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Environmental flow assessment in the rivers originating at the Western Ghats

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ABSTRACT:

Water resource the keystone element for all living entities, is being mismanaged, over exploited and is in the verge of depletion due to ever increasing demand and also due to the land use changes. Degrading landscape has led to massive loss of retaining water resources since the water fails to percolate or being stored in sub surfaces as it escapes as flash floods, there by affecting the availability of water (during all months) of the streams and failing to maintain the minimum quantity of flow, thus affecting the hydrological regime. The water resource availability in a watershed or a catchment depends on various factors such as the landscape, soil properties, rainfall, terrain etc., stream flow is dependent upon the surface runoff and subsurface runoff characteristics. The current communication models the hydrologic flow (environmental flow) regime considering landscape status of various river basins across rives originating at the central Western Ghats. The flow regime assessed based on water balance provides information about the hydrological status of every sub basin in catering the needs in the catchment. Remote sensing data acquired through space borne sensors were used in order to quantify the land uses across the basins. The meteorological data was integrated using GIS with the land use and the topography information to determine the hydrological parameters such as runoff, infiltration, ground water recharge, evapotranspiration in sub basins. Agricultural, Domestic and livestock water requirements were assessed every month in order to understand the basic water demands. The land use analysis carried out shows that the Ghat sections of Western Ghats is dominated by forests, and along the transition between Ghats to plains, horticulture plantations dominates, whereas the plains and coasts are dominated by agriculture. The water balance based modeling shows that the presence of large forest areas in the catchments helps in catering water demand during post monsoon for over 10 months and streams being perennial, whereas catchments with degraded space forests, forest plantations and other landscape show that the demand can be catered for very short term post monsoon, or even seasonal, leading to intermittent stream flows and hence devoicing the stream with minimum desired flow.

Key words: Western Ghats, Water resource, Water balance, Remote Sensing, GIS, Catchment, Environmental flow

1. INTRODUCTION:

Water is a limited natural resource [1, 2, 3] and is the right to all life forms on the blue planet for sustained growth and development [4]. The resource similar to other naturally available resources is being overexploited by human interventions in order to cater human oriented needs such as agricultural, industrial, domestic and other human need. Due to the anthropogenic activities the hydrological regime in terms of quantity and timing of water that are essential to maintain the processes and proper functioning [5] of the catchment are disturbed. The impacts of disturbances in the natural flow regime of rivers and streams have been accounted in various studies [6, 7]. To avoid the impacts on the ecosystems and the environment in which the various life forms are inter connected and dependent upon the natural resources, the water resource carrying capacity [8, 9, 10] of the catchment needs to be understood which defines the water availability. Large scale land use conversion such as degradation of forests to other land use categories affects the hydrological regime [11, 12, 13, 14]. Land use conversion to open lands and agricultural fields has led loss of potential of water retention capacity in soils [15, 16], hence affecting the productivity leading to exploitation of water. In order to maintain the structure of the environment and associated elements minimum flow across various seasons needs to be maintained in any river or stream. This minimum flow is also termed as Environmental Flow (EF). The term EF [17, 18, 19] defines the quality, quantity, duration and timing of water that needs to flow in order to keep the rivers and streams in healthy condition. Traditionally the water resource allocation was focused mainly upon human and agricultural needs ignoring the environmental sustainability [20, 21, 22] leading to diversions and variations in the natural flow regime. The goal of the environmental flow is to zone the river basins based on water quantity (flow) in the river basins that helps in strict management of water resources in the basin [22, 23, 24] and restrain the developmental activities based on carrying capacity [25, 26] maintain and enhance the ecological character and functions of floodplain, wetland and riverine ecosystems that may be subject to stress from drought, climate change or water resource development of each zones across the catchment. EF and its implication of mismanagement of flow are studied across various countries [25, 27, 28, 29, 30].

EF in the stream or a river is identified based on long term observations of the flow regime, thus EF assessment of a river is assessment to quantify the natural flow regime of a river that should continue to flow down it and onto its floodplains in order to maintain specified, valued features of the ecosystem [31, 32, 33, 34, 35]. The flow in the river basin is quantified through discharge measurements in field in association with the hydro meteorological data using GIS and Remote Sensing [36, 37], integrating various models such the water balance models, rainfall runoff models etc [38] involving various characteristics such as rainfall, soil, slope, land use, evaporation etc [15, 16, 39]. Advantage of using GIS and remote sensing technique [40, 41, 42] over other conventional methods such as wider synoptic view covering large surface of earth at various resolutions. Classification of the remotely sensed with proven algorithms such as maximum likelihood classifier [43, 44, 45, 46] is necessary in order to obtain the land use information. The information's based on the land use is integrated with the various spatial parameters such as the terrain, rainfall, temperature, solar radiation etc with the water balance [15, 16] model using GIS in order to predict the efficacy of water resource subjected to the demand. The objective of the paper is to understand the environmental water dynamics at various land use and meteorological conditions in varied catchments across rivers of Central Western Ghats of Karnataka.

2. STUDY AREA:

Central Western Ghats is the biodiversity hotspot with rich floral and faunal habitats, numerous perennial and intermittent streams. For the study, the river basins originating from the Western Ghats such as Kali, Bedthi, Agnashini, Sharavathi, Varada and Venkatapura were studied and is as depicted in fig. 1. Extending from $14^0$43'N to $15^0$33'N Latitude and $75^0$4'E to $74^0$41'E Longitude the region covers total area of 19108.24 km^2, table 1 describes the area under each river basin. The study area is spread across six districts namely Belgaum, Uttara Kannada, Shimoga, Haveri, Gadag, Dharwad (fig. 2). The topography of the study area is flatter near the coast and the plains, where as it is very undulating at the Ghats, this is supplemented by drainage density, the Ghat section have high drainage density, whereas the plains have lower drainage density but with presence of more lake bodies (fig. 3). Rainfall across the basin varies from as low as 900 mm at the plains and to as high as over 5000 mm at the Ghats (fig 4) with july receiving maximum amount of rainfall (fig. 5). Temperature (fig. 6) in the basin varies from as low as 15.44^{O}C in January to as high as 36.94^{O}C in April. The Population in the region has increased at a decadal rate of 15.4%. The population density (table 2) has increased from 165 persons per square kilometer to 187 persons per square kilometer.

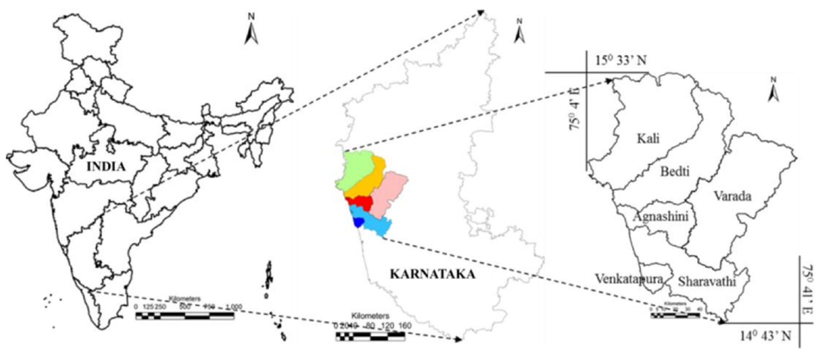


Figure 1: Study Area

Table 1: Study Area

River Basin	Area (sq.km)	Flow Direction
Varada	5135.40	East
Kali	5085.93	West
Gangavali (Bedthi)	3935.73	West
Agnashini	1448.77	West
Sharavathi	3042.71	West
Venkatapura	459.70	West
Gross Area	19108.24	

Figure 2: Administrative Division

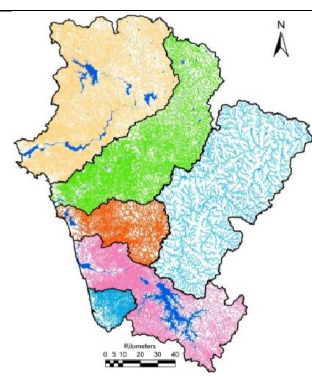


Figure 3: Drainage

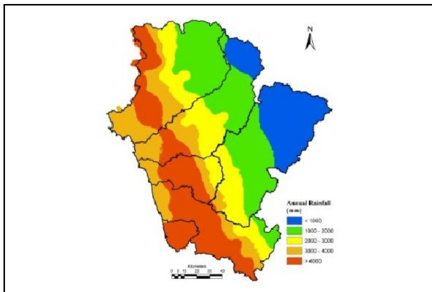


Figure 4: Rainfall Distribution

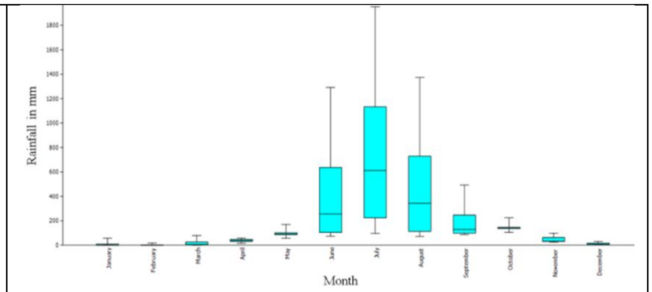


Figure 5: Rainfall Pattern

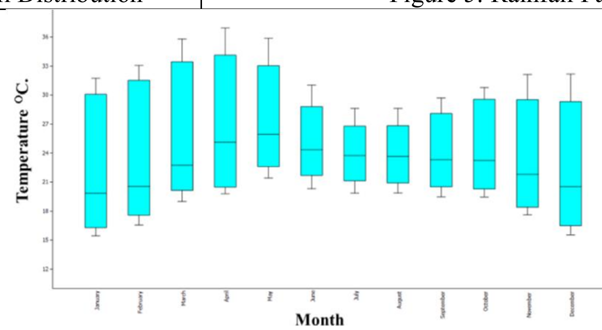


Figure 6 : Temperature variations

Table 2: Population

Basin	Population 2011	Population Density as persons per km^2
Varada	1214523	236.52
Kali	551032	108.34
Bedti	1044627	265.42
Agnashini	246067	169.85
Sharavathi	349518	114.87
Venkatapura	179744	391.00
Grand Total	3585511	187.65

3. DATA USED

Remote sensing data IRS P6 LISS IV and Landsat 8 were used for land use classification and quantification of hydrological parameters. Ancillary data such as survey of India topographic maps (1:50000, 1:250000), vegetation map (French institute, 1985) were used to delineate the drainage network, administrative boundaries, catchment, etc. Field data for geometric correction and classify the remote sensing data were obtained using GPS (Global Positioning System) apart from topographic maps and online remote sensing data [47, 48] (http://earth.google.com, bhuvan.nrsc.gov.in). Cartosat DEM of 30 m resolution was used in addition to toposheets to derive the basin and sub-basin boundaries, drainage network. Secondary data sources such as Census data of 2001 and 2011 [49] were used to compute population density in each sub basin. Publications such as 'district at glance' [50] were used in addition for obtaining data on livestock census, cropping status at taluk level. Rainfall data between 1901 and 2010 from the Department of Statistics, Govt of Karnataka [50], and India Meteorological Department [51] were used to determine the rainfall dynamics. Temperature data from WorldClim [52] and Extraterrestrial Solar Radiation data from FAO[53] were used along with land use, etc. to estimate the evapotranspiration losses. Information from Crop calendar, Web portals such as iKisan [54], Agriculture Department of Karnataka [55, 56] were used to understand the cropping pattern, season in order to estimate the crop water requirement in each month.

4. METHOD INVOLVED

Acquired satellite information is pre-processed and checked for errors, the errors are rectified (radiometric and geometric). Fig. 7 outlines the procedure followed for assessing the land use and hydrologic dynamics and the analysis of environmental flows. The training data sets derived from the field information with help of GPS, and other secondary source of data such as Google earth, Bhuvan and Topographic sheets was used in order to classify the obtained satellite data into various land use classes as specified in table 3. To understand he ecological flow, land use was integrated with the hydro-meteorological and topographical data. The rainfall data as point based information obtained from various rain gauging stations between 1900 and 2010 were interpolated to understand the rainfall variations across the basin (fig. 4 and fig. 5). Rainfall and land use along with the topographical data were used to understand the runoff characteristics across various sub catchments in each of the basin, which was estimated based on empirical equations [14, 15]. Potion of rainfall is lost in the process of interception [14, 15, 57, 58]; these losses are directly proportional to the rainfall and the land use type. The remaining portion of water after runoff and interception percolates into the substrata saturating the soils (vadose water) and recharging the ground water. The potion of recharge is estimated using Krishna Rao's equation [59] which is well suited for parts of Karnataka. Sub surface waters such as water in the vadose and the recharged ground water helps in catering the water demands post monsoon. Water percolating into the sub surfaces also helps in maintaining the river course by the process of lateral movement of water as pipe flow and base flow. The pipe flow and base flow are assessed based on the data derived based on field conditions, which were related with the catchment characteristics in order to assess the potential base flow and pipe flows in various sub catchments. The runoff water, soil water and the ground water as base flow contribute to the natural flow in the streams and as a natural supply of water.

To understand the dynamics in the demands, different source of water demands were estimated such as Evapotranspiration, Crop water requirement, Domestic water demand and Livestock water demand. Evapotranspiration is a process where in water evaporates from water bodies and transpires through vegetation to the atmosphere, this was estimated for each month spatially based Hargreevs equations [60 , 61], which takes into account the solar radiation and temperature along with the land use characteristics. The domestic demand was accounted based on water requirement for people which varies across seasons such as 135 lpcd (liters per capita per day) during monsoon, 150 lpcd during winter and 175 lpcd during summer, the population based on decadal increment between 2001 and 2011 was used in order to predict population for the year 2014. The livestock census was accounted and water requirement for different category of animals in order to maintain them was considered based on surveys with people and through telephonic interviews. Crop water requirements were estimated based on the crops grown across the sub basins based on the taluk level information based on district at glance of various districts, cropping pattern and water requirement for each crop were accounted based on the crop calendar and through telephonic interviews, the area under different crops were approximated based on the land use data and the crop information available from the district at a glance.

Table 3: Land use categories

Land Use Category	**Features**
Built up	Urban or rural buildings, roads, pavement and concrete structures
Water	Lakes, Rivers, Dams
Agriculture	Agriculture current sown and fallow lands
Open lands	Open lands, waste lands, quarries
Deciduous Forest	Moist deciduous Forest, Dry deciduous Forest
Evergreen to Semi Evergreen forest	Ever green and semi evergreen forests
Scrub/Grassland	Scrublands and grass lands
Forest plantation	Acacia Plantations, Eucalyptus plantations, Teak Plantations, Bamboo Plantations
Horticulture plantations	Areca nut Plantations and Eucalyptus Plantations

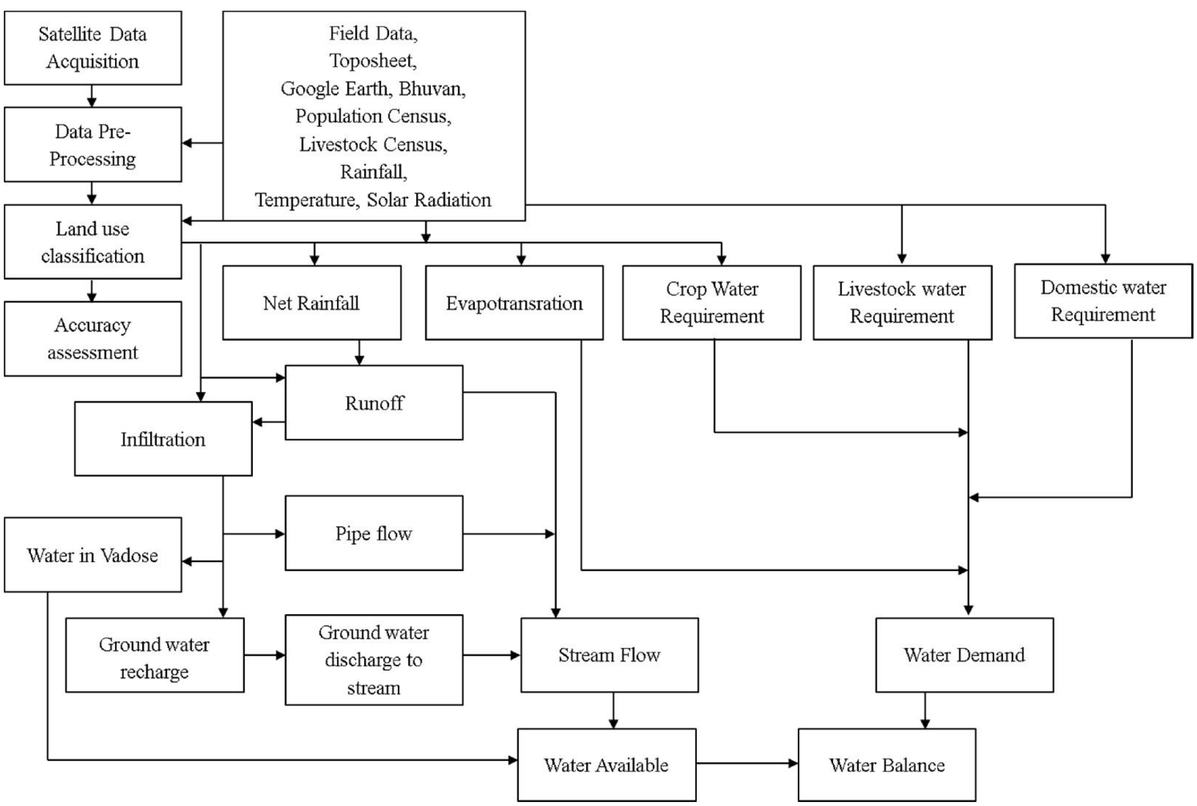


Figure 7: Method involved

Sub basin wise water balance is analysed as a function of water supply and demand for every month. The quantity of water in the basin is estimated as function of water available in the sub basins which defines the efficacy of the water resource in the catchment. Based on the filed investigations, depending on the flow, streams are categorized under various categories: **A)** Perennial (12 months), B**)** Intermittent (9 - 11 month) **C)** Intermittent (6 - 9 Months) D**)** Seasonal (3 - 6 Months) and E) Seasonal (less than 3 months). The basin experiences water stress if availability of water is lower than the demand, creating water deficit in that basin.

6. RESULTS AND DISCUSSIONS

Land use analysis: Land use analysis was carried out at basin level the results are as depicted in figure 8 and table 4, it can be observed and concluded that the ghat section of the study region has highest cover of forest to an extent of 22.61 % in 2013 and dominated by streams, Whereas towards the plains, are dominated by large number of lakes can be observed, hence behaving as source of water deposits during the monsoon in order to cater the demands during the post monsoons. Both Ghat section and plains are dominated by horticulture plantations along the drainage network. Agricultural land use dominates the plains of Shimoga, Haveri and Dharwad, and along the coasts with an area of 33.92%. The land use based on the MLC had overall accuracy of over 90% and kappa over 0.85.

Hydrological flow assessment: The hydrological assessment was carried out based on the water balance model, the efficiency of the water resource to cater the water demand is as depicted in fig.9, it could be observed that the locations with higher forest cover has no or less water deficiency with less than 3 months, the regions with degraded forests, horticulture and agriculture activates demand more water hence these regions have deficiency of water over 6 to 9months. The sub-basins of Kali and Gangavali (Bedti) towards the plains have higher water deficiency of over 6 months. The presence of horticulture plantations induces a higher amount of water demand in all seasons (post monsoon). Stream flow regime is as depicted in fig. 10. It can be observed the presence of forests has a major role in holding the water and catering to the demands across the catchment, these categories catchments show streams being perennial. On the contrary, the catchments with little or low forest cover, but with presence of large agriculture, horticulture and other landscapes, streams become intermittent or seasonal, along the plains, water is stored in lakes and regulated based on the requirements. In catchment towards the plains due to presence of inter connected lake structures, streams are intermittent but in some sub basins they are even seasonal, whereas the streams at the ghats with evergreen forests are perennial, others being intermittent with streams.

Table 4: Land use

Land Use	**Area (Ha)**	**Area %**
Urban	31848.97	1.60
Water	51314.89	2.58
Agriculture	674990.9	33.92
Open lands	40703.23	2.05
Deciduous Forest	282107.1	14.17
Evergreen forest	449896	22.61
Scrub/Grassland	70629.83	3.55
Forest Plantation	277822.7	13.96
Agriculture Plantation	110920.9	5.57

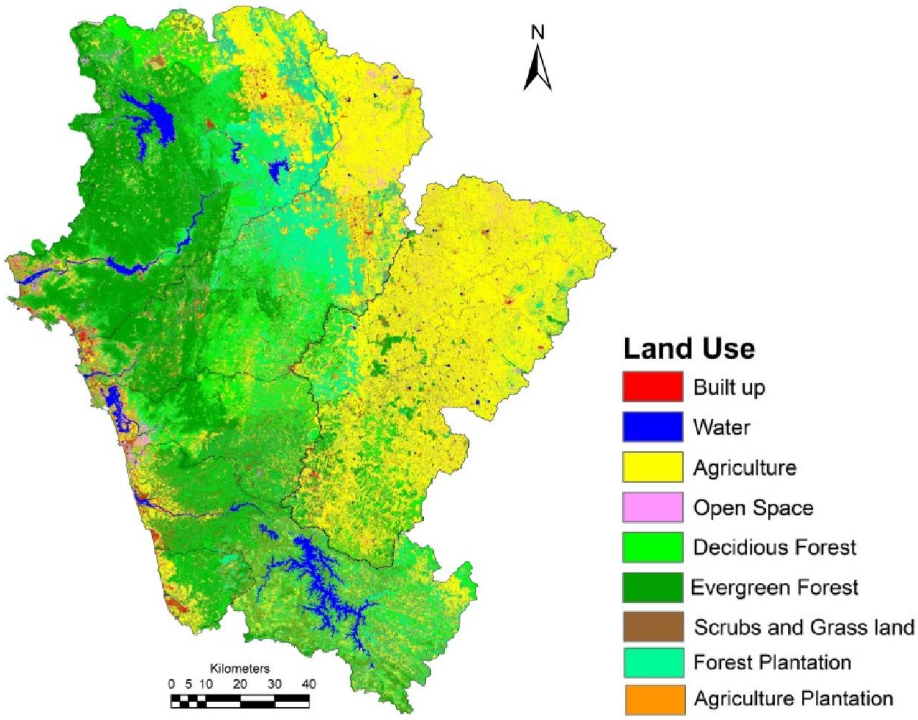
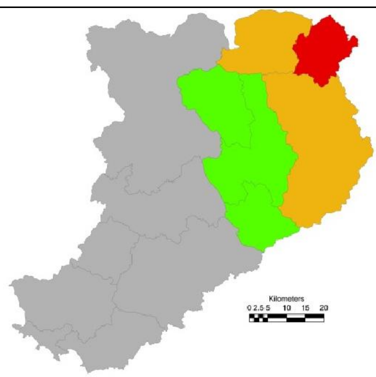
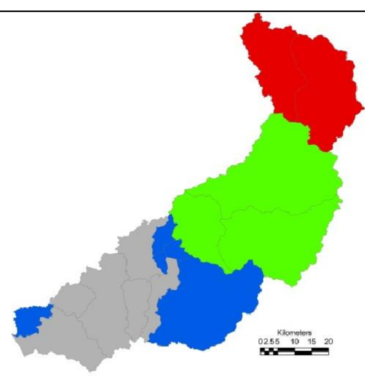
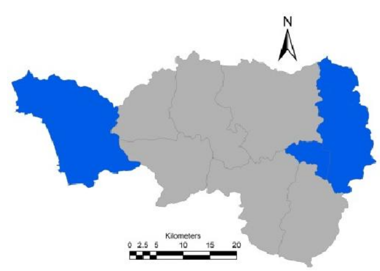


Figure 8: Land use

		
Kali	Bedti	Agnashini

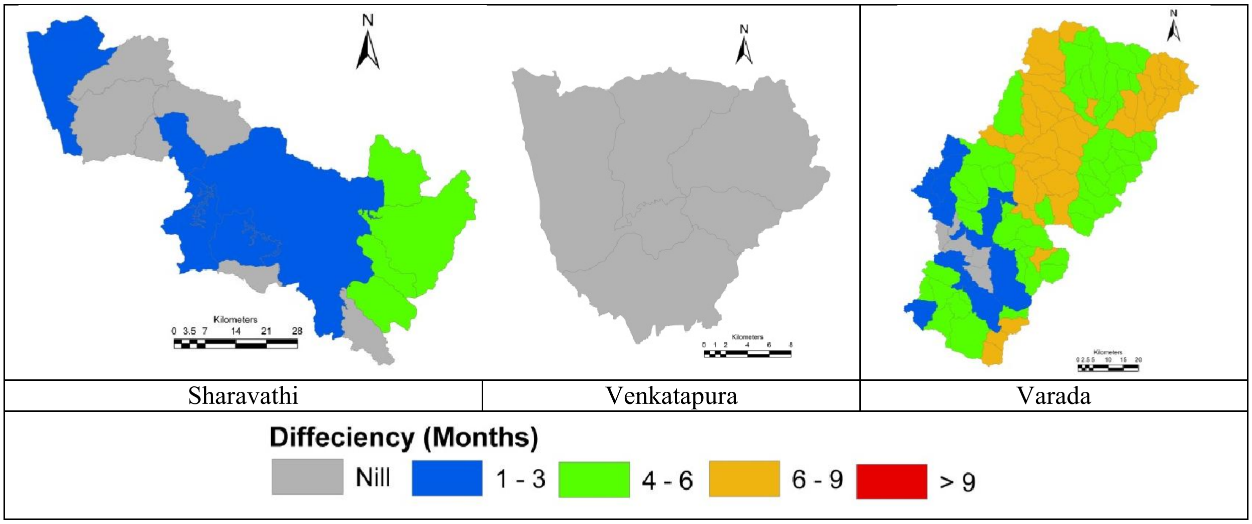


Figure 9: Efficiency of water resource

6. CONCLUSIONS

Environmental flow assessment based on the water balance model was analysed for various catchment characteristics such as the land use, meteorological, topographical, and hydrological characteristics. The study emphasizes on the land use dynamics and response towards the water needs in the watershed, use of GIS and remote sensing has enabled to better understand the land use across various watersheds and to understand bio-physical and hydrological aspects such as rainfall, population, temperature variations, etc. Basin wise assessment of hydrological status reveals that sub-basins with dominant land cover as forests of native vegetation have streams which are perennial and maintained the natural flow conditions compared to sub-basins with other land uses. The water balance model used in this study show that, the demand in basins with higher agriculture and horticultural activities is higher than that of forested areas. Study revealed that higher the forest cover in a catchment would help in catering the water demand during the post monsoon and hence catering for all the12 months, this suggests that the quantity of water flow in the streams of the sub-basins is satisfying the basic ecosystems water needs and hence maintaining at least the minimum desired environmental flow rather than those catchments which are not catering the demand of water during the non-monsoon months. The study suggests that any alterations in the land use have impact of natural flow regime hence depriving of water to cater the environment needs. It is necessary to adopt of approaches that are holistic in order to ensure minimum environmental flow in turn for the water management practices.

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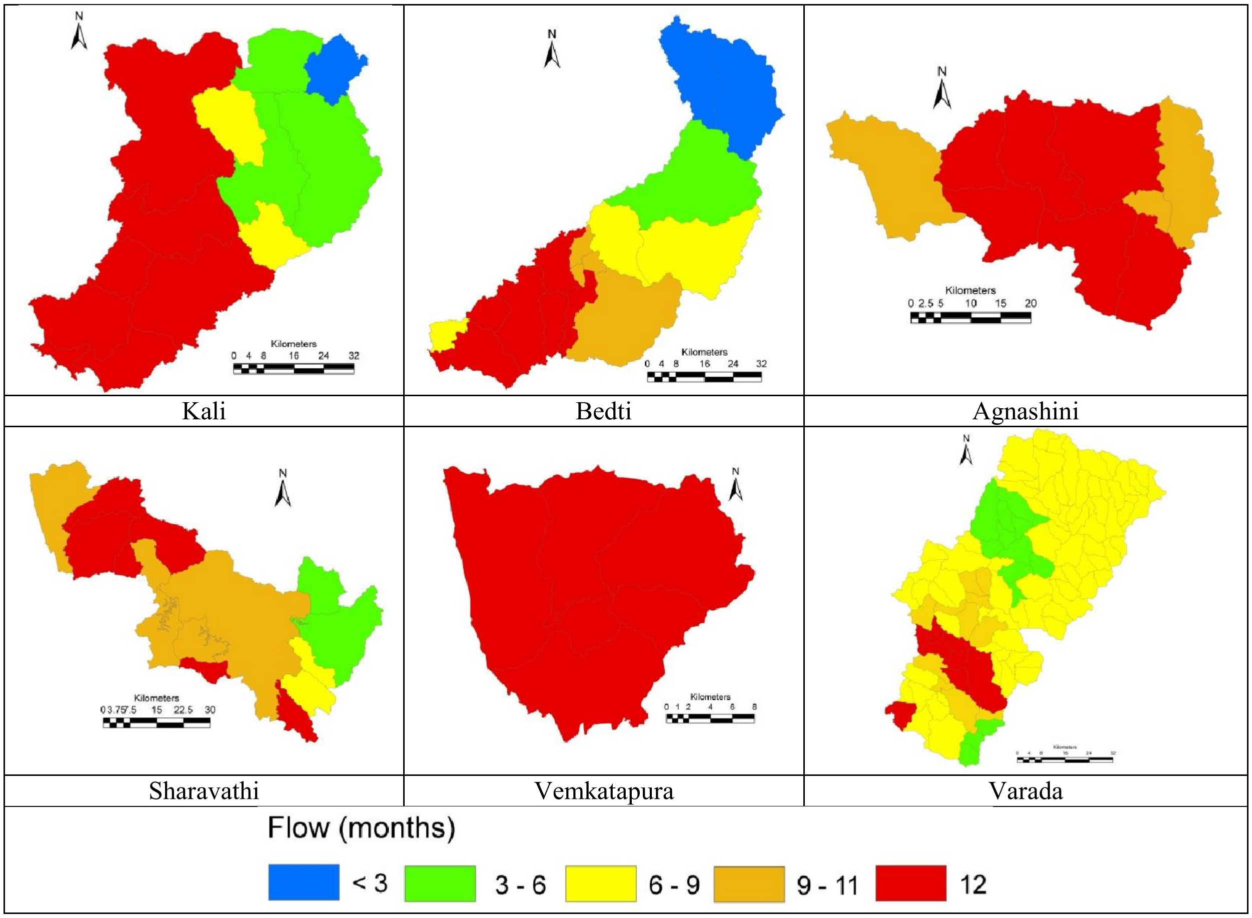

Figure 10: Stream flow regime

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