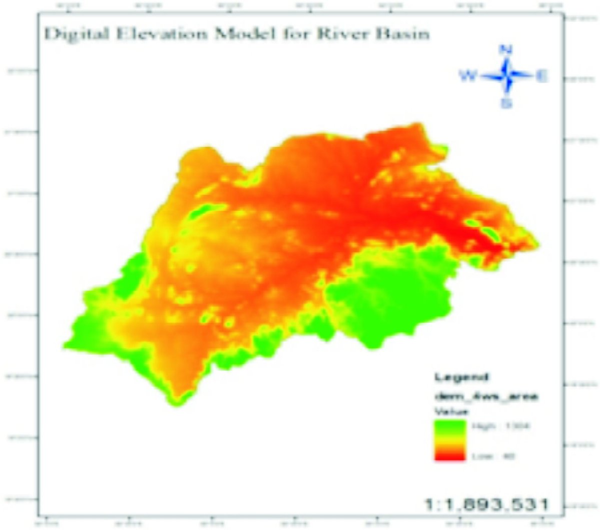
Digital Elevation Model for River Basin
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Low : 40
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Blocks Middile Reach of Mahanadi River Basin
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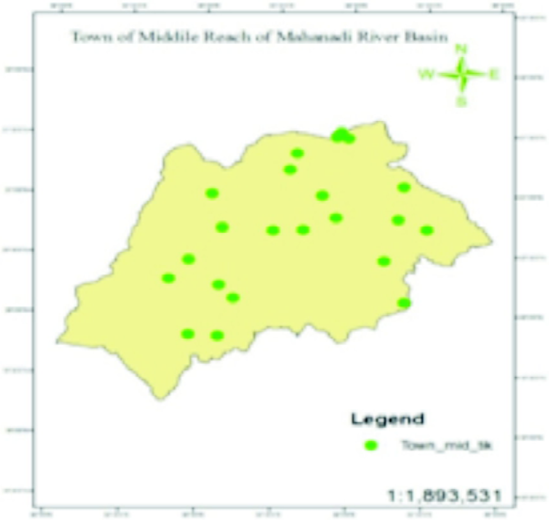
Town of Middile Reach of Mahanadi River Basin
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River Network of Middile Reach of Mahanadi River Basin
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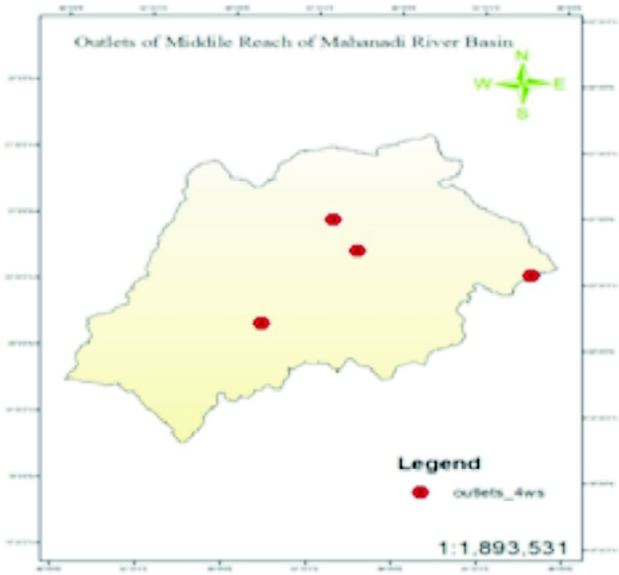
Outlets of Middile Reach of Mahanadi River Basin
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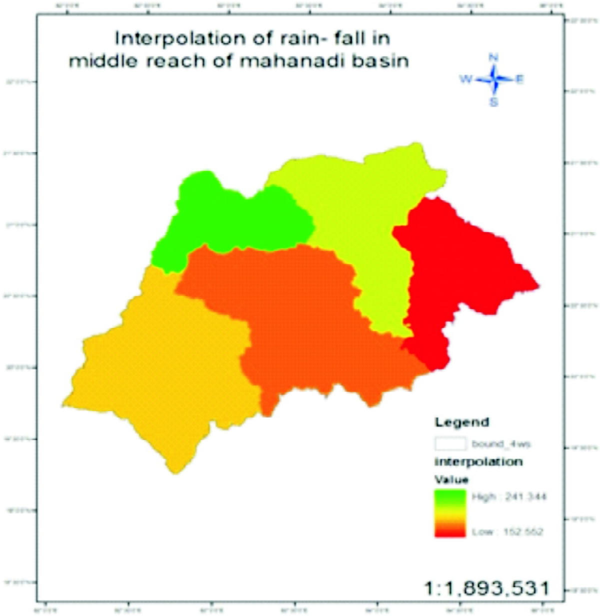
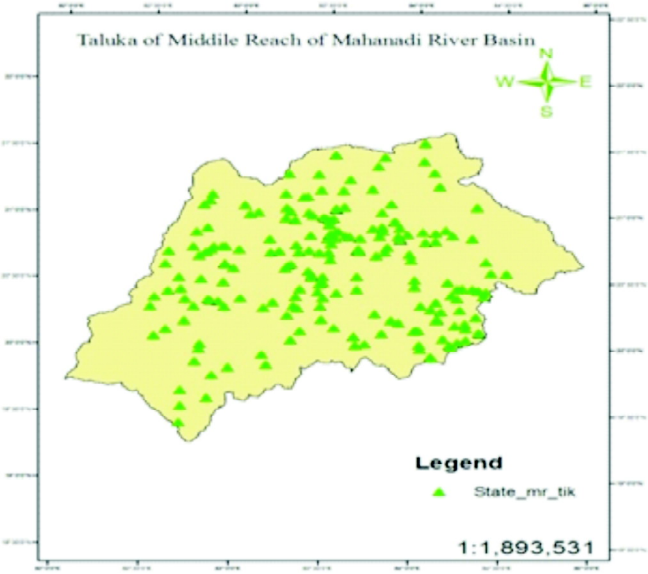




The 3 basic views of WEAP model are Schematic, Data and result view (Figure 9). Once the model is simulating the measured flow series satisfactorily, water demand sites can be added and WEAP can be run in its water allocation mode using the rainfall-runoff parameters determined from the first phase.

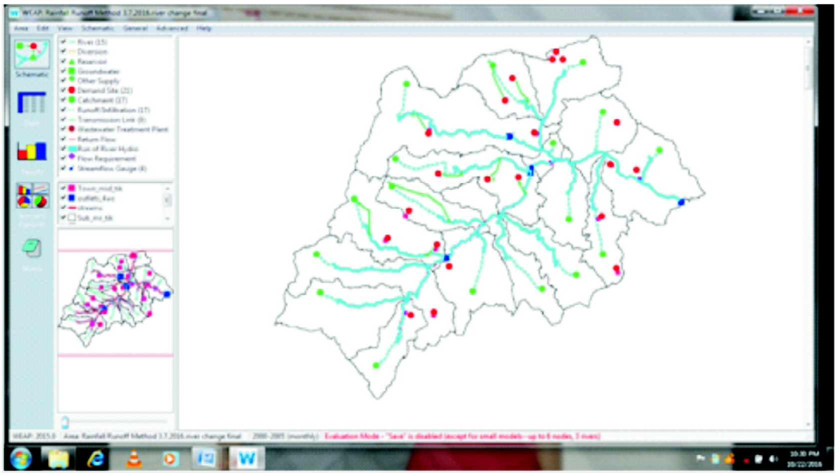
RESULTS AND DISCUSSION

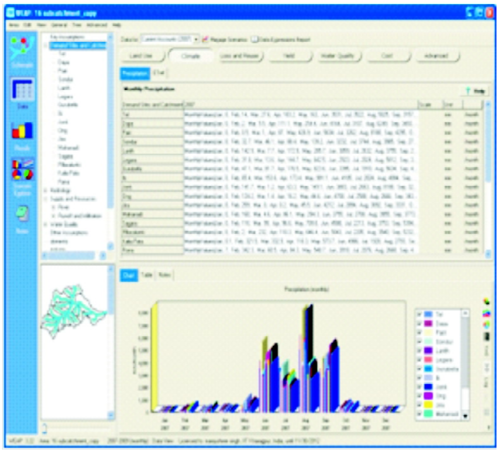
The rainfall runoff method was used to simulate river flows; this was constrained by the type of data available (Rainfall, Evaporation and crop data). The. Land use (Area, Kc, Effective precipitation) and Climate (precipitation and ETo) data are required to perform rainfall-runoff simulation.

Initially the WEAP model was run without calibration of parameters. There was huge variation in measured and simulated stream flow. At some points these values differs by almost twice.he WEAP model was calibrated using rainfall runoff component for year 2007. Calibration included changing the model parameters to better simulate historic patterns. WEAP has no automatic

Table 1
Results of parameter calibration

Parameter/ Catchment	*Kc*	*Effective precipitation*
Kesinga	5%	0.5%
Kantamal	–5%	0.5%
Salebhata	5%	–1%
Kheirmal	–1%	–0.5 %
Tikarapara	1%	1%
Mundali	–5%	1%





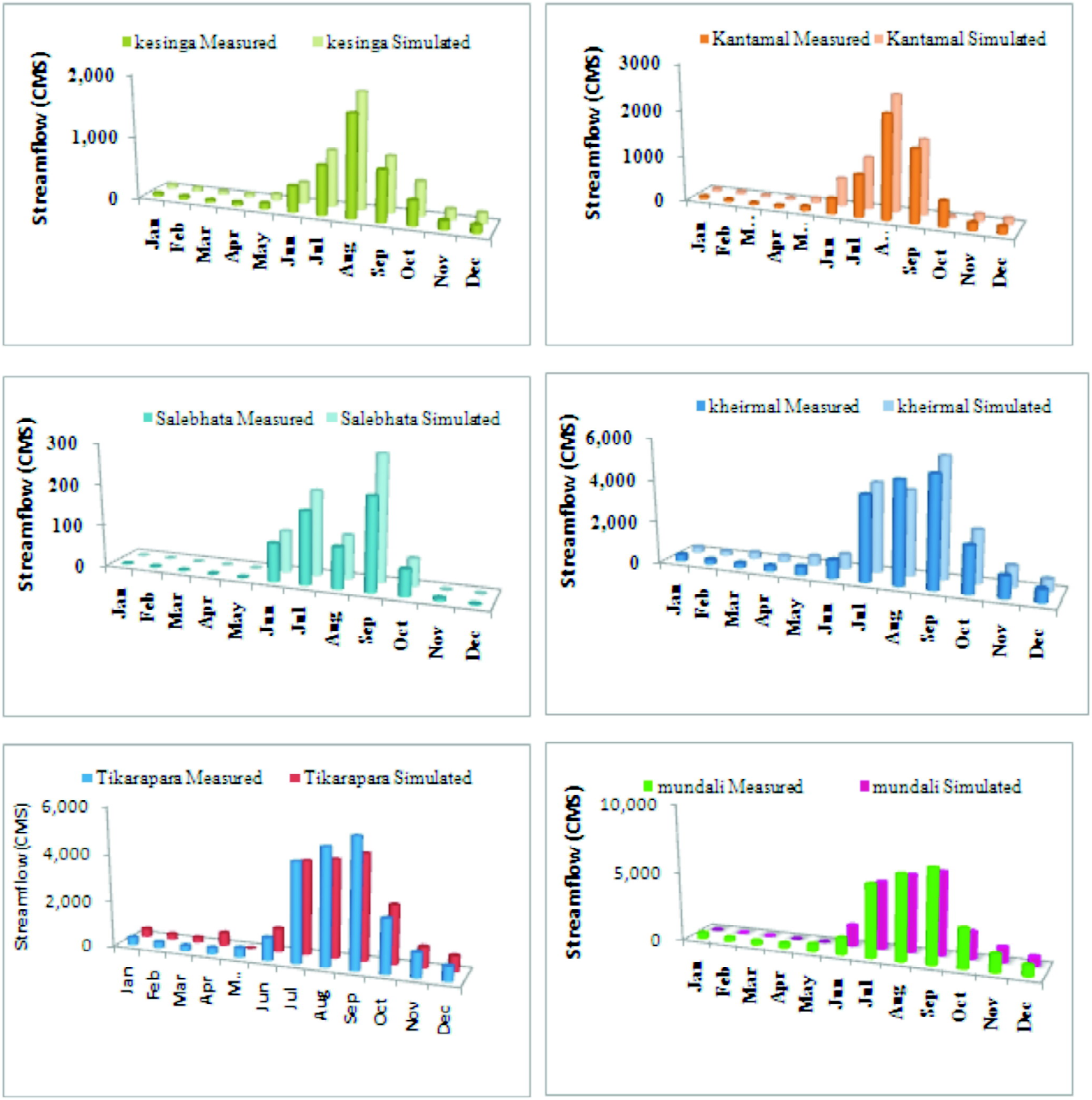


Figure 10: Simulated flows in different catchments after calibration of parameters

calibration routine; therefore the changes implemented were tested manually by comparing the simulated and observed time series. The results of parameter calibration are presented in Table 2. The calibrated parameters of each catchment were again used for simulation in WEAP model. These simulation results are presented in Figure 10.

After these simulations, the results were compared for the percent variation between measured and simulated values (Figure 8). It was found that most of the simulated values are falling in the range of 10% of measured stream flow. WEAP model was performing satisfactorily for simulation of runoff using rainfall and other required data for Mahanadi river basin using calibrated parameters. Therefore this calibrated model can also be applied to other river basins in India with similar hydro-meteorological conditions.

CONCLUSION

Modeling the hydrological processes and response of a 47,000 km² catchment is a complex task and the results of such a simulation have to be treated with caution. Data generation is a diffult task for this large basin. Errors are likely to be introduced from the structure of the model itself as well as from the sets of data that were used to run it. Instead of trying to model each hydrological component (*e.g.* evapotranspiration, runoff, infiltration) with accuracy, it was decided to use a system that relied on simplified equations and to run it at a much larger scale than it is usually done: the average sub catchment area in the study was approximately 3,000 km². There were two main reasons for adopting this approach: Firstly, because the aim of the study was to assess water resources in the whole catchment, it was not practical to set the model up using a finer spatial resolution. Secondly, most of the data required for the aquifer design are not available and it was easier to estimate them at a larger scale . So here Arc GIS data shows a good result for the model.

The work conducted the tested WEAP's ability to simulate the rainfall runoff process in the basin and assessed the impact of development on water resources. The study revealed that WEAP with interation with GIS tool was able to simulate well the measured flow time-series from six catchments. This constituted a good test of its ability to model the rainfall-runoff response of the catchment. There are very few studies that deal with water resource assessment and impact of development at the scale undertaken in the current study. However this seems to be a critical step as water management (especially with the establishment of Water Management Agencies) will have to be achieved at this scale. In that perspective, WEAP with integration with GIS could be a useful planning and management tool, not only in the Mahanadi basin or in India, but also in other areas.

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