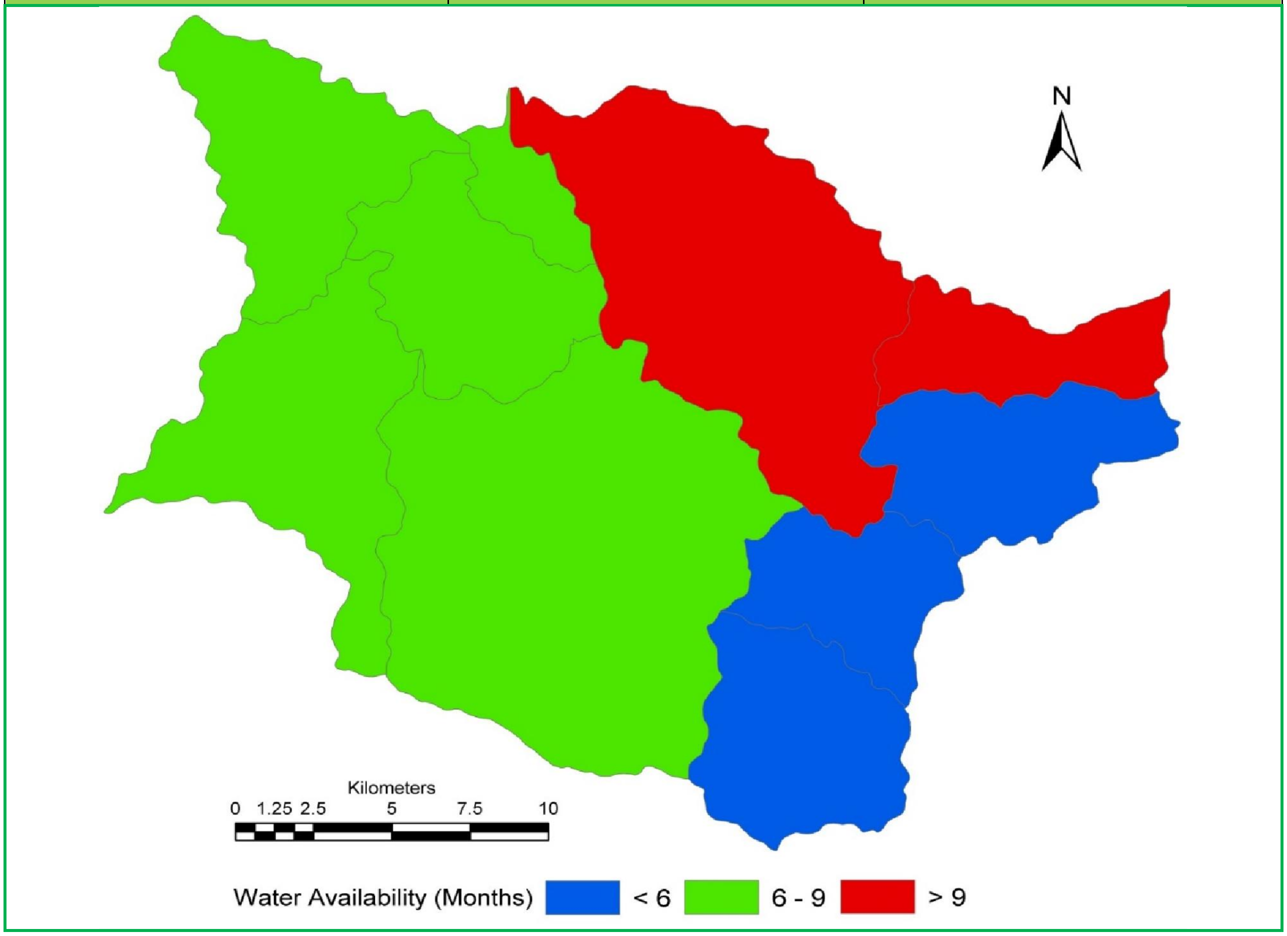
Sahyadri Conservation Series 45

Water Scarcity in Varada Catchment: Need to arrest Deforestation on Priority

Ramachandra T.V.	Subash Chandran M.D.	Vinay S.
	Bharath H. Aithal	



Vrikshalaksha Andolan, Sagar
The Ministry of Science and Technology, Government of India
The Ministry of Environment and Forests, Government of India

ENVIS Technical Report: 82
November 2014

Environmental Information System [ENVIS]
Centre for Ecological Sciences,
Indian Institute of Science,
Bangalore - 560012, INDIA
Web: http://ces.iisc.ernet.in/energy/
http://ces.iisc.ernet.in/biodiversity
Email: cestvr@ces.iisc.ernet.in

Water Scarcity in Varada Catchment: Need to arrest Deforestation on Priority

Ramachandra T.V.	Subash Chandran M.D.	Vinay S.
	Bharath H. Aithal	

Vrikshalaksha Andolan, Sagar
The Ministry of Science and Technology, Government of India
The Ministry of Environment and Forests, Government of India

Sahyadri Conservation Series: 45
ENVIS Technical Report: **82**
November 2014

Environmental Information System [ENVIS]
Centre for Ecological Sciences,
Indian Institute of Science,
Bangalore-560012.

Water Scarcity in Varada Catchment: Need to arrest Deforestation on Priority

Sahyadri Conservation Series: 45

ENVIS Technical Report: **82**

Water Scarcity in Varada Catchment: Need to arrest Deforestation on Priority

Abstract:

River Varada tributary of river Tungabhadra, is the north flowing river originating at Varadamoola of Western Ghats in Sagara taluk of Shimoga district. Origin of the Varada i.e., Varadamoola is surrounded with four hillocks. Before joining river Tungabhadra near Galaganath Village of Haveri District bordering Bellary, the river flow for about 245 km from the origin with a catchment area of 5462 sq.km. In Sagara taluk, river Varada flows for about 65.91km encompassing catchment area 607.97 km^2 and consist about 273 lakes which are interconnected through cascaded systems in the vicinity.

Land use of a catchment with various other parameters and factors defines the water availability and the water needs. Land use Land cover (LULC) dynamics is a major concern, as the abrupt changes has a negative impact on ecology, climate, hydrological regime, and also people's livelihood in the region. Land use analysis was carried out for Landsat 8 image of December 2013. The catchment is dominated by agriculture with over 45.32%, followed by forest land use encompassing an area of 33.38%. The crops in the catchment area are rain fed, and the plantations are dependent upon the lakes and ground water post monsoon.

The temporal land use dynamics of Varada river in Sagara taluk depict a decline of forests from 45.2% to 34.5% in the past 4 decades, attributed to intense horticultural activities that has increased from 10.9% to about 18.5%. The role of man-made plantations needs a re-evaluation, in the light of high soil erosion, weed infestation, poor hydrology and poor associated faunal diversity as compared to natural forests. The teak plantation areas in general, despite the high value of teak timber, were found to have lower biomass and needs enrichment planting by NTFP species, nectar species for honey bee promotion, Soil erosion from forests and forest plantations is a matter of grave concern. Forest restoration in the catchment areas of rivers will improve perennial nature of streams.

River and stream bank forests, including inland swamp area forests are to be considered as endangered ecosystems for various reasons, including for their high accumulation of biomass and higher levels of carbon sequestration. Forest rangewise river-stream-swamp protection action plans, incorporating adequate amount of inviolate vegetation growth for protection of ecology of these vital water courses along with their rare and endemic species is critical. The maps and action plans prepared for special protection of such areas should be included in the forest working plans of every forest division. If such working plans are already prepared these should be still prepared as supplements. Timber extraction, conversion into monoculture plantations, or encroachments or any developmental activities should not be allowed affecting

these inviolate forests. Villagers in close vicinity of forest areas may be commissioned to raise small scale nurseries of selected species flowering plants for replanting inn forest areas, roadsides etc. to reduce the load on the understaffed Forest Department which is required to spend considerable time and resources on large scale nurseries. This will increase rural employment, especially for women while also giving scope for application of indigenous planting techniques.

INTRODUCTION:

Water is an essential source of energy for all life forms on the planet and many a times managing this resources to meet the human needs has failed due to anthropogenic activities. Hence it is necessary to understand the relationships between the elements contributing to the water yield. Yield of water resource in any catchment is dependent upon various characteristics such as topographic, geologic, land use, meteorological criteria's, and so on.

Topographic conditions include the elevation, slope and drainages; the slope towards the plains is flat, where as they are high and variable towards the Ghats, these terrain features gives rise to the various drainage conditions such as dendritic drainage pattern, parallels and so on. The relation between the elevation, slope and the drainage can be established, example: higher variation in the altitude of the terrain would lead to higher slope variations in turn leading to higher density drainage network, higher drainage density locations indicate the Ghats whereas low density drainages indicate the plains. Along the plains due to depression in the terrain (natural/artificial), lakes are formed/created which are inter connected to each other through the surface and subsurface water network and thus storing water.

The geological criteria's includes the texture, structure, and other factors of rocks and soils. Rocks or soils based on their parent material have the capacity to absorb, store and release water with seasons, example: sandy soils have the ability to allow water to completely percolate but lack storing capabilities, granitic rocks since they have low pore spaces does not readily absorb water but allows slower rate of percolation, clay soils have ability to trap water for a longer duration but doesn't allow complete percolation of water. The available water as the soil water helps in agricultural activities; water in the vadose and ground water up to the hypomorphic zone allows flow in streams.

Land use of a catchment with various other parameters and factors defines the water availability and the water needs. Land use Land cover (LULC) dynamics is a major concern, as the abrupt changes has a negative impact on ecology, climate, hydrological regime, and also people's livelihood in the region. LULC dynamics are specific to a region and vary from region to region. Land Cover refers to the observed physical cover on the earth's surface. Land cover essentially distinguishes the region under vegetation with that of non-vegetation. Land use refers to use of the land surface through modifications by humans and natural phenomena. Land use in a region are classified into various classes such as water bodies, built up, forests, agriculture, open lands, sand, soil, *etc*. Land use modifications alter the structure of the landscape and hence the functional ability of the landscape. The modification includes conversion of forest lands, scrublands to agricultural fields, and cultivation lands to built-up, construction of storage structures for water bodies leading to submergence of land features that may vary from small scale to large scale. Landscape is heterogeneous land area of interacting systems which forms an interconnected system called ecosystem. The functional aspects (interaction of spatial elements, cycling of water and nutrients, bio-geo-chemical cycles) of an ecosystem depends on its structure (size, shape, and configuration) and constituent's spatial patterns (linear, regular, aggregated). The status of a land cover can be visualized using the LULC information which provides a base for accounting the natural resources availability, vulnerability and its utilization, example: decline in natural forest would lead more water draining off during monsoons, impacting on the hydrological regime of the catchment, forest land use has higher capability to infiltrate the precipitated water and store it in the sub strata's thus providing resource during post monsoon. This information pertaining to LULC provides a framework for decision making towards sustainable natural resources management.

Meteorological conditions play a major role along with other factors as discussed above in order to cater the water. Precipitation plays a major role in describing the water availability during a year; lower precipitation would lead to drought like conditions, whereas high and intense rainfall would lead to flash floods (w.r.t land use, topography, geology). Temperature, humidity, wind helps the water to evaporate/transpire from various land uses at different rates across seasons which helps the water bearing clouds to recharge during post monsoons. The rate of agriculture, cropping pattern and sowing time depends on the monsoon conditions. Other factors include domestic water demand, livestock water demand, etc.

The above criteria's that play a major role in define the water yield can be identified/estimated using Remote Sensing and GIS. Satellite remote sensing technology provide consistent measurements of landscape, meteorological condition, allowing detection of both abrupt changes and slow trends over time for managing natural resources. Remote Sensing (RS) data with Geographic Information System (GIS) and Global Positioning System (GPS) helps in effective measure of landscape dynamics in cost effective manner.

Varada is a north flowing river that originates at Varadamoola (Annexure 1) of the Western Ghats. The stream course had given birth to civilizations, such as kingdoms like Keladi. The river due to its sanctity owns its place in the literatures (*vedas*, *puranas*, etc.). Similar to any other neglected river coarse, river Varada and its catchment is also being mismanaged and ignored. Once a perennial river has now degraded to a seasonal river, depriving of the water resource to the dependent functional aspects such as agriculture, forest, domestic, animals and many more. The catchment encompasses several protected forest (sacred groves / *kans*) which are in many cases degraded for various purposes such as household, fuel wood, fodder etc. The *kans* attribute to adding of water resource into catchment post monsoon. The degradation of *kans* has led to depreciation in the water yield in catchment, and leading to serious water related issues in terms of domestic, agricultural, and other needs.

The objective of the study is to understand (i) land use variations with time (ii) water yield in the Varada catchment in Sagara taluk of Shimoga district in relation with the land scape dynamics, metrological variations and other depending factors, in order to identify the demands based on various needs. This work helps in identifying the ability of the sub catchments of Varada to cater the water demands within them, the study also helps to identify the locations which have deficiency of water which would also help planners to identify the reason, and plan for the management of this resource without damaging the natural ecosystem.

STUDY AREA:

River Varada (fig. 1a, b) tributary of river Tungabhadra, is the north flowing river originating at Varadamoola of Western Ghats in Sagara taluk of Shimoga district. Origin of the Varada i.e., Varadamoola is surrounded with four hillocks. Before joining river Tungabhadra near Galaganath Village of Haveri District bordering Bellary, the river flow for about 245 km from the origin with a catchment area of 5462 sq.km. In Sagara taluk, river Varada (fig. 1a, b) flows for about 65.91km encompassing catchment area 607.97 km^2 and consist about 273 lakes which are interconnected through cascaded systems in the vicinity. The terrain (fig. 2) in the catchment is highly undulating at the Ghats and flatter toward the plains. Annual precipitation in the catchment varies from 4000 mm at the ghats to 1600 mm at the plains, over years, rainfall in the catchment has declined (fig. 3), earlier to 1960's average annual rainfall in the catchment was over 4000mm. The temperature varies from as 15.61^{O}C low as during to 33.41^{O}C as high as during.

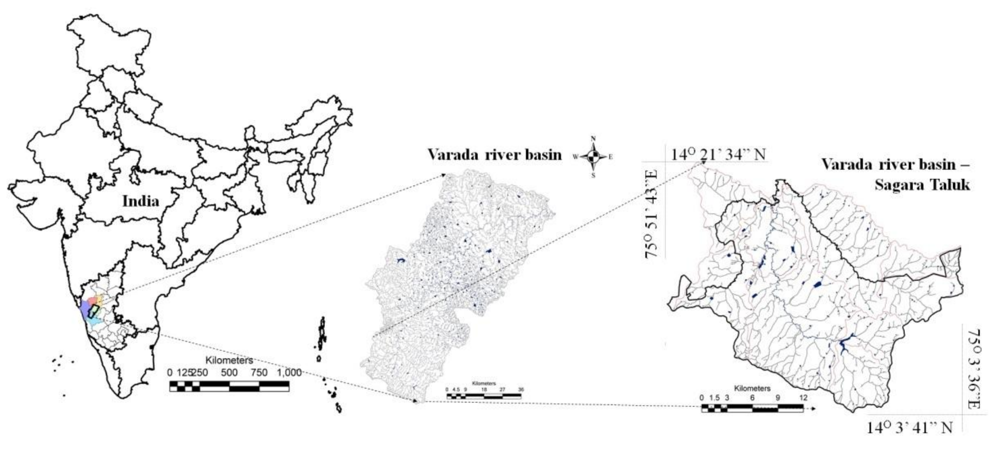


Figure 1a: Study Area

Figure 1b: Study Area overlaid on Google earth

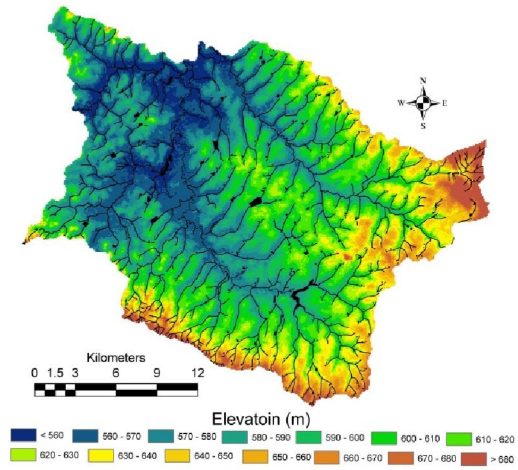


Figure 2: Topography

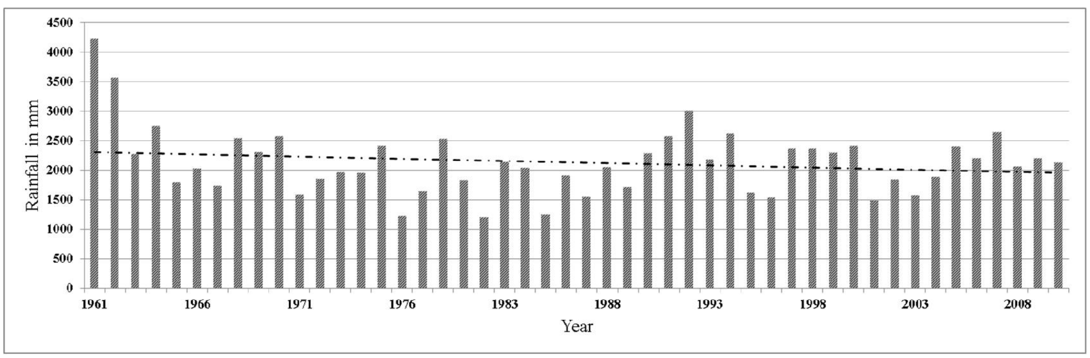


Figure 3: Rainfall variation

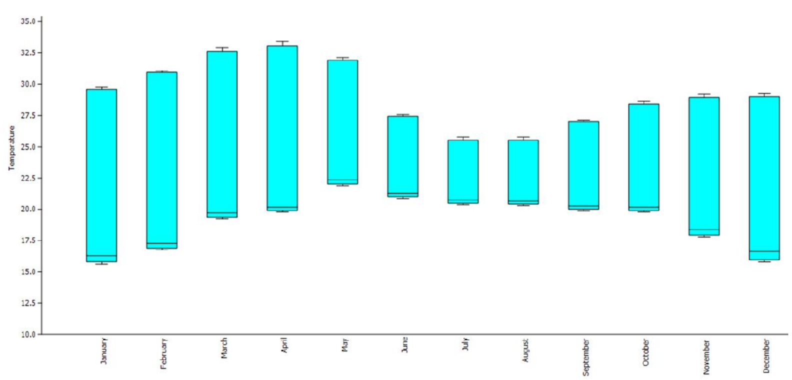


Figure 4: Temperature Variation

Similar to any other river of India, river Varada has been neglected, the Varada basin in Sagara has witnessed draw down of forest cover since 1960's (interaction with public) which has led to the decline of the rainfall in the catchment. The river once perennial in now intermittent, many lakes are encroached due to infrastructural activities such as construction of layouts, bus stands, *etc*. The agricultural and horticultural activities have led to severe decline in the forests along the streams. Historically and morphologically river Varada had its own importance, the drainages connecting the river course flood during monsoon where as they go dry and contaminate post monsoon harboring mosquitoes and other agents of diseases causing social new sense. Intense use of bore wells for agriculture and horticulture activities post monsoon has led to decline in ground water level, due to which the natural springs are lost which provides water to the natural ecosystem. The ground water status is as depicted in Annexure 3, on an average ground water in the catchment is available at a depth of 5 m to about 10 m in the catchment, with yield of about 1 to 5 litres per second. Both the depth of the ground water as well as the yield can be attributed to the land use characteristics and the geological conditions. The catchment fall in the safe zone of water utilization.

DATA USED:

Multiple data sources from various agencies were used in order to evaluate the hydrological scenario of the Varada River. Table1 describes the various data sources used for assessment of the hydrological regime across the catchments.

Table 1: Data

Data	Source	Description
Satellite data	Landsat series (from 1973 to 2013).	30 m spatial resolution, 16 bit radiometric resolution. Used to analyse the land use at catchment level
Rainfall	Rain gauge stations Department of Statistics - Karnataka, Indian Meteorological Department.	Daily rainfall data for 110 year between 1901 and 2010. Used to analyse the rainfall distribution over the basin
Crop Calendar	Agriculture Department of Karnataka, iKisan, National Food Security Mission.	To understand when, where and which crops are grown which helps in understanding the crop water requirement based on the growth phases
Crop Coefficient	Food and Agriculture Organisation- FAO, Agriculture Department of Karnataka.	Each land use has its own evaporative coefficients, used to estimate the Actual Evapotranspiration.
Temperature (max, min, mean), Extraterrestrial solar radiation	Worldclim, FAO	Temperature data of 1km spatial resolution, available for each month. Extra-terrestrial solar radiation, every 1^0 North latitude available across different hemispheres for various months. Used to estimate the Potential Evapotranspiration
Population Census	Census India 1991, 2001 and 2011	Data available at village level, used to estimate the population at sub basin level

		for the year 2014, and estimate the water requirement for domestic use at sub basin level
Livestock Census	Hassan District at a glance 2012-2013	Taluk level data are available, used to estimate the livestock population and estimate water requirement at each of the river basins.
Digital Elevation data	Cartosat DEM from NRSC-bhuvan	Carto-DEM of 30m resolution. Used to derive the catchment boundaries, stream networks in association with Google earth and Toposheets
Secondary Data	Google Earth, Bhuvan, French Institute Maps, Western Ghats biodiversity portal, Toposheets	Supporting data in order to assist land use classification, delineation of streams/rivers/ Catchment, Geometric correction
Field data	GPS based field data, Feedback form public	Geometric Corrections, Land use classification, Crop water requirement, livestock water requirement estimate

METHOD:

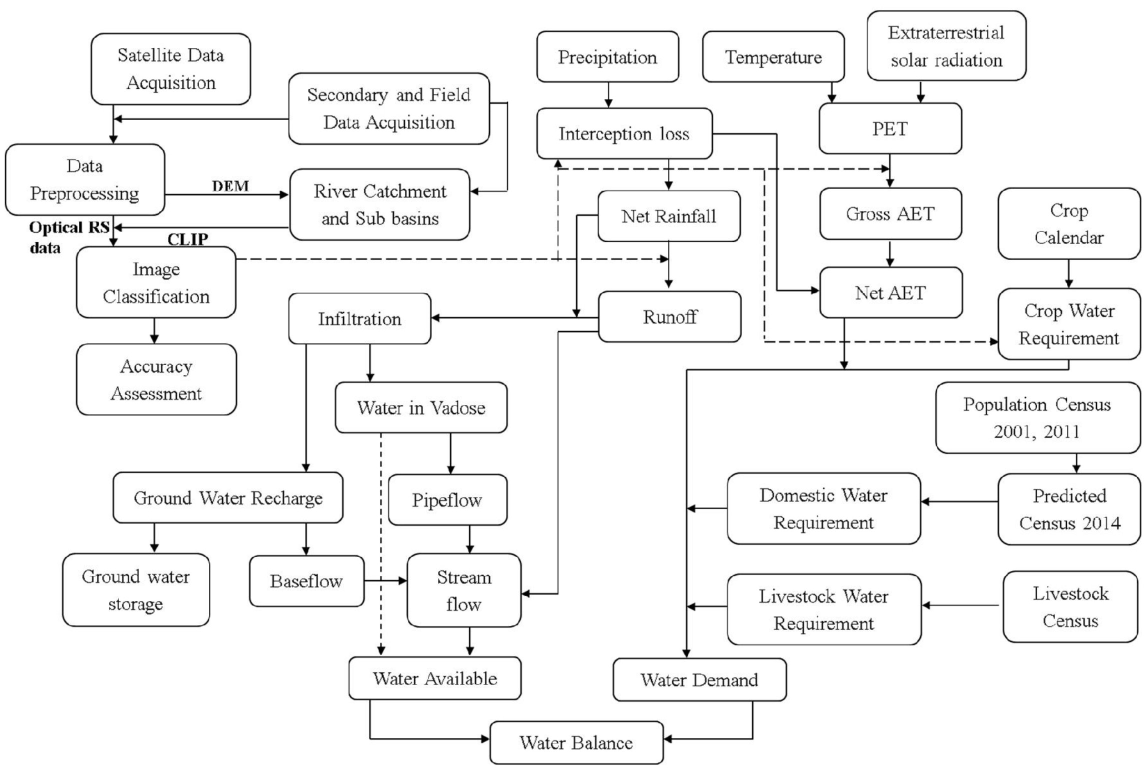


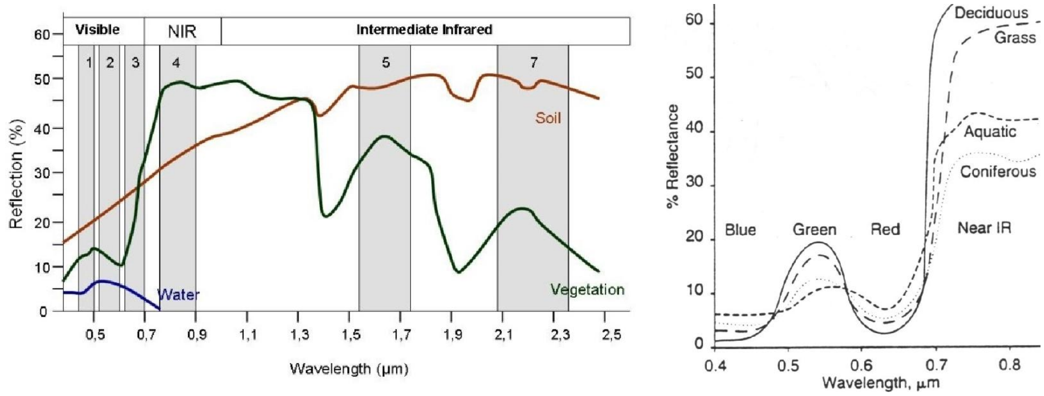
Figure 5: Method involved

The method involved in evaluation of the hydrological status is as depicted in figure 5. The process of evaluation involves 1) extraction of catchment boundary 2) land use analysis, 3) assessment of the hydro meteorological data, 4) analysis of population data, 5) public interactions 6) water requirement for domestic and agriculture/horticulture, 7) assessment of the hydrological status.

Extraction of catchment boundary: Catchment boundaries and the stream networks considering the topography of the terrain based on Cartosat DEM were extracted using the hydrologic modeling tool in GRASS GIS. Since DEM has inherent errors, the catchment boundaries were overlaid on the extracted boundaries from survey of India toposheets in order to check and correct the variations, these corrected catchment boundaries were further overlaid on Google earth in order to visualize the terrain variations more precisely (fig 1).

Land use Assessment: Land use refers to heterogeneous terrain with the interacting ecosystems and is characterized by its dynamics, which are governed by human activities and natural processes. Human induced land use and land cover (LULC) changes have been the major driver of the landscape dynamics at local levels. Land use assessment was carried using the maximum likelihood classification technique. Understanding of landscape dynamics helps in the sustainable management of natural resources. The process of assessing land use is as follows:

- **Satellite data acquisition:** Satellite data sets for the whole world (earth) at different resolutions are available since 1972 (Landsat1) up to date. For the land use analysis, Landsat 8 (2013) data was obtained from the public domain (USGS: *earthexplorer.usgs.gov/*).
- **Data pre processing:** Since the satellite data could contain errors such as shift (geometric errors) or erroneous pixels (radiometric errors), correction are applied on each band. Radiometric corrections involve contrast enhancement, elimination of noise *etc*. Geometric corrections involve precisely referencing the satellite data with the help of field data from GPS, Google earth, Toposheet or Bhuvan.
- **Preparation of False Colour Composite:** False colour composite is the representation of earth features in their non-original colours in order to identify the heterogeneity in various land scapes. FCC are prepared by combination of various spectral bands such as the NIR, GREEN and RED bands.
- **Preparation of signature data set:** Signatures are the training datasets which are used to classify the satellite image into various land use classes based. Signatures are developed for various land use categories based on the site knowledge (Field data, Toposheets, Google earth, Bhuvan, Western Ghats Biodiversity Portal, French institute maps) and based on spectral reflectance characteristic (fig. 6) of different land scape. Training data should be unique and homogeneously spread across the study area covering at least 15% of the total area.



Source: www.seos-project.eu Source: http://www.geog.ucsb.edu

Figure 6: Spectral reflectance curve

- **Classification of remote sensing data (Satellite images):** Classification process is carried out using the Gaussian maximum likelihood classifier. The classifier computes the mean and variance of digital numbers under each training data set, based on which new pixel is categorized under a land use class. Of the overall signatures, 65% of the total signatures are considered in classification of the image and 35% of the pure signatures are used for assessing the accuracy.

- **Accuracy assessment:** Accuracy is necessary in order to check if the classified satellite data agrees with that of the reference data. The reference data can be obtained based on the field data, or any other map. Kappa is estimated as a measure of agreement between the reference map and the classified map.

Assessment of the hydro meteorological data: This process involves assessment of the rainfall data obtained from various sources such as TRMM, Rain gauge stations in and around the study site. Based on the long term precipitation data are used in order to understand rainfall variation over decades. Isolines across the months were developed based on the spatial rainfall variation of rainfall w.r.t the raingauge stations across the basin. Along with rainfall, temperature (minimum, maximum and average), extra-terrestrial solar radiation across the catchment were used to hydrological behaviors of the catchments which enables to understand the hydrological status.

Rainfal: Point based daily rainfall data from various rain gauge stations in and around the study area between 1901 and 2010 were considered for analysis of rainfall. The rainfall data used for the study were obtained from

1. Department of statistics, Government of Karnataka
2. Indian metrological data (IMD), Government of India
3. Tropical rainfall Measuring Mission (TRMM), NASA

Since some rain gauge stations had incomplete records with rainfall missing for few months, analysis without these data would yield erroneous results and also stations with missing rainfall cannot be included in the analysis, which otherwise would give better representation of the results, these missing data's were evaluated through regression analysis and error data's were revised with respect to neighboring rain gauge stations. Rainfall trend analysis was observed for selected rain gauge stations to assess the variability of rainfall at different locations in the study area.

The points based long term daily rainfall data were used to calculate the monthly and annual rainfall in each rain gauge station based on mean and standard deviation of rainfall at selected rain gauge stations. The average monthly and annual rainfall data were used to derive rainfall throughout the study area through the process of interpolation (isohyets). The interpolated rainfall data was used to derive the gross yield (R_G) in the basin. Net yield (R_N) was quantified as the difference between gross rainfall and interception (In).

$$\mathbf{R_G = A * P}$$
$$\mathbf{R_N = R_G - In}$$

Where
R_G : Gross rainfall yield volume, A : Area in Hectares, P : Precipitation in mm
R_N : Net rainfall yield volume, In : Interception volume

Run off: This is the portion of rainfall that flows in the streams after precipitation. Runoff can be typically divided into two categories i) Surface runoff or Direct Runoff ii) Sub surface runoff

Surface Runoff: Portion of water that directly enters into the streams during rainfall. Surface runoff in the region is estimated based on the empirical equation (eq1)

$$\mathbf{Q = \Sigma(C_i * P_R * A_i)}$$

Where Q : Runoff in cubic meters per month
C : Runoff Coefficient which is dependent upon various land uses (table 2)
P_R : Net rainfall in mm (Gross rainfall – Interception)
i : Land use type

Table 2: Runoff Coefficients

Land Use	Runoff Coefficient
Urban	**0.85**
Agriculture	**0.6**
Open lands	**0.7**
Evergreen forest	**0.15**
Scrub/Grassland	**0.6**
Forest Planation	**0.65**
Agriculture Plantation	**0.5**
Deciduous Forest	**0.15**

Interception: During monsoons, portion of rainfall falls doesnot reach the surface of the earth, it remains on the canopy of trees, roof tops, etc. this portion of water is lost in the process of evaporation. Studies show that, losses due to interception is over 15% to 30%, based on the land use. Table 3 shows the interception loss across various rainy months and land uses

Table 3: Interception loss

Vegetation types	**Period**	**Interception**
Evergreen/semi evergreen forests	June-October	I = 5.5 + 0.3 (P)
Moist deciduous forests	June-October	I = 5 + 0.3 (P)
Plantations	June-October	I = 5 + 0.2 (P)
Agricultural crops (paddy)	June	0
	July-August	I = 1.8+ 0.1 (P)
	September	I = 2 + .18 (P)
	October	0
Grasslands and scrubs	June-September	I = 3.5 +0.18 (P)
	October	I = 2.5 + 0.1 (P)

Infiltration: Due to precipitation, apart from surface runoff and interception, the remain portion of water enters the subsurface of the earth saturating the sub soils, and percolating into the ground water table and hence recharging ground water. The infiltered water enters the streams during post monsoon, as pipe flow and baseflow.

$$\mathbf{Inf = R_N - Q}$$

Ground water recharge:

This is the portion of water that is percolated below the soil stratum (vadose) after soil gets saturated. Recharge is considered the fraction of infiltrated water that recharges the aquifer after satisfying available water capacity and pipe flow. Krishna Rao equation (1970) was used to determine the ground water recharge.

$$\mathbf{GWR = R_C * (P_R - C) * A}$$

Where

GWR : Ground water recharge
R_C : Ground water recharge coefficient (table 4)
C : Rainfall Coefficient
A : Area of the catchment

The recharge coefficient and the constant vary from location to location based on the annual rainfall.

Table 4: Ground water recharge coefficients

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

Sub Surface Flow (Pipeflow): Pipeflow is considered to be the fraction of water that remains after infiltrated water satisfies the available water capacities under each soil. Pipe flow is estimated for all the basins as function of infiltration, ground water recharge and pipeflow coefficient, i.e.,

$$\mathbf{P_F = (Inf - GWR) * K_P}$$

Where

P_F : Pipeflow
Inf : Infiltration volume
K_P : Pipeflow coefficient

Groundwater Discharge: Groundwater discharge or baseflow is estimated by multiplying the average specific yield of aquifer under each land use with the recharged water. Specific yield represents the water yielded from water bearing material. In other words, it is the ratio of the volume of water that the material, after being saturated, will yield by gravity to its own volume. Baseflow appears after monsoon and pipeflow has receded. This water generally sustains flow in the rivers during the dry season.

$$\mathbf{GWD = GWR * Y_S}$$

Where

GWD = Ground water discharge
GWR = Ground water recharge
Y_S = Specific yield

Evapotranspiration: Evaporation is a process where in water is transferred to atmosphere as vapour from open waters, whereas Transpiration is the process by which water from plants through leaves and other parts above ground. In the process of transpiration water is taken into the atmosphere from ground (soil) through the roots. On the other hand, evaporation continues throughout the day and night at different rates. The process of evaporation takes place on all different land uses other than vegetation. Evapotranspiration is the total water lost from different land use due to evaporation from soil, water and transpiration by vegetation.

Some of the important factors that affect the rate of evapotranspiration are:

1) Temperature
2) Wind
3) Light intensity
4) Sunlight hours

5) Humidity
6) Plant characteristics
7) Land use type
8) Soil moisture

If sufficient moisture is available to completely meet the needs of vegetation in the catchment, the resulting evapotranspiration is termed as potential evapotranspiration (PET). The real evapotranspiration occurring in specific situation is called as actual evapotranspiration (AET). These evapotranspiration rates from forests are more difficult to describe and estimate than for other vegetation types.

Potential evapotranspiration (PET) is determined using Hargreaves method (Hargreaves, 1972) an empirical based radiation based equation, which is shown to perform well in humid climates. PET is estimated as mm using the Hargreaves equation is given as

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

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

Actual evapotranspiration is estimated as a product of Potential evapotranspiration (PET) and Evapotranspiration coefficient (K_C) (table 5), the evapotranspiration coefficient is a function of land use varies with respect to different land use. Table 5 gives the evapotranspiration coefficients for different land use

$$\mathbf{AET = PET * K_C}$$

Table 5: Evapotranspiration coefficient

Land use	K_C
Built-up	0.15
Water	1.05
Open space	0.3
Evergreen forest	0.95
Scrub and grassland	0.8
Forest Plantation	0.85
Agriculture Plantation	0.8
Deciduous forest	0.85

As the crop water requirement was estimated for different crops and different seasons based on land use, assumption is individual crop water requirement based on their different growth phases need different quantum of water for their development inclusive of evaporation.

Analysis of population data and domestic water demand: Population dynamics in any region is necessary in order to understand and predict the domestic water demand. Population census for the year 2001 and 2011at village lever were considered in order to derive the population of the basin level. Based on the rate of change of population , the population for the year 2014 was predicted.

$$\mathbf{r = (P_{2011}/P_{2001} - 1)/n}$$

Where

P_{2001} and P_{2011} are population for the year 2001 and 2011 respectively
n is the number of decades which is equal to 1
r is the rate of change

$$\mathbf{P_{2014} = P_{2011} * (1 + n*r)}$$

Where

P2014 is the population for the year 2014
n is the number of decades which is equal to 0.3

Domestic water demand is assessed as the function of water requirement per person per day, population and season. Water required per person include water required for bathing, washing, drinking and other basic needs. Water requirements across various seasons are as depicted in table 6

Table 6: Seasonal water requirement

Season	Water lpcd
Summer	150
Monsoon	125
Winter	135

Data collection from public and Livestock water requirement: Public interviews were conducted in order to understand the agricultural cropping pattern and water needed for various crops in the catchment, livestock census was obtained from the district statistics and water requirement for different animals were quantified based on the interviews. Table 7 gives the various livestock water requirements

Table 7: Livestock water requirement

	Water Requirement in Liters per animal							
Season\Animal	**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

Crop water requirement: Based on the crops grown and cropping pattern in the catchment according to the district at a glance, department of agriculture assisted by the public interviews, the crop water requirement was estimated for various crops based on their growth phases. Land use information was used in order to estimate the cropping area under various crops. Table 8 provides the information of various crop water requirements based on their growth phase as cubic meter per hectare for Sagara Taluk.

Table 8: Crop water requirement

Crop	Paddy	Maize	Fruits	Vegetables	Ground nut	Cotton	sugarcane
Annual	14850	4450	30848	7500	6525	10550	32535
	Single	Single	Single	Single	Single	Single	Single
Month	June - Sept	June - Oct	Feb - May	Apr-Sept	Oct - Feb	June - Dec	Feb - Jan
Jan					2260		
Feb					889		5206
mar							2505
Apr							2505
May							2505
Jun	5940	266	4599			582	2831
Jul	2970	829	6018			1206	2831
Aug	3564	1478	5482	597		2335	2831
Sep	2376	1448	4485	1433		2572	2831
Oct		429	3597	2288	197	2039	2831
Nov			2209	2159	1094	1280	2831
Dec			1481	1025	2085	536	2831

Crop	Pulses and Others	Coconut & Arecanut	Other Oil Seeds	Cereals	Jowar	Ragi	Tobacco
Annual	2400	13496	6525	3500	6425	7450	9800
	Single	Single (Continuous)	Single	Single	Single	Single	Single
Month	Aug - Jan	All time in the year	Dec - April	Aug to Dec	June - Sept	June - Oct	Sept - Dec
Jan		1192		700			
Feb		1256		1120			
mar		1390		1260			
Apr		1346		420			
May		1390					

Jun		897			1092	373	
Jul		927			2442	2608	
Aug	482	1192	1305		2056	2161	
Sep	792	1154	1631		835	1639	1960
Oct	780	927	1958			671	3136
Nov	346	897	979				3528
Dec		927	522				1176

Assessment of the hydrological status: The hydrological status in the catchment is analysed for each month based on the water balance which take into account the water available to that of the demand. The water available in the catchment is function of water available in the water bodies such as lakes, streams and rivers, water in the soil, pipe flow and base flow, whereas the demand in the catchment is estimated as the function of crop water demand, domestic and livestock demand and the evapotranspiration waters. The catchments is said to be stable if the water available caters the water demand completely else the catchment is devoid of water and would lead to drought like conditions in the catchment.

RESULTS

Land use analysis: Land use analysis was carried out for Landsat 8 image of December 2013, the land use under each sub catchment is as depicted in fig. 7a and table 9a. The catchment is dominated by agriculture with over 45.32%, followed by forest land use encompassing an area of 33.38%. The crops in the catchment area are rain fed, and the plantations are dependent upon the lakes and ground water post monsoon.

Table 9a: Land use (all units in Ha)

Sub basin id	1	2	3	4	5	6	8	9	10	11	Total
Urban	6.3	1.8	1.3	71.5	1.9	56.1	5.8	3.3	6.1	10.9	165.1
Water	28.3	27.6	15.4	70.7	6.0	22.0	46.6	3.9	37.5	11.6	269.6
Agriculture	1144.7	1159.3	1560.0	6474.7	1177.7	3412.1	2399.8	811.2	4275.9	2367.2	24782.6
Open lands	6.2	4.8	6.6	88.8	7.3	45.7	45.5	19.0	73.0	77.5	374.5
Deciduous Forest	1120.4	613.2	925.8	2069.6	451.3	976.0	574.9	135.3	2303.4	1105.6	10275.6
Evergreen forest	833.0	461.7	880.5	2197.7	736.8	505.4	268.3	29.0	1749.4	293.3	7955.2
Scrub/Grassland	105.5	58.4	120.1	75.3	37.6	22.6	14.9	5.2	101.5	32.2	573.2
Forest Plantation	196.0	157.3	115.7	792.4	81.4	210.8	148.7	38.6	671.3	232.9	2645.2
Agriculture Planation	674.3	427.2	259.9	2354.2	196.7	926.9	588.7	144.0	1306.0	704.5	7582.6
Total Area	4114.8	2911.5	3885.4	14194.9	2696.7	6177.7	4093.2	1189.6	10524.2	4835.7	54623.5

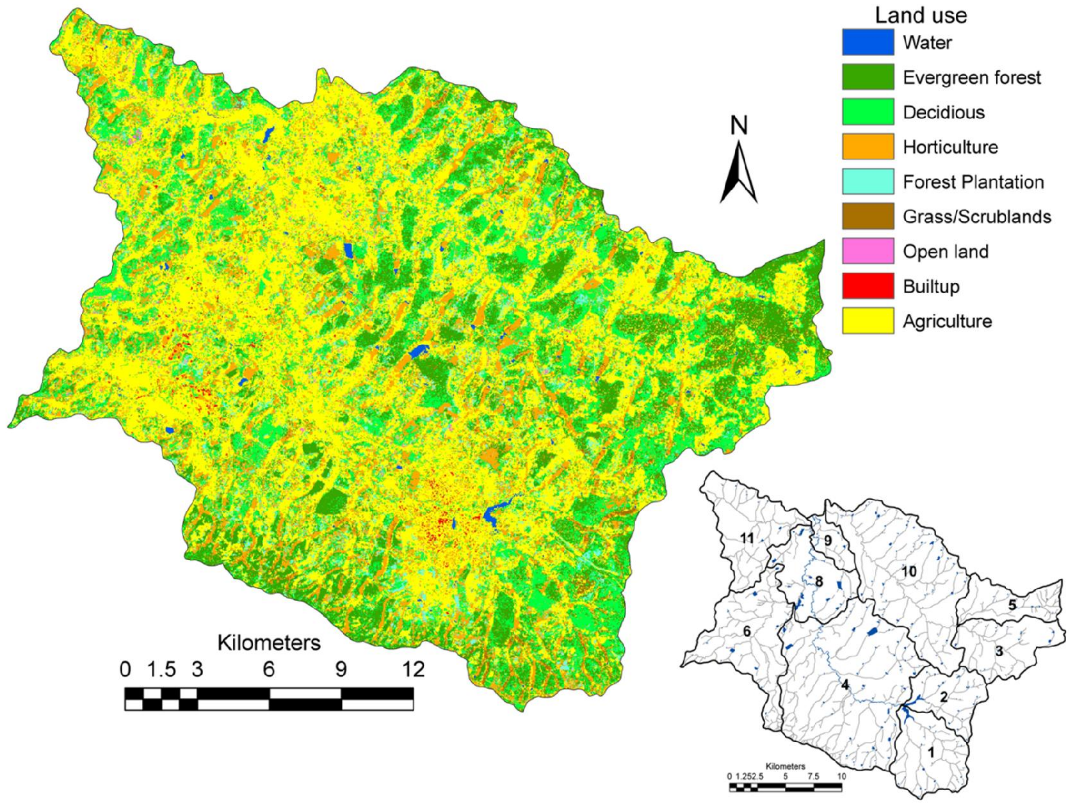
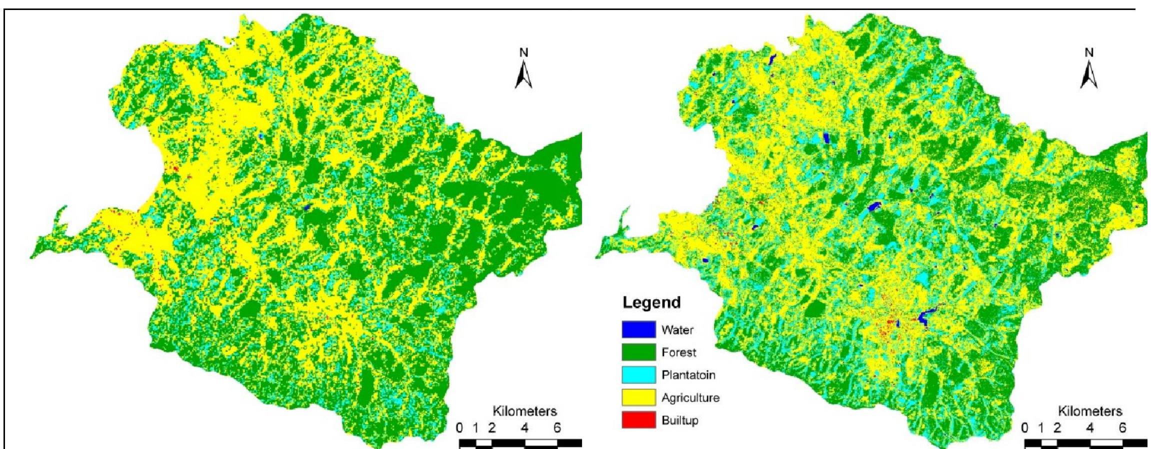


Figure 7a: Land use

Temporal land use dynamics: The temporal land use dynamics of Varada river in sagara taluk are as depicted in figure 7b and in table 9b, the wetlands have increased from 0.1% to 0.5% due to construction of bunds across the river for providing water to cater the domestic needs, forests have declined from 45.2% to 34.5% in the past 4 decades, attributed to intense horticultural activities has increased from 10.9% to about 18.5% in the past 4 decades.



1973	2013

Figure 7b: Land use dynamics

Table 9b: Temporal land use dynamics

Land use	1973	2013
Agriculture	43.7%	46.2%
Built up	0.1%	0.4%
Forest	45.2%	34.5%
Plantation	10.9%	18.5%
Water	0.1%	0.5%

Hydrology: Around 17 rain gauge stations (fig.8) in and around the catchment were considered for the analysis. The daily rainfall data from these stations between 1961 and 2010 were analysed for each of the rain gauge every month, in order to check for missing data and also to understand the trend in the monsoon variations across years (fig. 3). The assessment show that rainfall in the catchment is depleting over time. The spatial variation of rainfall is as depicted in fig. 9, rainfall in the region starts from June up to October. The annual variations indicate that the rainfall is less than 2500mm at the plains where as it is over 3000 mm towards the southwest.

Gross rainfall yield in each of the sub basins is as depicted in fig. 10. As gross rainfall is product of precipitation and area under each sub basin, the rainfall yield shows higher values even in cases where the rainfall is low in the basin. Interception in each of the basins based on the regional land use and precipitation was derived, and is as depicted in fig. 11, regions with higher canopy cover has higher interception losses; the intercepted water contributes to evaporation during monsoon. Net rainfall is the difference between the gross rainfall and interception loss in each sub basin and is depicted in fig. 12. Runoff assessment was carried out using the empirical equation as a function of land use, precipitation and area of sub basin as is as depicted in fig. 13. Direct surface runoff in the basin is between June and October, the overall runoff in the basin is about 375 Million cubic meters (i.e., about 13 TMC of water). Infiltration in each of the sub catchment were assessed as function of net rainfall and runoff, and is as depicted in fig. 14, during non-monsoon most of the precipitation water percolates into the soils and sub strata.

Ground water recharge was estimated based on Krishna Rao's equation and is as depicted in fig. 15, regions with higher forest and large water cover depict higher recharge capabilities. Water in the sub surface, stored as vadose water is as depicted in fig. 16, catchments with higher forests indicate that the water is stored in a larger volume and for a longer duration. Portion of the water in vadose due to lateral movement moves as Pipeflow supporting the flow in the streams, maintaining water in lakes, fig. 17 depict the annual pipe flow in various sub catchments. The base flow depending on the ground water yield identified in other catchments and based on literature, was estimated for all the sub catchments and is depicted in fig. 18.

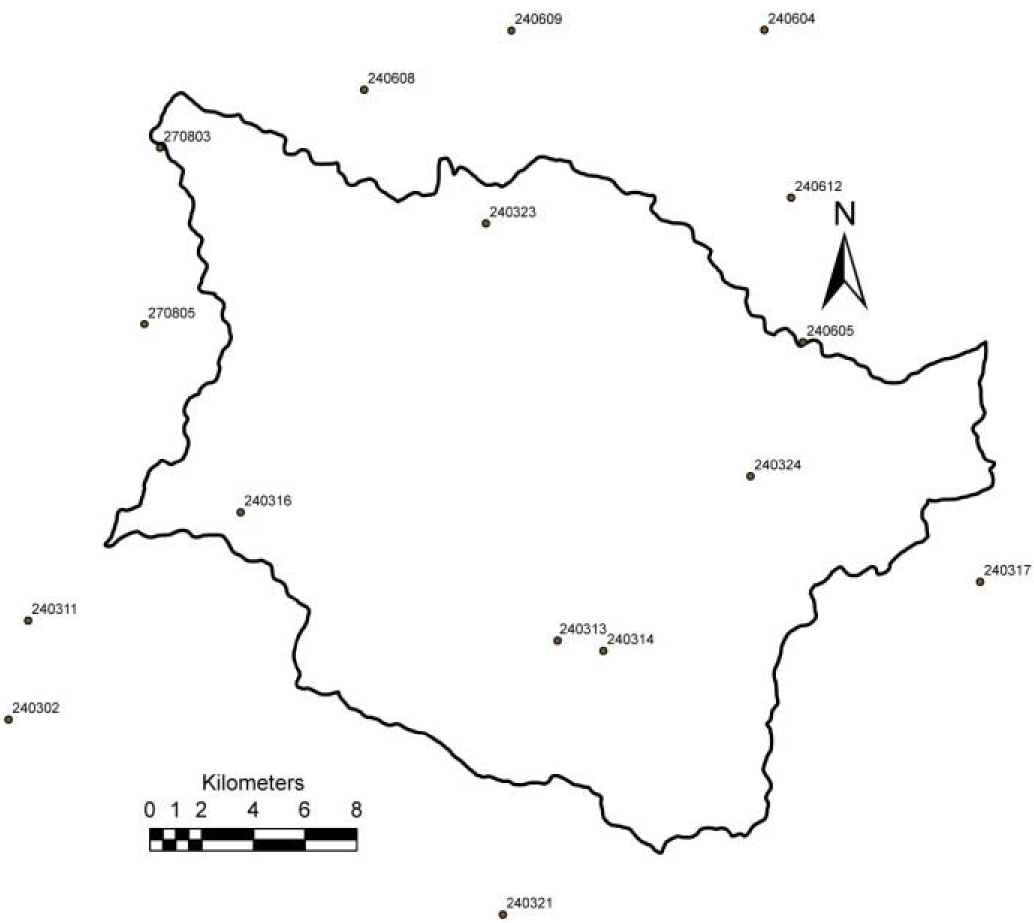


Figure 8: Rain gauge stations

Evapotranspiration for each of the months was estimated based on the Hargreaves equation and the evaporative coefficient (FAO and other resources) for various land uses. The AET during monsoon was negligible since interception (portion of water standing on tree top, buildings, etc. inclusive of evaporation), and transpiration from the crops were considered as nill since crop water requirements were inclusive of transpiration. Fig. 19 depicts monthly evapotranspiration from various land uses.

Crop water requirement was estimated based on literature, crop water data from irrigation department, agriculture portals and public interviews, it was established that most of the crops grown are only during monsoon, and few cash crops such as sugar cane, horticulture crops need long term water supply and in large quantity. The area under each crops were estimated based on the data available from district at a glance. Fig. 20 depicts monthly crop water requirements. Catchment with higher horticulture activities indicates that the crop water requirements are high in comparison with other catchments.

Domestic water requirements were estimated based on the population in each of the catchment, catchments with higher population demands higher water. Water requirement per person as product with population was used to derive the domestic water requirements and is depicted in fig. 21. The Livestock water requirements were quantified similar to the domestic but various categories of livestock were taken into account, fig. 22 depicts the monthly livestock water requirement.

The water demand in the catchment was estimated as the sum of crop water requirement, domestic water requirement, livestock water requirement and evapotranspiration. The total demand of water in each of the catchment is as depicted in fig. 23. Catchments with higher horticulture demand more water, rather than the forest which show that they use less water. Supply of water is taken as a function of runoff during the monsoon, followed by the sub surface waters (vadose water and ground water) during the post monsoon. The water catered as a part of supply is depicted in fig. 24. The ratio of supply to the demand was calculated in order to check what portion of water demand in the region being satisfied by the water available in the basin, and is as depicted in fig. 25. The results show that in most of the sub catchments, since the demand is higher due to various agricultural and horticultural practices, associated with lower forest cover, only partial demand of water is fulfilled. The lakes in series provide water acting as source during post monsoons. In many a cases lakes with kans on their upstream have water throughout the year, catering to most of the human needs.

The capability of the water resource to completely cater the demand is as in fig. 26. It could be seen that, water can cater to complete demands over 6 to 9 months. But during rest of the seasons post monsoon, only partial demand can be met with the naturally available water (**naturally refers to the water in the streams, lakes and water due to lateral flow of water from sub-surface (in vadose)*).

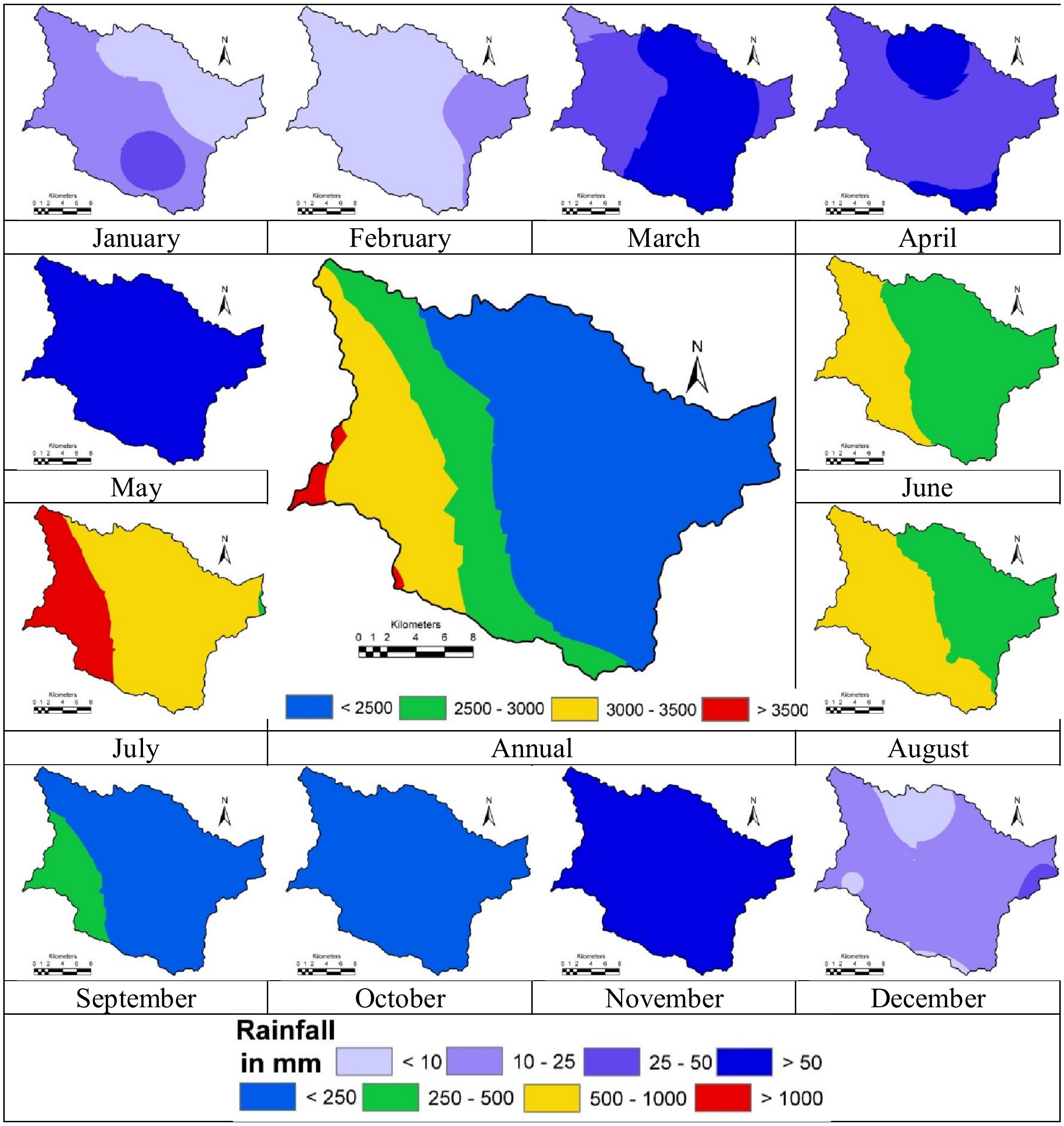


Figure 9: Rainfall variation (mm)

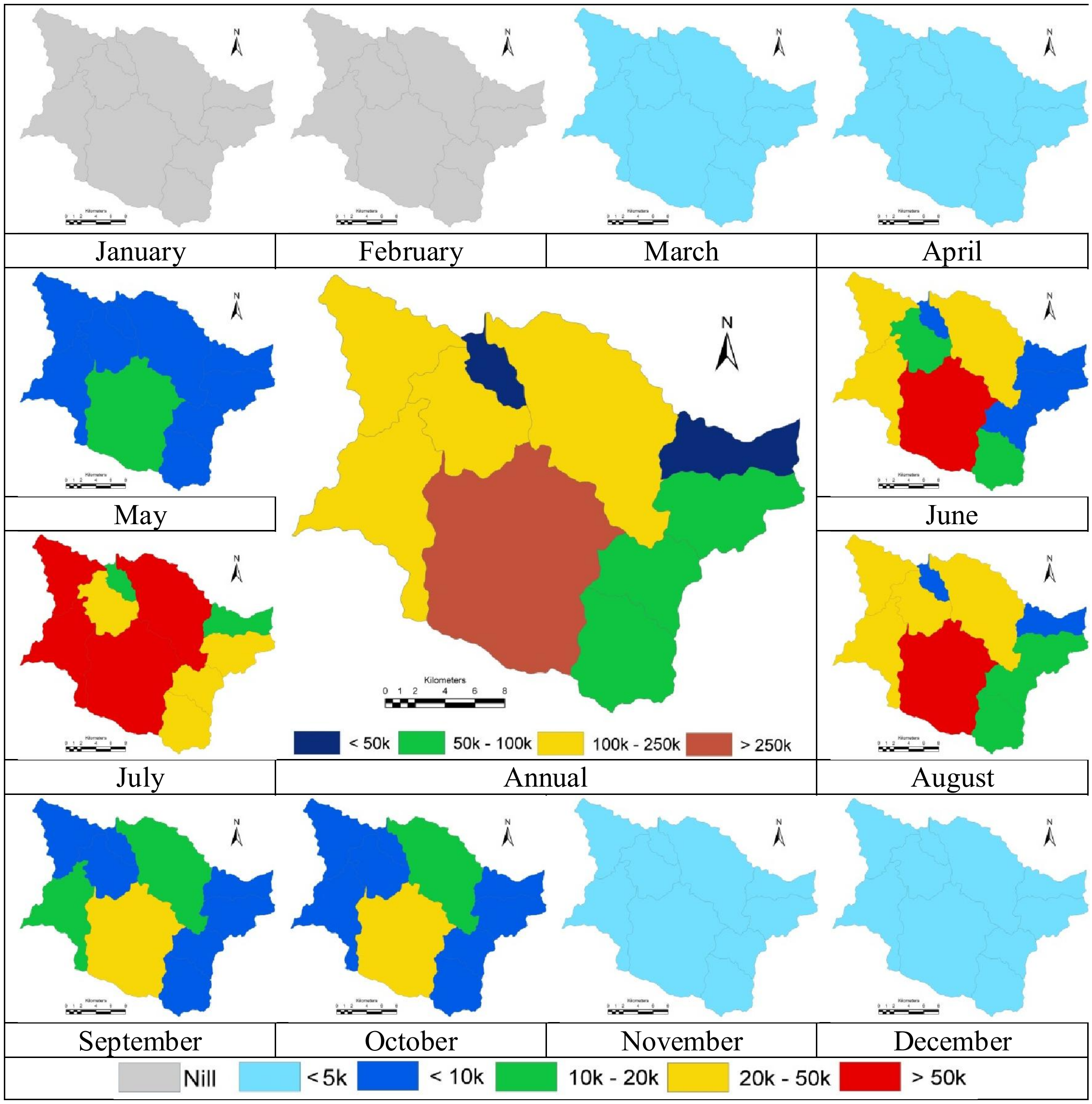


Figure 10: Gross Rainfall (kilo.cum)

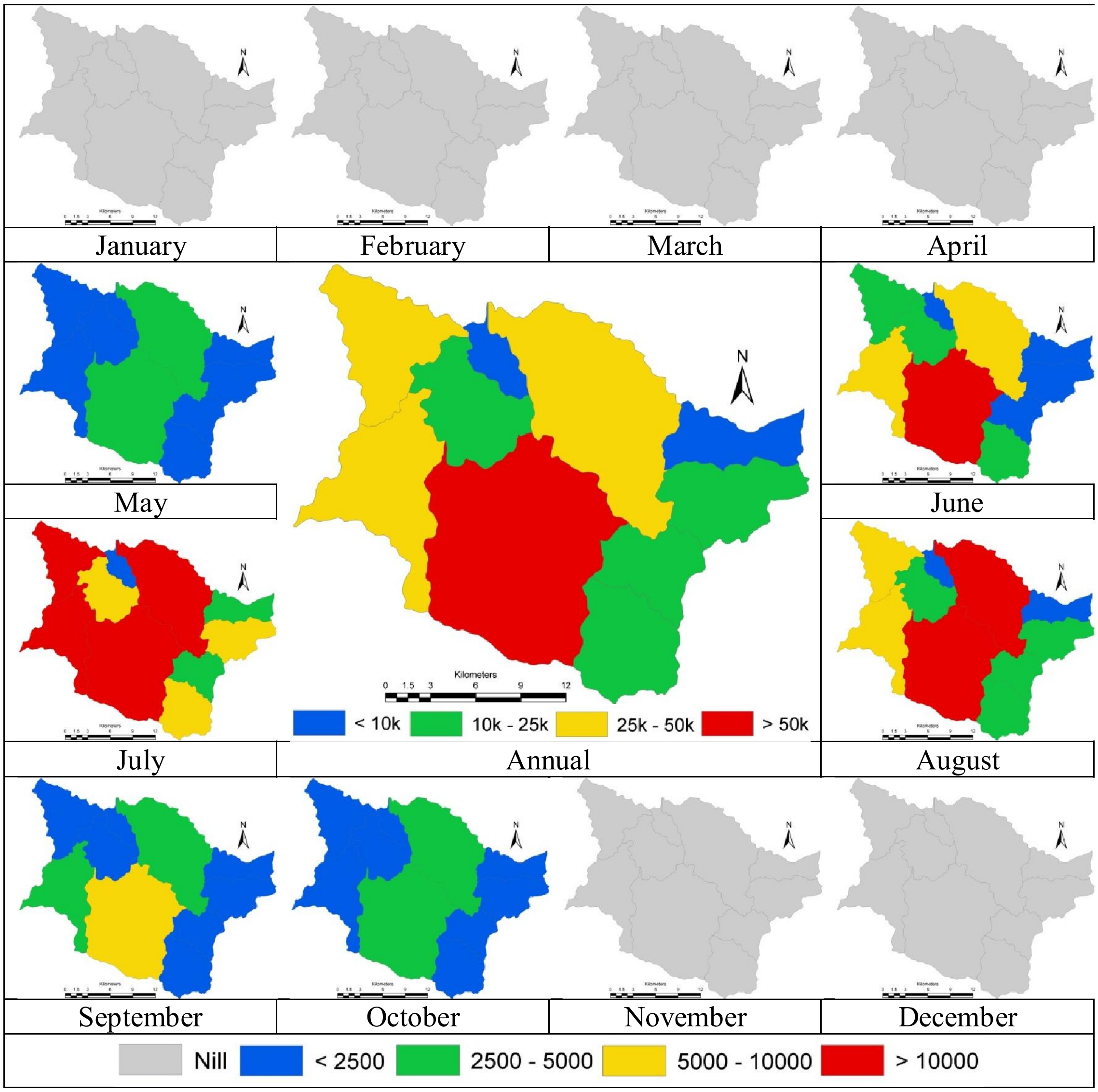


Figure 11: Interception (kilo.cum)

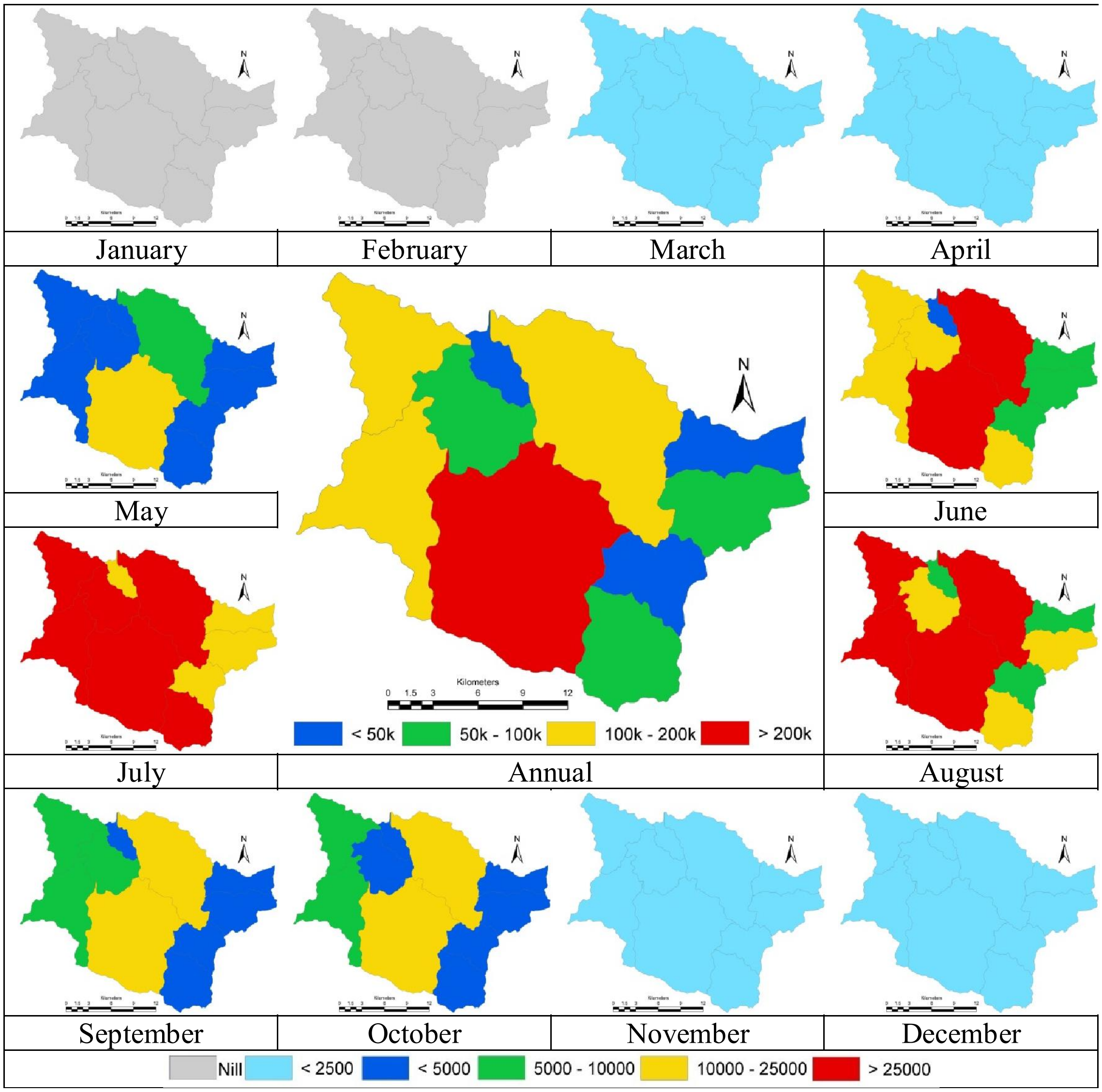


Figure 12: Net Raifall (kilo.cum)

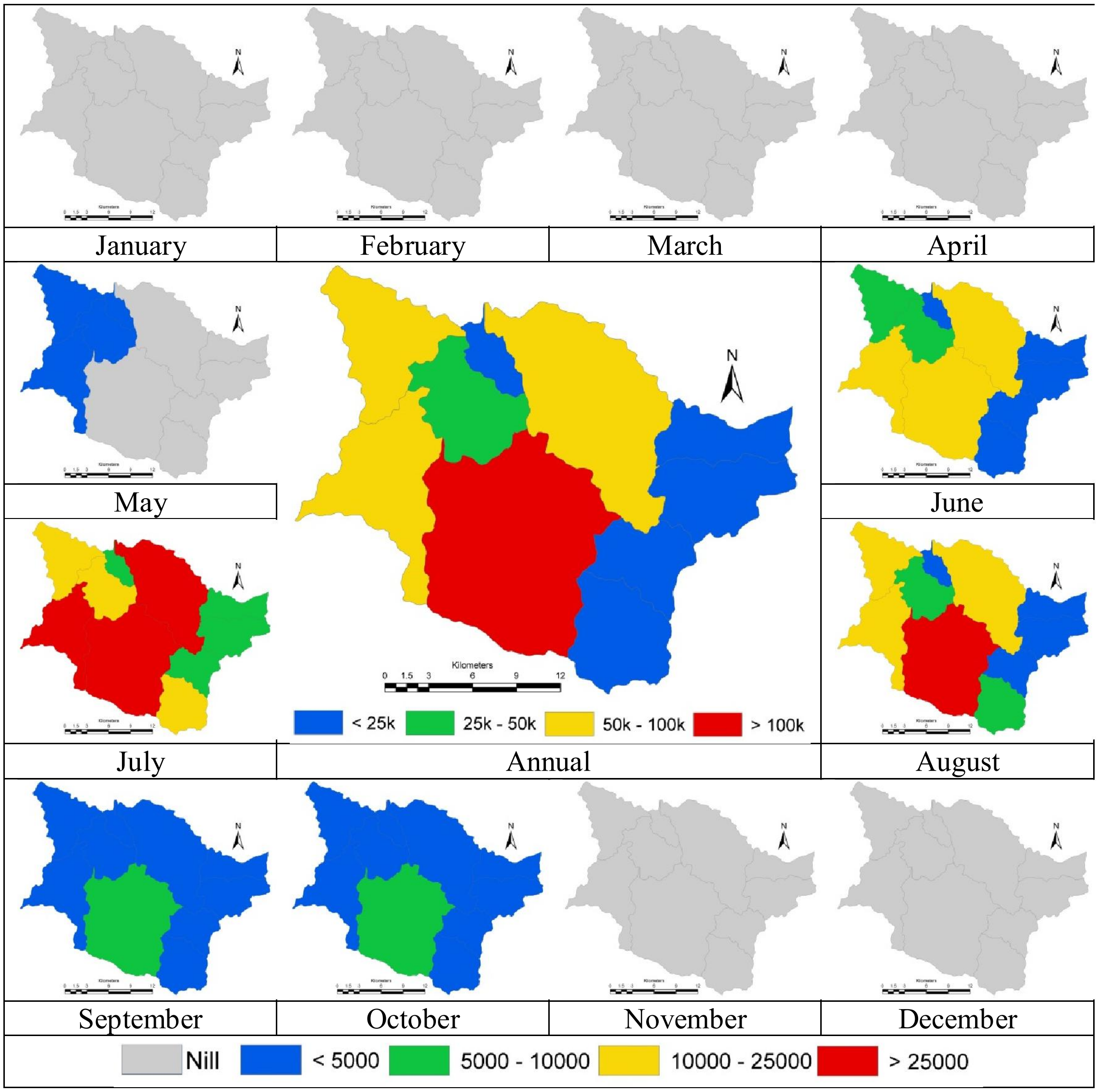


Figure 13: Runoff (kilo.cum)

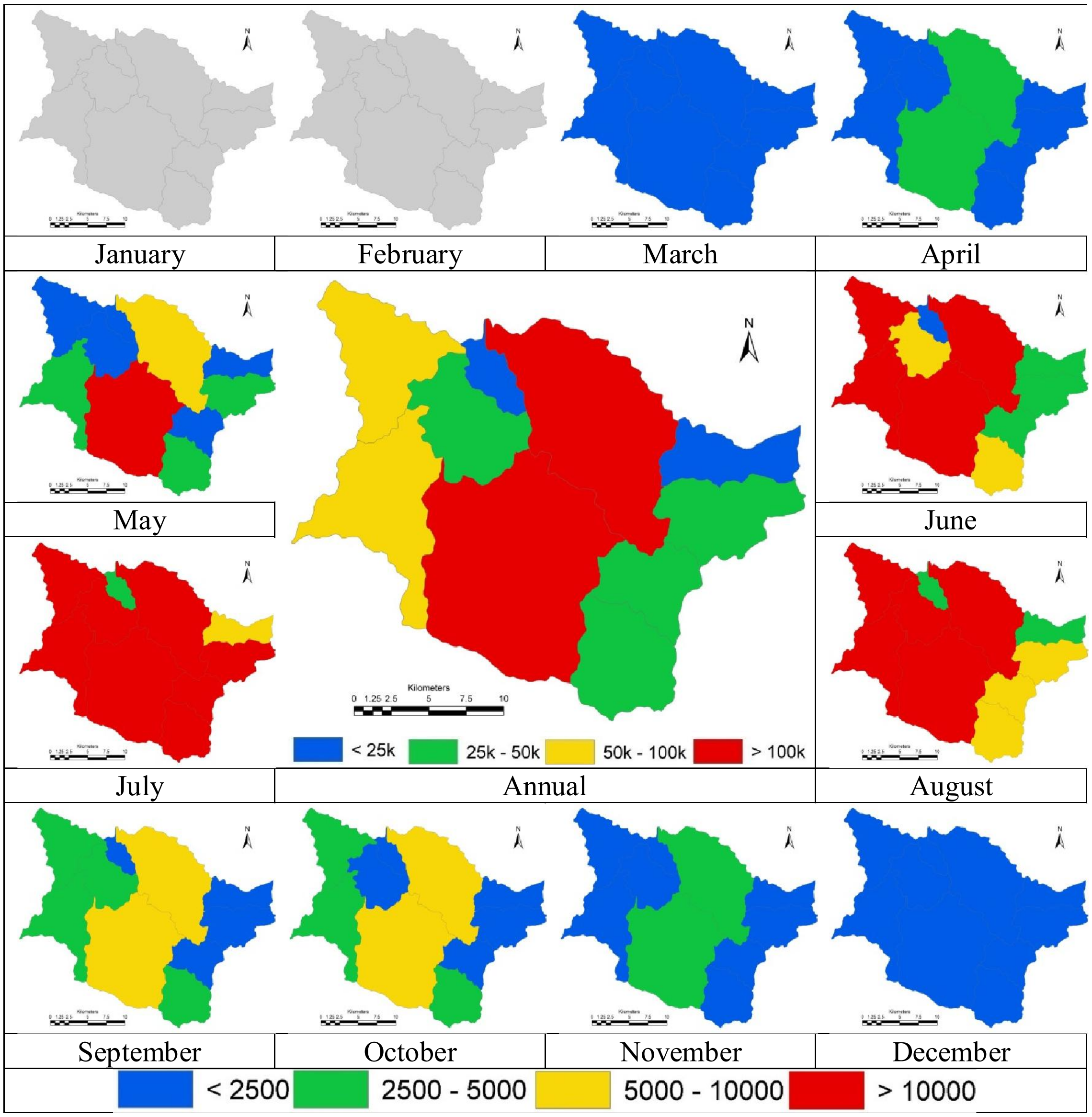


Figure 14: Infiltration (kilo.cum)

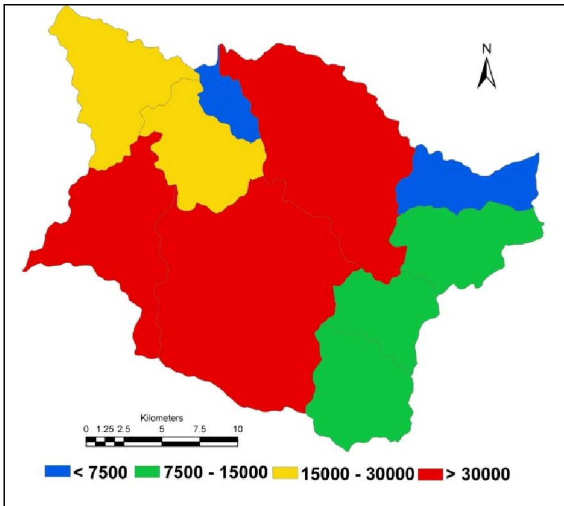


Figure 15: Ground water recharge (kilo.cum)

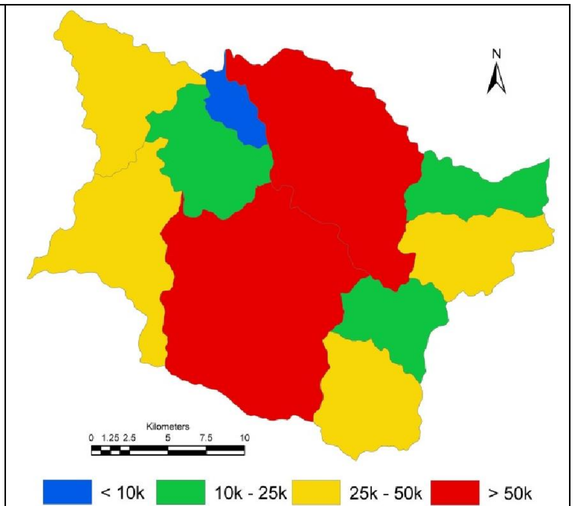


Figure 16: Water in Vadose (kilo.cum

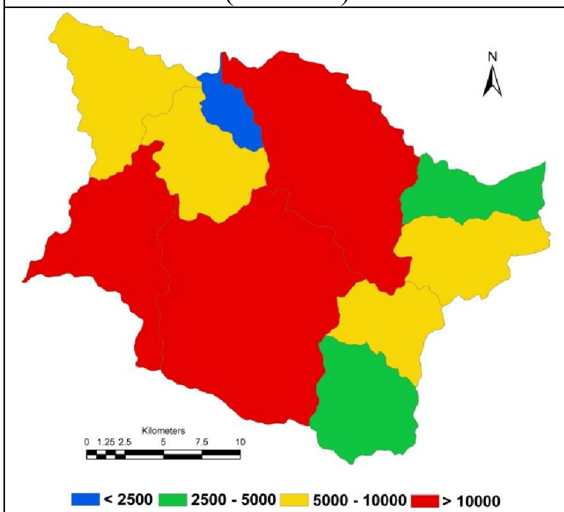


Figure 17: Pipe Flow (kilo.cum)

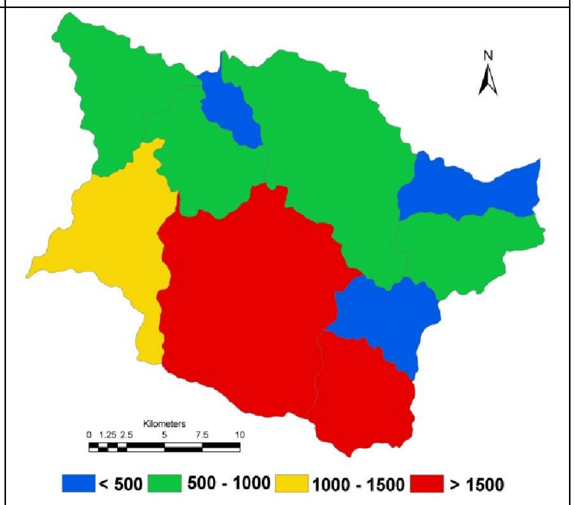


Figure 18: Base flow (kilo.cum)

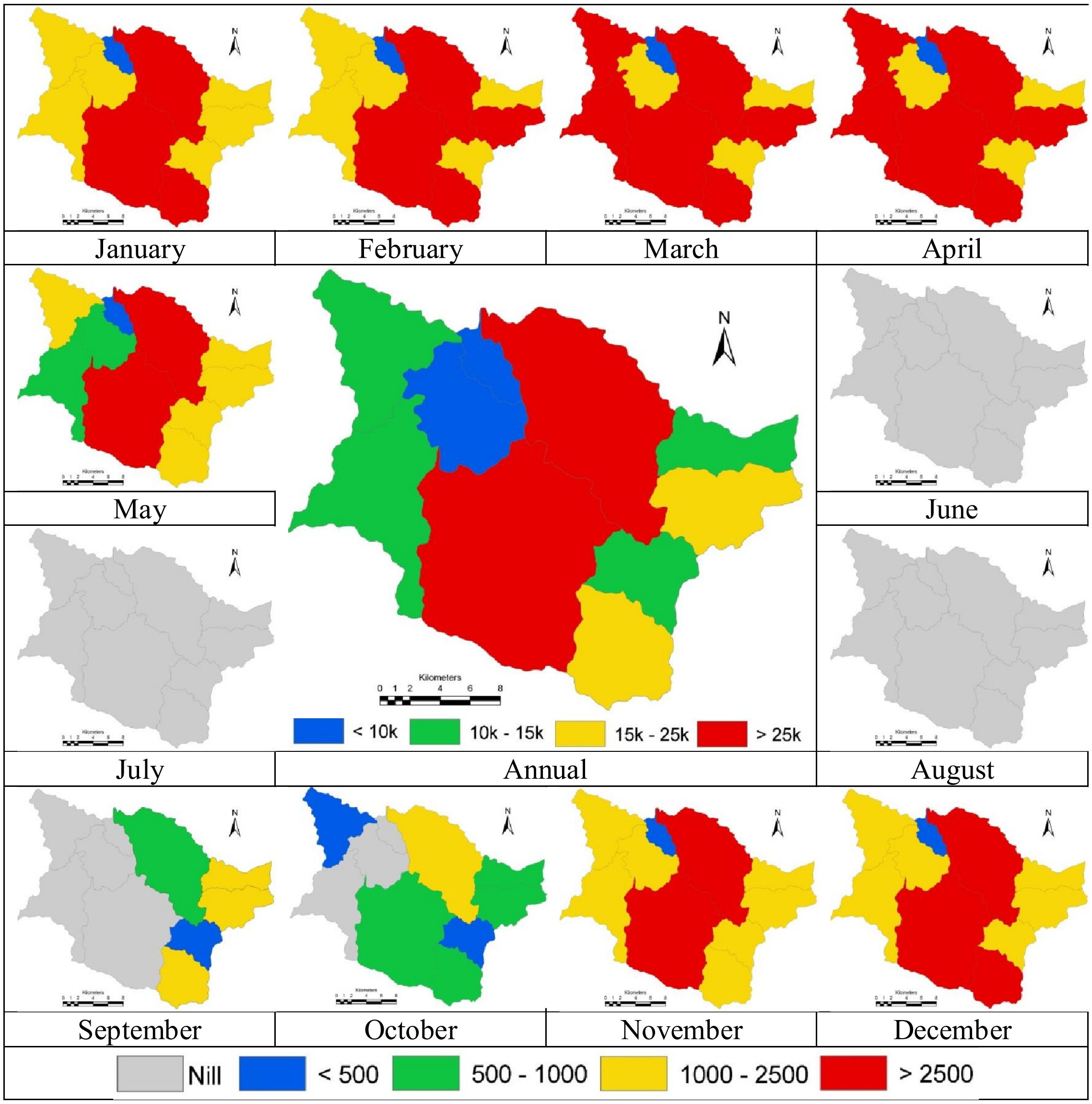


Figure 19: Evapotranspiration (kilo.cum)

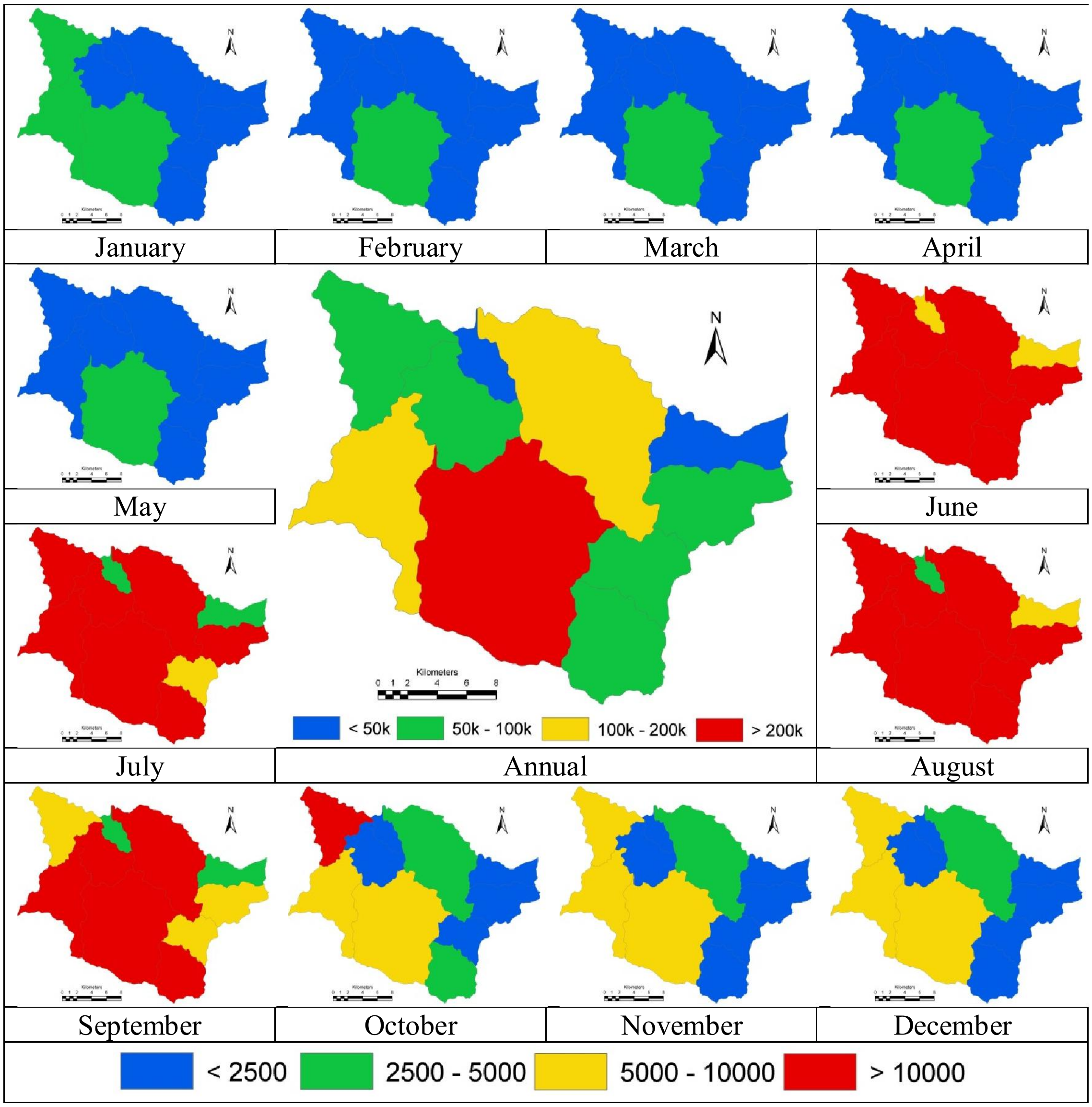


Figure 20: Crop water requirement (kilo.cum)

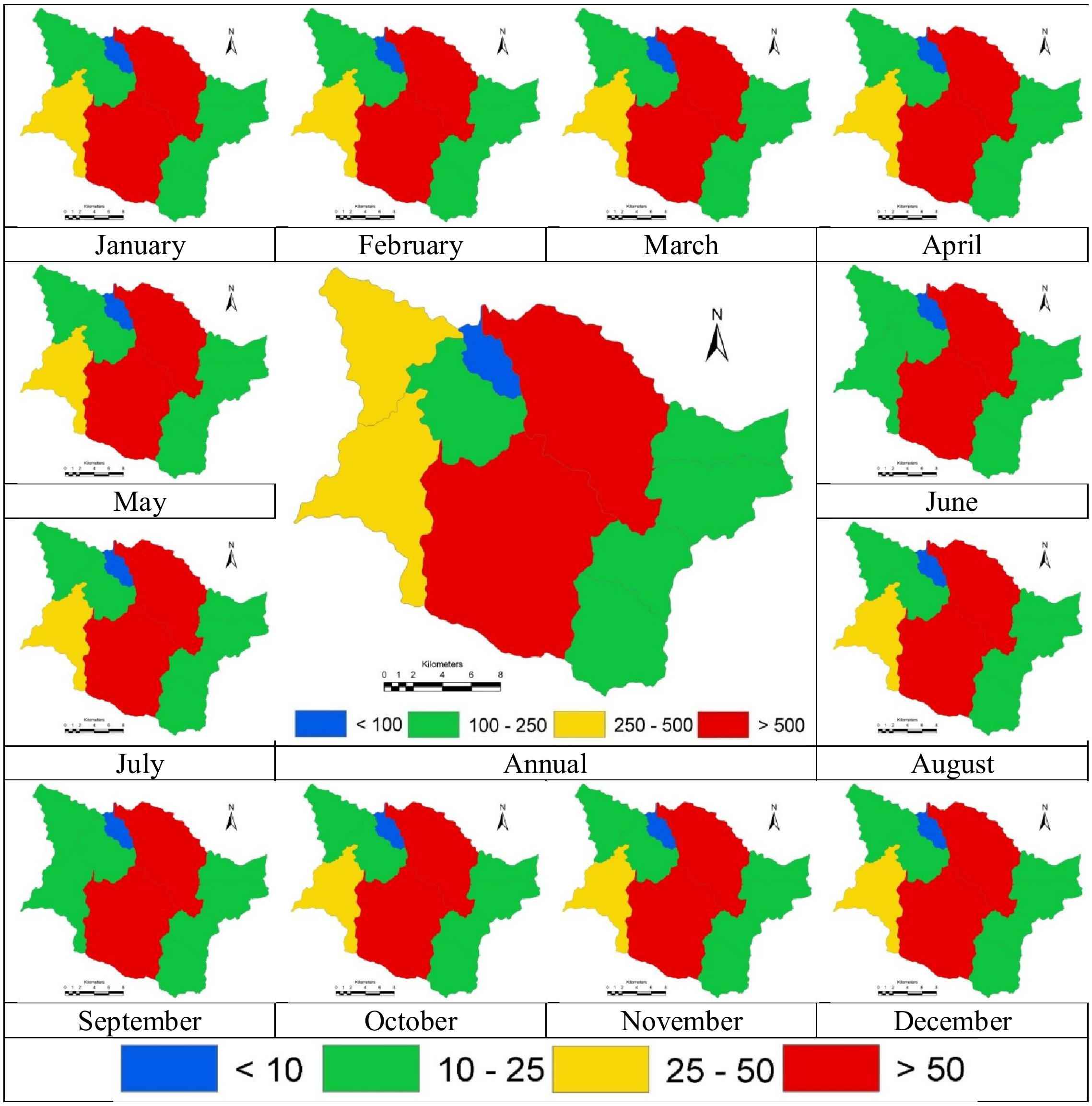


Figure 21: Domestic Water requirement (kilo.cum)

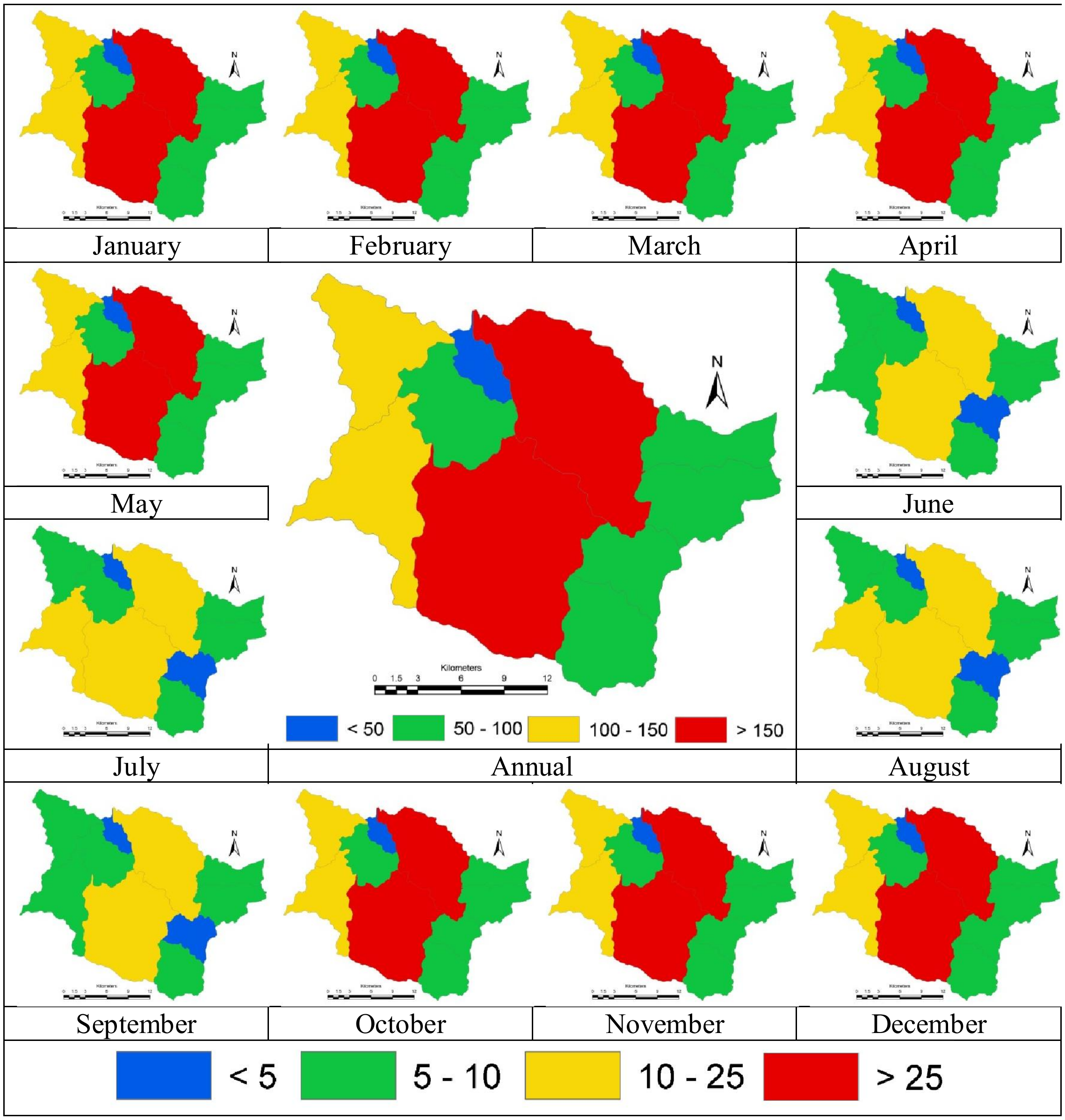


Figure 22: Livestock Water requirement (kilo.cum)

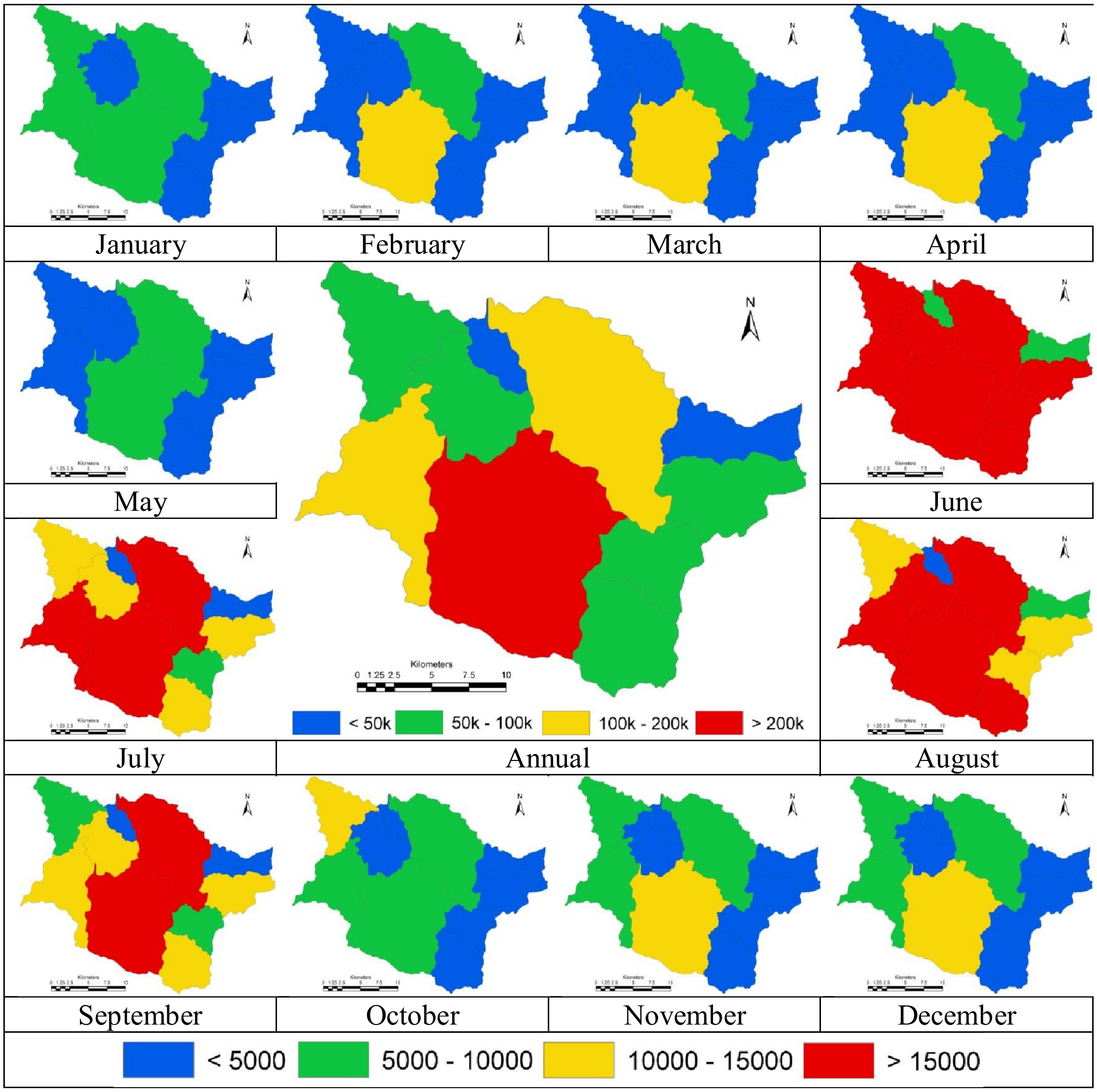


Figure 23: Total Demand (kilo.cum)

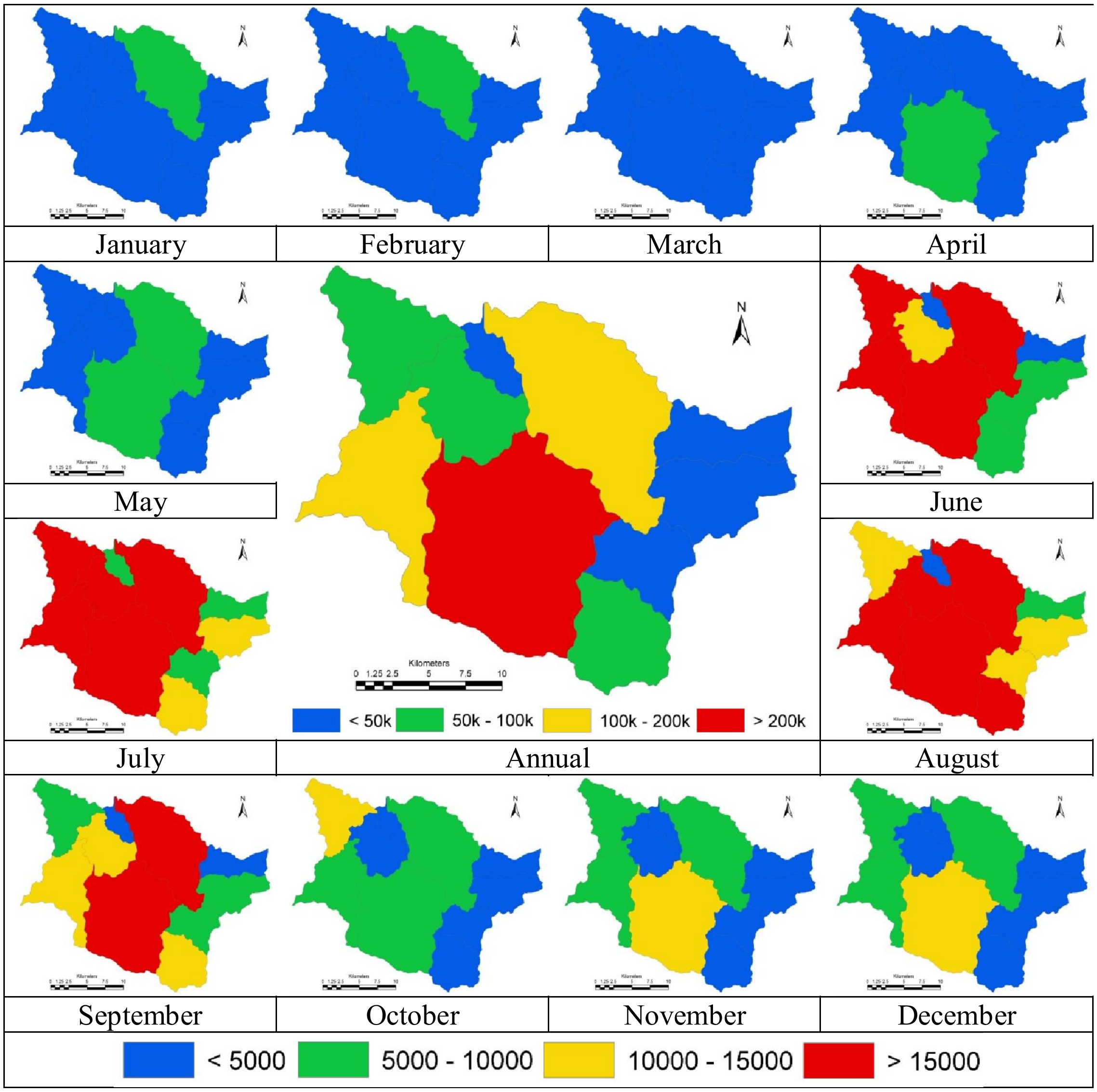


Figure 24: Supply (kilo.cum)

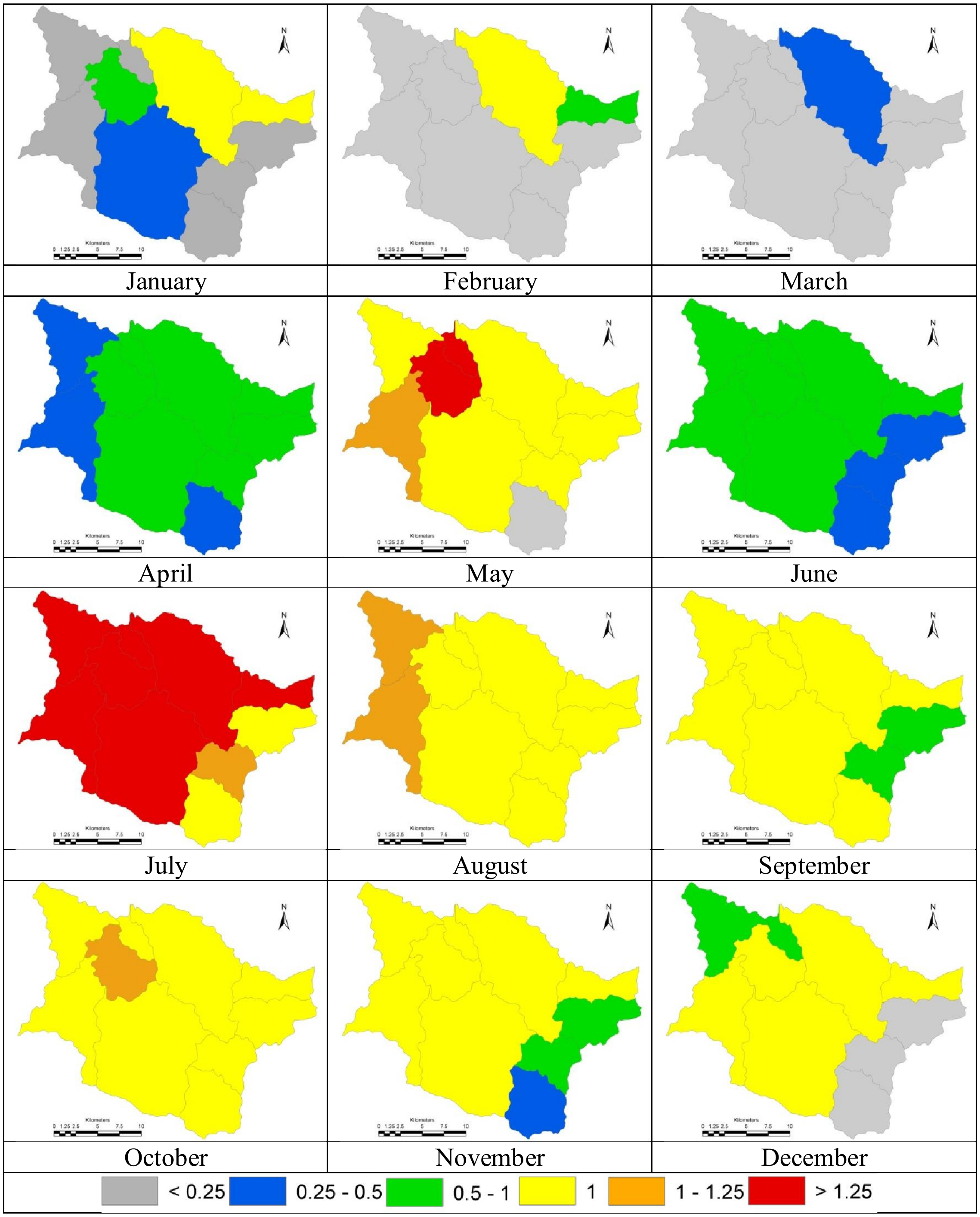


Figure 25: Water balance (supply to demand)

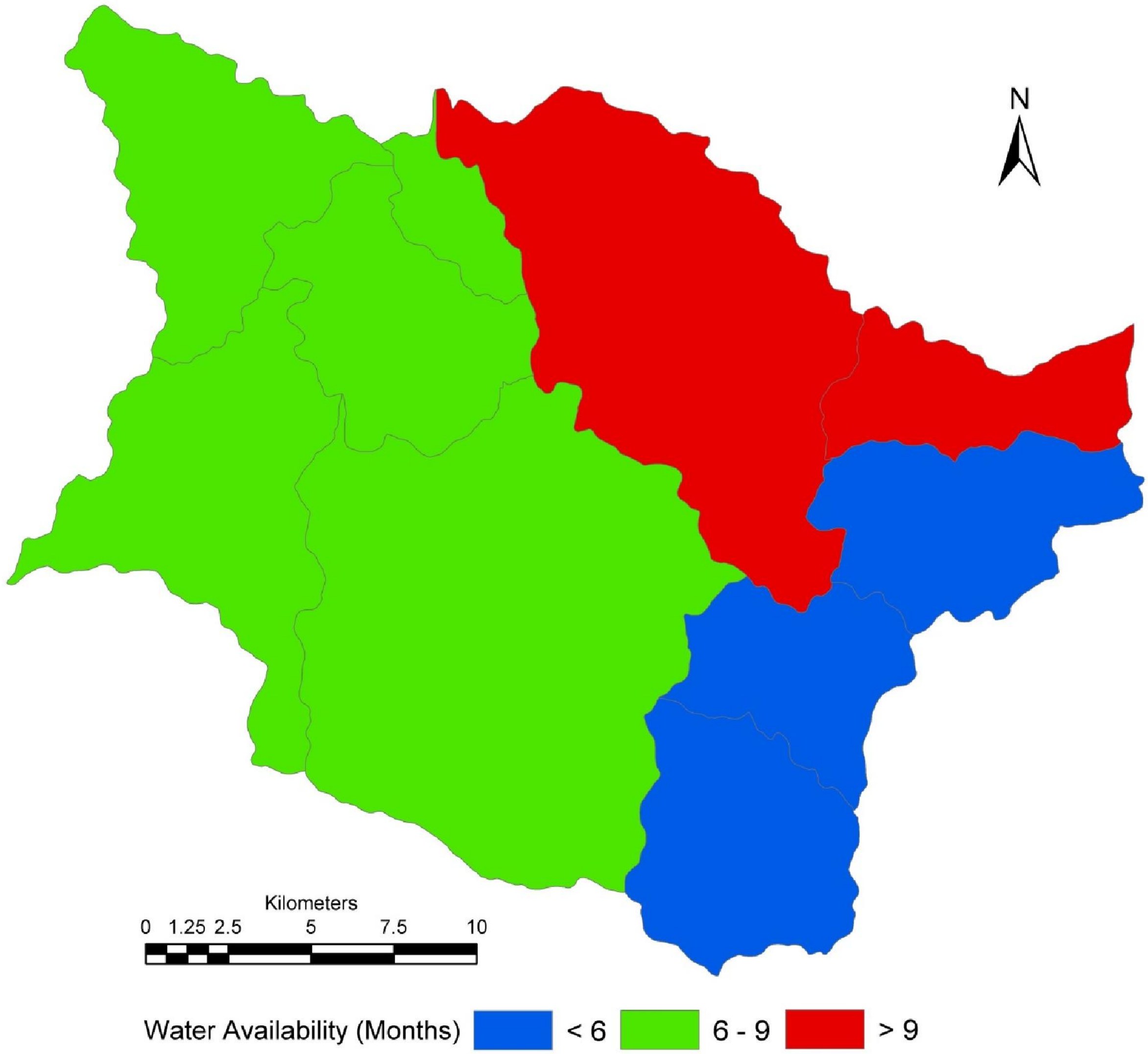


Figure 26: Hydrological status

Conclusions: The hydrological characteristics of the catchment are dependent upon landscape elements and hydro-meteorological conditions. Presence of forest patches in the catchment helps in catering to the needs post monsoon since these parts of the catchment hold water which are released as springs, maintain the ground water table. The catchments have interconnected cascading lakes helps in catering the agricultural, domestic and any other needs, replenishes the sub surface waters. In catchment with partial forest cover and lakes towards downstream of forests has helped in catering the agricultural and domestic needs post monsoon, this indicates that the presence of forests in a catchment plays a major role as a reservoir catering the post monsoon demands. The forests have declined from 45.2% in 1973 to 34.5% in 2013 whereas the horticultural activities have increased in a very large extent which uses intense water, forest lands have been planted with acacia and eucalyptus plantations rather than the native species. The decline in forest cover has also impacted the nature of rainfall, based on the meteorological data, the rainfall is declining at a rate of 50 mm per annum and thus creating water scarcity in the sub catchments. Similarly the runoff in basins increase with decline in forest cover and this can be observed in comparison with catchments causing flash flood like conditions during monsoons and drought like conditions in post monsoon and summer. With the increase in demand of water in according to the human requirement, large amount of water is being pumped from the ground water, with time depleting this resource .In order to replenish the water demand both for human purposes and for the nature, it is essential for any catchment to contain and retain necessary forest cover with the native tree species which have the capability to hold water and release them during post monsoons. Locations such as Varadamoola, Varadalli, and other locations in the Ghats have good patches of forest patches (*kans*), and origin of water source which enable them to cater to most of the downstream users for all 12 months in the year. These forest types in association with lakes downstream could be used/set as a good example in order to store water resource in plenty and cater to the needs of the downstream users post monsoon.

Acknowledgements

We dedicate this report to the people of Sagara Taluk We are grateful to Sri. Ananth Ashisar for assigning us the responsibility of preparing this report. We thank Mr Venkatesh, Mr Raghavendra, Mr Aaneguli Subbarao, Prof William, Na Disoza and all the people of Sagara for all the support on and off the field during this work. We are grateful to (i) NRDMS Division, The Ministry of Science and Technology, Government of India, (ii) The Ministry of Environment and Forests, Government of India and (iii) Indian Institute of Science for the sustained financial and infrastructure support for ecological research in Western Ghats.

References

1) Subramanya K, 2005, Engineering Hydrology, Tata McGraw-Hill publishing company limited New Delhi, Second Edition. ISBN: 0-07-462449-8
2) Raghunath H M, 1985, Hydrology, Wiley Eastern Limited, ISBN: 0-85226-746-0
3) Raghunath H M, 2005, Ground water, New age international publishers, Second Edition ISBN: 0-85226-298-1
4) Peter S Eagleton, 2002, Ecohydrology – Darwin in expression of vegetation form and function, Cambridge university press, ISBN: 0-521-77245-1
5) National Institute of Hydrology, http://www.nih.ernet.in
6) Hydraulic Design Manual, http://onlinemanuals.txdot.gov/txdotmanuals/hyd/rational_method.htm
7) Ananth kumar, 2012, Integrated basin management studies in Sitanadi basin, Western Ghats region, Karnataka, India Water Week 2012 – Water, Energy and Food Security: Call for Solutions, 10-14 April 2012, New Delhi.
8) Rainfall-Runoff modeling of Western Ghats region of Karnataka, National institute of hydrology, CS(AR)-31/98-99
9) Xu C Y and Singh V P, 2000, Evaluation and generalization of radiation-based methods for calculating evaporation, Hydrological processes, Vol.14, pp 339-349
10) Xu C Y and Singh V P, 2001, Evaluation and generalization of temperature-based methods for calculating evaporation, Hydrological processes, Vol.15, pp 305-319
11) Birhanu Zemadim , Felix Mtalo, Simon Mkhandi, Raj Kachroo and Matthew McCartney, 2011, Evaporation Modelling in Data Scarce Tropical Region of the Eastern Arc Mountain Catchments of Tanzania, Nile Basin Water Science & Engineering Journal, Vol.4(1), pp 1 - 13

12) Dunn S M and Mackay R , 1995, Spatial variation in evapotranspiration and the influence of land use on catchment hydrology, Journal of Hydrology, Vol.171, pp 49-73
13) Bapuji Rao B, Sandeep V M, Rao V U M and Venkateswarlu B, 2012, Potential Evapotranspiration estimation for Indian conditions: Improving accuracy through calibration coefficients, National Initiative on Climate Resilient Agricultre, Tech. Bull. No. 1/2012.
14) Alexandris S, Stricevic R and Petkovic S, 2008, Comparitive analysis of reference evapotranspiration from the surface of rainfed grass in central Serbia, calculated by six empherical methods against the Penman- Monteith formula,European Water21/22, pp 17-28
15) Marvin Jensen E, 2010, Estimating evaporation from water surfaces, CSU/ARS Evapotranspiration Workshop, Fort Collins, CO, 15-Mar-2010
16) Stan Wullschleger D, Hanson P J and Todd D E, 2001, Transpiration from a multi-species deciduous forest as estimated by xylem sap flow techniques, Forest Ecology and Management,Vol.143, pp 205-213
17) Venkatesh B, Lakshman Nandagiri, Purandara B K and Reddy V B, 2011, Modeling Soil Moisture under different land covers in a sub-humid environment of Western Ghats, India, Journal of Earth System Science , Vol.120 (3), pp 387-398
18) Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, eands.dacnet.nic.in/At_A_Glance-2011/Appendix-IV.xls
19) Bounteous Karnataka, Government of Karnataka, www.bounteouskarnataka.com/DP-PDF/DistrictProfile-UttaraKannada.pdf.
20) Subramanian D K, 1998, A framework for conducting carrying capacity studies for Dakshina kannada district, IISc Archive
21) Ying Zhang, Taihai Xu, Zhao Jiang, Xinran Peng, Lin Zhang and Shuang Kang, 2009, Quantitative Calculation Models and the Application of Ecological Carrying Capacity, IEEE Xplore, pp 1-3
22) Xilian Wang, 2010, Research Review of the Ecological Carrying Capacity, Journal of Sustainable Development, Vol. 3(3), pp 263 – 265.
23) Hegde D M, 2012, Carrying capacity of Indian agriculture: oilseeds, Current Science, Vol. 102(6), pp 867-873.
24) Venkateswarlu B and Prasad J V N S, 2012, Carrying capacity of Indian agriculture: issues related to rainfed agriculture, Current Science, Vol.102(6), pp 882 – 888
25) Masood Ali and Sanjeev Gupta, 2012, Carrying capacity of Indian agriculture: pulse crops, Current Science, Vol.102(6), pp 874 – 881
26) Ghosh S P, 2012, Carrying capacity of Indian horticulture, Current Science, Vol.102(6), pp 889 – 893
27) Li Ming, 2011, The Prediction and Analysis of Water Resource Carrying Capacity in Chongqing Metropolitan, China, Procedia Environmental Sciences, Vol.10, pp 2233 – 2239
28) Yuan Yan, Li Li and Li Yankui, 2010, An Analysis of Environment and Resources Carrying Capacity for Guiding Urban Planning: A Case Study of Hezhou, China, 2nd Conference on Environmental Science and Information Application Technology-2010, IEEE, pp 235 – 238
29) Xian Wei, Zhou Wancun and Shao Huaiyong, 2009, Study on the Ecological Carrying Capacity in Mining Areas: A case Study in Panxi Mining Concentrated Area, The 1st International Conference on Information Science and Engineering (ICISE2009), IEEE Computer Society, pp 2193 – 2197.
30) Hui Fu, Yijie Liu and Yinglan Sun, 2009, A Study on the Marine Ecological Carrying Capacity in Qingdao Based on Principle Component Analysis and Entropy, IEEE Xplore, pp 1-4
31) Dan Luo and Nai'ang Wang, 2010, Assessment of environmental carrying capacity of ecotourism for Maqu, 201O International Conference on Computer Application and System Modeling (ICCASM 2010), IEEE, Vol.15, pp 518 – 520.
32) Weizhuo Ji, 2010, Dynamic Analysis of Ecological Footprint and Ecological Carrying Capacity, 2010 Sixth International Conference on Natural Computation (ICNC 2010), IEEE, pp 3033 – 3036
33) Jianhong Huang and Jing Cai, 2011, Analysis of Environmental Carrying Capacity of Hainan against the Background of Island Economy, IEEE, pp 8054 – 8057.
34) Yizhong Zhu and Shilu Yan, 2011, Estimate of Eco-environment Carrying Capacity of Guangzhou, IEEE Xplore, pp 1 – 4
35) Du Min, Xu Zhenghe, Peng Limin, Zhu Yunhai and Xu Xiufeng, 2011, Comprehensive Evaluation of Water Resources Carrying Capacity of Jining City, Energy Procedia, Vol.5 ,pp 1654–1659
36) Goyal S K and Chalapati Rao C V, 2007, Air assimilative capacity-based environment friendly siting of new industries—A case study of Kochi region, India, Journal of Environmental Management, Vol. 84, pp 473–483

37) Li-Hua Feng, Xing-Cai Zhang and Gao-Yuan Luo, 2008, Application of system dynamics in analyzing the carrying capacity of water resources in Yiwu City, China, Mathematics and Computers in Simulation, Vol. 79, pp 269–278
38) Ying Li, Tingting Guo, and Jing Zhou, 2011, Research of Ecological Carrying Capacity - Comprehensive Evaluation Model, Procedia Environmental Sciences, Vol. 11, pp 864 – 868
39) Peng Kang and Linyu Xu, 2010, The urban ecological regulation based on ecological carrying capacity, Procedia Environmental Sciences, Vol. 2, pp 1692–1700
40) Xia Y Q and Shao M A, 2008, Soil water carrying capacity for vegetation: A hydrologic and biogeochemical process model solution, Ecological modeling, Vol. 214, pp 112–124
41) Yu Long, Zhou Li, ,Liu Wei and Zhou Hua Kun, 2010, Using Remote Sensing and GIS Technologies to Estimate Grass Yield and Livestock Carrying Capacity of Alpine Grasslands in Golog Prefecture, China, Pedosphere Vol. 20(3), pp 342–351
42) Gopal Thapa B and Giridhari Sharma Paudel, 2000, Evaluation of the livestock carrying capacity of land resources in the Hills of Nepal based on total digestive nutrient analysis, Agriculture, Ecosystems & Environment, Vol. 78(3), pp 223–235
43) Connor W P, Garcia A P, Connor A H, Garton E O, Groves P A and Chandler J A, 2001, Estimating the Carrying Capacity of the Snake River for Fall Chinook Salmon Redds, Northwest Science, Vol. 75(1), pp 363-371
44) Xie Fuju, Zjeng Mingx and Zhang Hong, 2011, Research on Ecological Environmental Carrying Capacity in Yellow River Delta, Energy Procedia, Vol. 5, pp 1784–1790
45) Jing Li, Xiaode Zhou and Wen Chen, 2011, Study on Prince Edward River Basin's Water Ecological Carrying Capacity based on Water Ecological District, IEEE Xplore, pp 1244-1249
46) Xu Ling, Liu Zhihong and Du Jing, 2011, Study on Evaluation of Water Ecological Carrying Capacity, 2010 International Conference on Biology, Environment and Chemistry, IPCBEE , Vol. 1, pp 458 – 462
47) Ramachnadra T V, Bharath H A and Vinay S, 2013, Land use Land Cover Dynamics in a rapidly urbanizing Landscape, SCIT journal (in press)
48) Faith Love, Elisha Madamombe, Brian Marshall and Evans Kaseke, 2006, Preliminary estimate of environmental flow requirements of the Rusape River, Zimbabwe, Physics and Chemistry of the Earth, Vol. 31, pp 864–869
49) Bonella M, Purandara B K, Venkatesh B, Jagdish Krishnaswamy, Acharya H A K, Singh U V, Jayakumar R and Chappell N, 2010, The impact of forest use and reforestation on soil hydraulic conductivity in the Western Ghats of India: Implications for surface and sub-surface hydrology, Journal of Hydrology, Vol. 391, pp 47–62
50) Yong Lin and Xiaohua Wei, 2008, The impact of large-scale forest harvesting on hydrology in the Willow watershed of Central British Columbia, Journal of Hydrology, Vol. 359, pp 141–149
51) Chen H and Zhao Y W, 2011, Evaluating the environmental flows of China's Wolonghu wetland and land use changes using a hydrological model, a water balance model, and remote sensing, Ecological Modelling, Vol. 222, pp 53–260.
52) Das Gupta A, 2008, Implication of environmental flows in river basin management, Physics and Chemistry of the Earth, Vol. 33, pp 298–303
53) Jorge Alcázar and Antoni Palau, 2010, Establishing environmental flow regimes in a Mediterranean watershed based on a regional classification , Journal of Hydrology, Vol. 388, pp 41–51
54) Japhet Kashaigili J, Reuben Kadigi M J, Bruce Lankford A, Henry Mahoo F and Damus Mashauri A, 2005, Environmental flows allocation in river basins: Exploring allocation challenges and options in the Great Ruaha River catchment in Tanzania, Physics and Chemistry of the Earth, Vol. 30, pp 689–697
55) Hyoseop Woo, 2010, Trends in ecological river engineering in Korea, Journal of Hydro-environment Research, Vol. 4, pp 269-278
56) Fucheng YANG, Ziqiang XIA, Lanlan YU and Lidan GUO, 2012, Calculation and Analysis of the Instream Ecological Flow for the Irtysh River, Procedia Engineering Vol. 28, pp 438 – 441
57) Hughes H A, 2001, Providing hydrological information and data analysis tools for the determination of ecological instream flow requirements for South African rivers, Journal of Hydrology, 241, 140–151
58) Lillesand M T, Kiefer W R, and Chipman W J, "Remote Sensing and Image Interpretation", 5th ed. John Wiley and Sons. 2004

59) Sudhira H S, Ramachandra T V and Jagadish K S, 2004, Urban sprawl: metrics, dynamics and modelling using GIS. International Journal of Applied Earth Observation and Geoinformation, Vol. 5, pp 29-30.
60) Ramachandra T V, Bharath H A and Durgappa D S, 2012, Insights to urban dynamics through landscape spatial pattern analysis, International Journal of Applied Earth Observation and Geoinformation, Vol. 18, pp 329-343.
61) Ramachandra T V, and Bharath H A, 2012, Spatio-Temporal Pattern of Landscape Dynamics in Shimoga, Tier II City, Karnataka State, India, International Journal of Emerging Technology and Advanced Engineering, Vol. 2(9) , pp 563-576.
62) Ramachandra T V, Bharath H A and Sreekantha S, 2012, Spatial Metrics based Landscape Structure and Dynamics Assessment for an emerging Indian Megalopolis, International Journal of Advanced Research in Artificial Intelligence, Vol. 1(1), pp 48 – 57.
63) Vinay S, Bharath H A and Ramachandra T V, 2012, Spatio-temporal dynamics of Raichur City, LAKE 2012: National Conference on Conservation and Management of Wetland Ecosystems 06th – 09th November 2012
64) Neil Sims C and Matthew Colloff J, 2012, Remote sensing of vegetation responses to flooding of a semi-arid floodplain: Implications for monitoring ecological effects of environmental flows, Ecological Indicators, 18, 387–391.
65) Amoghavarsha Murthy, Gouda K C, Reshma Bhat, Prabhuraj D K, and Lakshmikantha B P, 2012, Monitoring of 2009 Krishna River Flood using Remote Sensing and GIS, Proceedings of AGU Fall Meeting 2012, San Francisco, December 3rd - 7th 2012
66) Ramachandra T V, Subhash Chandran M D, Sreekantha, Diwakar Mesta, Rao G R and Sameer Ali , 2004, Cumulative impact assessment in sharavathi river basin, Internationan Journal of Environmental and Development, Vol. 1(1), pp 113 - 135
67) Ramachandra. T V, Subash Chandran M D, Joshi N V, Sreekantha, Raushan Kumar, Rajinikanth R, Desai S R and Subhash Babu, 2012. Ecological Profile of Sharavathi River Basin., Sahyadri Conservation Series 22, ENVIS Technical Report : 52, November 2012, Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012
68) Ramachandra T V, Subash Chandran M D, Surya Prakash Shenoy H, Rao G R, Vinay S, Vishnu Mukri and Sreekanth Naik, 2013. Kumaradhara River Basin, Karnataka Western Ghats: Need for Conservation and Sustainable Use., Sahyadri Conservation Series 24, ENVIS Technical Report : 54, April 2013, Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012.
69) Reshma Bhat, Gouda K C, Amoghavarsha M, Lakshmikantha B P, Prabhuraj D K, 2012, Decadal Variation In The Rainfall Characteristics over River Basins across the Western Ghats of India, Proceedings of AGU Fall Meeting 2012, San Francisco, December 3rd - 7th 2012.
70) Vaithiyanathan P, Ramanathan A and Subramanian V, 1992, Sediment transport in the Cauvery River basin: sediment characteristics and controlling factors, Journal of Hydrology, Vol. 139(1–4), pp 197–210
71) Mallikarjuna V, Prasad K R K, Udaya Bhaskar P and Sai Lakshmi M, 2013, Water Balance Study of Krishna Delta, Andhra Pradesh, using GIS & RS Techniques, International Journal of Emerging Technology and Advanced Engineering, Vol. 3(6), pp 59 – 64
72) University of Kentucky, College of Agriculture Food and Environment, Lexington, http://www2.ca.uky.edu/poultryprofitability/Production_manual/Chapter12_Water_quality/Chapter12_introduction.html, table 12.1
73) Water Requirement of rabbits and Guinea Pigs, Nature, August 1943, V 152, pp-157 http://www.nature.com/nature/journal/v152/n3849/abs/152157b0.html
74) My Cocker Spaniel, http://mycockerspaniel.com/h2o.htm
75) Ramachandra T V, Subash Chandran M D, Joshi N V and Bharath Setturu, 2013, Land use changes with the implementation of developmental projects in Uttara Kannada district, Sahyadri Conservation Series 31, ENVIS Technical Report : 61, August 2013, Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012.
76) District at a Glance 2012 – 2013, (Shimoga, Uttara kannada)
77) Ramachandra T V, Subash Chandran M D, Joshi N V and Bharath Setturu, 2013, Land use land cover (lulc) dynamics in Uttara Kannada district, central Western Ghats , Sahyadri Conservation Series 28, ENVIS Technical Report : 56, August 2013, Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012.

78) Forman R T T and Gordron M., 1986. Landscape Ecology. John Wiley & Sons, New York, ISBN 0-471-87037-4.
79) Kennedy R E, Townsend P A, Gross J E, Cohen W B, Bolstad P, Wang Y Q and Adams P, 2009. Remote sensing change detection tools for natural resource managers: understanding concepts and tradeoffs in the design of landscape monitoring projects. Remote Sensing of Environment, Vol. 113, pp. 1382–1396.
80) Fraser R H, Olthof I, and Pouliot D, 2009. Monitoring land cover change and ecological integrity in Canada's national parks, Remote Sensing of Environment, Vol. 113, pp. 1397–1409
81) Ramachandra, T.V., Subashchandran, M. D., Joshi, N.V. and Boominathan. M., 2012, "Edible Bivalves of Central West Coast, Uttara Kannada District, Karnataka, India.", Sahyadri Conservation Series 17, ENVIS Technical Report : 48, Energy & Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore 560 012
82) Ramachandra, T. V., Nupur, N., Vinay, S., Bharath, H. A., 2014, "Modeling Hydrologic regime of Lakshmanatirtha watershed, Cauvery River", Conference proceedings of IEEE, GHTC-SAS 2014, Trivandrum, September 26-27, 2014
83) Vinay, S., Bharath, H.A., Ramachandra, T.V., 2013, "Land use Land Cover Dynamics in a Rapidly Urbanizing Landscape", SCIT Journal, August 2013, Vol. XIII.

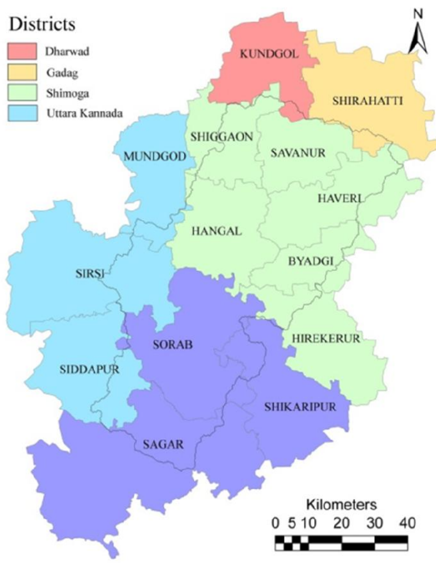
Web Portals

1) http://www.waterboards.ca.gov/water_issues/programs/swamp/docs/cwt/guidance/513.pdf
2) http://www.fao.org
3) http://ces.iisc.ernet.in/energy/water/proceed/section7/paper5/section7paper5.htm
4) http://www.slideshare.net/cpkumar/estimation-of-groundwater-potential-2490240
5) National Food Security Mission , http://nfsm.gov.in/nfsmmis/RPT/CalenderReport.aspx
6) Krishiseva Agriculture Information Hub, http://krishisewa.com/cms/crops-calendar.html
7) IKisan Agriculture portal, http://www.ikisan.com/
8) Indian Agriculture Research Institute, www.iari.res.in
9) http://censusindia.gov.in/
10) www.worldclim.org
11) Ministry of Environment and forest, http://envfor.nic.in/
12) India Water Portal, http://www.indiawaterportal.org/.
13) India WRIS, http://india-wris.nrsc.gov.in/wrpinfo/index.php?title=Krishna
14) IUCN, 2011. eFlowNet Summary 2010. International Union for Conservation of Nature, http://cmsdata.iucn.org/downloads/newsletter_print.pdf
15) North California State University, http://www.ncsu.edu/project/swine_extension/healthyhogs/book1995/almond.htm, table 1
16) http://www.mfe.govt.nz/laws/standards/ecological-flows-water-levels/workshops-ecological-flows-water-levels-faqs.html
17) Directorate of Census operations, Karnataka, http://censuskarnataka.gov.in

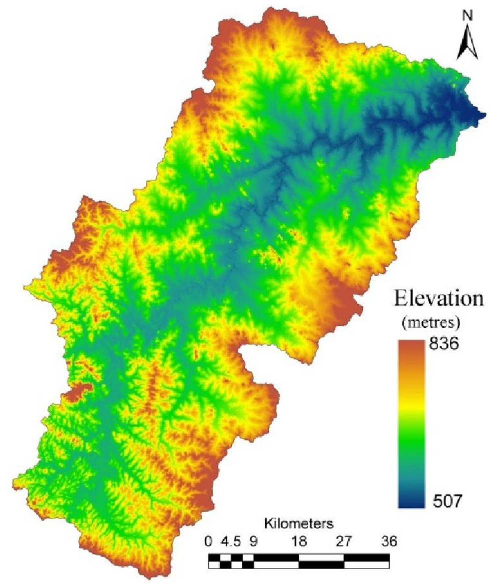
Annexure

Annexure 1: Varadamoola and Varadalli

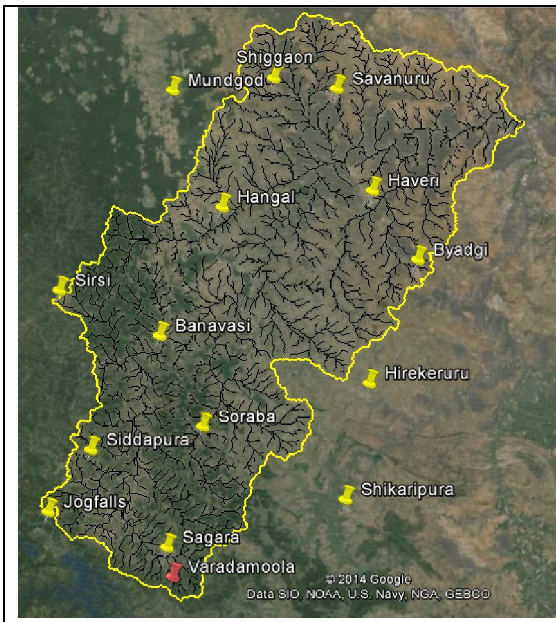
Annexure 2: Varada River Catchment characteristics



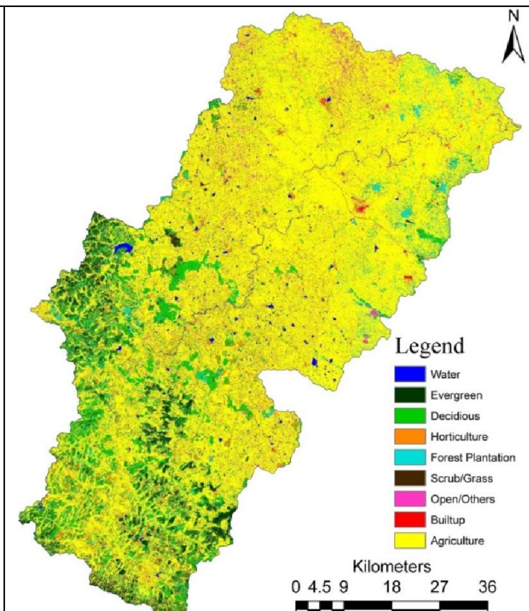
Administrative Divisions



Digital Elevation Model



Varada River Drinage (overlaid on GE)

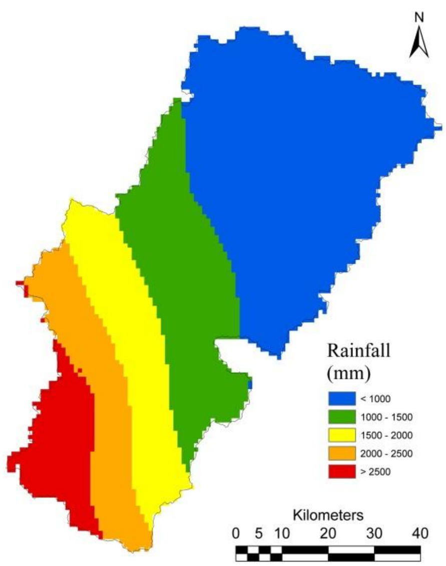


Land use (2013) of Varada river

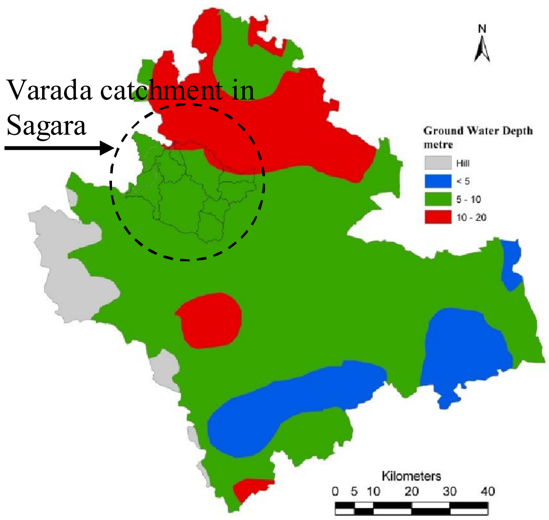
Varada river land use (2013 December)

Landuse	Area (Ha)	Area (%)
Water	5546.56	1.08
Evergreen Forest	26909.61	5.24
Deciduous Forest	52515.13	10.23
Horticulture	35695.07	6.95
Forest Plantation	17718.61	3.45
Scrub/Grass	6469.662	1.26
Open/Others	9998.387	1.95
Built up	3796.016	0.74
Agriculture	354891	69.11
Total Area	513540.1	

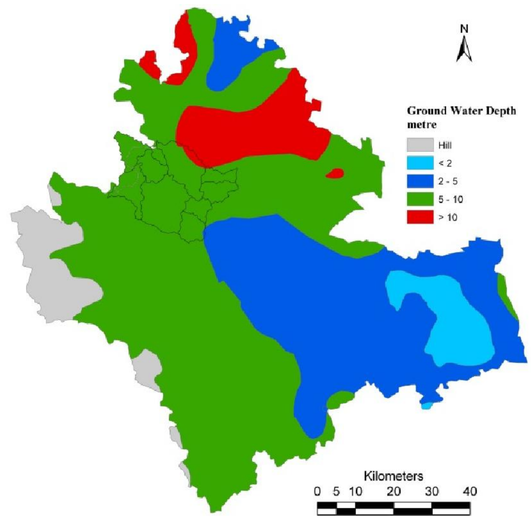
Rainfall distribution in Varada river catchment (WorldClim)



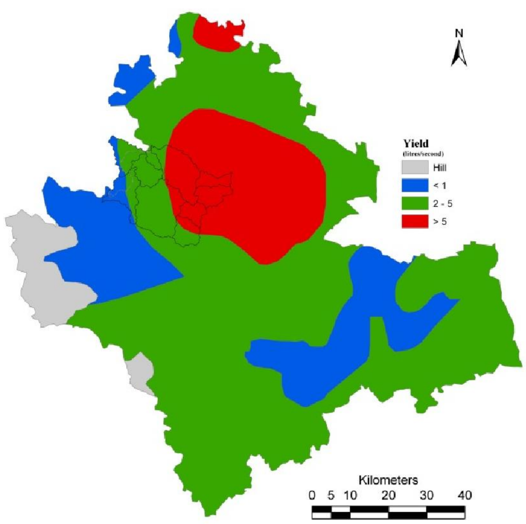
Annexure 3: Ground Water Studies (reference: CGWB)



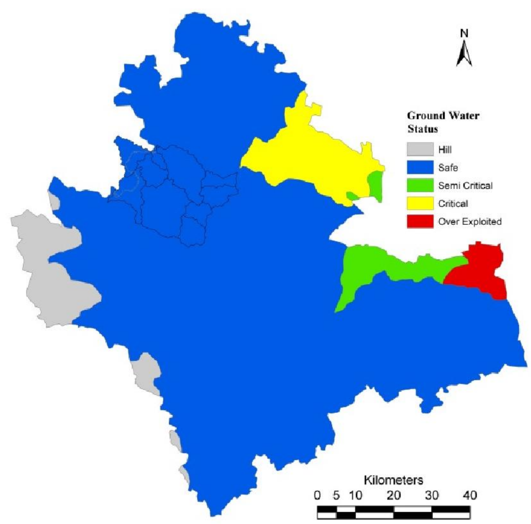
Ground Water Depth Pre Monsoon



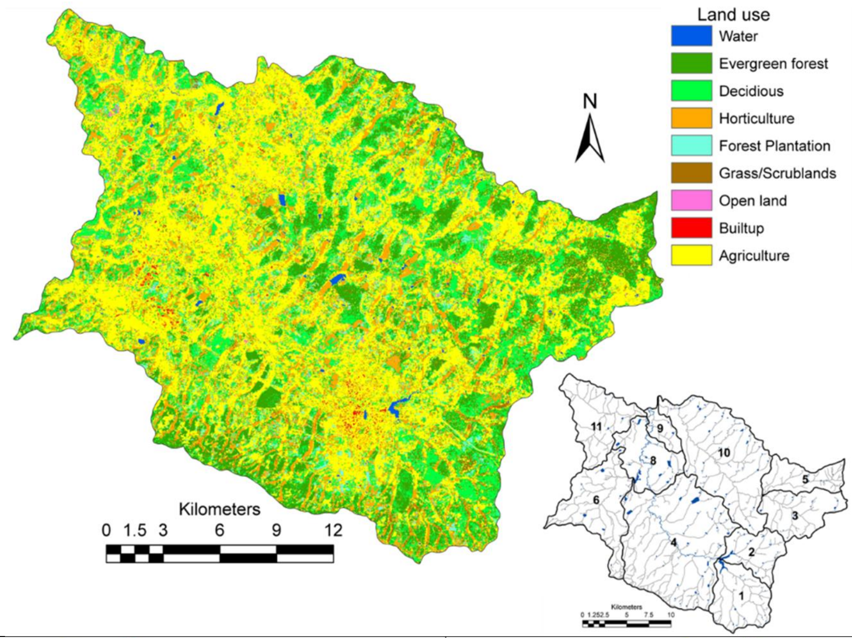
Ground Water Depth Post Monsoon

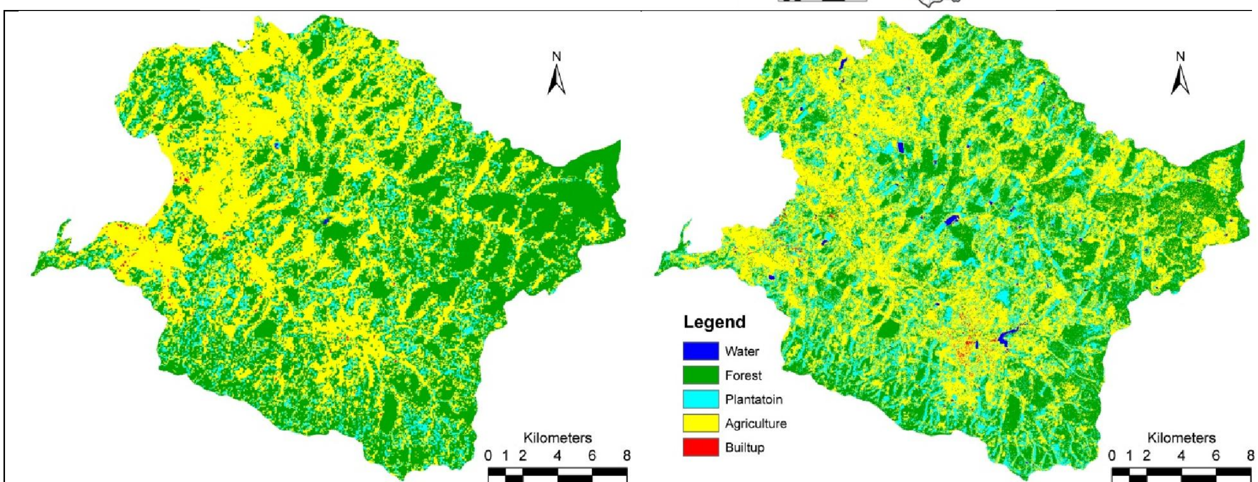


Ground Water Yield



Ground Water Status





1973	2013

ENERGY AND WETLANDS RESEARCH GROUP, CES TE15
CENTRE FOR ECOLOGICAL SCIENCES,
New Bioscience Building, Third Floor, E Wing
Near D Gate, INDIAN INSTITUTE OF SCIENCE, BANGALORE 560 012
Telephone: 91-80-22933099/22933503 extn 107
Fax: 91-80-23601428/23600085/23600683[CES-TVR]
Web: http://ces.iisc.ernet.in/energy
http://ces.iisc.ernet.in/biodiversity
Open Source GIS: http://ces.iisc.ernet.in/grass

Ramachandra T.V., Subash Chandran M.D., Vinay S, 2014, Water Scarcity in Varada Catchment: Need to arrest Deforestation on Priority, Sahyadri Conservation Series 45, ENVIS Technical Report 82, CES, Indian Institute of Science, Bangalore 560012, India