Modelling Hydrologic regime of Lakshmanatirtha watershed, Cauvery river

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***Abstract* - Basic amenities such as clean water, air and food are essential not only for human livelihood but also for the surrounding biotic habitats in the environment for sustainable development. Due to the human habitation, and the anthropogenic activities, large scale change in land use has affected the hydrologic regime across watersheds. The water resource availability in a catchment depends upon the integrity of the land use, terrain and meteorological parameters such as rainfall, temperature, etc. The land use of the catchment plays an important role in maintaining the water flow in the rivers or streams as either surface or subsurface runoff (Pipeflow and Baseflow), holding water in the sub strata's, recharging the aquifers and hence catering the water demands as per the human and environmental needs. The study was conducted in order to understand the dynamics of land use and its implication on the catchment capabilities in catering the demands of environment (forests), agriculture, domestic and livestock needs on Lakshmanatirtha catchment of the Cauvery river basin which has an area of 3969 km^2. The land use assessment using remote sensing and GIS showed the catchment is dominated (61.94%) by agriculture and horticulture, followed by forests with as area of 14.3% followed by other land uses. The Ghats (uplands) of the catchment is dominated by forests where as the plains are with agriculture and horticulture activities. Hydrologic assessment is done using the land use and the meteorological data was carried out at watershed level. The assessment showed that out of five watersheds, four of the watersheds had very high deficiency of water for over 3 months, and one of the watersheds had no deficit. The deficiency of water indicated that the watersheds were not able cater the both the human and environmental needs but also the streams were devoid of water flow which explains the deficiency in maintaining ecological flow.**

Index Terms - **Remote Sensing, GIS, Lakshmanatirtha, Watershed (catchment / basin), Hydrologic Assessment**

I. INTRODUCTION

Water is the essential limited natural resource [1] for all life forms on the planet for their growth and sustenance; production of food, economic development, social wellbeing [2]. Water is one of the unique natural resource capable of being transported, diverted, stored and recycled [2], these properties of water imparts itself as a great utility for agro-socio-economic development to the mankind. The water resource is being over utilized [3, 4] to cater the increasing agriculture and human demands in order to maintain the food security of a region. Water allocation priorities according to National Water Policy of India, 2002 [5] are: (i) drinking water, (ii) irrigation, (iii) hydropower, (iv) ecology, (v) agro-industries and non-agricultural industries, and (vi) navigation. Traditionally the water resource allocation was focused mainly upon human and agricultural needs ignoring the environmental sustainability [6, 7] leading to diversions and variations in the natural flow regime. These variations in the natural flow of water has led to massive loss of wetlands, decline of riparian's, unauthorized cultivation practices in the river beds and banks [8], loss of aquatic species [9], etc. Recent studies highlight trend of increasing global awareness in maintaining the hydrology (flow regime) that acts as a key driver in maintaining the ecology of aquatic ecosystem including wetlands [10, 11, 12, 13], land cover in a watershed [4] the flow cycles as flooding and drying that are critical for sustaining variety of plants and animals [14, 15], recognizing the need for making provision for the environmental requirements. Rivers are also the water users, and has to have an untouchable reserve [16] which has led to the concept of the ecological flow that emphasized on maintaining a flow that resembles the natural flow regime is critically important in sustaining the native biodiversity and ecosystem integrity in aquatic ecosystems [17], trying to cater the environmental water requirements while ensuring the availability of water to the basic domestic needs.

Environmental water describes the quality, quantity and timing of water flow required in the stream to sustain freshwater ecosystems, human livelihood and wellbeing that depend on the surrounding environment [18]. Environmental water availability as hydrologic variation in any river basin is dependent upon the land use and the climatological factors [19]. The change in land use adversely affects the catchment dynamics in maintaining the hydrologic conditions. Large scale land use [20, 21, 22] alterations has transformed water resource carrying capacity [23, 24, 25] required to cater the environmental water needs in the basin. In order to analyse and manage the capacity of the basins to supply resources without losing its current potential through water balance studies [26, 27] in combination with GIS and remote sensing [28, 29, 30]. Studies have used land use information derived from the remote sensing data is integrated with the long term climatological information such as rainfall [31, 32, 33], temperature and solar radiation [31, 34] etc. to evaluate the water balance in the watershed by quantifying hydrological parameters such as surface runoff, evapotranspiration, Ground water recharge, agro-domestic-livestock demands etc. Several watershed management studies in India [35, 36, 37, 38, 39, 40, 41] have been carried out in order to assess the potential of the rivers or streams in catering the demands in the basin. In this respect the objective of the study is to quantify the environmental water availability through water balance studies by understanding the dynamics of land use and its implication on the river capabilities in catering the demands.

II. STUDY AREA:

The study area considered here is Lakshmanatirtha catchment (fig1) of river Cauvery. The river originates at Bramhagiri hills [42, 43] near Irupu, of Madikeri, and meets Krishnarajasagara in Mandya [44, 45]. Extending from $12^{O}6'$ N to $12^{O}45'$ N and $75^{O}38'$ E to $76^{O}34'$ E the catchment is spread across four districts of Karnataka state namely Kodagu, Hassan, Mandya and Mysore, with an area of 3969 km^2. The altitude (fig2) of the terrain varies from 700m at plains and goes up to 1600m towards the Ghats. Geologically soils contain gravelly to well drain clay to loamy soils and rock types include Gneiss, Granite. The basin receives most of its rain (fig 2) from the South-West monsoon during June to October; rainfall in the region varies from as low as 750mm at the plains to over 3000mm at the Ghats. The temperature (fig4) in the basin on an average varies from as low as 14^{O}c in January month to as high as 32^{O}c in May month. Agriculture and horticulture activities includes paddy cropping during monsoon, ragi, maize, sugarcane, tobacco, areca nut, coconut, ground nut, other pulses, oil seeds and food crops .The population density (fig 5) in the basin has increased from 272 persons per square kilometre in 2001 to 288 persons per square kilometre in 2011at a rate of 5.8% in a decade.

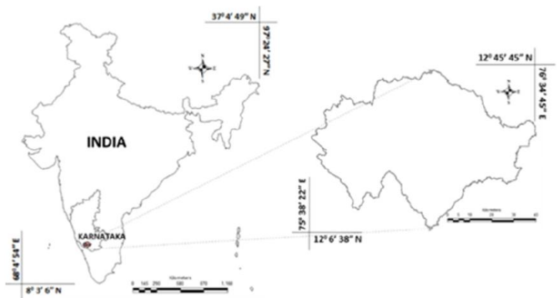


Fig. 1: Study Area

III. Data:

Table 1 lists the data used in this study. Land use in the basin was analysed using remotely sensed data of the year 2014 acquired from Landsat 8 with resolution of 30 m. Collateral data includes base layers (boundary, drainage network, etc.) digitised from the Survey of India topographic maps of scale 1:50000 and 1:250000, Bhuvan, Google Earth and Western Ghats land use vector data of French Institute of Pondicherry, Puducherry (available at India Biodiversity Portal http://indiabiodiversity.org). Daily Rainfall data starting obtained from Karnataka statistics Department, Bangalore and National Climatic Data Centre, NOAA between 1901 and 2012. Average monthly temperature data were obtained from Worldclim (http://worldclim.org), and monthly average rainfall data of WorldClim derived from NOAA was used to compare the interpolated data. Solar Irradiation data which is used to calculate the Potential

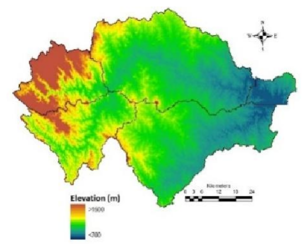


Fig. 2: Digital Elevation Model

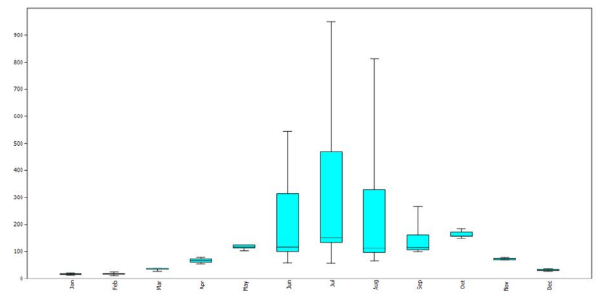


Fig. 3: Rainfall variation

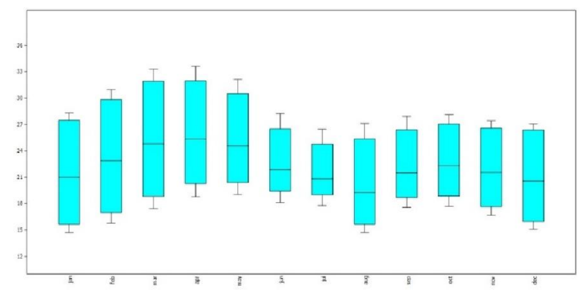


Fig. 4: Monthly Temperature variation

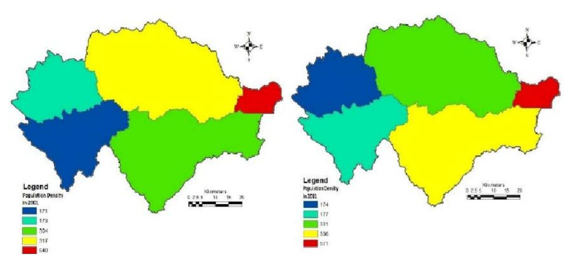


Fig. 5: Population density maps of 2001 and 2011

Evapotranspiration was obtained from Food and Agriculture Organization. Watershed extent was delineated from topographic maps along with ASTER Digital Elevation Model (DEM) of 30 m resolution. Population data of 2001 and 2011 were obtained from Census of India data (http://censusindia.gov.in). District at a glance (http://des.kar.nic.in) publications were used to obtain data regarding livestock population and net agricultural area sown for different agricultural products. Crop calendar National Food Security Mission along with the water requirement during different growth phases were used to estimate the monthly water requirement of crops grown in the sub-catchment.

IV. METHOD

Method involved in understanding the dynamics of landscape on the hydrologic regime is as depicted in fig 6. The raw satellite data both optical and radar data were downloaded from the USGS [46] public domain. Ground control points were acquired from the Surevy of India topographic maps, field data, Google earth or Bhuvan to correct the remote sensing data.

TABLE 1: DATA USED

Data	Source
Remotely Sensed Satellite data	Landsat 8 Satellite, 2013 [46]
Rainfall	Rain gauge stations from National Oceanic and Atmospheric Administration – NOAA [32], Department of Statistics – Karnataka [47]
Crop Calendar	Agriculture Department of Karnataka [48]. iKisan [49], National Food Security Mission [50].
Crop Coefficient	Food and Agriculture Organisation- FAO [34], Agriculture Department of Karnataka [48].
Temperature (max, min, mean), Extra-terrestrial solar radiation	Worldclim [31], Food and Agriculture Organisation- FAO [34]
Population Census	Census India 2001 and 2011 [51]
Livestock Census	District at a glance, Hassan, 2011-2012 [52] District at a glance, Kodagu, 2011-2012. [53] District at a glance, Mandya, 2010-2011. [54] District at a glance, Mysore, 2011-2012. [55]
Digital Elevation data	Satellite Radar Topographic Mission-SRTM, Advanced Space borne Thermal Emission and Reflection Radiometer-ASTER from USGS Earth Explorer [46] and CARTOSAT DEM from NRSC-bhuvan [56]
Secondary Data	Google Earth [57], Bhuvan [56], French Institute Maps from India Biodiversity Portal [58], The Survey of India (SOI) topographic maps (1:50000 and 1:250000 scales)
Field data	GPS based field data, Feedback from public

Optical images were checked for any inherent radiometric errors from the source. The digital elevation data from SRTM was used in order to delineate the catchment, watershed maps and stream network of the Lakshmanatirtha River, the DEM was supported in addition with the topo-sheets, Carto-DEM, ASTER to increase the precision in delineation. The catchment boundary and watershed maps were further used for the land use and hydrologic analysis. The Optical and Infrared bands of satellite data were used in order to characterize the land use of the catchment as well as the watersheds. To understand the information obtained from the satellite image, the optical and infrared bands such as Green, Red and Near-Infrared were combined together to prepare FCC i.e., false colour composite, to identify the heterogeneity in land use across the catchment. Training data were collected basin on ground knowledge and secondary data sources such as Bhuvan and Google earth, of which 70% of the training polygons were used to classify the image and the remaining 30% for accuracy assessment. Of the different soft classifiers, a very well proven algorithm i.e., Gaussian maximum likelihood algorithm [29, 30, 59] was used to classify the satellite image into various land use information as in table 2. Accuracy assessment and kappa analysis was carried out in order to check the accuracy and agreement of the classification result with the reference

Rainfall data for over 110 year from Statistics department of Karnataka and NOAA for the rain gauge stations inside and surrounding the catchment were interpolated in order to evaluate the rainfall spread across the catchment in different months. The interception loss was accounted as this is the water that is stored on the canopy of the vegetation and effectively doesn't reach the earth surface, but escapes into atmosphere as evaporation. The net rainfall reaching the surface of the earth is derived as the difference between the gross rainfall and the interception in the watershed, and is used to effectively understand the hydrological variations in each of the watershed.

Runoff is the amount of water that flows in excess after the soil reaches its saturation condition and with reduction in the infiltration capacity of the soil under different land use criteria's. Runoff ***Q*** is estimated empirically [26, 27] using equation 1, where ***C*** is the Coefficient of land use, ***A*** is the area under the land use and ***P*** is the Net Precipitation in mm. The Coefficient of Runoff for different land uses were considered is as in table 3.

$$Q = C*A*P \qquad (1)$$

Of the percolated rain water, portion replenishes the ground water zone (saturated zone) and the balance is stored in the soil and sub soils up to the **hypomorphic** layer [60] referred to as vadose water. Portion of the vadose flows into the streams as pipe flow and portion of the ground water recharged, flows into the streams as base flow and the remaining recharges the aquifer. The ground water recharging capability of the basin is estimated using the Krishna Rao's equation (equation 2), which is well suited for the study area.

$$G_R = R_C * (P - K) * A \qquad (2)$$

where,

G_R is the annual ground water recharge, RC is the recharge coefficient, K is the rainfall coefficient. Table 4 gives the details of the coefficients.

TABLE 2: LAND USE CATEGORIZATION

Land Use	**Description**
Agriculture	Current Fallow and Sown Crop lands
Agricultural Plantations	Arecanut, Coconut, Coffee/Tea, Rubber
Forest Plantations	Acacia, Bamboo, Eucalyptus, Teak
Evergreen Forest	Evergreen and Semi Evergreen Forest
Moist Deciduous Forest	Moist Deciduous Forest
Dry Deciduous Forest	Dry Deciduous Forest, Grassland and Scrub lands
Built-up land	Buildings, Roads, and other paved surfaces
Water Bodies	Lakes, Rivers, Ponds, Reservoirs
Open/ Barren lands	Rocky Outcrops, Open spaces/Grounds, Wastelands

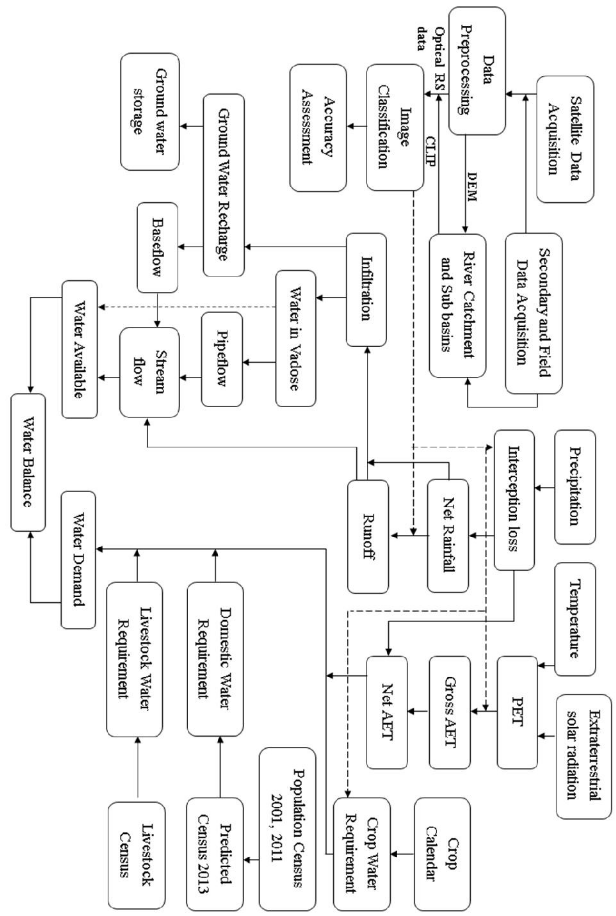


Fig. 6 : Method involved

TABLE 3: RUNOFF COEFFICIENTS

Land Use	**Runoff Coefficient C**
Built-up	0.9
Agriculture	0.5
Open lands	0.6
Moist Deciduous Forest	0.15
Evergreen to Semi Evergreen forest	0.1
Forest Plantation	0.6
Agriculture Plantation	0.5
Dry Deciduous Forest	0.15

TABLE 4: GROUND WATER RECHARGE COEFFICIENT AND RAINFALL COEFFICIENT

Annual Rainfall	**R_C**	**K**
400 to 600mm	0.20	400
600 to 1000 mm	0.25	400
> 2000 mm	0.35	600

The water in the vadose zone is taken as the difference of infiltration and ground water recharge. Partial of the recharged ground water goes to the stream as base flow B_F, based on studies conducted earlier and field data, base flow B_F into the stream is given by equation 3, the yield Y_S characteristics based on the geological criteria's.

$$B_F = G_R * Y_S \qquad (3)$$

The characteristics of the watershed such as runoff, vadose water and base flow contribute toward the water supply, whereas the demand in the watershed are due to evapotranspiration, agriculture and horticulture water requirement, domestic and livestock water requirement. The evapotranspiration is dependent upon characteristics such as temperature, solar radiation, and land uses in the basin, portion of the evaporation of the basin is taken care by the intercepted water. Evapotranspiration is calculated using equation 4.

$$AET = A*(PET - Interception)*Kc \qquad (4)$$

Where AET is the actual evapotranspiration, PET is the potential evapotranspiration and Kc is the evaporation coefficient based on the land use. PET (eq 5) is estimated using the Hargreaves equation which accounts the minimum and maximum temperatures and extra-terrestrial solar radiation. The evaporative coefficients for various land uses area as in table 5. The croplands and horticulture lands were not accounted for estimating the AET since the crop water requirements included the water requirement for each crop based on their growth phase.

$$PET = 0.0023 * (R_A/\lambda) * \sqrt{Tmax - Tmin} * \left(\frac{Tmax+Tmin}{2} + 17.8\right) \qquad (5)$$

where,
R_A = Extra-terrestrial radiation (MJ/m2/day)
Tmax = Maximum temperature
Tmin = Minimum temperature
λ = latent heat of vaporization of water (2.501 MJ/kg)

TABLE 5: EVAPORATIVE COEFFICIENTS

Land Use	**K_C**
Built-up Land	0.15
Moist deciduous Forest	0.95
Dry Deciduous Forest	0.85
Evergreen forest	0.95
Water	1.05

The crop water demand (eq 6) for each crops were estimated by calculating the area under each crop, growth phase of each crop and water requirement based on different growth phases. Water requirement for livestock was estimated based on livestock type [61], number of animals under each category, water requirement per animal (table 6) and season. Livestock type and population were as per the publication - district at a glance.

Crop water Requirement (monthly) = Σ (Area under each crop * Crop water required under each crop) (6)

$$P_{2013} = P_{2011} * (1 + 0.2 * r_{2001\text{-}2011}) \qquad (7)$$

TABLE 6: LIVESTOCK WATER REQUIREMENT AS LITRE/ANIMAL

Season	Cattle	Buffalo	Sheep	Goat	Pigs	Rabbits	Dogs	Poultry
Summer	100	105	20	22	30	2	10	0.35
Monsoon	70	75	15	15	20	1	6	0.25
Winter	85	90	18	20	25	1.5	8	0.3

Domestic demand, similar to live stock, was estimated as product of population for the year 2013 under each basin and water requirements based on season (table 7). Population for the year 2013 P_{2013} was estimated by using the growth rate between 2001 and 2011 $r_{2001\text{-}2011}$, and population of the year 2011 P_{2011}, to estimate the population rate of interest method (equation 7) was used

TABLE 7: DOMESTIC WATER REQUIREMENT AS LPCD

Season	Demand
Summer	150
Monsoon	120
Winter	135

Both the demand and supply for every month were analysed to assess the hydrological status of the basin in order to cater the needs of the environment, agricultural, domestic and livestock needs. If the supply is lesser than that of demand, the catchment is said to be in high water stress condition, else the water in the watershed catering the current needs there by in other words maintaining the environmental flow of the catchment. For more precision, the needs such as industrial, hydro-power, fish and other water requirement along with characteristics such as timing of flow, quality, and quantity can be supplemented.

V. RESULTS AND DISCUSSION

Land use analysis was carried out for the year 2013 using Landsat 8 dataset, and the results area as depicted in fig 7 and in table 8. The accuracy of the classification was 94% and the kappa was 0.92.

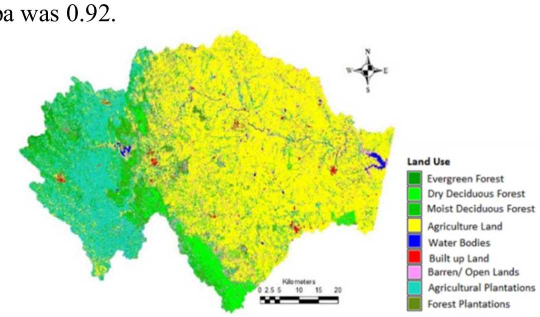


Fig. 7: Land use Lakshmanatirtha

Rainfall data of 22 rain gauge stations (inside and surrounding the catchment) were interpolated in order to assess the rainfall distribution and is depicted in fig 8. Ghats shows presence of very high rainfall over 3000 mm and the plains with less than 1000 mm annually, and the annual net rainfall in each of the watershed is as depicted in fig 8.

TABLE 8: LAND USE OF LAKHSHMANATIRTHA CATCHEMENT

Land Use	Area (ha)	Percent
Agriculture	208125.9	52.44
Agricultural Plantations	77380.91	19.50
Forest Plantations	24490.53	6.17
Evergreen Forest	8962.47	2.26
Moist Deciduous Forest	18040.5	4.55
Dry Deciduous Forest	30133.53	7.59
Built-up land	2805.39	0.71
Water Bodies	2545.47	0.64
Open/ Barren lands	24432.39	6.16
Total Area	396916.89	100

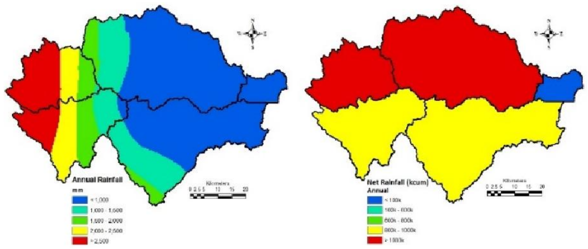
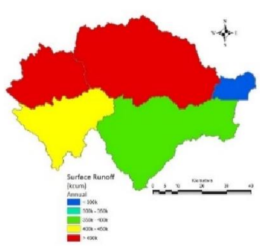
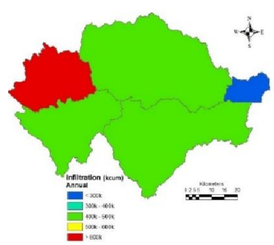


Fig. 8: Rainfall distribution

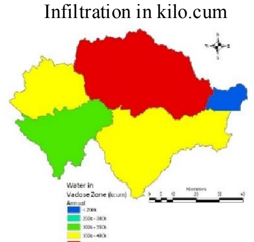


Runoff in kilo.cum



Infiltration in kilo.cum

Ground Water Recharge in kilo.cum



Water in Vadose kilo.cum

Fig. 9: Net Rainfall, Infiltration, Ground Water recharge and Water in Vadose in kilo.cum

The hydrologic characteristics of the watersheds are depicted in fig. 9. It can be visualized that, the presence of forest in the Ghats has its role in reducing the surface runoff, increased infiltration levels, higher water storage capacity in the vadose and higher recharge into the ground water. On the contrary, the presence of open land, agriculture fields, and plantation activities has led to higher runoff, followed by lower infiltration levels. The demand of water as domestic, agriculture, livestock and the evapotranspiration is as shown in fig. 11 and the total demand calculated as sum of domestic, agriculture, livestock and evapotranspiration is as depicted in fig 12. To estimate the demand of domestic water, population for the year 2013 was estimated and is as depicted in fig. 10. From fig. 12, i.e., the total demand, it could be observed that in which ever the watershed, the population is high and higher agricultural activates exists, the demand for water is rather high compared to those in watersheds with higher natural vegetation cover this contributes to evapotranspiration only.
Based on the monthly supply and demand of water the water balance in the catchment was assessed and is as depicted in fig. 13, it was found that the water availability in the watersheds to cater the demand was higher in those with higher forest cover and less in that where in forests is very sparse, accompanied by variations in the rainfall. The Ghats regions of the catchment showed higher water availability than that of the plains which showed higher water deficiency and hence it can be said that these watersheds are failing to maintain the environmental flow.

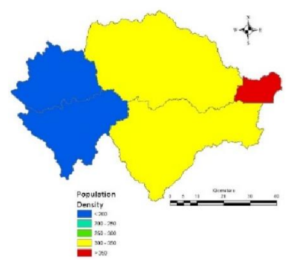
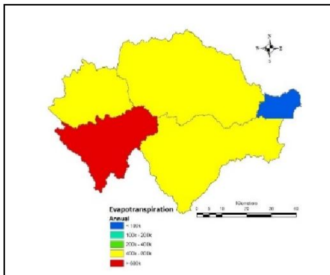
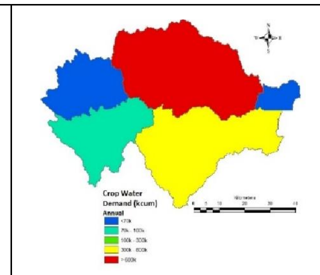


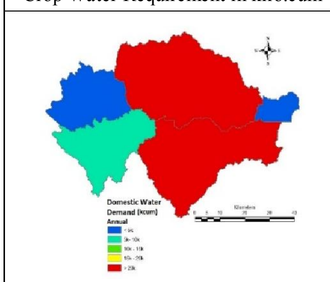
Fig. 10: Population density for the year 2013 as persons per sq.km



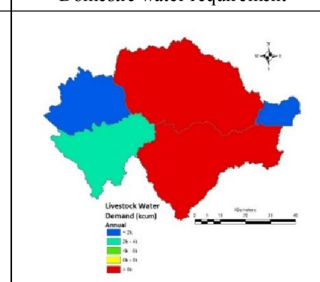
Crop Water Requirement in kilo.cum



Domestic water requirement



Livestock water requirement kilo.cum



Evapotranspiration in kilo.cum

Fig. 11: Crop water requirement, Domestic Water requirement, Livestock Requirement and Evapotranspiration

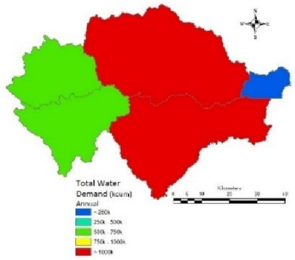


Fig. 12: Total Demand

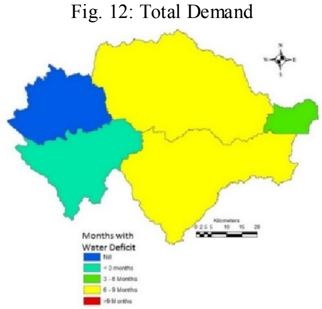


Fig. 13: Water Deficiency in the basin

VI. Conclusions

The study emphasizes the land use dynamics and their response towards the water needs in the watershed. The 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, *etc*. The landuse was analysed for the year 2013, the catchment is covered with 14.4% of vegetation, it could be observed that the Ghats regions of the catchment has higher vegetation cover compared to that of the plains. The hydrologic assessment demonstrated that with high rainfall towards the Ghats, the characteristics such as water holding capacity with lower runoff, higher infiltration capacity are towards regions with good vegetation cover. The presence of higher forest cover in a catchment would help in catering the demands of water during the post monsoon hence catering for all the12 months, this suggests that the flow of water in the basin 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.

Acknowledgment

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