Prioritized irrigation options for Baitarini river basin of India

R. R. Sethi*[1], R. K. Panda[2], P. S. Brahmanand[3], A. K. Singh[4] and S. K. Ambast[5]

[1, 2, 3] *Principal Scientist, ICAR-Indian Institute of Water Management, Bhubaneswar*
[4]*SRF, ICAR-IIWM, Bhubaneswar, Odisha*
[5]*Director, ICAR-IIWM, Bhubaneswar, Odisha*
**ranurani@yahoo.com*

Abstract: Baitarini river basin is third largest river basin of Odisha with geographical area of 13482 sq km and water availability of 7.104 BCM. Flooding in lower part of basin has been the major constraints to achieve sustained crop production. Though cropping intensity varies from 136 to 198%, there is need to prioritize irrigation options through advanced and scientific water management practices. In this paper hydrological analysis has been carried out by considering DEM, slope, fill, flow direction, flow accumulation, stream network and stream order. Basic spatial maps like soil, groundwater prospect, land use land cover maps with monsoon cropped area, area with more than two season crop, fallow lands were delineated by using remote sensing and GIS. The drainage density was worked out as 0.527 km/sq km which are inadequate to meet the drainage requirement of the basin. From the hydrological analysis, dry and wet areas within the basin were demarcated. The existing water bodies like water harvesting structures, natural ponds and wells were superimposed on this map to identify potential areas for developing water resources. Thematic maps of cropping intensity, groundwater potential and stream net were superimposed to find out the prioritized options for enhancing irrigation/drainage facilities within the basin. Accordingly three major water resource management options i.e. (i) salinity control, drainage and sluice based irrigation system (ii) Groundwater exploitation and development and (iii) Watershed management were proposed.

Key words: river basin; hydrological analysis; GIS; irrigation/drainage facilities

I. Introduction

India occupies 2.4% of the world's total area, 16% of population and 4% of the total available fresh water in the world. River basins support 70% of global population but due to impact of climate variation and rapid population growth, many countries might experience water shortages in the coming decades (Falkenmark et al. 1989, Gleick 2000). Global water and food crisis has emerged in many parts of World including India (Seckler and Amarasinghe 2000). In India, per capita availability of water has declined from 5,177 cubic meters in 1951 to 1,508 cubic meters in 2014 and it is in declining trend. As per eleventh five year plan report, nine out of 20 river basins with 200 million populations are already facing a water-scarcity problem. River basin planning for long term use of water for different sectors is the need of hour. Under Pradhan Mantri Krishi Sinchayee Yojana (PMKSY), there is scope to develop integrated water resources and its proper management for enhancing irrigated area, focusing for higher crop productivity thereby fulfilling the food security issues. Odisha, located in eastern part of India is blessed with rich water resources from both surface and groundwater. Net sown area of the State is 5424 ha (34.8%). Irrigation facilities were created for 1.83 lakh hectares in 1951 to 38.15 lakh hectares in 2017. The gross irrigation potential created till 2013-14 from all sources was 50.05 lakh ha

(33.53 lakh ha during *Kharif* and 16.52 lakh ha during *Rabi*) and gross irrigated area during the year was 35.21lakh ha (22.54 lakh ha during *Kharif* and 12.67 lakh ha during *Rabi*) which is 70.35% of the irrigation potential created. State Irrigation plan (basin wise) has been proposed under PMKSY to enhance the irrigation options and increase the water productivity of the area. Baitarini is one of the east flowing rivers of India. It is third largest river basin of Odisha. Total water availability within the basin including surface and groundwater resources is 7.104 BCM where as water demand from all sectors was estimated at 4.36 BCM. Flooding in lower part of basin has been the major constraints to achieve sustained crop production. As per ICID report based on Country Policy Support Programme (CPSP) studies, Baitarini river basin presently lies in the category of basins having little or no stress on account of surface water withdrawals and it is very moderately stressed in groundwater withdrawal. It is in the category of low or no threat in respect of surface water quality and it is in the category of moderate threat in respect of groundwater quality. In this paper prioritized irrigation options for Baitarini river basin has been proposed through hydrological analysis.

II. Materials and Methodology/Study Area and Methods

Baitarini river basin boundaries were delineated from base maps from Odisha Remote Sensing Application Centre (ORSAC). Other base maps like soil type, groundwater prospects, land use and land cover, existing water bodies were used for the analysis.

1. Preparation of Digital Elevation Model (DEM) and hydrological analysis by using remote sensing and GIS

DEM images (32 numbers) in tiff format covering Odisha state was downloaded from the USGS earth explore web site. All the images were mosaic and Odisha boundary was extracted from the map. Then DEM, slope map for the state was prepared. Using the DEM shape file, fill maps were prepared and then using fill, flow direction maps were prepared. Finally, basin wise flow accumulation and stream network maps of Odisha were prepared. Morphological parameters were estimated based on the standard formula and the detail reference is given in Table 1.

S. No.	Morphological parameters	Formula	References
1	Stream order (U)	Hierarchical rank	Strahler (1964)
2	Stream number (Nu)	No of streams	Horton (1945)
3	Stream length (Lu)	Length of the stream (Kilometers)	Hortan (1945)
4	Mean stream length (Lsm)	Lsm = Lu/Nu Lu = Total stream length of order u Nu = Total no. of stream segments of order u	Strahler (1964)
5	Length of overland flow (Lg)	Lg = 1/2D ; D = Drainage density	Horton (1945)

6	Bifurcation ratio (Rb)	Rb = Nu/(Nu + 1) Nu = Total no. of stream segments of order u Nu + 1 = Number of segments of the next (u+1)th order	Schumn (1956)
7	Mean bifurcation ratio (Rbm)	Average of bifurcation ratios of all orders	Strahler (1964)
8	Basin length (Lb)	Lb=1.312×A 0.568	Nookaratnam (2005)
9	Drainage density (Dd)	$D_d = L_u/A$ A = Area of the basin	Horton (1945)

Table 1 Morphological parameters for the basin

2. Delineation of dry and wet areas

From the stream network, the geographical coordinate system (GCS) was changed to projection coordinate system (PCS) and length of streams were calculated. Drainage density was calculated for Baitarini river basin. Stream network file (PCS) was converted to feature class image and focal statistics were calculated with neighbourhood with 3 kilometre radius with sum statistics. Then reclassification was conducted by natural breaks with dry and wet classes depending upon the range values for river basin. Then dry and wet areas of the basin with drainage density values were prepared. Superimposing the existing water bodies like water harvesting structures, natural ponds and wells, the potential areas were delineated for developing water resources.

3. Prioritizing the suitable options for enhancing cropping intensity

Thematic maps of stream net, district maps, cropping intensity and groundwater potential maps were superimposed in GIS to find out the prioritized options for enhancing irrigation facilities for the basin. The low cropping intensity area was given the first priority to identify the suitable options within the basin.

II. Results discussion

The Baitarini river basin has a total drainage area of about 14,218 km^2 of which 13,482 km^2 lies in Odisha covering 42 blocks of 8 districts i.e. Balasore, Bhadrak, Jajpur, Kendrapada, Angul, Keonjhar, Mayurbhanj and Sundergarh. The basin has a sub-humid tropical climate, with an average rainfall of 1305 mm, most of which is concentrated in southwest monsoon season June to October. Maximum and minimum temperature varied from 6^0 to 48.5^0 C. Rain-fed agriculture is predominant in all over the basin. In lower deltaic parts due to provision of canal irrigation options and shallow groundwater table depth, two and three season crops are grown. Red, lateritic, deltaic alluvial and coastal salt affected alluvial soils in lower areas are present within the river basin. Water availability from surface and groundwater resources was 7.104 BCM where as water demand from domestic, crop, livestock and industrial sector was estimated at 4.36 BCM. Water gap analysis showed that no stress on water availability and demand upto 2025. Groundwater development varies from 5 to 64% with average of 31% which could be increased further.

Hydrological analysis

Stream net of Baitarini river basin is shown in Fig.1. This basin is of 6th order drainage basins. Drainage patterns are mainly dendritic pattern which indicates that the rock formations are impervious and the permeability is low. This can act as guidelines to locate vulnerable areas requiring different kinds and degrees of soil conservation measures. Stream originating in the upper reaches are first order streams; when two first order stream unite, a segment is designated as a second order stream; when two second order segments join a channel segment is a third order stream, and so on. The trunk stream or the main stream through which all the discharge of the water is carried out is the stream of the highest order. Stream analysis was carried out based on stream order and bifurcation ratio (Table 2). Streams are classified into different orders according to the number of bifurcations. The stream order is a dimensionless number and hence can be used for the comparison of geometry of drainage network on different linear scales. The mean bifurcation ratio is 1.79. The stream lengths plays a significant role in deciding about surface run off and the volume of water flow through the channel. The stream length ratio has been calculated for all orders of streams in the basin. It was observed that each stream order has a characteristic number of channels, length and drainage area. The 1st order streams have a highest total length of 3446.33 Km and with a mean length of 1.18 Km. similarly, for 6th order stream have lowest length of 138.27 km with a mean length of 0.78 km. It is observable that the mean length of all streams decreased with increase in order.

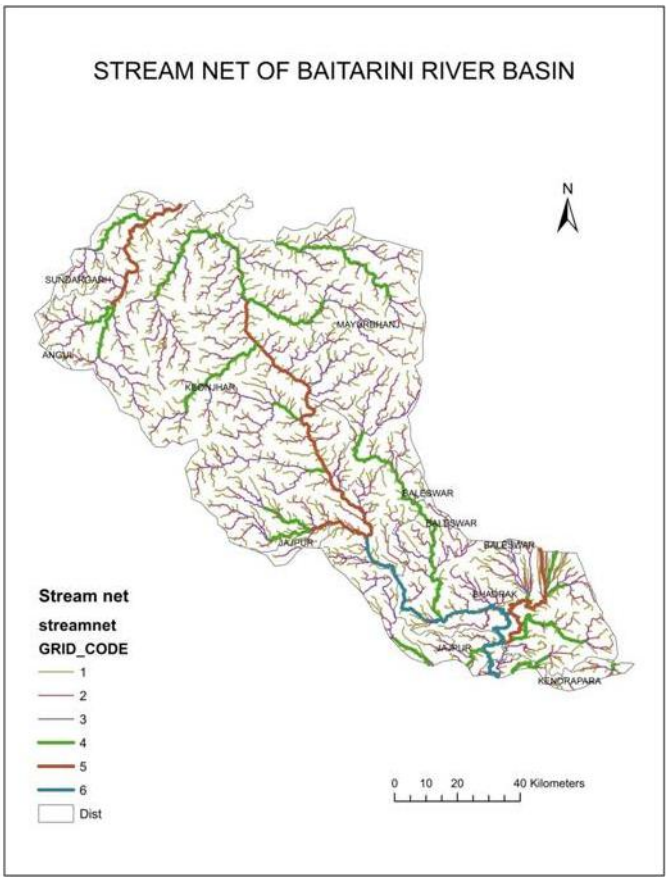

Fig. 1 Stream net and stream order of Baitarini river basin

River basin	Stream order	Stream segment (Nos)	Stream length (Km)	Mean stream length (Km)	Stream length ratio	Bifurcation ratio	Length of overland flow
	1^{st}	2926	3446.33	1.18		1.87	
	2^{nd}	1567	1651.96	1.05	0.48	1.93	
	3^{rd}	812	866.47	1.07	0.52	1.17	
	4^{th}	694	553.56	0.80	0.64	1.85	
	5^{th}	375	270.65	0.72	0.49	2.12	
	6^{th}	177	138.27	0.78	0.51		
Mean						1.79	0.95
Total		6551	6927.24	5.59	0.53		

Table 2. Stream order with bifurcation ratio of Baitarini river basin

Site specific approach for irrigation plan

Stream order could be useful in deciding irrigation options within the basin. Watershed activities at micro and macro scale could be proposed in 1^{st}, 2^{nd} and 3^{rd} order stream net. Minor irrigation projects should always be preferred on 4^{th} order stream net areas. Irrigation schemes like AIBP (major/medium irrigation projects) should be proposed for planning beyond 5^{th} order stream net (5^{th} and 6^{th}) in this river basin. All command area development (CAD) activities in command areas of all the irrigation projects should be carried out irrespective of major, medium and minor irrigation systems. The extent of coverage of irrigated area along the stream net, in the present context one kilometer buffer zone has been considered and presented in Fig. 2.

Drainage density was worked out as 0.527 km km^{-2}, which can enable the drainage engineers for designing more of surface drainage systems. This is a characteristic feature of dry regions in upper part and wet region in lower part of the basin. The coarse drainage density indicates the watershed development in upper region of the basin mainly rainwater conservation structures and water management options to increase the water productivity in lower region of the basin. About 8622 numbers of existing water bodies with variation of sizes from 0.05 ha to 20 ha were superimposed in the dry wet areas of the basin. Statistical analysis showed size of water bodies was less than 1 ha for 7078 numbers (82%) of structures out of total 8622. Nearly 1376 numbers of structures were of size of 1-5 ha, 115 number sizes is within 5-10 ha, 53 number of structure is having size more than 10 ha. In Baitarini river basin, there is nearly 1900 micro watersheds has been delineated and many watershed activities are being carried out through these programme. There is scope to develop location specific water harvesting structures in Sundargarh, Mayurbhanj and Keonjhar districts. Tank cum well system has been a proven technology for plateau region which could be implemented for providing reliable irrigation to croplands. The system comprises of a series of tanks with open dug wells in the recharge zone of the tank that re harvest back the seepage water (Srivastava et al, 2009)

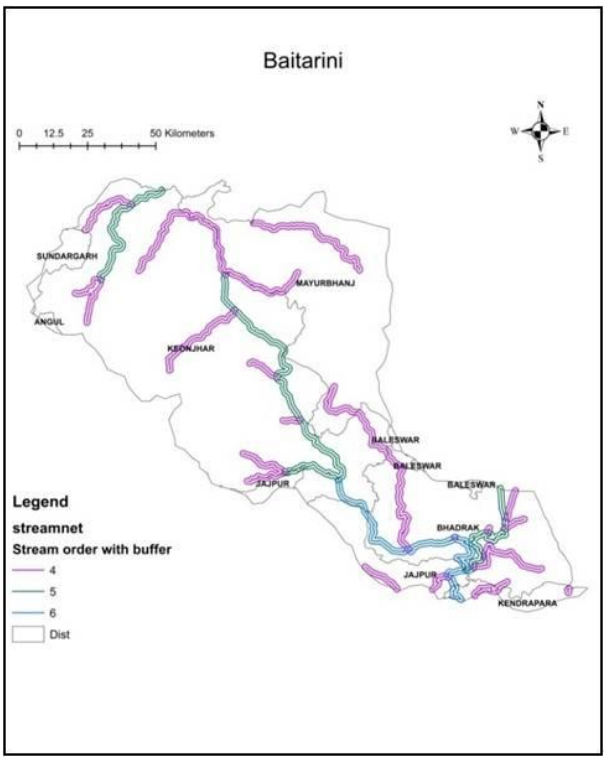

Fig.2 Surface irrigation locations (within 1 km buffer zone) in Baitarini River Basin

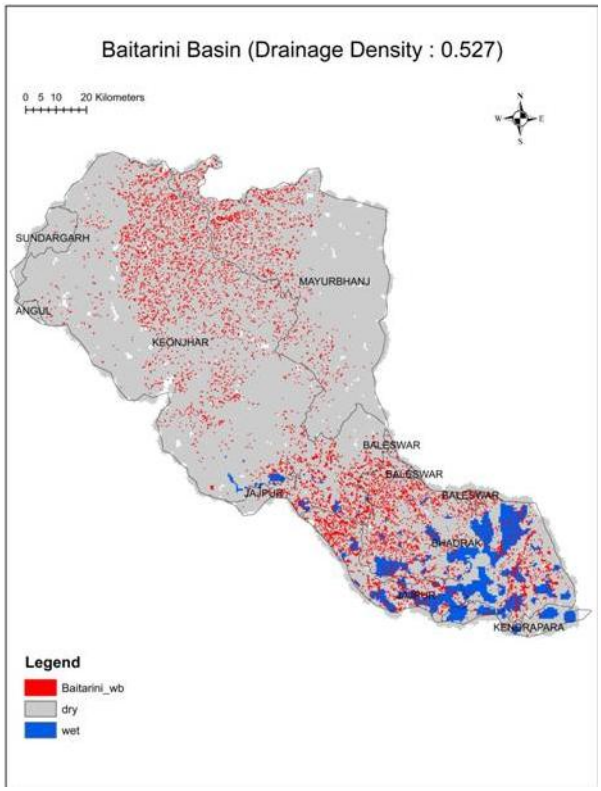

Fig.3 Drainage density of Baitarini river basin

Prioritized irrigation options within the basin

Thematic maps of stream net, district maps, cropping intensity and groundwater potential maps were superimposed in GIS to find out the prioritized options for enhancing irrigation facilities in different river basin of Odisha. Cropping intensity in this river basin varies from 136 to 198%, and there is need to prioritize irrigation options through advanced and scientific water management practices. The low cropping intensity area was given the first priority to identify the suitable options within the basin. Based on ground water potential, and availability of surface water/stream net; three major options i.e. (i) Watershed management, (ii) Groundwater exploitation and development and (iii) Salinity control, surface drainage as well as sluice based irrigation options were listed out.

Based on ground water potential, areas are classified as (Excellent: 40lps; very good to excellent: 20-40lps; very good: 15-20 lps; good: 10-15 lps, Moderate:3-10lps; Moderate to poor: 1-3 lps and Poor: <1lps) and availability of surface water/stream net (upto 7th order); three major options i.e. (i) Watershed management, (ii) Groundwater exploitation and development and (iii) Salinity control, surface drainage as well as sluice based irrigation options were listed out (Fig. 4). A coastal district like Bhadrak, Kendrapara, parts of Jajpur faces the major problem like saline water intrusion and drainage. In these areas, sluice gate based irrigation system in branch river canal and creeks would be helpful to check the saline water intrusion and also drain the excess water through these structures. Areas with shallow good quality groundwater could be further exploited to bring more area under irrigation and increase the cropping intensity of the region. Similarly districts like Mayurbhanj and Keonjhar are demarcated for conservation of rain water and other watershed activities so that it could be helpful to increase the groundwater recharge which could be reflected in lower basin areas (Table 3).

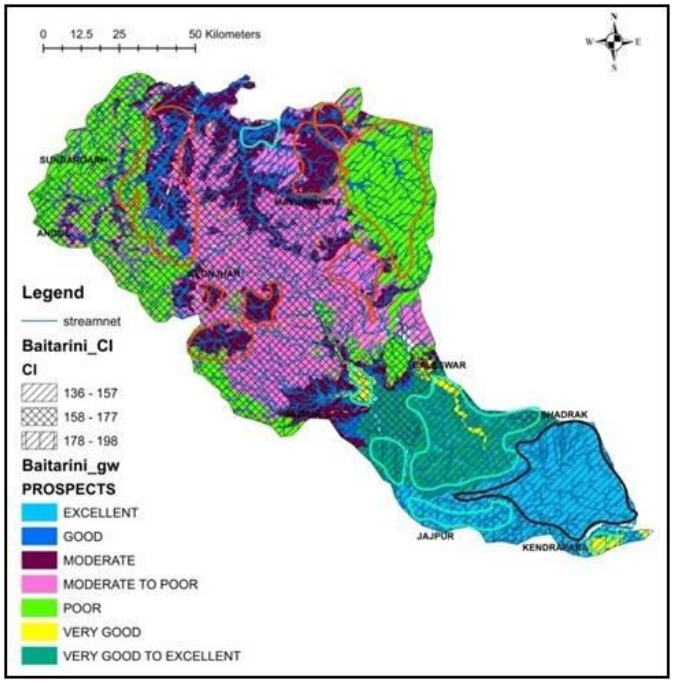

Fig. 4 Prioritized map of Baitarini River Basin

Cropping Intensity (%)	Groundwater status/Yield potential	Surface water/Stream net	Districts covered	Prioritized options
136-157	Excellent (>40 lps)	Up to 7th stream order	Parts of Bhadrak, Kendrapada, Jajpur	Salinity control, drainage and sluice based irrigation system
	Very good to excellent(20-40 lps)		Parts of Bhadrak, Kendrapada, Jajpur, Balasore	Groundwater development
158-177	Very good to excellent(20-40 lps)	Up to 4th stream order	Parts of Jajpur	
178-198	Moderate (3-10 lps)	Up to 7th stream order	Parts of Mayurbhanj, Keonjhar	Watershed development

Table 3 Prioritized irrigation options in Baitarini river basin

III. Conclusions

Out of 30 districts of Odisha, 8 districts covering 42 blocks lie within Baitarini river basin. Irrigation planning was considered based on land topography (hard rock and coastal plain), surface and groundwater resources. Location specific water resource development options were analyzed. It is proposed that after development of water resources, major emphasis should be given on its utilization for achieving enhanced crop production and water productivity including increased irrigation and cropping intensity. Location specific proven technologies like watershed development program, groundwater development and sluice gate irrigation system should be adopted through various government schemes for increasing crop area within the basin.

Acknowledgements

Authors acknowledge Department of soil conservation & watershed development, Govt. of Odisha for providing funding to prepare State Irrigation Plan of Odisha.

References

Annual report 2014-15, 2015-16, 2016-17, Department of Water Resources, Govt. of Odisha.

PMKSY (2018). Reports of District irrigation Plan (Districts of Odisha), PMKSY (https://pmksy.gov.in)

Falkenmark, M. and Molden, D. (2008). Wake up to realities of river basin closure. *Water Resources Development*, 24(2): 201–215.

Gleick, P. H. (2000). The world's water 2000–2001: the biennial report on freshwater resources, Washington, DC: Island Press.

Horton, R. E. (1945) Erosional development of streams and their drainage basins, hydro-physical approach to quantitative morphology. *Geological Society of American Bulletin.* 56: 275-370.

Nookaratnam, K., Srivastava, Y. K.,Venkateswara, W., Amminedu, E. and Murthy, K. S. R. (2005). Check dam positioning by prioritization of micro watershed using SYI model and morphometric analysis remote sensing and GIS perspective. *Journal of Indian Society of Remote Sensing*. 33(1): 25-28.

Schumm, S. A. (1956). Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. *Geol. Soc. Am. Bull*., 67: 597-646.

Seckler, David and Amarasinghe Upali. (2000). Water supply and demand, 1995 to 2025. IWMI. Annual report 1999-2000.

State Water Policy-2007, Department of Water Resources, Government of Odisha. P: 17. (www.dowrodisha.gov.in/swp2007/swp%202007.pdf)

Strahler, A. N. (1964). Quantitative geomorphology of drainage basins and channel networks. In: V. T. Chow (ed.), *Handbook of Applied Hydrology*. McGraw Hill Book Company, New York, section 4-1I.

R. C. Srivastava, Kannan, K., Mohanty, S., Nanda, P., Sahoo, N., Mohanty, R. K., Das, M. (2009). Rainwater management for smallholder irrigation and its impact on crop yields in Eastern India, *Water Resources Management* . 23(7):1237-1255.