

A Novel Approach for Sub-Basin Wise Water Resources Assessment

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ABSTRACT: The increase in industrialization, unplanned urbanization, and population growth leads to the decrease in available natural resources like Water. There are some other reasons of depletion of water resources like lack of appropriate technical knowledge, change in the pattern of agriculture and non-implementation of suitable technology at River Basin level. In recent years, inadequate supply of uncontaminated and fresh water has been observed due to high water demand and pollution. There is an urgent need for optimum utilization of water so that future generation could survive. In India irrigation is considered as the major consumer of water along with the water demand for urban and industrial processing gradually due to increasing economic growth and development activities. The aim of this paper is to evaluate the accessible water demand and water supply optimally for domestic (urban and rural), agriculture, industry and the environment for sustainable water management in Brahmani river basin, India. In this present work, a generic modified approach has been developed and has been fruitfully applied in Brahmani river basin and its eight sub-basins (Tilga, Jaraikela, Panposh, Gomlai, Rengali, Samal, Jenapur and Delta). Satellite data like NDVI (Normalized Difference Vegetation Index) has been used to obtain the Rabi and Kharif season agricultural practices. This generic modified approach has been successfully used to maximize the benefit and helped in understanding the variables involved in reducing the production cost and increasing the benefits. It is found that in the present condition, very less water is being utilized for different purposes and the concept of consumptive use is missing.

KEYWORDS: Agriculture, BAWRA, Brahmani river basin, NDVI, Water resources.

I. INTRODUCTION

Fresh water is naturally occurring water on earth surface. The clean potable water is used for drinking, cooking, cleaning, bathing, and watering our lawns. The importance of clean potable water, coupled with its scarcity due to pollution, overuse, and climate change has resulted in increased concerns about water quality as well as quantity. It is stated that 1.6 billion people live in areas experiencing economic water scarcity, where the lack of investment in water or insufficient human capacity makes it impossible for authorities to satisfy the demand for water [1]. It is, therefore, essential to assess the available water resources for integrated water resources planning, development and management [2]. Water availability and water resources management are key aspects of the environment and socio-economic systems [3]. The combinations of economic valuation techniques have the potential to provide a balanced perspective to the allocation and management of water resources [4]. Various optimization models linking basin wide hydrologic and economic systems have been applied to various locations such as the Adra River Basin system, Spain [5]; the Dong Nai River Basin, Vietnam [6]; and several river basins in California [7]. However, these models do not consider the deficiencies in water allocation and how the existing water supply might be integrated into the overall water supply system [8] at sub-basin and basin scale.

The present work describes the basic components and structure of a prototype model that is able to provide capability for determining rational and effective water management strategies at the river basin scale. This study focuses on one of the most important basins in Brahmani River Basin, Odisha, India [9], [10], [11], [12] which have been a primary agricultural center and now transforming in to industrial hub at various locations. It is a water surplus

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basin, but has water scarcity as well as water logging / flooding at different reaches. It is expected that the competition among water use sectors would increase in the next decades, as the river basin is lying in three different States and each States is enhancing their irrigation water requirement, industrial water requirement and urban water requirement. Further, the variability in precipitation may increase due to possible impact of climate change. Historically, the majority of the flow in the basin has been allocated to different purposes without prior potential analysis and the river flow at the outlet is significantly reduced, groundwater is not utilized and salinity increased.

II. THE STUDY AREA

Brahmani river basin is an inter-state river basin (Figure 1). River Brahmani is the second largest river (Mahanadi river is 1st) in the State of Odisha. River Sankh originating in Chattishgarh and river Koel originating in Jharkhand are the two major tributaries of River Brahmani. After their confluence at Vedvyas, Panposh in Odisha, the river is known as Brahmani. The river flows through the central part of Odisha, in between the Baitarani basin on the left and Mahanadi Basin on the right till it mingles in the deltaic plain and out falling into the Bay of Bengal at mouth of Dhamara. The left bank tributary known as South Koel river, which originates near village Nagri in Ranchi district of state Jharkhand at an elevation of nearly 700 m. above m.s.l, with a latitude of 23°20' N and longitude of 85°12' E. The River Koel drains from a total catchment of 13378 Km² up to Panposh, out of which 1438 Km² lies in Odisha and 11940 Km² in Jharkhand. The river Sankh, other main tributary of the Brahmani river, originate at an elevation of nearly -1000m near village Lupungpat in district Ranchi of state Jharkhand at Latitude of 23°14' and Longitude 84° 16'. The total length of the Sankh River is 205 Km. It drains from an area of 7353 Km². Out of which 900 Km² lies in Chhattisgarh, 3760 Km² in Jharkhand and 2893 Km² in Odisha. Brahmani basin spreads in the districts of Raigarh, Jashpur and Sarguja in state Chhattisgarh. Ranchi, Lohardega, Simdega, Gumla and West Singhbhum districts in state Jharkhand and Sundargarh, Sambalpur, Deogarh, Angul, Dhenkanal, Keonjhar, Jajpur and Kendrapara districts of state Odisha. The total drainage area of the river basin is 39116 Km². Of this, basin area inside Orissa is 22516.08 Km² which constitutes 57.36-% of the total basin area. The basin area inside Jharkhand and Chattishgarh are 15700 Km² and 900Km² respectively. Below the confluence, river Brahmani heads its way generally in southeast direction up to sea and travels a total length 461 km. This basin is located within the geographical co-ordinates of north latitude 20°28' to 23°35' and east longitude 83°52' to 87°03'.

The topography of the basin consists of ghat areas, northern plateau, central table land and the coastal plains. The upper regions of the basin are mostly hilly and forested. The lower region of the basin is deltaic plains. The elevation values ranges from minimum of 1m to maximum of 1176m above mean sea level. The average elevation is about 341m in the basin. Figure 2 show the digital elevation map, drainage, flow direction, aspect, land use land cover and slope map of Brahmani river basin, which is developed using STRM data (90m) freely available from the website. The land use statistics have been compiled using district level records collected from the co-basin States. It is found essential to obtain Normalised Difference Vegetation Index (NDVI) of the study area using satellite data for the years 2008, 2009, 2010 and 2014. The NDVI is obtained using the following equation:

$$NDVI = \frac{NIR - VR}{NIR + VR}$$

Here, NIR is the near infrared digital number value; VR is the visible range digital number value. The NDVI ranges between -1 to 1 and higher the values indicate more vegetation. Figure 3 indicates that a large part of the basin is agriculture area. However, deep green patches indicate dense forest and light green indicates shrubs. The light colour is indicator of agriculture land where harvesting has been done or is being done during the month of March. It has been observed that the basin is rich in forests which occupy about 38% of the area. Agriculture occupies about 55% of total basin area constituting the main source of rural livelihood and incomes. Rice is the main food crop grown in the basin. Other food crops grown are wheat, millets, pulses, groundnut, mustard, ragi, maize etc.

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A. DATA COLLECTION AND ANALYSIS

Rainfall, discharge, evapotranspiration, groundwater, population (urban and rural), irrigation (Kharif and Rabi) and industrial data were collected from different sources for the years 1990-2012 for each sub-basin of the study area and then analysed (Table1). Rainfall is a crucial component in hydrologic cycle. The climate of the entire Brahmani river basin is of tropical monsoon type with four distinct seasons viz, summer, winter, autumn and monsoon. The rainfall characteristic and temperature of the four physical regions of the basin differ from one region to another. The average annual rainfall in the basin is 1359.70 mm. To estimate the mean rainfall over the entire basin, the Thiessen polygon method was used. Ground water data are very important for water resources management and conjunctive use of surface water, groundwater, existing water bodies, canal water and rainfall. It has been observed that 1980.33 MCM ground water is available from the whole basin out of which only 552.15 MCM (27.88%) has been used on an average for different purposes with maximum utilization of 62% at Joda in Keonjhar district. It has been observed that the Surguja district shows highest ground water level depletion whereas Kendrapada district shows lowest ground water level depletion. Discharge data of Tilga, Jaraikele, Panposh, Gomlai, Rengali, Samal, and Jenapur are collected from different sources for the years 1970-2012. It has been observed that there is significant decrease in discharge (in cumec) of Jenapur as the flow obtained from Rengali Dam is being used by stakeholders for industries, agriculture and other domestic purposes. Irrigation development has been accelerated with the advent of Five Year Plans in Brahmani river basin. A number of medium and major projects including the Rengali multipurpose dam project were taken up. Irrigation is very important for food production due to the erratic and uneven time distribution of monsoon rainfall. During the months of March to May, the soil moisture deficit becomes rather large and shallow-rooted crops and vegetation cannot survive without irrigation.

Table 1: Sources of data collection

Sl. No.	Data Types	Sources
1	Rainfall	http://www.indiawaterportal.org/ http://www.imd.gov.in/
2	Discharge	http://www.cwc.nic.in/
3	Ground water level	http://cgwb.gov.in/
4	Meteorological data	http://www.indiawaterportal.org/
5	Population	http://censusindia.gov.in/
6	Digital elevation model(DEM)	http://srtm.csi.cgiar.org/
7	Daily TRMM Rainfall 3B42 (V7)	http://trmm.gsfc.nasa.gov/
8	Soil map & Land use land cover(2004-2011)	http://www.nrsc.gov.in/
9	Agriculture	http://www.cesorissa.org/
10	Industries water requirement	http://www.dowrorissa.gov.in/
11	Drainage/River Network(30 sec)	http://hydrosheds.cr.usgs.gov/
12	Land use land cover (2000)	http://landcover.usgs.gov/

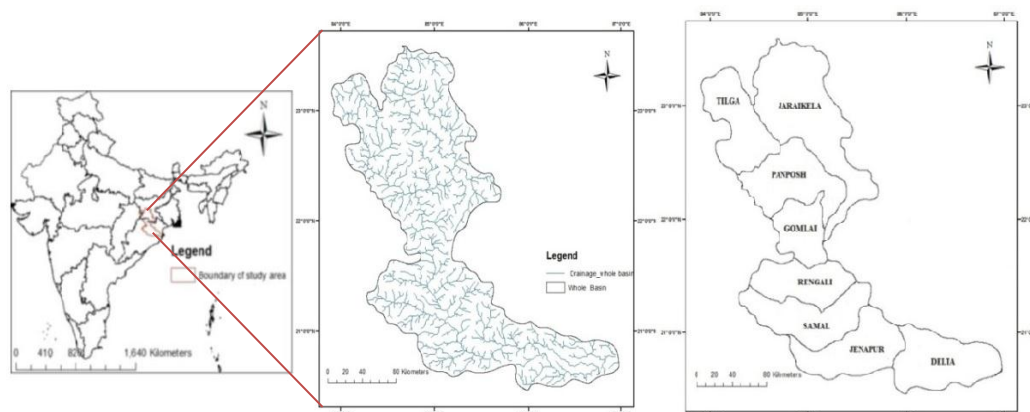


Figure 1: Location of Brahmani river Basin and its sub-basins

III. METHODOLOGY

The methodology has been evolved considering various existing methods with some modifications. Basin-wise Analytical Water Resources Assessment (BAWRA) model has been developed to provide an integrated computational framework for a basin and/ or sub-basin level assessment of water resources. The model considers the integral land phase of the hydrologic cycles. It is capable of representing anthropological impacts such as changes in land and water use, environmental flows, impacts of water storage and depletion through withdrawals for various water uses and addition through returns/ inter-basin water transfers. The secondary data collected from different government sources and research organizations in India have been used for the analysis.

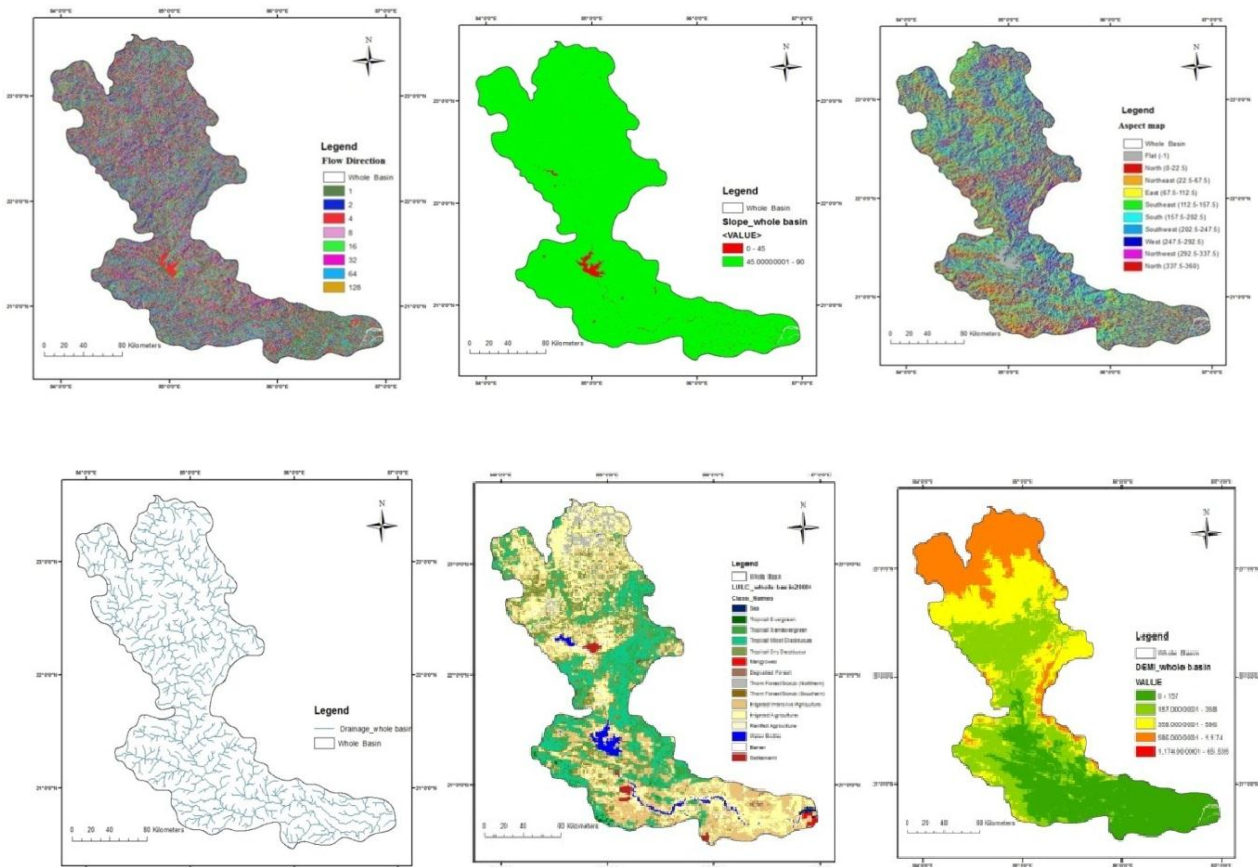


Figure 2: Maps of Brahmani river basin developed in Arc-GIS environment

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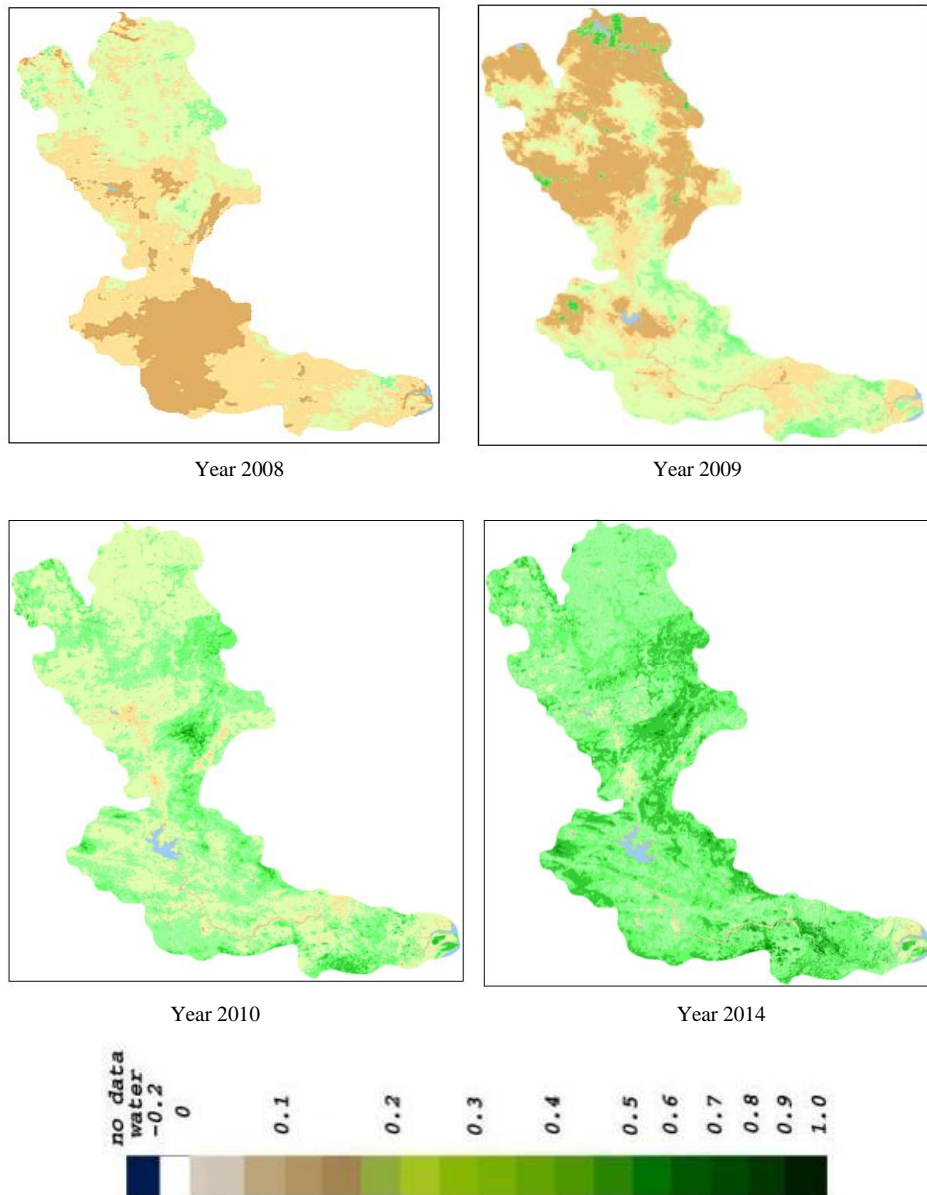


Figure 3: NDVI for the month of March of the years 2008, 2009, 2010 and year 2014

This section includes the approaches used to estimate and develop relationships among various demand and supply of water resources at basin and sub-basin scale. In general, the inflow (supply) and outflow (demand) relationship can be understood by a very simple equation:

$$\text{Inflow} - \text{Outflow} = \text{Supply} - \text{Demand} = \text{Storage} \quad (1)$$

Or

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$$\frac{\text{Inflow}}{\text{time}} - \frac{\text{Outflow}}{\text{time}} = \frac{\text{Supply}}{\text{time}} - \frac{\text{Demand}}{\text{time}} = \frac{\text{Storage}}{\text{time}} \quad (2)$$

For surface water and ground water balance analysis, the above relationships can be further elaborated by considering physical parameters and basin characteristics. The equation can be written as:

$$\sum_{t=1}^n [P_{basin} + Q_{in_us} + Q_{nps_ssf} + Q_{nps_irf} + Q_{ps_indf} + Q_{ps_munf} + Q_{ob} + Q_{gw}]_t - \sum_{t=1}^n [I_{abs} + I_{fil} + E_{tp} + D_{ir} + D_{ur} + D_{rr} + D_{id} + D_{soil}]_t = \sum_{t=1}^n (Q_{out_ds})_t + \frac{Q_s}{t} \quad (3)$$

Where

- P_{basin} = Rainfall of the basin in m^3 ;
- Q_{in_us} = Inflow discharge at upstream in m^3 ;
- Q_{nps_ssf} = Inflow discharge from sub-surface flow in m^3 ;
- Q_{nps_irf} = Inflow discharge as irrigation return flow in m^3 ;
- Q_{ps_indf} = Inflow discharge from Industries in m^3 ;
- Q_{ps_munf} = Inflow discharge from Municipality in m^3 ;
- Q_{ob} = Inflow discharge from other basins in m^3 ;
- Q_{gw} = Inflow discharge from groundwater in m^3 ;
- Q_s = Storage of discharge in reservoir in m^3 ;
- I_{abs} = Initial abstraction losses in m^3 ;
- I_{fil} = Infiltration losses in m^3 ;
- E_{tp} = Potential Evapo-transpiration losses in m^3 ;
- D_{ir} = Demand for irrigation in m^3 ;
- D_{ur} = Demand for population and livestock in urban area in m^3 ;
- D_{rr} = Demand for population and livestock in rural area in m^3 ;
- D_{id} = Demand for industries in m^3 ;
- D_{soil} = Demand for soil's field capacity in m^3 ;
- Q_{out_ds} = Outflow discharge at downstream in m^3 ;
- t = Time in days

B. MODEL FOR AGRICULTURAL SECTOR

i. Water availability for agriculture

The gross availability for agricultural sector is estimated using the following relationships:

For rain-fed based agriculture

$$WA_{agrf} = \int_{t=1}^n (P_{basin} + C_1 * Q_{gw} + Q_{nps_ssf} + Q_{nps_irf})_t \quad (4)$$

For irrigation based agriculture

$$WA_{agir} = \int_{t=1}^n (P_{basin} + C_2 Q_{in_us} + C_3 Q_{ob} + C_4 Q_{gw} + Q_s + Q_{nps_ssf} + Q_{nps_irf})_t \quad (5)$$

Where

- WA_{agrf} = Water supply required for rain-fed regions for agriculture in m^3
- WA_{agir} = Water supply required for irrigation regions for agriculture in m^3
- t = Time in days
- C_1, C_2, C_3 and C_4 = Coefficients for different variables.

ii. Water requirement for agriculture

It is to be noted that, for the supply of water in rain-fed or irrigation based agricultural areas, we need to estimate the crop water requirement for different crops at different time periods. Crop water requirement depends on several factors, including cropping pattern, crop-growth periods, crop coefficients (K_c), potential evapotranspiration (E_{tp}), effective rainfall and percolation in paddy areas. Crop water requirement (C_{wr}) of the paddy crop is estimated as [13]

$$WR_{paddy} = A_p * [\sum_{i=1}^m \{ \sum_{j=1}^n (K_{p(i,j)} * E_{tp(i,j)} - R_{e(i,j)}) - \sum_j P_{p(i,j)} \}] \quad (6)$$

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And the crop water requirement of other crops is estimated as:

$$WR_{other} = A_p * [\sum_{i=1}^m \{ \sum_{j=1}^n (K_{o(i,j)} * E_{to(i,j)}) - \sum_j P_{o(i,j)} \}] \quad (7)$$

Where

- WR_{paddy} = Crop water requirement for paddy in m^3 for i^{th} cell (plot area) and j^{th} time period (days)
- WR_{other} = Crop water requirement for other crops in m^3 for i^{th} cell (plot area) and j^{th} time period (days)
- $K_{p(i,j)}$ = Crop coefficient for paddy for i^{th} cell (plot area) and j^{th} time period (days)
- $K_{o(i,j)}$ = Crop coefficient for other crops for i^{th} cell (plot area) and j^{th} time period (days)
- $E_{tp(i,j)}$ = Evapo-transpiration for paddy area in m^3 for i^{th} cell (plot area) and j^{th} time period (days)
- $E_{to(i,j)}$ = Evapo-transpiration for other cropped area in m^3 for i^{th} cell (plot area) and j^{th} time period (days)
- $R_{e(i,j)}$ = Rainfall excess in m^3 for i^{th} cell (plot area) and j^{th} time period (days)
- $P_{p(i,j)}$ = Percolation during paddy crop in m^3 for i^{th} cell (plot area) and j^{th} time period (days)
- $P_{o(i,j)}$ = Percolation during other crops in m^3 for i^{th} cell (plot area) and j^{th} time period (days)

The equations (4), (5), (6) and (7) can be balanced and re-written as

$$WA_{aagr} = \int_{t=1}^n (P_{basin} + C_1 * Q_{gw} + Q_{nps_ssf} + Q_{nps_irf})_t * (Eff) = WR_{other} = A_p * [\sum_{i=1}^m \{ \sum_{j=1}^n (K_{o(i,j)} * E_{to(i,j)}) - \sum_{j=1}^n P_{o(i,j)} \}] \quad (8)$$

$$WA_{aagir} = \int_{t=1}^n (P_{basin} + C_2 Q_{in_us} + C_3 Q_{ob} + C_4 Q_{gw} + Q_s + Q_{nps_ssf} + Q_{nps_irf})_t * Eff = WR_{paddy} = A_p * [\sum_{i=1}^m \{ \sum_{j=1}^n (K_{p(i,j)} * E_{tp(i,j)} - R_{e(i,j)}) - \sum_j P_{p(i,j)} \}] \quad (9)$$

Where

- WA_{aagr} = Absolute water supply required for rain-fed regions for agriculture in m^3
- WA_{aagir} = Absolute water supply required for irrigation regions for agriculture in m^3
- Eff = Summation of all efficiency for the water supply (rainfall + ground water pumping + irrigation efficiency + flow from upstream as pumping + flow from other basins)

iii. Maximizing the benefit from agriculture

To maximize the benefit (profit), it is essential to consider the following decision variables (a) allocations of water among water use sectors and crop areas, (b) ground water head (state variable), and (c) hydrological information (rainfall, discharge) of the current year and previous years. The following equations can be derived:

$$MaxAG = \sum_{j=1}^n \sum_{i=1}^m [(CY_{Kharif(i,j)} * A_{Kharif(i,j)} * INR_{Kharif(i,j)} + CY_{Rabi(i,j)} * A_{Rabi(i,j)} * INR_{Rabi(i,j)}) - (A_{Kharif(i,j)} * INRI_{Kharif(i,j)} + A_{Rabi(i,j)} * INRI_{Rabi(i,j)})] \quad (10)$$

Where

- $MaxAG$ = Maximized Agriculture profit (Rs.)
- $CY_{Kharif(i,j)}$ = Crop yield during Kharif for i^{th} cell (plot area) and j^{th} time period (days) (tons/ha)
- $A_{Kharif(i,j)}$ = Cropped area of Kharif for i^{th} cell (plot area) and j^{th} time period (days) (ha)
- $INR_{Kharif(i,j)}$ = Cost of the produced crop in Kharif for i^{th} cell (plot area) and j^{th} time period (days) (Rs./tons)
- $INRI_{Kharif(i,j)}$ = Cost of the seed of the crop, transportation of surface water or pumping of groundwater and other expenses in Kharif for i^{th} cell (plot area) and j^{th} time period (days) (Rs./tons)
- $CY_{Rabi(i,j)}$ = Crop yield during Rabi for i^{th} cell (plot area) and j^{th} time period (days) (tons/ha)
- $A_{Rabi(i,j)}$ = Cropped area of Rabi for i^{th} cell (plot area) and j^{th} time period (days) (ha)
- $INR_{Rabi(i,j)}$ = Cost of the produced crop in Rabi for i^{th} cell (plot area) and j^{th} time period (days) (Rs.)
- $INRI_{Rabi(i,j)}$ = Cost of the seed of the crop, transportation of surface water or pumping of groundwater and other expenses in Rabi for i^{th} cell (plot area) and j^{th} time period (days) (Rs. /tons)

C. MODEL FOR DOMESTIC SECTOR

i. Water availability for domestic purpose

The gross water supply for the domestic purposes (urban population, urban livestock, rural population and rural livestock) is estimated using the relationship:

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$$WA_d = \int_{t=1}^n (C_5 * Q_{in_us} + C_6 Q_{gw} + Q_s + P_{rwh})_t \quad (11)$$

Where

WA_d = Water availability for domestic purposes in m^3
 P_{rwh} = Rainfall availability by rain-water harvesting technique in m^3
 C_5 and C_6 = Coefficients for different variables

ii. Water requirement for domestic purposes

The human demand for drinking, cooking, bathing, recreation, etc., is 24 km^3 and accounts for 79 percent of domestic withdrawals. The drinking-water demand of livestock is estimated at 6.7 km^3 [14]. The water withdrawal per person in urban areas (140 liters per day) is assumed to be more than those in rural areas (70 liters per day). The demand for livestock depends on the number of animals and consumptive use per head. However, it is considered as 50 liters per day in the present work. The equations can be written as:

$$WR_{durp} = \sum_{i=1}^m \sum_{j=1}^n (C_7(i,j) * P_{ur(i,j)} * WR_{pcur(i,j)}) \quad (12)$$

$$WR_{drrp} = \sum_{i=1}^m \sum_{j=1}^n (C_8 * P_{rr(i,j)} * WR_{pcrr(i,j)}) \quad (13)$$

$$WR_{durls} = \sum_{i=1}^m \sum_{j=1}^n (C_9 * P_{urls(i,j)} * WR_{pcurls(i,j)}) \quad (14)$$

$$WR_{drrls} = \sum_{i=1}^m \sum_{j=1}^n (C_{10} * P_{rrls(i,j)} * WR_{pcrrls(i,j)}) \quad (15)$$

Where

WR_{durp} = Water requirement for urban population in m^3
 WR_{drrp} = Water requirement for rural population in m^3
 WR_{durls} = Water requirement for urban livestock population in m^3
 WR_{drrls} = Water requirement for rural livestock population in m^3
 P_{ur} = Urban population in million
 P_{rr} = Rural population in million
 P_{urls} = Urban livestock population in million
 P_{rrls} = Rural livestock population in million
 WR_{pcur} = Per capita water requirement of urban population in m^3/day i^{th} cell (plot area) and j^{th} time period (days)
 WR_{pcrr} = Per capita water requirement of rural population in m^3/day i^{th} cell (plot area) and j^{th} time period (days)
 WR_{pcurls} = Per capita water requirement of urban livestock in m^3/day i^{th} cell (plot area) and j^{th} time period (days)
 WR_{pcrrls} = Per capita water requirement of rural livestock in m^3/day i^{th} cell (plot area) and j^{th} time period (days)
 $C_7, C_8, C_9,$ and C_{10} = Coefficients for different variables

The equations (11), (12), (13), (14) and (15) can be balanced and re-written as

$$WA_{adurp} = \int_{t=1}^n (C_5 * Q_{in_us} + C_6 Q_{gw} + Q_s + P_{rwh})_t * Eff = WR_{durp} = \sum_{i=1}^m \sum_{j=1}^n (C_7(i,j) * P_{ur(i,j)} * WR_{pcur(i,j)}) \quad (16)$$

$$WA_{adrpp} = \int_{t=1}^n (C_5 * Q_{in_us} + C_6 Q_{gw} + Q_s + P_{rwh})_t * Eff = WR_{drrp} = \sum_{i=1}^m \sum_{j=1}^n (C_8 * P_{rr(i,j)} * WR_{pcrr(i,j)}) \quad (17)$$

$$WA_{adurls} = \int_{t=1}^n (C_5 * Q_{in_us} + C_6 Q_{gw} + Q_s + P_{rwh})_t * Eff = WR_{durls} = \sum_{i=1}^m \sum_{j=1}^n (C_9 * P_{urls(i,j)} * WR_{pcurls(i,j)}) \quad (18)$$

$$WA_{adrlls} = \int_{t=1}^n (C_5 * Q_{in_us} + C_6 Q_{gw} + Q_s + P_{rwh})_t * Eff = WR_{drrls} = \sum_{i=1}^m \sum_{j=1}^n (C_{10} * P_{rrls(i,j)} * WR_{pcrrls(i,j)}) \quad (19)$$

Where

WA_{adurp} = Absolute water availability for urban population in m^3
 WA_{adrpp} = Absolute water availability for rural population in m^3
 WA_{adurls} = Absolute water availability for urban livestock in m^3
 WA_{adrlls} = Absolute water availability for rural livestock in m^3

iii. Maximizing the benefit from domestic uses

In domestic sector, we do consider the direct as well as indirect benefits. However, indirect benefits are many. The following equation can be used to maximize the domestic benefits:

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$$MaxD = \sum_{i=1}^m \sum_{j=1}^n [(C_{11} * INR_{durp(i,j)} + C_{12} * INR_{drpp(i,j)} + C_{13} * INR_{durts(i,j)} + C_{14} * INR_{drrts(i,j)} + IB_{(i,j)}) - (C_{15} * INR_{durpws(i,j)} + C_{16} * INR_{drppws(i,j)} + C_{17} * INR_{durtsws(i,j)} + C_{18} * INR_{drrtsws(i,j)})] \quad (20)$$

Where

$MaxD$ = Maximized domestic benefits (Rs.)

$INR_{durp(i,j)}$ = Gain from Domestic urban population (Rs.) from i^{th} cell (plot area) and j^{th} time period (days) (in terms of production, all taxes and salary)

$INR_{drpp(i,j)}$ = Gain from Domestic rural population (Rs.) from i^{th} cell (plot area) and j^{th} time period (days) (in terms of production and all taxes)

$INR_{durts(i,j)}$ = Gain from Domestic urban livestock (Rs.) from i^{th} cell (plot area) and j^{th} time period (days) (in terms of production as milk)

$INR_{drrts(i,j)}$ = Gain from Domestic rural livestock (Rs.) from i^{th} cell (plot area) and j^{th} time period (days) (in terms of production as milk)

$INR_{durpws(i,j)}$ = Cost of water transportation urban population (Rs.) from i^{th} cell (plot area) and j^{th} time period (days)

$INR_{drppws(i,j)}$ = Cost of water transportation rural population (Rs.) from i^{th} cell (plot area) and j^{th} time period (days)

$INR_{durtsws(i,j)}$ = Cost of water transportation urban livestock (Rs.) from i^{th} cell (plot area) and j^{th} time period (days)

$INR_{drrtsws(i,j)}$ = Cost of water transportation rural livestock (Rs.) from i^{th} cell (plot area) and j^{th} time period (days)

$IB_{(i,j)}$ = Indirect benefits (Rs.) for i^{th} cell (plot area) and j^{th} time period (days)

$C_{11}, C_{12}, C_{13}, C_{14}, C_{15}, C_{16}, C_{17}$ and C_{18} = Coefficients for different variables

D. MODEL FOR INDUSTRIAL SECTOR

i. Water availability for Industries

The gross water supply for the industries is estimated using the relationship:

$$WA_{in} = \int_{t=1}^n (C_{19} * Q_{in_us} + C_{20} Q_{gw} + P_{rwh})_t \quad (21)$$

Where

WA_{in} = Water availability for industry in m^3

C_{19} and C_{20} = Coefficients for different variables

ii. Water requirement for industries

Industrial water demand includes water demand for unit material and the quantity of the material. For industries, the initial water demand and subsequent recurring water demand are separate. The equation for industrial water demand can be written as:

$$WR_{in} = \sum_{i=1}^m \sum_{j=1}^n (C_{21(i,j)} * WR_{ini(i,j)} + C_{22} * WR_{inr(i,j)}) \quad (22)$$

$$WR_{inr(i,j)} = WR_{inum} * M_q \quad (23)$$

Where

WR_{in} = Industrial water demand in m^3 from i^{th} industry and j^{th} time period (days)

$WR_{ini(i,j)}$ = Initial Industrial water demand in m^3 from i^{th} industry and j^{th} time period (days)

$WR_{inr(i,j)}$ = Recurring Industrial water demand in m^3 from i^{th} industry and j^{th} time period (days)

WR_{inum} = Water requirement for unit material in m^3 /tons from i^{th} industry and j^{th} time period (days)

M_q = Total quantity of the material in tons from i^{th} industry and j^{th} time period (days)

C_{21} and C_{22} = Coefficients for different variables

The equations (21) and (15) can be balanced and re-written as

$$WA_{ain} = \int_{t=1}^n (C_{19} * Q_{in_us} + C_{20} Q_{gw} + P_{rwh})_t * Eff = WR_{in} = \sum_{i=1}^m \sum_{j=1}^n (C_{21(i,j)} * WR_{ini(i,j)} + C_{22} * WR_{inr(i,j)}) \quad (24)$$

Here WA_{ain} = Absolute Water availability for industry in m^3

iii. Maximizing the benefit from industries

The benefit has been maximized by considering the various factors except the cost of the land provided by the Government and the cost of the inception of the Industry by the Industrialist.

$$MaxIN = \sum_{i=1}^m \sum_{k=1}^n [(I_{p(i,j)} * INR_{p(i,j)} + IB_{(i,j)}) - (C_{23} * I_{rm(i,j)} * INR_{rm(i,j)} + C_{24} * INR_{om(i,j)})] \quad (25)$$

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Where

$MaxIN$ = Maximized industrial production as revenue (Rs.)
 $I_{p(i,j)}$ = Industrial production (tons) for from i^{th} industry and j^{th} time period (days)
 $INR_{p(i,j)}$ = Cost of the produced material as revenue (Rs./tons) from i^{th} industry and j^{th} time period (days)
 $I_{rm(i,j)}$ = Quantity of Industrial raw material (tons) from i^{th} industry and j^{th} time period (days)
 $INR_{rm(i,j)}$ = Cost of raw material for the product (Rs./tons) for i^{th} industry and j^{th} time (months)
 $INR_{om(i,j)}$ = Cost of operation and maintenance for the product (Rs.) from i^{th} industry and j^{th} time period (days)
 C_{23} and C_{24} = Coefficients for different variables

E. MODEL FOR ENVIRONMENTAL SECTOR

i. Water availability for Environment as E-flows

Environmental flows (E-flows) are very essential to maintain the ecology and aquatic life in the river. The gross water supply for the environmental purposes is estimated using the relationship:

$$WA_{eflow} = \int_{t=1}^n (C_{25} * Q_{in_us})_t \quad (26)$$

Where

WA_{eflow} = Water availability for environmental flow in m^3
 C_{25} = Coefficients for different variables

ii. Water requirement for Environment as E-flows

Environmental water demand includes water demand for aquatic life and ecology of the river reach. For environmental flows, the water demand can be obtained as:

$$WR_{eflow} = \sum_{i=1}^m \sum_{j=1}^n (C_{26(i,j)} * WR_{aquatic(i,j)} + C_{27} * WR_{wq(i,j)} + C_{28} * WR_{eco(i,j)}) \quad (27)$$

Where

WR_{eflow} = Water requirement for environmental flow in m^3 from i^{th} reach and j^{th} time period (days)
 $WR_{aquatic(i,j)}$ = Water requirement for aquatic life in m^3 from i^{th} reach and j^{th} time period (days)
 $WR_{wq(i,j)}$ = Water requirement for maintaining water quality in m^3 from i^{th} reach and j^{th} time period (days)
 $WR_{eco(i,j)}$ = Water requirement for ecology in m^3 from i^{th} reach and j^{th} time period (days)
 C_{26} , C_{27} and C_{28} = Coefficients for different variables

iii. Maximizing the benefit from Environmental Sector

Increase in fish-culture, sea-food and recreational activities near the wetlands or river system would increase the revenue. To maximize the benefit from the environment, the following equation can be used:

$$MaxEflow = \sum_{i=1}^m \sum_{j=1}^n [(FP_{(i,j)} * INR_{fp(i,j)} + INR_{rc(i,j)} + IB_{(i,j)}) - (INR_{rcm(i,j)})] \quad (28)$$

Where

$MaxEflow$ = Maximized environmental benefits in Rs.
 $FP_{(i,j)}$ = Fish production (Kg.) m^3 from i^{th} reach and j^{th} time period (days)
 $INR_{fp(i,j)}$ = Cost of fish (Rs./Kg.) m^3 from i^{th} reach and j^{th} time period (days)
 $INR_{rc(i,j)}$ = Cost chargeable for recreation (Rs.) m^3 from i^{th} reach and j^{th} time period (days)
 $INR_{rcm(i,j)}$ = Cost required for maintenance of recreation area (Rs.) m^3 from i^{th} reach and j^{th} time period (days)
 $IB_{(i,j)}$ = Indirect benefits (Rs.) m^3 from i^{th} reach and j^{th} time period (days).

IV. RESULTS AND DISCUSSION

In the present work, the integrated water resources management analysis has been done for the sub-basins Tilga, Jaraikela, Panposh, Gomlai, Rengali, Samla, Jenapur, the Delta and the whole basin. The model parameters have been estimated and the runoff at the outlet has been estimated using the equations derived earlier.

i. Tilga sub-basin

The Tilga sub-basin is lying in Sankh river above the Mandira dam. Minor part of the basin is lying in Chattishgarh and the major part of the basin lies in Jharkhand. It has been observed that 75 percent of the Tilga basin area (3060 Km²) is suitable for agricultural purposes. However, it is not being utilized properly for irrigation purposes. The area is having no irrigation projects and, therefore, the agriculture production depends mostly on the rainfall and the groundwater. Most of the area is cultivating rice and other kharif crops, which covers 79.21% of the crop production. The rabi crops cover only 20.79 % of the total crop production. It is also observed that the area has lot of potential for developing water resources projects for irrigation, hydropower and domestic purposes. The basin receives more than 2000 MCM of rainfall per year and its monthly distribution is also very significant, which may be used for different purposes. The available ground water is 177 MCM and utilizable groundwater is 84.95 MCM by considering efficiency and correction coefficient values are 0.8 and 0.6, respectively. The crop water requirement (CWR) is obtained using the equations (6) and (7). The crop coefficient has been observed to vary between 0.4 -1.2 for different stages of the crops. The evapo-transpiration has been obtained using the following Penman-Montieth equation:

$$ET = \frac{0.408 * \Delta(R - G) + \gamma \frac{900}{T + 273} u(e_s - e_a)}{\Delta + \gamma(1 + 0.34u)}$$

Where, ET= Reference evapo-transpiration (mm/day), R= net radiation at the crop surface (MJ/m²/day), G= soil heat flux density (MJ/m²/day), Δ= slope vapour pressure curve (kPa/ °C), T= mean daily air temperature (°C), u=wind speed (m/sec), e_s= saturation vapour pressure (kPa), e_a= actual vapour pressure (kPa), γ= psychometric constant (kPa/ °C).

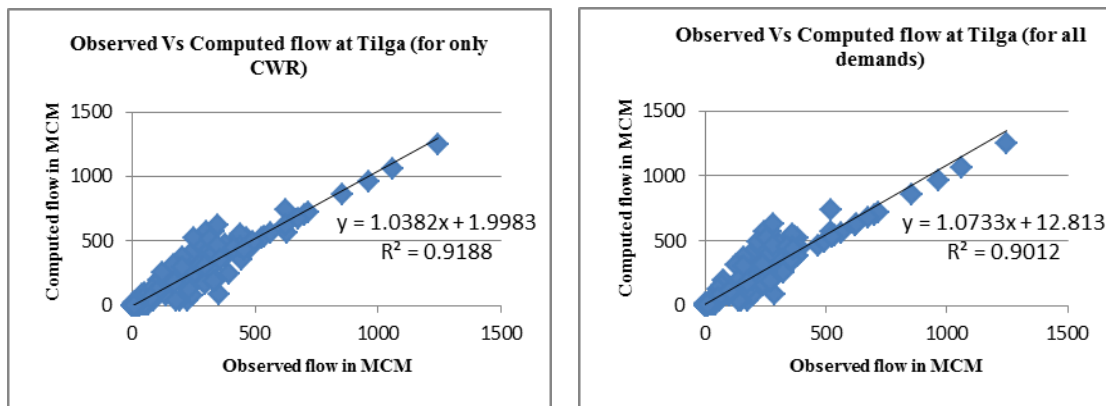


Figure 4: Comparison of discharges at the outlet.

Now, the model parameters are calibrated and validated. The results are obtained for two situations. First, only existing agricultural demand has been considered and the estimated outflow runoff at Tilga has been compared with the observed runoff values (using equations 6 and 7). In the second step, the other existing demands such as domestic, industrial and environmental (5%) have also been considered (using equations 6, 7, 12, 13, 15, 16, 22 and 23) and compared with observed values. The results obtained are given in Figure 4 for both the conditions. It has been observed that the R² values are very high and the calibrated model parameters are suitable for generating future scenarios. The values of coefficients c1 to c27 have been varying between 0.6 to 0.9, all the efficiency varies between 0.6 to 0.8 and the crop coefficient varied between 0.4 -1.20 for different stages of the crops. The results obtained clearly indicate that a large amount of water is available and ground use is less than 20% in most of the regions of the Tilga sub-basin. It has been observed that the crop water requirement is much below the available rainfall. If the agricultural area is utilized fully, irrigation is done by storing the water and consumptive use is utilized, the crop production can be maximized and cost of production can be reduced. Moreover, the crop water requirement is required to be increased by

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increasing the crop production with multiple crops and by using more agricultural land for crop production. There is vast scope of having water resources project to store available water obtained from rainfall and use it for irrigation purposes. The profit of production comes out to be less 35 million Rupees from agriculture, livestock and fisheries, which can be maximized by increasing production and reducing investment for production (equations (10), (20) and (25)). Likewise the integrated water resources management analysis has been done for rest sub-basins like Jaraikela, Panposh, Gomlai, Rengali, Samla, Jenapur, and the Delta.

V. CONCLUSION

The developed model, BAWRA, is a generic model and has been utilized to estimate the optimum integrated water resources management by considering: (a) water available (supply) at eight sub-basins (Tilga, Jaraikela, Panposh, Gomlai, Rengali, Samal, Jenapur and Delta) and Brahmani river basin as a whole including rain water, river water and the groundwater; and (b) the water demand by various sectors including irrigation, domestic purpose (urban and rural demand), industries and environment. The results obtained are very promising for all the sub-basins and the Brahmani river basin. The model coefficients and efficiencies provide space to the user for considering conservative estimate of water availability (supply) and maximizing the use of water demand for different purposes. With the variation of coefficients, the model is suitable for use at different basin and can be transformed into simple model in the absence of some variables. By increasing agricultural areas, industrial areas and domestic areas and their respective demands, different future scenarios can be generated. At present very little land is being utilized for agricultural purposes and rabi crops are limited, which is obtained by NDVI analysis of the data. Multiple crops are not being grown at different sub-basins (Tilga, Jaraikela, Panposh, Gomlai) due to non-availability of sufficient irrigation facilities, rain water harvesting mechanisms and groundwater withdrawal facility. The model has been successfully in Brahmani river basin and its eight sub-basins. It is suitable for other river basins too with modifications in model coefficients, efficiencies and parameters.

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