

# HYDROLOGIC MODEL WITH LANDSCAPE DYNAMICS FOR DROUGHT MONITORING

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**KEY WORDS:** Remote sensing, Western Ghats, Sharavathi, water budget, Water stress Drought.

## ABSTRACT:

Drought refers to the deficiency in the surface or underground water over extended period of time affecting the regional economy and livelihood. Alterations in the hydrological regime at sub-basin level could be due to either natural phenomenon or due to anthropogenic activities. The current communication models the hydrologic regime considering landscape status in the central Western Ghats. Hydrological regime assessed based on water balance, gives information about the hydrological status of basin. Temporal remote sensing data with geoinformatics aids in quantifying landscape dynamics, while hydrological state variables were based on the meteorological data. The quantification has been done at sub-basin level for select rivers in Uttara Kannada district of Karnataka. Rivers were chosen based on the level of anthropogenic activities such as dam constructions, conversion of forests to monoculture plantations, etc. Regional meteorological data such as precipitation, temperature, evaporation, etc., along with crop water requirement, domestic and livestock water requirements were used for water budget at sub basin levels. The hydrological status in different basins was expressed as function of water available to that of water demand. The analysis brings out the relationship of catchment land use dynamics with the water availability and stress. The model based on meteorological and land use parameters help in detecting the levels of water stress and linkages with land cover in the respective sub-basin. This helps the decision makers in adopting appropriate mitigation measures to overcome the water stress.

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## 1. INTRODUCTION

Landscape refers to a portion of heterogeneous terrain with the interacting ecosystems and is characterized by its dynamics, which are governed by human activities and natural processes (Ramachandra et al., 2012a). Human induced land use and land cover (LULC) changes have been the major driver of the landscape dynamics at local levels. Understanding of landscape dynamics helps in the sustainable management of natural resources (such as water, land, etc.). Forests are degrading due to large scale anthropogenic activities involving the conversion into agriculture fields (Lin and Wei 2008), or horticulture lands, hydro schemes etc. in turn affecting the hydrological regime (Ramachandra et al 2013, Bonella et al 2010, Lin and Wei 2008). This also has led to higher soil loss through erosion affecting the productivity and water holding capacity of the soils (Subramanian 1998), increased agricultural activities and human interference leads to higher water requirement, if not catered through other available sources leads to agriculture drought conditions. Altered and lower flows in the river are key contributors to the decline in river health and its environs manifested in ways such as increasing algal blooms, a decline in native fish numbers and increases in exotic species, and a decline of wetlands (Sahbaz Khan, 2004). To overcome such issues, it is necessary to analyse and manage the capacity of the basins to supply resources without losing its current potential through water balance studies (Subramanya 2005, Raghunath 1985) in conjunction with GIS and remote sensing (Neil and Matthew 2012, Mallikarjuna et al 2013). Remote Sensing (Ramchandra et al 2012a, Vinay et al 2012) has advantages such as wider synoptic coverage of the earth surface with varied temporal, spatial and spectral resolutions to monitor these changes.

Drought is a natural phenomenon that has significant adverse effect on the socio-economic, agricultural, and environmental conditions (Nezar and Ali, 2007; Bhuiyan et al, 2006) caused due to the water deficiency either meteorologically or due to anthropogenic activities such as excessive human activities (agriculture, horticulture etc.) due to, increasing population and increased demand of natural resources that are exploited at a very large scale (Ramachandra and Bharath, 2012, Ramachandra et al 2012a). A drainage basin perspective is essential for understanding the upstream downstream connectivity of water supplies, water demands, and emerging water problems. The land use information derived from temporal remote sensing data integrated with the long term meteorological information such as rainfall (Reshma et al 2012), temperature, etc. aid in assessing the water balance of a river basin through quantification of hydrological parameters such as runoff, infiltration, base flow etc. The objective of the study is to model hydrological dynamics of a river basin to monitor the water availability including drought conditions. The current work is done at sub basin level in the Sharavathi river basin, central Western Ghats.

## 2. STUDY AREA

Sharavathi is a west flowing river located in the Central Western Ghats of Karnataka State (figure 1). The river basin extends  $17^{\circ} 24' 14''\text{E}$  to  $75^{\circ} 19' 31''\text{E}$  Longitude and  $13^{\circ} 43' 2''\text{N}$  to  $14^{\circ} 25' 52''\text{N}$  Latitude, with area of  $3042.7\text{ km}^2$ . Originating from Shimoga (Ambhu Thirtha), has spread across two districts: a) Shimoga and b) Uttara Kannada, joins Arabian Sea at Honnavara of Uttarakannada. Sharavathi catchment receives an annual rainfall (figure 2) of 2000 mm to more than

6500 mm with 5 rainfall month over 100 mm between June to October. The terrain (figure 3) is undulating and varies from as low as 0 m at sea to more than 1000 m in the Sahyadri's. The population density (figure 4) of the basin on an average has increased from 90 persons per square kilometer in 1991 to 105 in 2001 and 115 persons per square kilometer in 2011. From early 80's the region is started experiencing changes in land use for various developmental activities. This conversion has occurred largely at the expense of forests and grassland (Ramachandra et al., 2007; Bharath and Ramachandra, 2012).

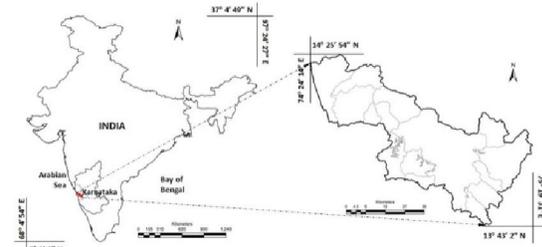


Figure 1: Study Area

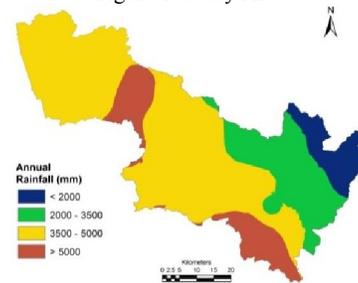


Figure 2: Annual Rainfall Spatial distribution

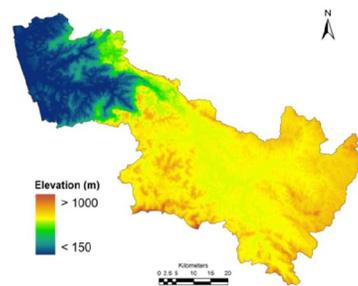
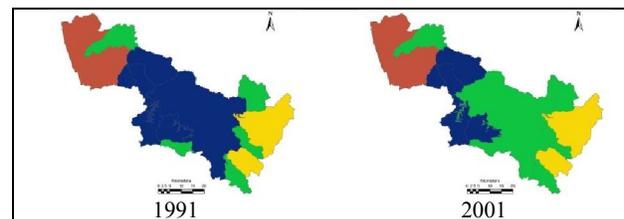


Figure 3: Terrain



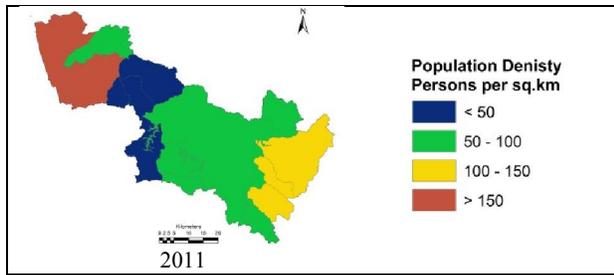


Figure 4: Population

### 3. DATA USED

Remote sensing data IRS P6 LISS IV of 5 m resolution was used for land use classification and quantification of hydrological parameters. Ancillary data such as topographic maps (1:50000, 1:250000), vegetation map (French institute, 1985) were used to delineate the drainage network, administrative boundaries, catchment, etc. Training data to geometric correction and classify the remote sensing data were obtained from field using GPS (Global Positioning System) apart from topographic maps and online remote sensing data (<http://earth.google.com>). 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 2011 (<http://censusindia.gov.in>) was used to compute population density in each sub basin. Publications such as 'district at glance' was used in addition for livestock data in sub basins. Rainfall data between 1901 and 2010 from the Department of Statistics, Govt of Karnataka (<http://des.kar.nic.in>), and India Meteorological Department (<http://www.imdpune.gov.in>) were used to determine the rainfall dynamics. Temperature data from WorldClim (<http://worldclim.org>) was used along with land use, etc. to estimate the evapotranspiration losses. Crop calendar was used to estimate the crop water requirement in each month.

### 4. METHOD

Figure 5 outlines the procedure followed for assessing the land use and hydrologic dynamics and the analysis of drought episodes. Remote sensing data procured from NRSC, Hyderabad (<http://nrsc.gov.in>) were rectified using the ground control points (GCP's) acquired from field using GPS and other ancillary sources (like SOI Topographic maps, etc.). River catchment and sub-basins are delineated using topographic maps (of the Survey of India, 1:50000 scale) along with DEM. Training data to classify remote sensing data and validate classified data were acquired from field using GPS in addition to online resources such as Google Earth (<http://earth.google.com>) and Bhuvan (<http://bhuvan.nrsc.gov.in>). Classification of remote sensing data was done using the Gaussian Maximum likelihood algorithm which is proved to perform better than other classification algorithms (Duda et al., 2002; Bharath et al., 2012; Ramachandra et al., 2013). Of the field data, 60% of the data was used to classify and the rest 40% of the data was used for accuracy assessment of the classified database. The classified land use data was used to estimate the water balance using the other hydro meteorological parameters such as rainfall, temperature, solar radiation, etc. The Net rainfall based on the

land use was estimated to eliminate the loss of water due to interception of water by the vegetation during the down pour.

The net rainfall, along with the land use was used to estimate the runoff in each of the river sub basins using the rational formula (equation 1), where  $R$  is the surface runoff,  $P_{net}$  is the net rainfall in mm,  $C$  is the land use runoff coefficient and  $A$  is the area of the catchment. The amount of water in-filtered (Inf) into the subsurface is calculated as the difference between the Net Rainfall and Runoff, based on equation 2 for Western Ghats, where  $G_R$  is the Ground water recharge,  $R_C$  is the Ground water recharge coefficient (listed in table 1),  $K$  is the rainfall coefficient. The water in-filtered flows to the stream as either base flow (equation 3) or as ground water discharge (equation 4), where  $B_F$  is the base flow,  $K_P$  is the base flow coefficient,  $G_D$  is the ground water discharge into the stream,  $Y_S$  is the specific yield.

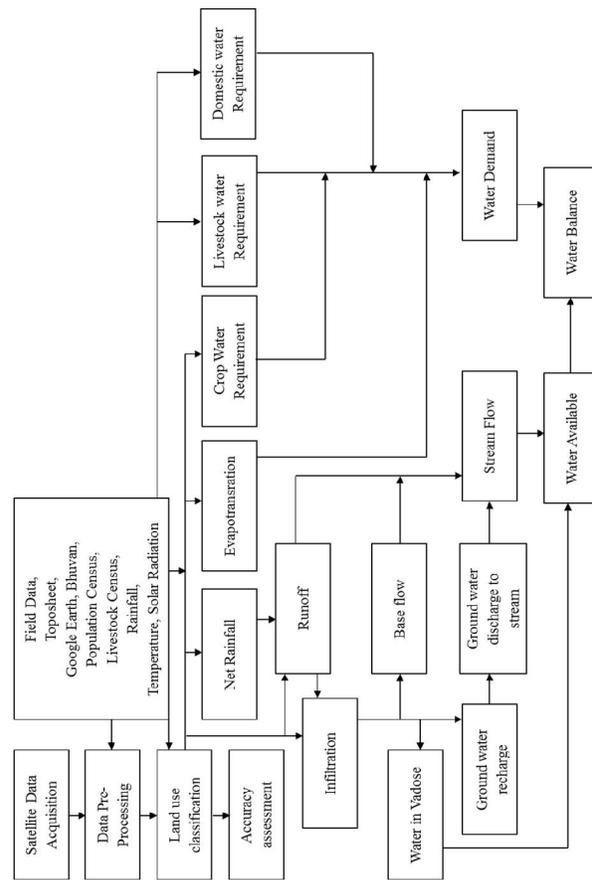


Figure 5: Method involved

Based on the land use, the coefficient of base flow and ground water discharge varies in each sub-basin. Table 2 lists coefficients of base flow and water discharge for each sub-basin based on land uses in the respective basin. All these factors such as  $R$ ,  $B_F$  and  $G_D$  contribute to the flow in the stream during different seasons in a year through satisfying the demands and losses. The water available in the basin is estimated as function of flow in the stream, and other stored water sources such as soil water/ water in vadose zone.

$$R = P_{net} * C * A \quad (1)$$

$$G_R = R_C * (P_{net} - K) * A \quad (2)$$

$$B_F = (I_n - G_R) * K_P \quad (3)$$

$$G_D = G_R * Y_S \quad (4)$$

Annual Rainfall	R <sub>c</sub>	C
400 to 600mm	0.20	400
600 to 1000 mm	0.25	400
> 2000 mm	0.35	600

Table 1: Ground water recharge coefficient

Sub basins	K <sub>p</sub> %	Y <sub>s</sub> %
Yennehole	10	15
Hurlihohle	10	15
Nagodihohle	10	27
Hilkunji	10	15
Sharavathi	10	15
Mavinahole	30	3

Table 2\*: Baseflow and ground water discharge coefficients  
\* Based on field data

The demand of water is calculated as function of evapotranspiration, crop water, household (domestic water) and livestock water requirements. Evapotranspiration is calculated using the Hargreaves equation (equation 5) based on the average monthly maximum and minimum temperature (T<sub>max</sub>, T<sub>min</sub>), solar radiation (S<sub>r</sub>) and the evapotranspiration coefficient (E<sub>c</sub>) which varies from land use to land use. The crop coefficient was calculated for different time frames based on individual crop water need based on various growth phases of the crop, and cropping pattern in the year based on the annual crop calendar. The water required for livestock or for the domestic purpose varies from season to season, in case of livestock, the water required varies on type of animal.

$$E = 0.0023 - \frac{S_r}{2.501} * \sqrt{T_{max} - T_{min}} * \left( \frac{T_{max} + T_{min}}{2} + 17.8 \right) * E_c \quad (5)$$

Sub-basin wise water balance is estimated as a function of water supply to that of demand in the respective month. The flow in the basin is estimated as function of water available as stream flow in sub basins. Based on the filed investigations, depending on the flow, streams are categorized under four categories: A) Perennial (12 months), B) Seasonal (9 month) C) Seasonal (6 Months) D) Seasonal (less than 4 Months). The basin experiences water stress if availability of water is lower than the demand, creating water deficit in that basin.

## 5. RESULTS AND DISCUSSIONS

Figure 6 depicts the land use based on the classification of remote sensing data of 2010 and land use statistics are listed in table 3. Sharavathi river basin has a total forest cover of 33.7% followed by forest plantations (22%), and agriculture (14 %). The overall classification accuracy is 91.51% with kappa of 0.90. Figure 7 depicts sub basin wise hydro-meteorological parameters such as net rainfall, runoff, infiltration, ground water recharge, and evapotranspiration.

The hydrological parameters together contribute to the water supply. The demand given in Figure 8 is estimated as a function of crop water, domestic and livestock water demand, and losses such as evapotranspiration. Water demand is higher in sub-basins with higher human population coupled with agriculture and horticultural activities.

Figure 9 illustrates the water balance in each basin considering water availability and the requirement in each basin. The coastal sub basins experiences water stress, due to higher water demand Figure 10 groups the basins depending on the availability of water in streams as A, B, C or D. This also highlight the linkages of water availability with the land use as basins with higher cover of forests with native vegetation have water availability all 12 months or A type streams catering all demand (agriculture, domestic, horticulture and livestock), while the basins where large scale land use changes also witness water scarcity evident from the presence of C or D type streams.

## 6. CONCLUSIONS

Water balance assessment at catchment level helps in identifying the factors playing the role in the water yield. Impending climate change due to global warming has necessitated adoption of holistic approaches in the water resources management to ensure sustainability. Land use dynamics and quantification of hydrological parameters using remote sensing and GIS helps in the planning and sustainable management of natural resources. Basin wise assessment of hydrological status reveals that basins with dominant land cover as forests of native vegetation have streams which are perennial 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, where only water is lost through evapotranspiration. This analysis would help in hydrologists and land use managers in identifying basins that would be prone to water stress, and suitably plan for restoration of natural forests through afforestation, differ the cropping pattern, avail the water resource though the aquifers to satisfy the exact demand or plan for check dams to store water considering the topography and land use to overcome drought like conditions.

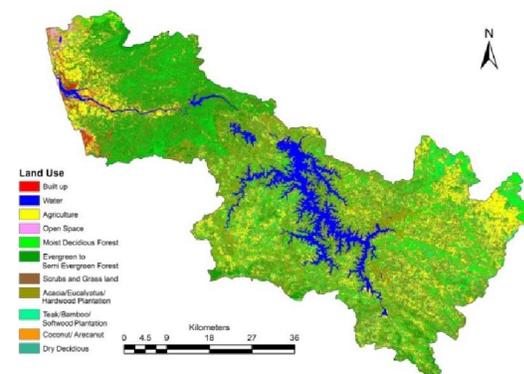


Figure 6: Land use 2010

Land use	Area Ha	Percent
Urban	2937.248	0.97%
Water	21017.41	6.91%
Agriculture	42803.92	14.07%
Open lands	3443.096	1.13%
Moist Deciduous Forest	42954.99	14.12%
Evergreen to Semi Evergreen forest	59711.55	19.62%
Scrub/Grassland	27592.47	9.07%
Acacia/Eucalyptus	41290.43	13.57%
Teak/Bamboo	25922.35	8.52%
Coconut/Arecanut	36595.8	12.03%
Dry Deciduous	0	0.00%
<b>Total Area</b>	<b>304269.3</b>	

Table 3: Land use 2010

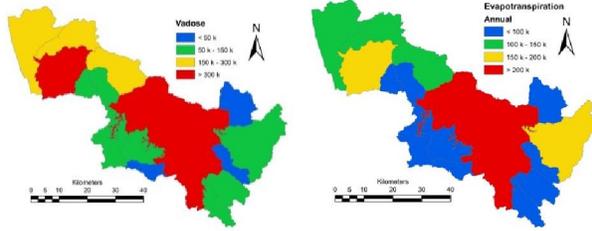
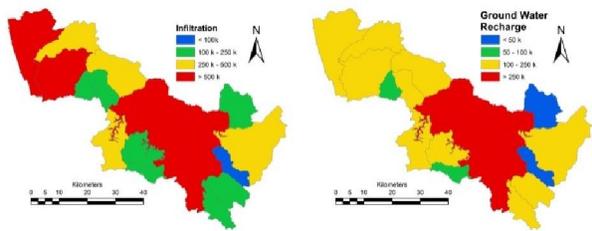
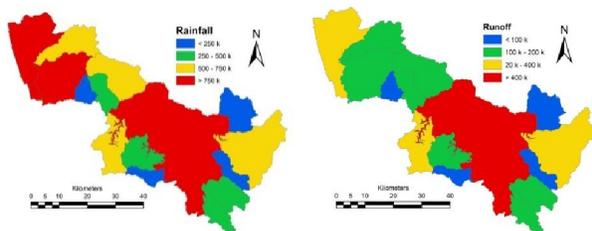
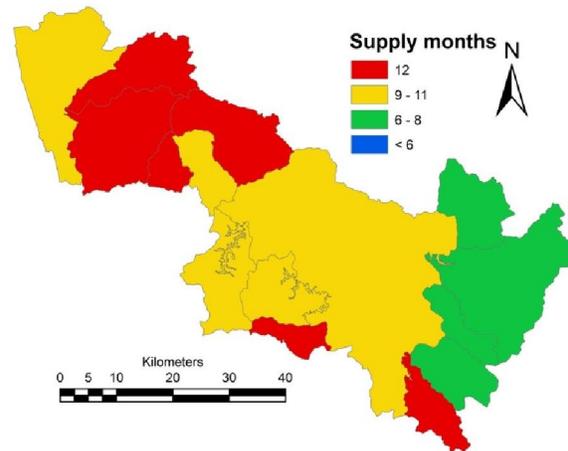
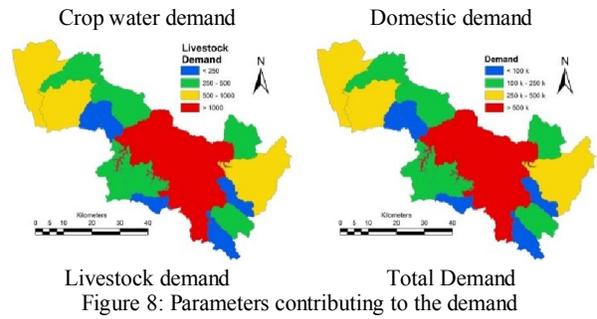


Figure7: Hydro-meteorological parameters (all units in Million litres)

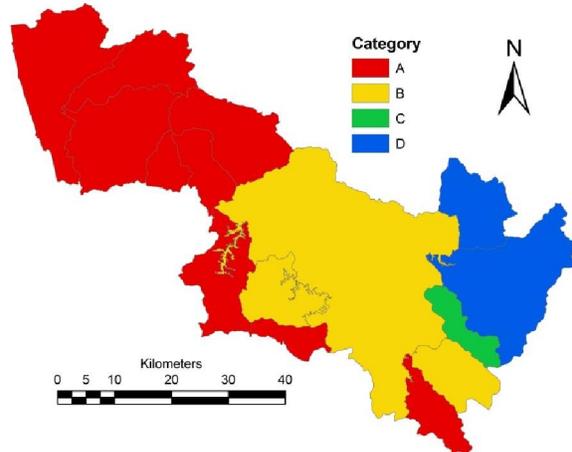
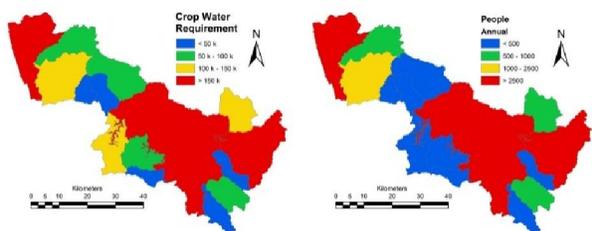


Figure 10: Flow regime



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#### ACKNOWLEDGEMENTS

We are grateful to the Ministry of Science and Technology (DST), Government of India and Indian Institute of Science for the financial and infrastructure support. NRSC Hyderabad is acknowledged for providing IRS data.