Sahyadri Conservation Series 36

CARRYING CAPACITY OF RIVER BASINS CONSIDERING ECOLOGICAL AND SOCIAL DEMANDS

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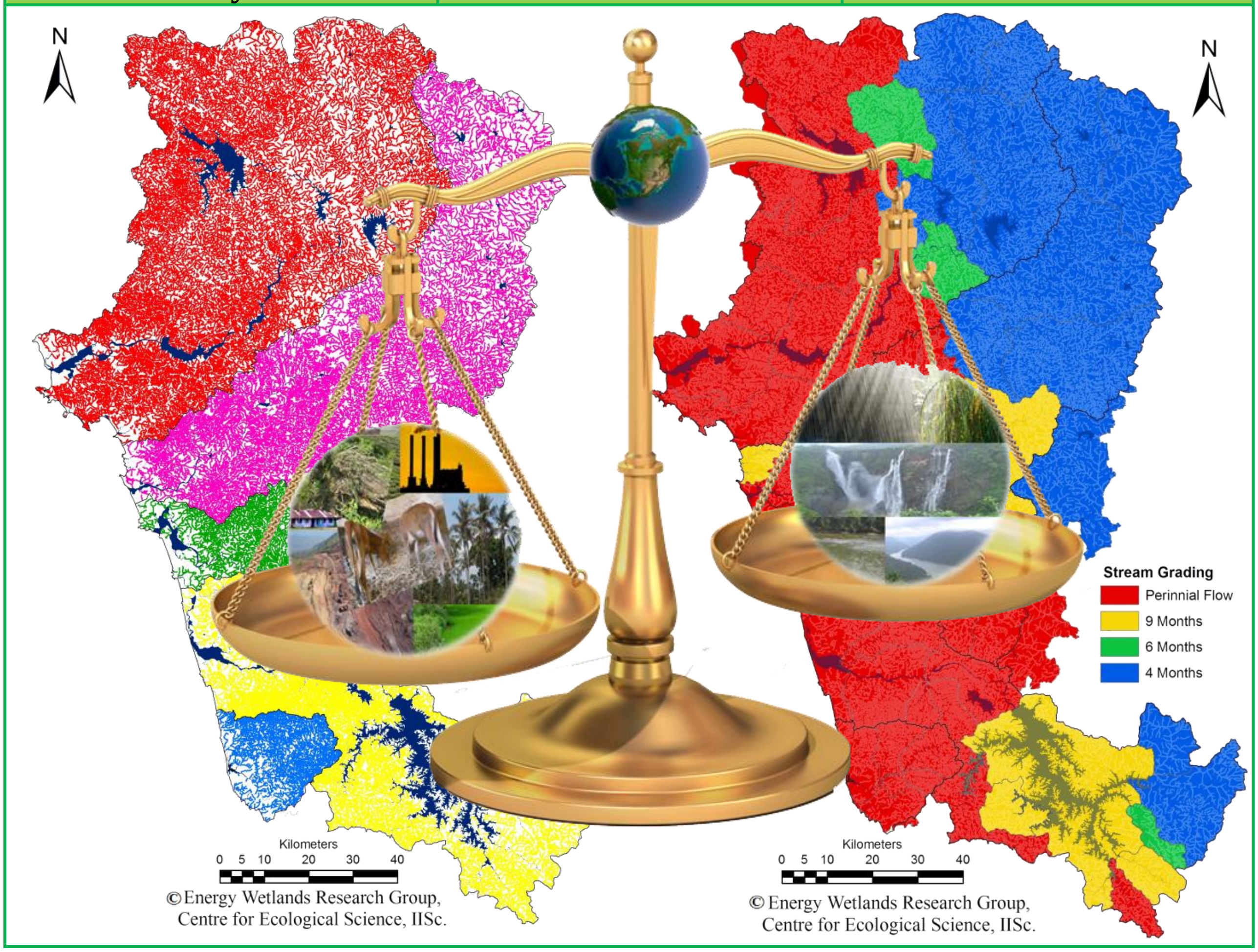

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Carrying Capacity of River Basins considering Ecological and Social Demands

Summary: Carrying capacity refers to the maximum number of activities (biological, developmental, agricultural, and industrial, population) that can be supported over a period of time in the habitat without damaging the existing quality of life, balance of resources, ecology and productivity of the ecosystem. Ecological Carrying Capacity provides physical limits as the maximum rate of resource usage and discharge of waste that can be sustained for economic development in the region. This provides theoretical basis with practical relevance for the sustainable development of a region. Carrying capacity of a river basin refers to the maximum amount of water available naturally as stream flow, soil moisture etc., to meet ecological and social (domestic, irrigation and livestock) demands in a river basin. Monthly monitoring of hydrological parameters reveal that stream in the catchments with good forest (evergreen to semi-evergreen and moist deciduous forests) cover have reduced runoff as compared to catchments with poor forest covers. Runoff and thus erosion from plantation forests was higher from that of natural forests. Forested catchment have higher rates of infiltration as soil are more permeable due to enhanced microbial activities with higher amounts of organic matter in the forest floor. Streams with good native forest cover in the catchment showed good amount of dry season flow for all 12 months. While strems in the catchment dominated by agricultural and monoculture plantations (of Eucalyptus sp. and *Acacia auriculiformis*) are sesonal with water availability ranging between 4-6 months. This highlights the impacts of land use changes in tropical forests on dry season flows as the infiltration properties of the forest are critical on the available water partitioned between runoff and recharge (leading to increased dry season flows). This emphises the need for integrated watershed conservation approaches to ensure the sustained water yield in the streams. Assessment show that most Gram panchayats of Karwar and Bhatkal taluks, the Ghats of Supa, Ankola, Kumta, Honnawara, Siddapura, Sirsi and Yellapura have water for all 12 months (perennial). Gram panchayath in the coasts of Honnavara, Kumta and Ankola along with the Ghats of Siddapura, Sirsi, Yellapura and Supa towards the plains have water for 10 – 11 months, the plain regions of Haliyal and Mundgod taluks with part of Yellapura and Sirsi taluks show water availability for less than 9 months (intermittent and seasonal).

Quantification of silt yield highlights the linkage of silt yield with the land use in the respective sub-basin. Lower silt yield in sub-basins with good vegetation cover of thick forests, forest plantations, etc. The plains due to the higher lands under irrigation and are open lands, the silt yield is comparatively higher than that of other topographic regions. Strategies to regulate sand extraction are

- **Creation of No Development Zones (NDZ)**: Industries needs to be classified based on their type, and polices shall be amended upon which between 500 m to 10 km either sides of the river as listed in Table 4 and CRZ 1 (Coastal Regulation Zone 1).
- **Fixing of time for silt removal**: Removal of sand be permitted between 7 AM and 4 PM
- **Fixing of sand removal location and quantity**: Based on category of river, sand removal shall be allowed only from the river bed, and no sand removal operation be allowed within 10 m of the river bank. No sand removal is allowed within 500 m from any bridge, irrigation project, pumping stations, retaining wall structures, religious places, etc. Quantity of sand extracted at particular location shall not exceed the quantity of silt yield per annum. Weighing bridges are to be fixed at identified locations to regulate the quantity of sand extracted during a year.
- **Fixing vehicle loading points**: Vehicles shall be parked at least 25 to 50 m away from the river banks, no vehicles shall be brought near the river bank. Erecting of pillars to demarcate vehicle restriction regions, beyond which vehicle should not be allowed
- **Restriction on mechanized removal**: No pole scooping or any method shall be carried out in sand removal operation
- **Restriction or ban on sand removal**: Sand shall not be removed from likely places where saline waters mixes with fresh water. Sand removal quantity per year based on scientific assessment and approval of on expert committee of district. Sustainable harvesting of sand considering the yield at point of extraction. Regions such as breeding habitat of fishes and other aquatic organisms, endemic species of riparian vegetation, and basins where ground water extraction is prevalent, are to be identified in the river basins for restricting sand mining. District collector may ban sand removal in any river or river stream during monsoons, based on the Expert Committee. Based on the acts, rules and orders made by the GOI/ state the expert committee shall prepare river development

plans for protection of river to keep up the biophysical environment along the river banks

- **Liability of District Collector**: Fifty percent of the amount collected by the local authorities shall be contributed as river management fund and shall be maintained by the district collector.
- **No construction between 500 m to 1 km from flood plain**: To protect life and property damages in cases of flash floods
- **Different stretch of rivers different regulations:** Rivers are dynamic, they come across different geomorphic, climatic, sociopolitical settings. Due to this different stretches of rivers faces different issues. Rivers where rivers originate, they are at the highest purity level which needs to be maintained as it is the source contributor for the downstream.
- **Flood Plain protection**: To protect against the damage that affects the floral and faunal diversity, intern maintaining the aesthetical and economic value of the river basins. No chemical based agriculture or fertilizers shall be used in the agricultural fields that affect the river channel polluting and affecting the ecosystem

Keywords: Carrying capacity, river basin, silt yield

1.0 Introduction

Uttara Kannada is one of the ecologically sensitive districts of Karnataka State. It is one of the districts with the higher vegetation cover in India. Being situated on the Western Ghats, which is now considered one of the mega biodiversity regions of global importance has all the three major landscape system of the state namely; the coastal region on the west, the high hill mountain region of Sahyadri in the middle and a Deccan plateau margin in the eastern side. Due to factors like growing population and mega developmental projects, much of its natural landscape and the natural resource are under severe pressure in Uttara Kannada district. Deforestation, encroachment, submergence, forest fragmentation, river pollution and degradation and so many other impacts are already being witnessed. Keeping this fragile situation in mind, an integrated ecological carrying capacity study of the district was undertaken to provide the guidelines for the future conservation and sustainable development works.

Carrying capacity refers to the maximum number of activities (biological, developmental, agricultural, and industrial, population) that can be supported over a period of time in the habitat without damaging the existing quality of life, balance of resources, ecology and productivity of the ecosystem. Carrying Capacity provides physical limits as the maximum rate of resource usage and discharge of waste that can be sustained for economic development in the region. This provides theoretical basis with practical relevance for the sustainable development of a region. **Carrying capacity of a river basin refers to the maximum amount of water available naturally as stream flow, soil moisture etc., to meet ecological and social (domestic, irrigation and livestock) demand in a river basin.**

Carrying Capacity has been defined as the rate at which the resource can be consumed and discharged into the habitat without affecting the ecological integrity and biological productivity (MOEF, 2013, Subramanian 1998, Weizhuo Ji 2010, Jianhong Huang and Jing Cai 2011, Ying Li 2011, Ying Zhang et al 2009). The study of carrying capacity is carried out based on various aspects such as Population (Xilian Wang 2010, Subramanian 1998), Agriculture (Hegde 2012, Venkateswarlu and Prasad 2012, Masood Ali and Sanjeev Gupta 2012, Ghosh 2012), Industries (Subramanian 1998, Li Ming 2011), Livestock (Yu Long et al 2010, Gopal and Giridhari, 2000), Water and water bodies (Subramanian 1998, Li Ming 2011, Du Min et al 2011, Li-Hua Feng et al 2008, Connor et al 2001, Xie Fuju et al 2011), Forest, Soil (Xia and Shao 2008), Urban (Yuan Yan et al 2010, Peng Kang and Linyu Xu 2010), Mining (Xian Wei et al 2009), Marine (Hui Fu et al 2009), Ecotourism (Dan Luo and Nai'ang Wang 2010), Air (Goyal and Chalapati Rao 2011) etc.

Developing countries in the tropics are facing threats of rapid deforestation due to the unplanned developmental activities based on ad-hoc approaches and also due to lopsided policies that considers forest as national resource to be fully exploited. Anthropogenic activities coupled with skewed policies have resulted in the disappearance of pristine forests and wetlands in the form of logging, afforestation by plantation trees, dam constructions, and conversion of lands for other uses. This is evident from barren hilltops and increased spatial extent of barren or unproductive land. The structural changes in the ecosystem has affected the functional aspects namely hydrology, bio-geo chemical cycles and nutrient cycling. These are evident in many regions in the form of conversion of perennial streams to seasonal and disappearance of water bodies leading to a serious water crisis (Ramachandra et al., 2007; 2013a, b, c,d).. Thus, it is imperative to understand the causal factors responsible for changes in order to improve the hydrologic regime in a region. It has been observed that the hydrological variables are complexly related with the vegetation present in the catchment. The presence or absence of vegetation has a strong impact on the hydrological cycle. This requires understanding of hydrological components and its relation to the land use/land cover dynamics. The reactions or the results are termed hydrological response and depends on the interplay between climatic, geological and land use variables (Ramachandra et al., 2007).

Burgeoning population with an enhanced demand of natural resources, there have been large scale over exploitation of natural resources such as water, forest, land etc. Changes in land cover leading to deforestation (Yong Lin and Xiaohua Wei 2008) and conversion to other land uses such as agriculture, horticulture, urban areas, *etc*., have affected the hydrological regime at regional scale (Ramachandra et al 2013d, Bonella et al 2010, Lin and Wei 2008). Large scale changes with increased open lands and agriculture land leads to higher water loss as runoff during the monsoon compared to forested landscape which has higher water holding capacity with sustained water supply during the post monsoon. The open lands and agriculture/horticulture fields, degraded forests lead to higher soil loss through erosion affecting the water holding capacity of the soils and crop productivity (Subramanian 1998). This necessitates an analysis and evolve apt management strategies to ensure sustenance of resources without losing its current potential. In any river basin, availability of water plays a prominent role in the productivity of forest and agriculture goods, while maintaining and restoring the ecological health in a basin (Faith Love et al 2006). Thus for sustainable utilization of water in a region and to meet the demands of water optimally, it is necessary to assess the **water resource carrying capacity** (WRCC) considering the water availability and demand in a basin (Li Ming 2011, Du Min et al 2011, Faith Love et al 2006). WRCC is one of the key factors that define the limits up to which any developmental activities could take place without harming the regional or global ecology. The concept of ecological carrying capacity of a river basin integrates river basin management (Jing Li et al 2011) based on the basin structure and functional capabilities. The goal of the environmental water resource carrying capacity is to zone the river basins based on water quantity (flow) in the river basins that helps in the optimal management of water resources in the basin (Jing Li et al 2011, Das Gupta 2008) and identify the suitable developmental activities (Xu Ling 2011) based on the threshold in each zones. This also gives an opportunity to identify the basins/catchments that require an immediate attention of catchment restoration involving afforestation of location specific native species.

The flow in the river basin is quantified through discharge measurements in field associating with the volumetric analysis based on the hydro meteorological data using GIS and Remote Sensing (Chen and Zhao 2011). In any river, a ***minimum flow has to be maintained within a river, wetland, or coastal zone to maintain the functional abilities of ecosystems and the benefits they provide to people and the environment***, these flows area referred to as ***ecological flows or environmental flow*** (Chen and Zhao 2011, Das Gupta 2008, Ramachandra et al., 2007; 2013). "**Environmental flows**" relate to protecting a range of environmental and community values including ecological systems, cultural and social values, recreational values and other amenity value; "Ecological flows" relate only to protecting specific ecological components , ecosystem health and/or functioning/processes (http://www.mfe.govt.nz). The process of ecological flow is being studied in many countries and also across countries such as China (Chen and Zhao 2011, Zhu and Yan 2011), India (Das Gupta 2008; Ramachandra et al., 2007; 2013d), Spain (Jorge Alcazar and Antoni Palau and Palau 2010), Tanzania (Japhet Kashaigili 2005), Korea (Woo 2010), Russia-China-Kazakhstan (Fucheng Yang et al 2012), South Africa (Hughes 2001), and many more. Analysis of environmental flow in streams and rivers are necessary to ensure that the need of humans and that of environment are met, based on which other potential users such as industries etc., can be accommodated to abstract water (Hughes 2001), in determining the health of river (Yang et al 2012), manage flow and protect the water bodies and river networks (Chen and Zhao 2011), maintain and enhance the ecological character and functions of floodplain, wetland and riverine ecosystems that may be subject to stress from drought, climate change or water resource development (ICUN 2011, Neil and Matthew 2012).

The study of ecological carrying capacity based on the ecological flow in each of the river basin of Uttara Kannada has been carried out by integration of the hydrological model with a water balance model and remote sensing data into a GIS (Neil and Matthew 2012, Mallikarjuna et al 2013, Ramachandra et al., 2007; 2013d). Remote sensing technique (Lillesand 2004, Sudhira et al 2004, Ramachandra et al 2012a, b, c) has advantages such as wider synoptic coverage of the earth surface with varied temporal, spatial and spectral resolutions. Classifications of these data through already proven classification algorithms (Ramachandra et al 2007; 2012a, b, Vinay et al 2012) provide land use information. Land use information derived from remote sensing is integrated through with the hydro-meteorological information to study the water balance in the respective basin. The hydro-meteorological studies and analysis has been carried out as per the standard protocol using the remote sensing data and other associated parameters such as rainfall, runoff, evaporation, transpiration, ground water monitoring and so on in determining famine, drought, cyclones, silt, flood monitoring etc. comparable to earlier work in Krishna basin (India-WRIS http://india-wris.nrsc.gov.in, Amoghavarsha et al 2012, Mallikarjuna et al 2013), Western Ghats (Ramachandra et al 2004, Ramachandra et al 2012a, Ramachandra et al 2013a, b, c, d, Reshma et al 2012), Cauvery river basin (Vaithiyanathan et al 1992), etc. The hydrological parameters were transformed to spatial layers of the basin for assessing the carrying capacity in each sub-basin, based on the water budgeting (Peter 2002, Subramanya 2005, Raghunath 1985, Ramachandra et al., 2007).

The current study highlights the ecological carrying capacity of river basins of Uttara Kannada district of Karnataka. River basins were subdivided into sub- basins based on the tributaries. The sub basins were classified based on the flow in the third order streams, and based on the supply of water as a function of rainfall and losses, demand based on the domestic water needs, crop water needs and livestock water requirement. The water supply and water demand is used to identify the hydrological status of the river basins and flow assessment is carried out to identify the perennial and non-perennial streams in the river basin.

2.0 Study Area

Uttara Kannada District located (at$74^0$05'13" - $75^0$05'58" E and $13^0$55'26" - $15^0$31'23" N) towards the centre of the Western Ghats, along the coast of Karnataka has geographical area of about 10,280 sq.km (Figure 1). It is a region of gentle undulating hills, rising steeply from a narrow coastal strip bordering the Arabian Sea to a plateau at an altitude of 500 m with occasional hills rising above 600–860 m. It is surrounded by Belgaum District and State of Goa in the North, by Dharwar District in the East, Shimoga and Udupi Districts in the South. Arabian Sea forms the West border. The district capital is at Karwar. The district has 11 taluks covering three different zones i.e. coastal lands (Karwar, Ankola, Kumta, Honnavar and Bhatkal taluks), Sahyadrian interior (Supa, Yellapur, Sirsi and Siddapur taluks) and the eastern margin plains (Haliyal, Yellapur and Mundgod taluks). According to 2011 census the ppopulation of district is 14, 36, 847 and population density is 140 persons per sq. km. There has been 10.9 % increase in population density from 118 (1991) to 132 (2011) persons per sq. km.

There are five west flowing rivers namely Kali, Gangavali, Agnashini, Sharavathi and Venkatapura (Figure 1) and two east flowing rivers Dharma and Varada. These river basins extend from N $13^0$43'4" to N $15^0$33'38" Latitude and E $75^0$4'54" to E $75^0$19'52" Longitude, and are spread across neighboring districts such as Belgaum, Hubli, Dharwad, Haveri and Shimoga (Figure 2, Table 1). Ecological carrying capacity of major river basins have been done considering respective catchment (which extend beyond the political boundary of the district, listed in Table 1). The decadal population (aggregate of all river basins, beyond Uttara Kannada) has increased from 2071675 in 2001, to 2327710 in 2011 with a decadal increase of 12.4%. The population density has increased from 118 persons per square kilometer to 166 persons per square kilometer. At Basin level, population of Gangavali has the highest population, whereas Venkatapura highest population density with Kali being the lowest (Figure 3). These rivers give raise to magnificent waterfalls in the district. The Jog fall drops by 259 meters in Sharavathi, Lushington falls drops 116 meters in Aghanashini, Magod falls, where the Bedti river plunges 180 meters in two leaps, Shivganga falls, where the river Sonda (Bedthi) drops 74 meters, and Lalguli and Mailmane falls on the river Kali. Kali river origins in Joida taluk flows through Karwar taluk, Gangavali (Bedthi) origins in Dharwad District flows through Yellapur and Ankola taluks. Aghanashini river origins in Sirsi flows through Siddapur and Kumta taluks. Sharavati origins in Shimoga district, which forms the famous Jog Falls flows through Honnavar (Ramachandra et al., 2013c).

Figure 1: Study area – Major river basins in Uttara Kannada district, Karnataka State, India

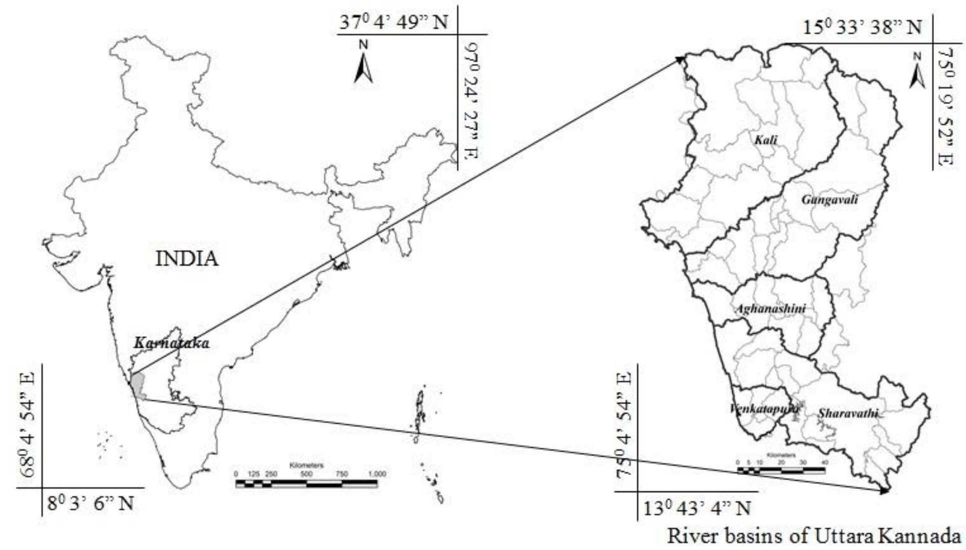


Figure 2: Rivers with their catchment (and respective regional administrative boundaries)

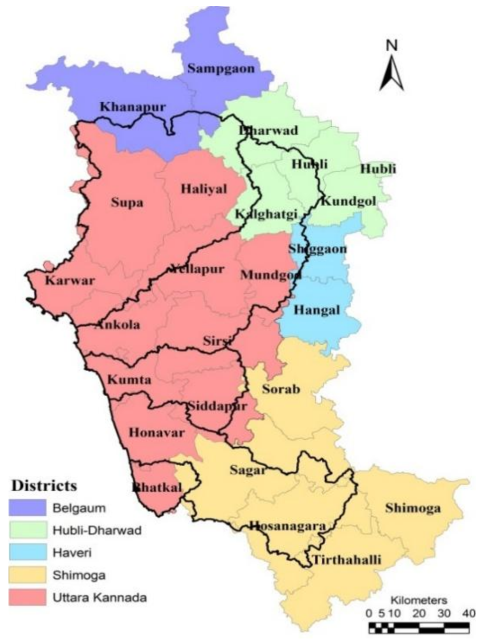
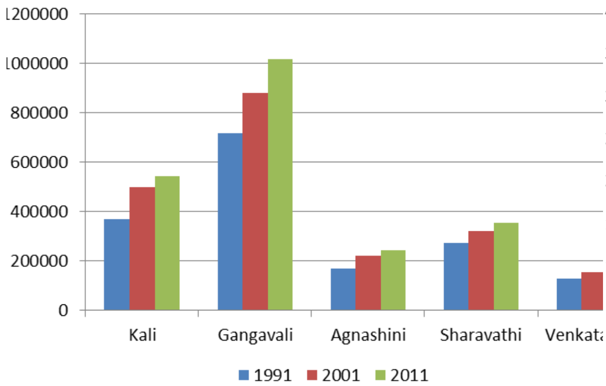
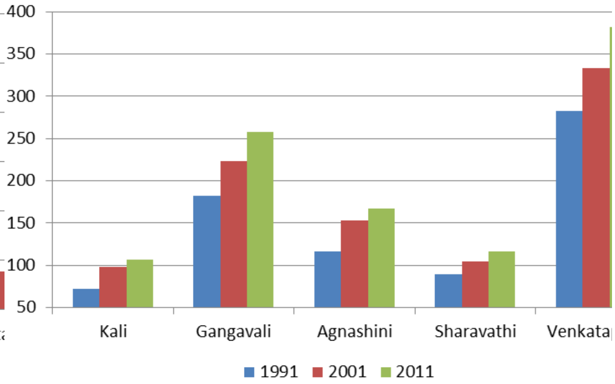


Figure 3: Basin wise population



Population



Population Density persons per sq.km

With tropical climate the region receives an average annual rainfall in the range of 700mm at the plains in the north east to more than 5500 mm at the Ghats; the coasts receive annual rainfall of 3000 to 4000 mm. The maximum amount of rainfall is received during the month of June, July, August and September due to the South west monsoon (Ramachandra et al., 2013c, District at a glance 2011 – 2012 of Various Districts, Reshma et al 2012). The year may broadly be classified into four seasons. The dry season is from January to February with clear and bright weather. It is followed by hot weather from March to May. During this season thunderstorms are common in the month of May. On an average, temperature in the region varies from 15.4^{0}C during January to about 35.62^{0}C in April.

Table 1: River basins with the spatial extent and respective administrative regions

River Basin	Area (sq.km)	Districts	Taluks
Kali	5085.93	Uttara Kannada, Hubli Dharwad, Belgaum	Karwar, Supa, Haliyal, Ankola, Yellapura, Dharwad, Kalghatgi, Khanapura, Sampagaon.
Gangavali (Beedthi)	3935.73	Uttara Kannada, Hubli Dharwad, Haveri	Ankola, Yellapura, Mundgod, Sirsi. Dharwad, Kalghatgi, Hubli, Kundgol. Shiggaon, Hangal.
Agnashini	1448.77	Uttara Kannada, Shimoga	Kumta, Sirsi, Siddapura Soraba
Sharavathi	3042.71	Uttara Kannada, Shimoga	Kumta, Siddapura, Honnavara. Sagar, Hosanagara, Shimoga, Tirtahalli
Venkatapura	459.70	Uttara Kannada, Shimoga	Bhatkal Sagar

3.0 Method

3.1 Land Use Land Cover Dynamics: Land use Land cover (LULC) dynamics is a major concern, as the abrupt changes has a negative impact on ecology, climate, hydrological regime, ecological flow, 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 can be classified into various classes such as water bodies, built up, forests, agriculture, open lands, sand, soil, e*tc*. 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.

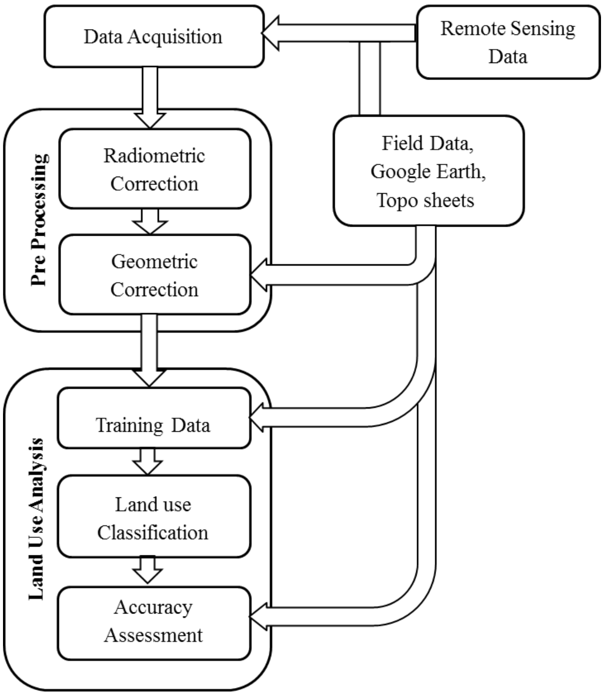
Landscape is heterogeneous land area of interacting systems which forms an interconnected system called ecosystem (Forman and Gordron, 1986). The functional aspects (interaction of spatial elements, cycling of water and nutrients, bio-geo-chemical cycles) of an ecosystem depends on its structure (size, shape, and configuration) and constituent's spatial patterns (linear, regular, aggregated). The status of a Land use land cover can be visualized using the LULC information. Land use land cover information of a region provides a base for accounting the natural resources availability and its utilization. The information pertaining to LULC provides a framework for decision making towards sustainable natural resources management sensors (Ramachandra et al 2013b, c).

Satellite remote sensing technology provide consistent measurements of landscape condition, allowing detection of both abrupt changes and slow trends over time for managing natural resources (Kennedy et al. 2009; Fraser et al., 2009). 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 (Lillesand et al., 2004, Ramachandra et al., 2012, 2013b,c,d). Method involved in classification of a remotely sensed data is depicted in Figure 4.

Data Acquisition involves collection of the remotely sensed satellite data, ancillary data include cadastral revenue maps (1:6000), the Survey of India (SOI) topographic maps (1:50000 and 1:250000 scales), vegetation map of South India developed by French Institute (1986) of scale 1:250000. Remote sensing data IRS P6 LISS IV and LISS III data with a spatial resolution of 5.8 m and 23.5 m respectively for the year 2010 were used for the analysis, along with the Cartosat DEM of 30 m spatial resolution. Topographic maps provided ground control points (GCP's) to rectify remote sensing data and scanned paper maps. French institute maps were delineated to identify the forest cover and used to classify the RS data. Other ancillary data includes land cover maps, administration boundary data, transportation data (road network), etc. Pre-calibrated **GPS** (Global Positioning System - **Garmin GPS units)** were used for field data collection, which were used for RS data preprocessing, classification as well as for validation.

Pre-processing of data: The remote sensing data is checked for radiometric errors and geometric errors, the radiometric errors are rectified through radiometric correction, and the image is geometrically rectified by geo-referencing the image. Geo-registration of remote sensing data has been done using ground control points collected from the field using pre calibrated GPS and also from known points (such as road intersections, etc.) collected from geo-referenced topographic maps published by the Survey of India. The geo-referenced image is cropped to the study area. Vector data of the district, taluk, river basins and village boundaries, drainage network, water bodies (lakes, ponds) were digitized from the Survey of India topographic maps, cadastral maps and digital elevation models. Population census and taluk wise village boundaries were collected from the Directorate of Census Operations (http://censuskarnataka.gov.in).

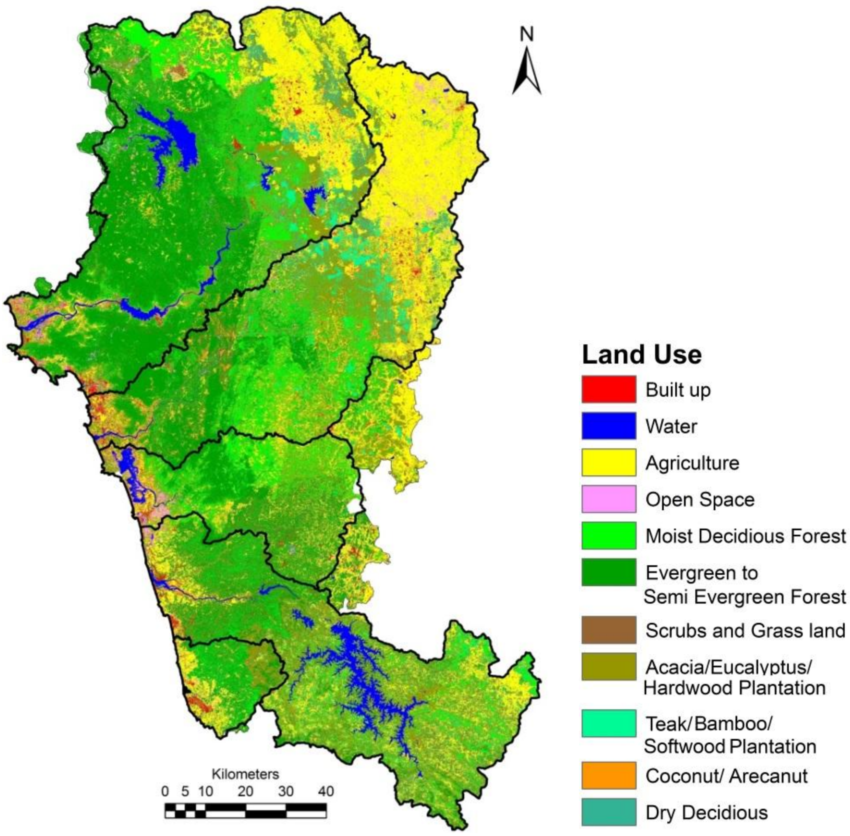
Figure 4: Method of LULC analysis



Land use classification and accuracy assessment: This involved i) generation of False Colour Composite (FCC) of remote sensing data (bands – green, red and NIR). FCC helped in locating heterogeneous patches in the landscape ii) selection of training polygons covering 15% of the study area and uniformly distributed over the entire study area, iii) loading these training polygons co-ordinates into pre-calibrated GPS, vi) collection of the corresponding attribute data (land use types) for these polygons from the field, iv) Supplementing this information with Google Earth/Bhuvan. Land use classification was done using supervised pattern classifier -

Gaussian maximum likelihood algorithm based on various classification decisions using probability and cost functions Land uses during the different period were computed using the temporal remote sensing data through open source GIS: ***GRASS- Geographic Resource Analysis Support System*** (http://ces.iisc.ernet.in/grass). The land use was classified into eleven groups such as Built up, Water, Agriculture, Open spaces, Moist Deciduous forest, Semi evergreen to evergreen forest, Scrub and Grass land, Acacia / Eucalyptus plantations, Teak / Bamboo plantations, Coconut/ Arecanut plantations and Dry Deciduous. 60% of the derived signatures (training polygons) were used for classification and the rest for validation. Statistical assessment of classifier performance based on the performance of spectral classification considering reference pixels is done which include computation of kappa (κ) statistics.

Figure 5: River basin wise Land use



Land uses in the respective river basins of Uttara Kannada district is given in Figure 5 and table 2. The urban landscape is about 1.9 % of the total area, and are prominent along the coast and plains, water bodies are about 3.1%, whereas the forest cover an area about 44.1 % with 28.6% of evergreen species and 15.5% of deciduous species. The overall classification accuracy was 91.51% with agreement (kappa) of 0.90.

Table 2: Land use categories with spatial extent

Land Use	Area (Ha)	Percentage
Urban	28052.95	1.9
Water	45768.33	3.1
Agriculture	320099.9	21.7
Open lands	30704.84	2.1
Moist Deciduous Forest	213254.1	14.4
Evergreen to Semi Evergreen forest	422986.4	28.6
Scrub/Grassland	64160.17	4.3
Acacia/Eucalyptus	191511	13.0
Teak/Bamboo	68593.07	4.6
Coconut/Arecanut	75225.83	5.1
Dry Deciduous	16337.86	1.1

3.2 Quantification of Hydrological Regime: Sub-basin wise hydrological assessment for major rivers of Uttara Kannada has been done using land use information with meteorological and lithological parameters. Figure 5 outlines the method adopted for assessing the hydrological parameters and water budgeting with ecological flows.

Water Balance: Sub-basin wise water balance (W_B) is a function of water availability (W_A) and water demand (W_D) and is given by equation 1.

$$\mathbf{W_B = \mathit{f}(W_A, W_D)} \qquad .....1$$

Where, W_B = Water balance, W_A = Water available, W_D = Water demand

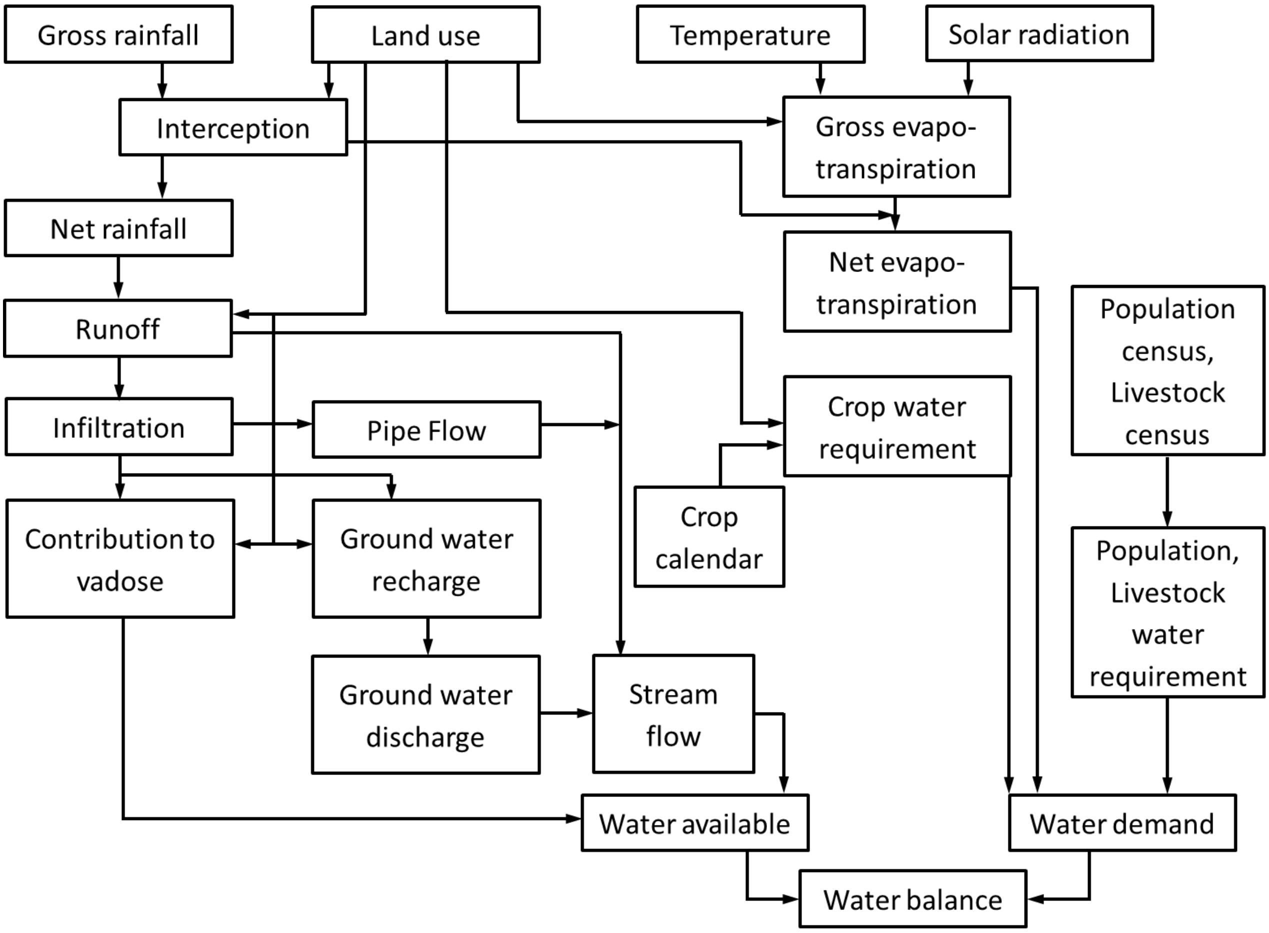
The water availability in the sub basin depends on hydro-meteorological factors (Raghunath 2005) and demographics (land use, slope, soil…etc.) of the region, where as the water demand depends on the irrigation, domestic and livestock water requirements along with evapotranspiration. In any river basin if W_A is less than W_D, then this condition in the river basin during the month can be referred to as water deficit period.

Hydrological water balance (Peter 2002, Subramanya, 2005; Raghunath, 1985) equation is used to quantify the amount of water that goes through various phases of the Hydrological Cycle (Subramanya, 1994). The water balance equation is based on the law of conservation of matter (Raghunath, 1985) and is given by equation 2 (Subramanya, 2005; Raghunath, 1985).

$$\mathbf{Inflow = Outflow + \Delta_{Storage}}. \qquad ....2$$

Inflow into a river sub basin includes precipitation and groundwater discharge, whereas out flow from sub basin involves interception, surface runoff, pipe flow (lateral flow), transpiration, evaporation, groundwater recharge.

Figure 5: Method for hydrological assessment



***Rainfall*:** Daily rainfall data of various rain gauge stations (point data) in and around the study area for the period 1901 to 2010 were considered to assess the trends of rainfall. The rainfall data used for the study were obtained from (a) Department of statistics, Government of Karnataka and (b) Indian metrological data (IMD), Government of India

Some rain gauge stations did not have complete rainfall records (rainfall details missing for few months). These missing data's were evaluated through regression analysis and error data's were revised with respect to neighboring rain gauge stations. This has been done as the analysis without considering the missing data gives erroneous results and also stations with missing rainfall cannot be included in the analysis. Rainfall trend analysis was done to understand the variability of rainfall at different locations in the study area.

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 at selected rain gauge stations. The average monthly and annual rainfall data (point data) were used to derive spatial rainfall information for entire basin through interpolation (isohyets). The interpolated rainfall data was used to derive the gross yield (R_G) in a respective basin (equation 3). Net yield (R_N) was quantified as the difference between gross rainfall and interception (In), given in equation 4.

$$\mathbf{R_G = A_S * P} \qquad \ldots\ldots\ 3$$

$$\mathbf{R_N = R_G - In} \qquad \ldots\ldots\ldots 4$$

Where, R_G = Gross rainfall yield volume, A_S = Area in Hectares, P = Precipitation in mm, R_N = Net rainfall yield volume and In = Interception volume

Rainy days and months per year was derived at each of the rain gauge stations considering two cases as:

1) Case I : Rainfall more than 50 mm per month.
2) Case II: Rainfall more than 100 mm per month.

Interception: In any catchment, not all portions of rain reaches directly on to the ground as some portion of it is intercepted due to foliage, buildings and some is evaporated (returned back to the atmosphere without reaching the ground surface). This kind of water loss to atmosphere is referred as interception loss. Interception loss accounts to about 20% to 30% of the total seasonal precipitation. Table 3 gives the interception loss based on the vegetation in the Western Ghats.

Table 3: Interception Characteristics of Western Ghats

Vegetation types	*** Canopy storage capacity (C) (mm)**	****Evaporative fraction (α) or net interception loss (%)**
Evergreen/semi-evergreen	4.5-5.5	20-30
Moist deciduous forests	4-5	20-30
Plantations	4-5	20-30
Grasslands and scrubs	2.5-3.5	10-18
Agricultural crops (paddy)	1.8-2	10-18

*Source: Putty and Prasad, 2000

** Source: Modified evaporative fraction from Shuttleworth, 1993.

Interception is considered as a function of canopy storage capacity C and evaporative fraction (α) (Singh, 1992) as given by the equation 5. Interception based on vegetation types is listed in

$$I = C + \alpha * P \quad \ldots. 5$$

Table 4: Interception Equations for upstream River Basin

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)

The rate of evaporation of intercepted water from a wet canopy commonly exceeds the potential evaporation for open water surfaces and depends on the locally available energy (Shuttleworth, 1993). The net amount of water, which the canopy can store, i.e. the interception storage capacity, depends partly on the nature of rainfall, in particular the intensity and duration of the rainstorm since up to 50% evaporation occurs during the storm itself. Intense, short-lived, convective storms, more common in tropical regions are associated with a lower fractional interception loss or evaporative fraction. Thus interception would be about 10-18 percent of precipitation (Lloyd et al., 1988; Shuttleworth, 1989) in forests with complete canopy cover. Storms associated with frontal rainfall, which may be less intense but lasts longer tend to give a higher fractional interception loss of say 20-30 percent of precipitation (Calder and Newson, 1979; Gash et al., 1980).

The following assumptions have been made for interception loss under each vegetation type in the upstream of river basins. Major portion of the rainfall is received from the south west monsoon, which is of low intensity and longer duration. Thus, the evaporative fraction is considered similar to that of frontal precipitation.

Assumptions Vegetation type wise assumptions are:

Evergreen/semi-evergreen forests

- Dominated by evergreen trees
- Leaves all year around- high storage capacity

	• Thick and multi layered canopy- higher evaporative fraction
Moist deciduous forests	• Dominated by deciduous trees • Full leaves during monsoon season- maximum storage capacity • Large leaves- higher evaporative fraction
Plantations	• Dominated by monoculture trees • Full leaves during monsoon season- maximum storage capacity • Narrow and vertically aligned leaves- lower evaporative fraction
Agricultural crops	• Young leaves (July-August)- lower storage capacity and evaporative fraction • Mature leaves (September)- higher storage capacity and evaporative fraction
Grasslands and scrubs	• Fully grown grass and scrubs-(June-September)- higher storage capacity and evaporative fraction • Dry grass and scrubs (October)-lower storage capacity and evaporative fraction

***Runoff*:** Runoff is a process which involves draining off the precipitated water from a catchment into stream. Runoff represents the response of the catchment towards precipitation, climate and demographic characteristics. True runoff can be represented as the stream flow in natural conditions i.e., without any human intervention. Runoff can be characterized into two categories namely a) direct runoff or storm runoff and b) base flow.

Direct runoff is part of runoff that enters into the stream immediately after precipitation. During precipitation, portion of water gets percolated to the underlying strata (vadose and groundwater zones). Runoff in stream of a catchment dominated by vegetation begins on saturation of underlying strata of water. While, in open area or surface, without vegetation severe run off is observed, often as flash floods.

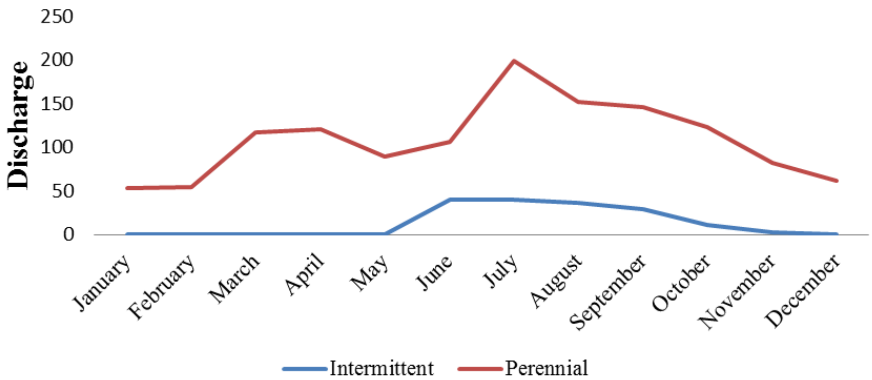
Base flow is the delayed water flow in the streams. This happens during post monsoon depending on the amount of water stored in the soil stratum (above the ground water table) and as ground water discharge (water stored in saturated / ground water zone). Plot of water discharge with time gives the hydrograph for a particular stream / river. Investigation of hydrographs enables one to classify the stream (Figure 6) as (i) Perennial, (ii) Intermittent and (iii) Ephemeral

i). **Perennial**: Streams which has the flow of water in all seasons, suggesting there is considerable amount of base flow and ground water discharge into the streams throughout the year.

ii). **Intermittent**: Streams which have a very little contribution from the ground water post monsoon. During the wet season, the water table in the stream is over the bed, whereas during dry seasons, the water table would go below the stream bed.

iii). **Ephemeral**: These are the streams which doesn't have contribution from base flow, the flow in these streams occur during storms as flash floods. The stream becomes dry soon after the end of the storm. These storms don't have any well-defined channel of flow.

Figure 6: Stream classification depending on the duration of flow



The flow characteristic of the streams depends upon:

a) Rainfall characteristics such as magnitude, intensity, distribution in time, space and variability.
b) Catchment characteristics such as soil, vegetation, slope, geology, shape, drainage density
c) Climatic factors such as temperature, humidity…*etc*.
d) Infiltration depending on soil permeability.

Surface runoff has been determined by rational method, which assumes a suitable runoff coefficient to determine the catchment yield, which is given by equation 6:

$$\textbf{Runoff} = \textbf{C} * \textbf{A} * \textbf{R}_\textbf{N} \quad \ldots\ldots\ldots..6$$

$$\textbf{R}_\textbf{N} = \textbf{R}_\textbf{G} - \textbf{I} \quad \ldots\ldots\ldots\ldots.. 4$$

Where

C = Runoff coefficient, depends on the land use in the catchment (given in table 5)

A = Area of catchment under different land use in square units

R_N = Net rainfall in mm

R_G = Gross rainfall in mm

I = Interception in mm

Table 5: Land use and their surface runoff coefficients

Land Use	***C***
Urban	0.8
Agriculture	0.5
Open lands	0.6
Moist Deciduous Forest	0.15
Evergreen to Semi Evergreen forest	0.1
Scrub/Grassland	0.55
Acacia/Eucalyptus	0.6
Teak/Bamboo	0.5
Coconut/Arecanut	0.5
Dry Deciduous	0.15

Sub Surface Flow (Pipe flow): Pipe flow is considered to be the fraction of water that remains after infiltrated water satisfies the available water capacities under each soil. This corresponds to the amount of water stored in vadose zone (during precipitation). Pipe flow is estimated for all the basins as function of infiltration, ground water recharge and pipe flow coefficient as given in equation 7.

$$\mathbf{P_F = (Inf - GWR) * K_P} \qquad \text{.........7}$$

Where P_F = Pipe flow

Inf = Infiltration volume

GWR = Ground water recharge

K_P = Pipe flow coefficient (table 6)

Coefficients for pipe flow are determined from comparing the relief ratio of each sub basin. It has been observed that higher the relief ratio, lower the pipe flow coefficients and vice versa (Putty and Prasad, 2000). Table 6 lists coefficients considered based on relief ratio (Ramachandra et al., 2007). Observed pipe flows were related to the forest vegetation cover in the respective sub-basins: forests up to 50% of the area, pipe flow was observed to be 0.1 indicating higher water holding capacity in the region.

Table 6: Pipe flow Coefficients

Sub basins	**Relief ratio (%)**	**Vegetation cover (%)**	**K_P %**
Yennehol̕é	3.03	50	10
Hurliholé	3.39	50	10
Nagodiholé	9.9	50	10
Hilkunji	4.45	50	10
Sharavathi	2.98	50	10
Mavinaholé	1.66	40	30

Infiltration: Infiltration is the process of water percolating the soil surface by action of gravity. Portion of the infiltered water is stored as soil moisture and in vadose zone and ground water zones. This water gets released to the respective streams during lean seasons (after monsoon season). As runoff recedes in the stream, water stored in vadose zones moves laterally, as stream flow. Then water stored in ground water zone would be the water available in streams. Portion of water getting in streams, referred as base flow depends on the amount of water stored during monsoon. This depends upon the land use in the basin, precipitation rate, soil characteristics, slope, drainage density, etc. Infiltration is estimated as a difference between net rainfall yield (R_N) to Runoff (equation 8)

$$\mathbf{Inf = R_N - Runoff} \qquad \ldots\ldots 8$$

Where, Inf = Infiltration Volume

R_N = Net Rainfall Yield (Volume)

Runoff = Runoff Volume

Ground Water Recharge**:** Recharge is considered the fraction of infiltrated water that recharges the aquifer / ground water zone. After saturation of groundwater zone, water gets stored in vadose zone. Ground water recharge is given by equation 9 (Krishna Rao, 1970).

$$\mathbf{GWR = R_C * (R_N - C) * A} \qquad \ldots\ldots\ldots 9$$

Where

GWR = Ground water recharge

R_C = Ground water recharge coefficient, depending on the amount of annual rainfall, as given in table 7

R_N = Net Rainfall in mm

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 7: 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

Groundwater Discharge: Groundwater discharge or base flow is estimated by multiplying the average specific yield of aquifer under each land use with the recharged water (equation 10). 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. Base flow appears with the receding of pipe flow in a stream. Pipe flow and base flow sustains water flow in a river during the dry season.

Groundwater storage-discharge is considered to be linear (Maillet, 1905, Wittenburg and Sivapalan, 1999). The exponential function has been widely used to describe base flow recession, where Q_t is discharge at time 't' and Q_0 is the initial discharge and a is a recession constant. The exponential function describes that the groundwater aquifer behaves like a single linear reservoir with storage linearly proportional to outflow i.e.

$$\mathbf{S = a * Q} \qquad \ldots\ldots. \ 10$$

This equation represents a first order process or an exhaustion phenomenon expressed by

$$\frac{ds}{dt} = -Q$$

$$\mathbf{Q(0) = Q_0}$$

The most widely used base flow recession equations, given below (Barnes, 1939).

$$\mathbf{Q_t = Q_0 * k^t} \qquad \ldots\ldots \ 11$$

Where, Q_0- initial discharge

k – Base flow recession constant (0.85-0.99) (Subramanya, 2005).

t - Time

In absence of discharge data, volumes can be used. Replacing discharge with volume does not change its form and is less sensitive to errors (Singh, 1992). This is useful for partitioning surface and sub-surface flows (Shirmohammadi et al., 1984). Groundwater volume at any time't' is determined by equation 12.

$$V_t = V_o * k^t \qquad ....12$$

Assumptions

- The entire river basin is considered to be an unconfined aquifer
- Base flow recession constant is assumed to be 0.95

Based on the basin characteristics and rock type, ground water discharges for different basins were characterized as a function of ground water recharge and specific yield (equation 13).

$$\mathbf{GWD = GWR * Y_S} \qquad .... 13$$

Where, GWD = Ground water discharge

GWR = Ground water recharge

Y_S = Specific yield, depending on rock type (table 8)

Table 8: Average Specific Yields of Sub basins

Sub basins	**Rock type**	**Y_S (%)**
Yenneholé	Gneisses/granites, Greywackes	15
Nagodiholé	Greywackes	27
Hurliholé	Gneisses/granites, Greywackes	15
Hilkunji	Gneisses/granites, Greywackes	15
Sharavathi	Gneisses/granites, Greywackes	15
Linganamakki	Gneisses/granites, Greywackes	15
Mavinaholé	Gneisses/granites	3
Haridravathi	Gneisses/granites	3
Nandiholé	Gneisses/granites	3

3.3 Supply: During monsoon and in the initial stages, water supply is a function of runoff in the respective stream in each sub-basin. Water available as surface run off during monsoon, while the water stored in underlying strata (vadose and ground water zones) moves laterally to the stream during non-monsoon. Water recharge potential and discharge potential is a cumulative of monthly potentials during monsoon and is used during runoff deficits.

Stream Characterization: Stream discharge is the rate at which a volume of water passes through a cross section per unit of time. It is expressed in cubic meters per second (m^3/s) or cumecs. The velocity - area method using current meter was used for estimating discharge. The cup type current meter was used in a section of a stream, in which water flows smoothly with velocity reasonably uniform in the cross section. A cross-section was chosen where the current was reasonably regular over the whole width. This measurement was done for three consecutive days every month for 36 months and 5 readings were taken at each point in order to take into account day-to-day fluctuations and seasonal variations. Table 9 lists stream wise flow and relative grading of streams (as A, B, C and D) depending on the availability of water in a stream.

Table 9: Stream flow data for major tributaries of streams

Stream	**Location**	**Stream flow measurement (Discharge m³/sec)**				**Stream Grading***
		Oct.	Nov.	Dec.	Jan	
Nandiholé	Northeast	01.23	03.68	0.09	0	D
Haridravathi	East	16.23	03.02	0.46	0	D
Mavinaholé	**East**	05.93	03.00	0.44	0	D
Sharavathi	**Southeast**	26.73	5.83	1.08	0.964	C
Hilkunji	**Southeast**	46.27	10.64	2.64	1.67	B
Nagodiholé	**West**	22.56	4.84	1.90	1.42	A
Hurliholé	**West**	06.30	1.37	0.78	0.661	A
Yenneholé	**West**	NM	13.40	1.81	1.68	A

* Based on numbers of months with flow a: 12 months, B: 9 months; C: 6 months and D: 4 months

3.4 Water Demand: Water demand in each basin is calculated as the sum of Domestic demand, Livestock demand, Crop water requirement and Evapotranspiration for each month (Equation 14).

Water demand = Evapotranspiration + Crop Water Requirement + Domestic water demand + Livestock water demand …… 14

Evapotranspiration: Evapotranspiration is the total water lost from different land use due to evaporation from soil, water and transpiration by vegetation. Transpiration is the process by which water escapes to atmosphere as vapour from plants through leaves and other parts above ground. The water is taken from ground (soil) through the roots. On the other hand, evaporation continues throughout the day and night at different rates (Subramanya 2005, Birhanu et al 1995). The process of evaporation takes place on all land uses (other than vegetation). Some of the important factors that affect the rate of evapotranspiration are (Dunn and Mackay 1995, Raghunath 1985, Subramanya 2005) Atmospheric vapour pressure, precipitation, temperature, wind, light intensity, sunlight hours, humidity, plant characteristics (roots, steam and leave system, growth phase), soil moisture, etc.

If sufficient moisture is available to completely meet the needs of vegetation in the catchment, the resulting evapotranspiration is termed as potential evapotranspiration (PET), PET is also defined as the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water (Bapuji et al 2012). The real evapotranspiration occurring in specific situation is called as actual evapotranspiration (AET). These evapotranspiration rates from forests are more difficult to estimate than for other vegetation types. The difficulty in estimation arises because the turbulent diffusion in the atmosphere above the forests is much more efficient than for crops. For this reason, the rate of evaporation when the canopy is wet can be much greater than when it is dry. Thus, it becomes necessary to separate transpiration from evaporation of rainfall by forest canopy rather than considering the average effect of controlling processes within the canopy in terms of a single (effective) surface resistance (Shuttlewoth, 1993).

Potential evapotranspiration (PET) is determined using Hargreaves method (Hargreaves, 1972, Xu and Singh, 2004; Xu and Singh, 2005, Alexandris et al 2008) an empirical based radiation based equation (equation 15), which is shown to perform well in humid climates. PET is estimated as mm using the Hargreaves equation is given as

$$\mathbf{PET = 0.0023 * (R_A/\lambda) * \sqrt{Tmax - Tmin} * \left(\frac{Tmax+Tmin}{2} + 17.8\right)} \quad .....15$$

Where R_A = Extra-terrestrial radiation (MJ/m2/day)

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) as in equation 16. Evapotranspiration coefficient is a function of land use varies with respect to different land use (FAO, Marvin 2010, Stan et al 2001, Venkatesh et al 2011) and are listed in Table 10.

$$\mathbf{AET = PET * K_C} \quad .... 16$$

Table 10: Evapotranspiration coefficient

Land use	***K_C***
Built-up	0.15
Water	1.05
Open space	0.3
Semi-evergreen moist deciduous forest	0.95
Evergreen forest	0.95
Scrub and grassland	0.8
Acacia	0.85
Teak and bamboo	0.85
Dry-deciduous	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.

***Crop Water Requirement*:** The crop water requirement for each crop type based on their growth phases were used to determine the crop water requirement under each river sub basins. Crop water requirement is computed basin-wise as per equation 17.

Crop water Requirement (monthly) = Σ (Area under each crop * Crop water required for each crop) in a basin …..17

Spatial extent of each crop (agriculture, horticulture) under irrigation for each sub basin was computed (as part of land use analysis) using remote sensing data. District at a glance 2011-2012 of all the covering districts was used to determine taluk-wise area under different types of crops. This information was used to estimate the area under each type in each sub basin. Crop water requirement for individual crops based on their sowing period and growth phases were based on field estimates and literatures (http://nfsm.gov.in/ - National Food Security Mission, http://krishisewa.com - Krishiseva Agriculture Information Hub, http://www.ikisan.com/ - IKisan Agriculture portal, http://www.iari.res.in - Indian Agriculture Research Institute, http://eands.dacnet.nic.in - Directorate of Economics and Statistics http://www.bounteouskarnataka.com - Bounteous Karnataka, http://www.fao.org - FAO. The crop water requirement under each crops include water losses due to transpiration loses during their growth phase. Crop water requirement (kilo litres per hectare) under various crops based on their growth period are listed in Tables 11a and 11b respectively.

Table 11a: Cropping season and water requirement (cum per crop per ha)

Crop	Paddy	Maize	Fruits	Vegetables	Ground nut	Cotton	sugarcane	Wheat
Annual	14850	4450			6525	10550	32535	3700
Season	June - Sept	June - Oct	Annual	Annual	Oct - Feb	June -Dec	Annual	Nov - Jan
Jan			2209	1025	2260			1295
Feb			2209	1025	889		5206	555
Mar			2977	1025			2505	
Apr			4599	597			2505	
May			6018	1433			2505	
Jun	5940	266	5482	2288		582	2831	
Jul	2970	829	4485	2159		1206	2831	
Aug	3564	1478	3597	1025		2335	2831	
Sep	2376	1448	2209	597		2572	2831	
Oct		429	1481	1433	197	2039	2831	
Nov			2209	2288	1094	1280	2831	370
Dec			2209	2159	2085	536	2831	1480

Table 11b: Crop Water Requirement (cum per crop per ha)

Crop	Pulses & Others	Coconut & Arecanut	Other Oil Seeds	Cereals	Jowar	Ragi	Tobacco
Annual	2400	13496	6525	3500	6425	7450	9800
Season	Aug - Jan	Annual	Dec - April	Aug to Dec	June - Sept	June - Oct	Sept -Dec
Jan	346	1192	1631				
Feb		1256	1958				
mar		1390	979				
Apr		1346	522				
May		1390					
Jun		897			1092	373	
Jul		927			2442	2608	
Aug		1192			2056	2161	
Sep		1154		700	835	1639	1960
Oct	482	927		1120		671	3136
Nov	792	897		1260			3528
Dec	780	927	1305	420			1176

***Domestic water requirement*:** This is the water required for domestic purposes (cooking, bathing, etc.) in the river basin. Domestic water requirement is calculated as product of water required per person per day and population in the basin. Population for the year 2013 was computed using the growth rate based on the population of 1991, 2001 and 2011 for each village. Aggregation of villages, provided the population for the respective sub basin.

$$\mathbf{P_n = P_{n-1} * (1 + n*r)} \quad ....18$$

Where

Pn = Estimated population for the current year

Pn-1 = Earlier population (Census)

n = number of decades

r = population growth rate

Domestic water requirement is computed for each basin considering the population and per capita daily water requirement and number of days in a month (equation 19).

Domestic Water Required = Population * per capita Daily Water Requirement * Number of day in a month ……. 19

The domestic water requirement in India varies from season to season and also from urban to rural areas (India Water Portal, http://www.indiawaterportal.org, National Institute of Hydrology, http://www.nih.ernet.in). On an average Daily water requirement during various seasons are; Summer 150lpcd, Monsoon 120 lpcd, Winter 135 lpcd.

***Livestock water requirement*:** Livestock water demand is estimated as the product of livestock population and monthly water requirements under each category of livestock (equation 20). Taluk wise livestock population was acquired from the publication - District at a glance 2011-2012.

Livestock Water Required = Livestock Population * Daily Water Requirement * Number of day in a month ………20

Daily water requirement varies depending on the season and animal type (table 12).

Table 12: Livestock water requirement

	Water Requirement in Liters per 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

The livestock water requirement for the above animals were derived through telephonic interviews with the locals and experts apart from published literatures (http://www2.ca.uky.edu/ - University of Kentucky, http://www.nature.com - Nature, , North http://www.ncsu.edu - California State University.

3.5 Water balance: Depending on the supply and demand of water, hydrological status of a sub-basin is computed. Hydrologic status is the ratio of water supply to water demand. If the is less than 1, the basin is said to be water deficit, otherwise surplus. If the ratio falls below 0.3 then there is very low flow or no flow in stream. Flow in stream is categorized as perennial (A – type, all 12 months water) or seasonal (B – water for 9 months, C: 6 months water flow and D – 4 months or only during monsoon).

4.0 Results and Discussions:

4.1: Water availability / supply

***Rainfall*:** Rainfall analysis was carried out using daily rainfall data for the period 1901 and 2010 of 144 Rain gauge stations in and around the study area (covering all sub basins of major rivers in Uttara Kannada). Mean annual rainfall ranges from 550 mm (in the plains towards Hubli-Dharwad District) to over 6500 mm (in the Ghats of Sagara and Hosanagara taluks of Shimoga district). Within the region, rainfall varies between 750 mm to over 5500 mm. Figure 7a indicates the annual rainfall distribution across the region. Ghats section with thick forest cover receives annual rainfall of over 4000 mm, whereas the coast receives annual rainfall between 3000mm to 4000 mm and the plains with moderate forests receive annual rainfall between 1000 to 3000 mm (Figure 7b). Plains with no/very little forest cover or scrubs receive very low annual rainfall of less than 1000 mm. Figure 8 shows annual rainfall received in the whole catchment by interpolating the rainfall (rain gauge station) and isohyets.

Forest vegetation depend on the quantity of rainfall and number of rainy days/wet days. Number of rainy days computed, rain gauge station wise considering rainfall (i) more than 50 mm/month and (ii) more than 100 mm/month. Figure 9a and figure 9b shows the spatial distribution of rainy days and rainy months on an average in a year for both cases. For both the cases coasts and the Ghats receive rainfall for over 90 days in a year, indicating higher annual rainfall, good vegetation (forest) cover and high variations in terrain at these rain gauge stations, rainy months at these rain gauge stations are over 6 months in both cases, and extend over 8 months when rainfall is over 50 mm per month. With terrain getting flatter and less undulating towards the plains, the rainfall intensity decreases with less dense or degraded vegetation (forest) cover, the number of rainy days dropdown to less than 90, and 6 or less rainy months in an year in both cases, and drops to 2 months in case of rainfall less than 100 mm/month in parts of Hubli and Dharwad. The plains in the north east receives rainfall in 2 rainy seasons, one during the south west monsoon, the other during north east which results in higher rainy months/days. Sub basins surrounding the dam sites and large lakes receive local rains during summer, observed near Linganamakki reservoir of the sharavathi river basin, at Supa, Bommanhalli, Tattihalla, Kadra, Kaneri and Kodsalli dam sites of Kali basin, and Gangavali basin respectively. Monthly rainfall given in figure 10 shows higher rainfall during monsoon months between June and September, with maximum rainfall during July.

Figure 7a: Annual Rainfall in mm (Rain gauge station wise) with Rainfall Contours

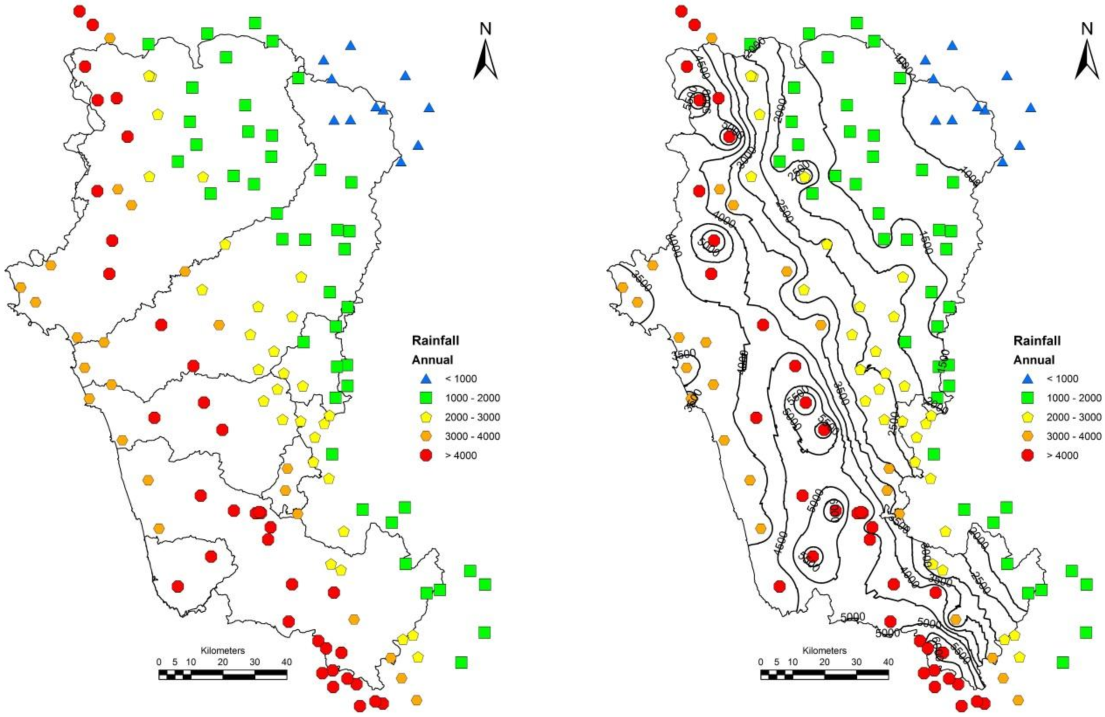


Figure 7b: Annual Rainfall in mm overlaid on DEM

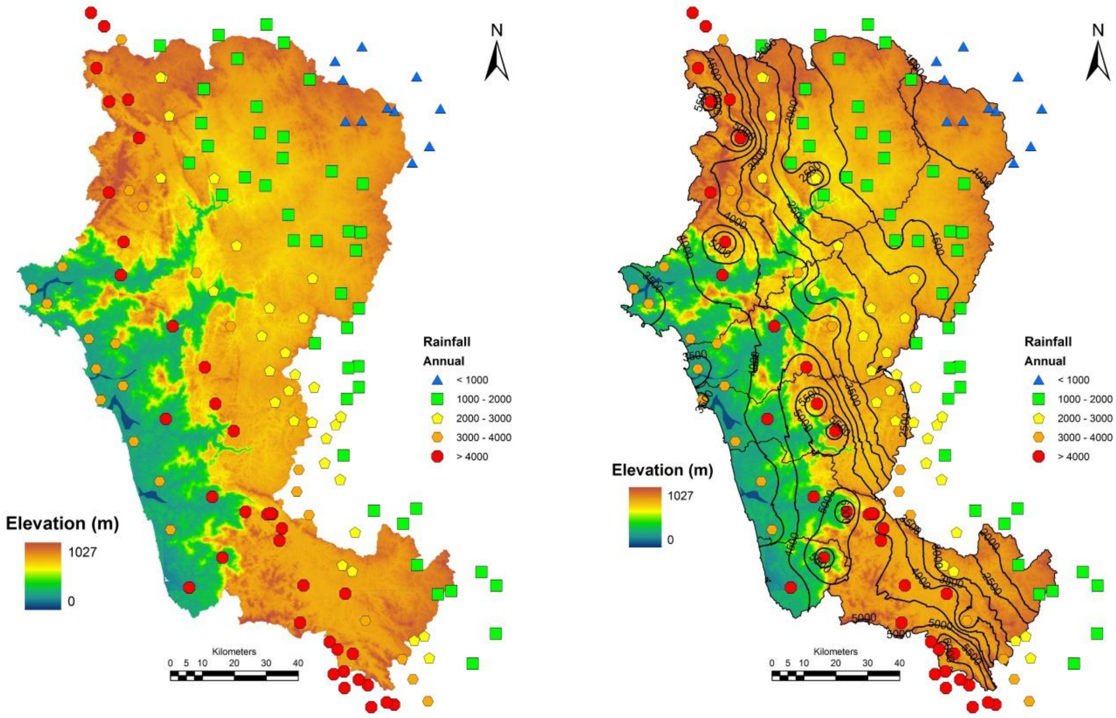
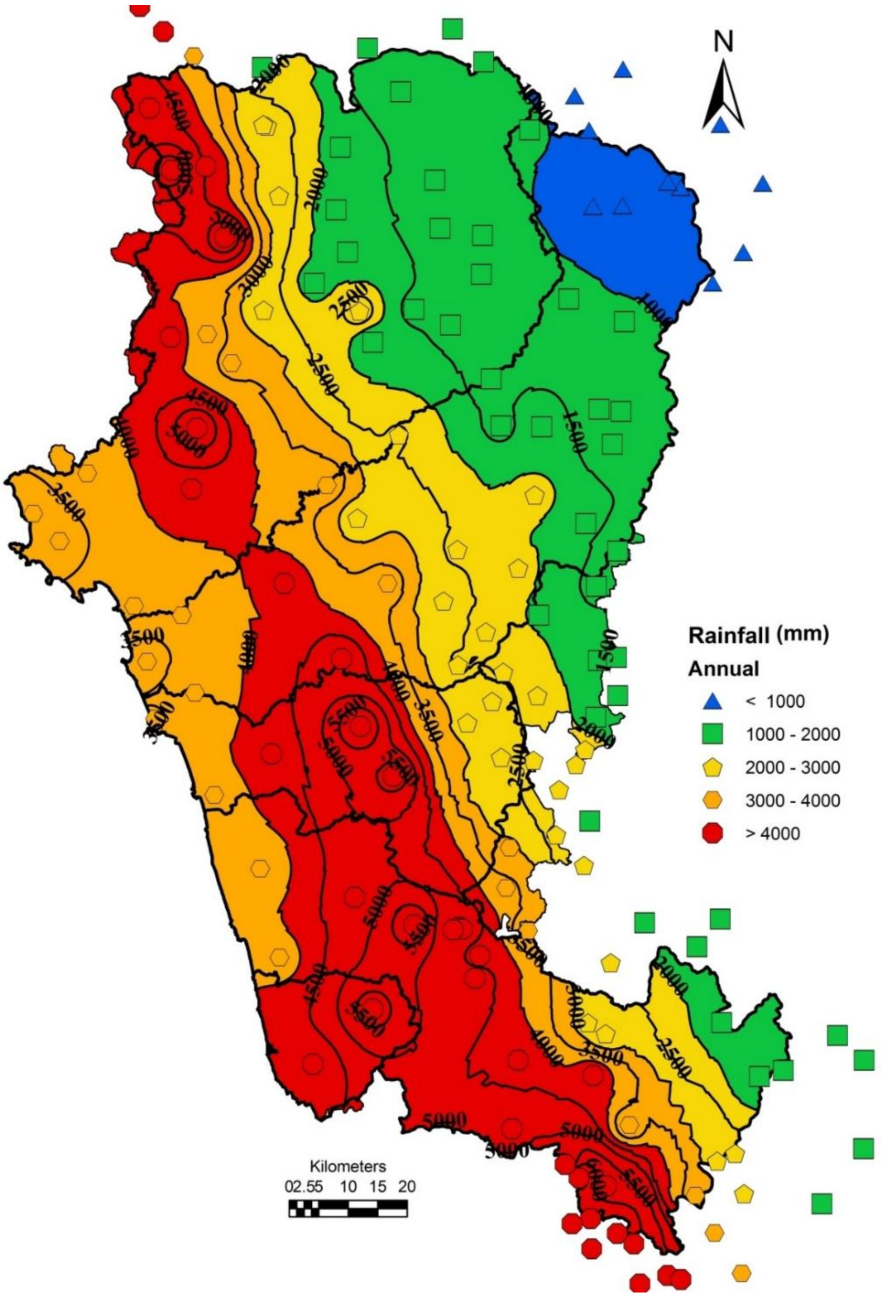


Figure 8: Annual Rainfall (in mm) with contours and rain gauge stations



Sub basin wise distribution of gross rainfall is given in figure 11. Gross rainfall is the product of precipitation and area under each sub basin, and the rainfall yield depends on the spatial extent of sub-basin. Some sub-basin shows higher values even in cases when the rainfall is low due to the large spatial extent of the respective basin. Interception in figure 12 for each basins is based on the regional land use and precipitation. The region with denser canopy cover has higher interception losses; the intercepted water contributes to evaporation during monsoon. Net rainfall is depicted in figure 13, is the difference between the gross rainfall and interception.

Figure 9a: Rain gauge stations with monthly rainfall more than 50 mm

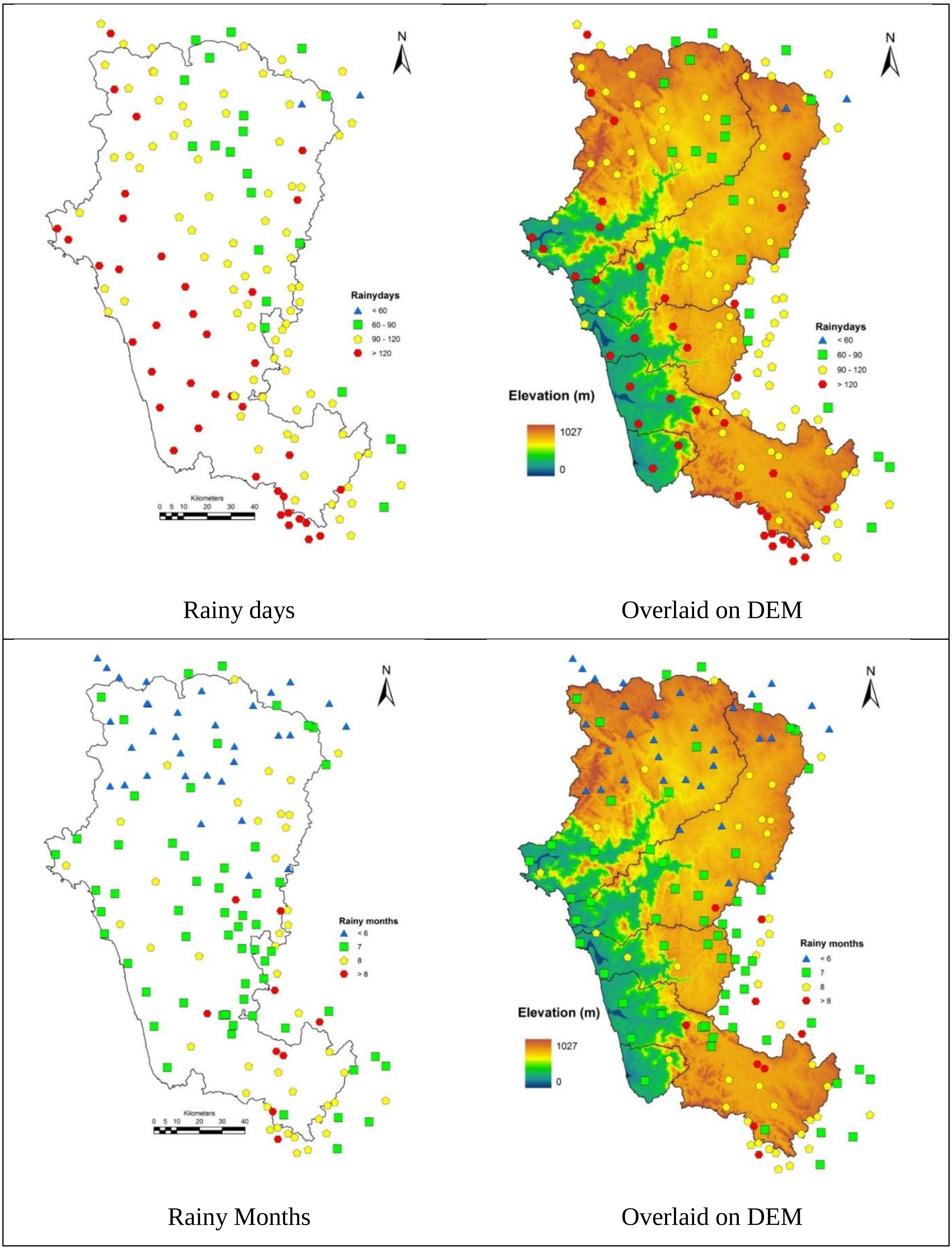


Figure 9b: Rain gauge stations with monthly rainfall more than 100 mm

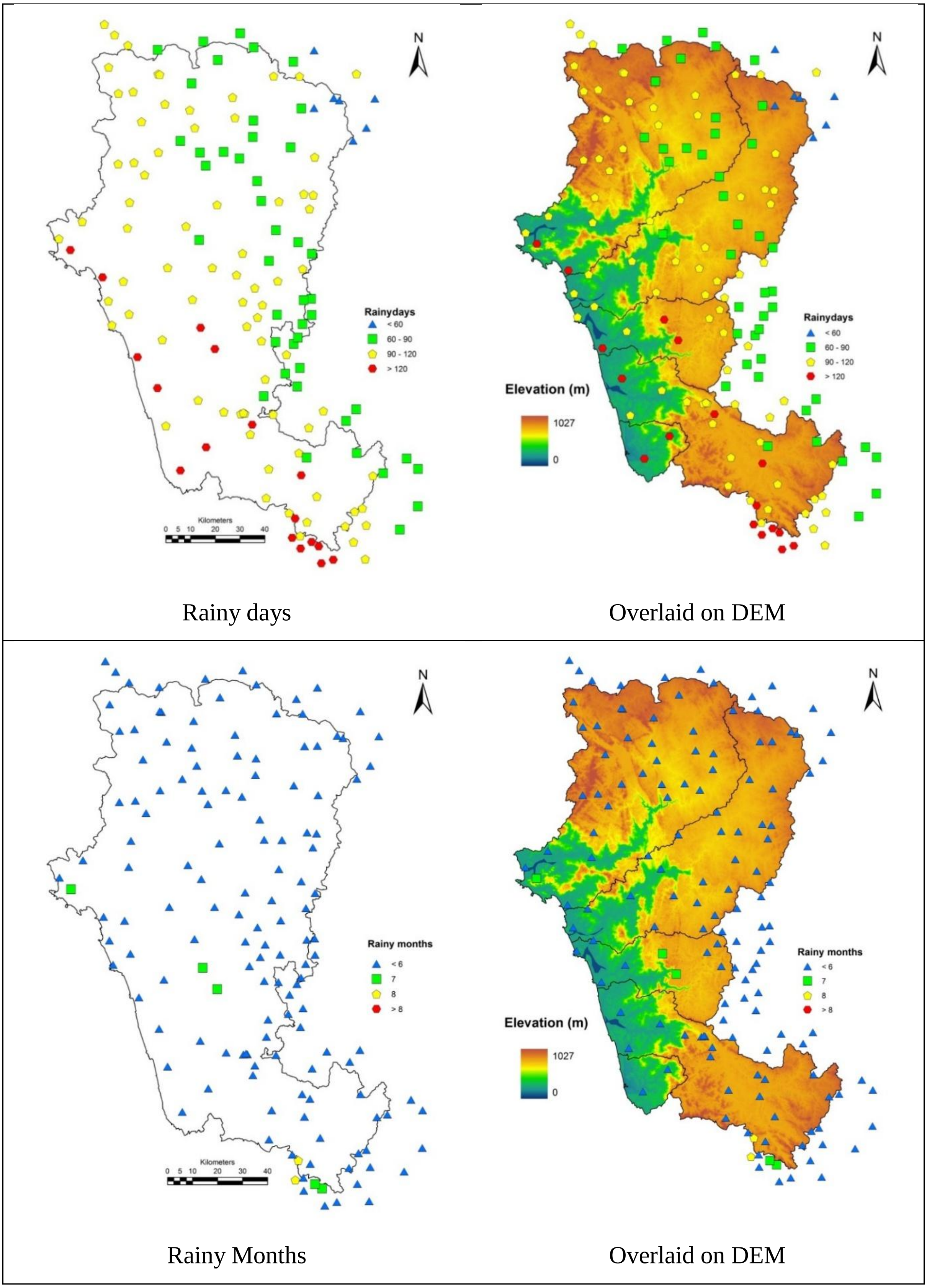


Figure 10: Month wise Rainfall (in mm)

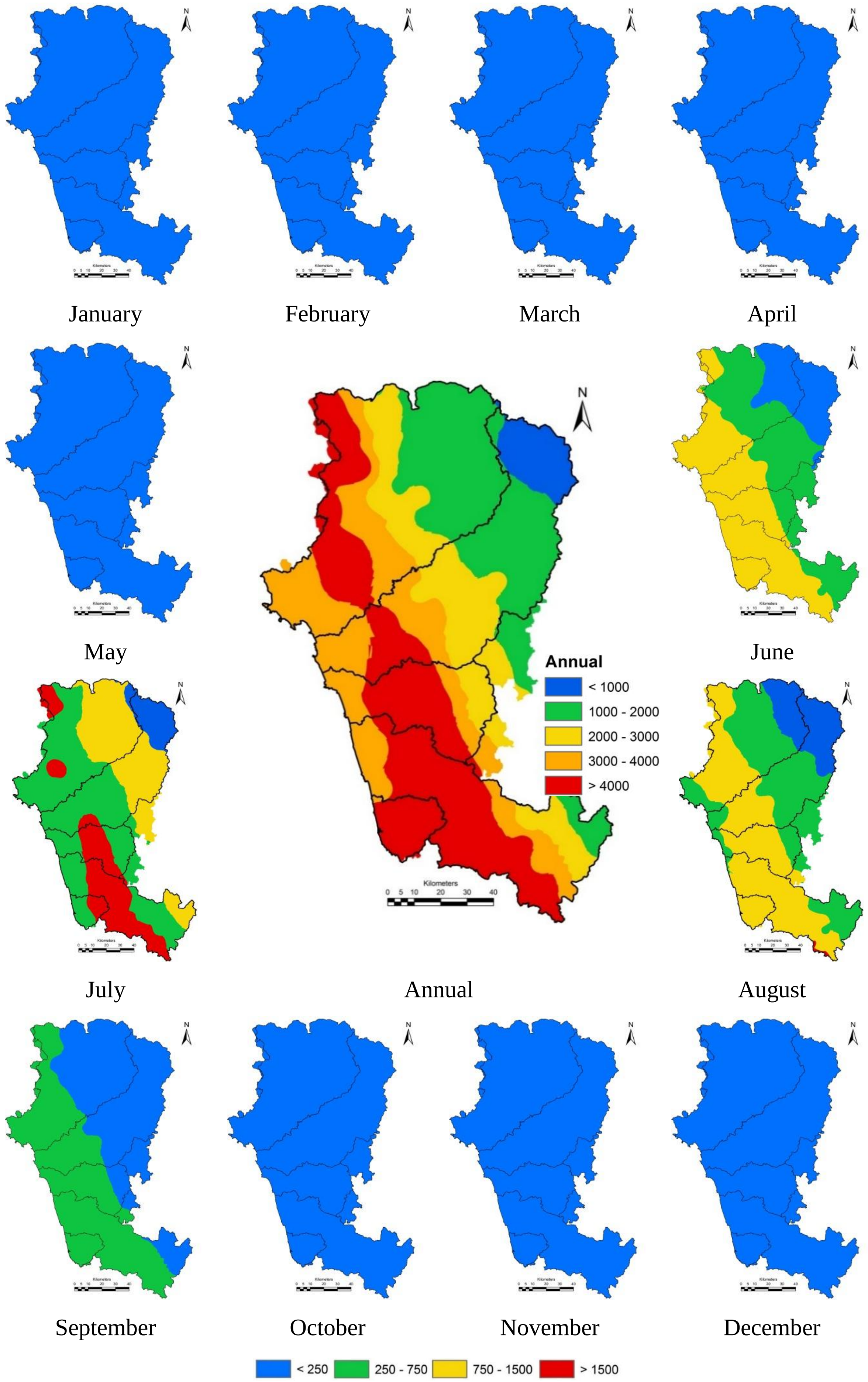
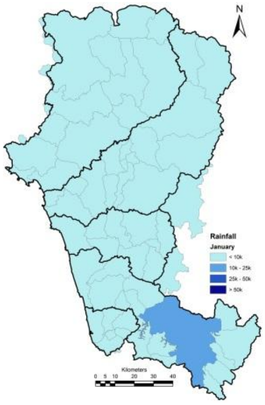
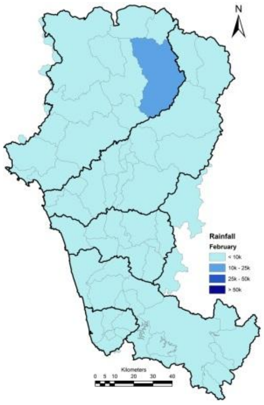


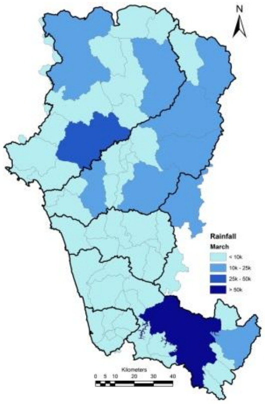
Figure 11: Sub basin wise Gross Rainfall Yield in Million Liters



January



February



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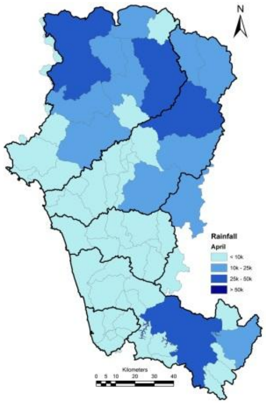

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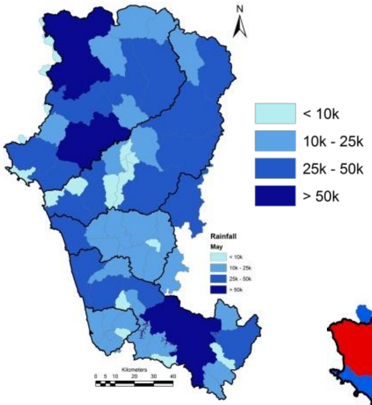
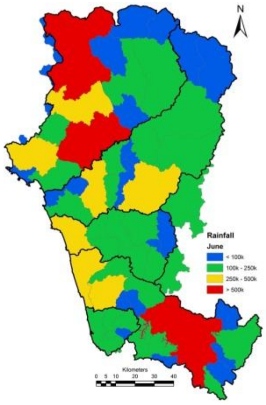
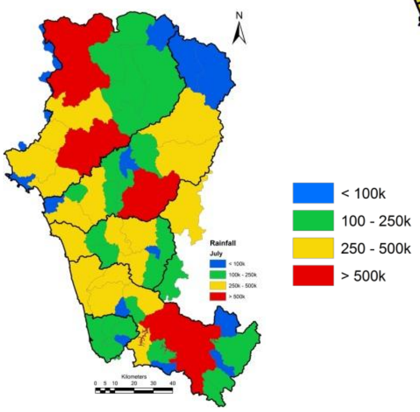


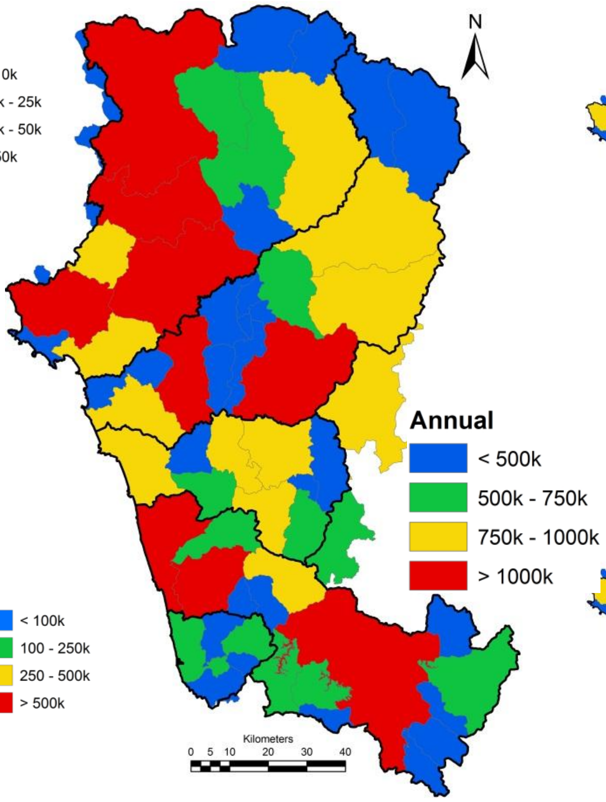
May



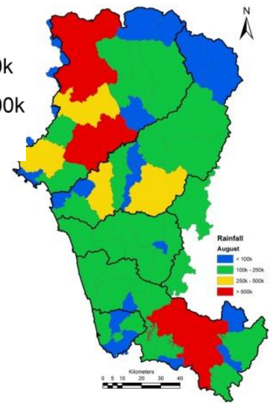
June



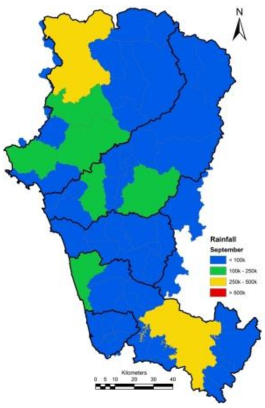
July



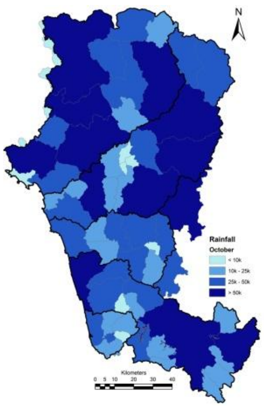
Annual



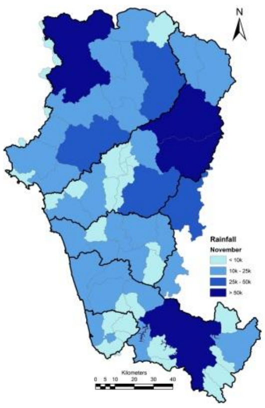
August



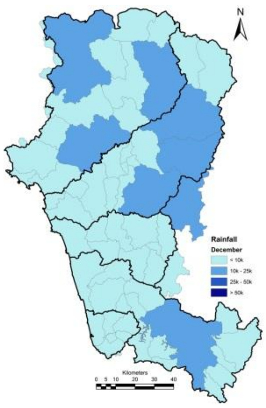
September



October



November



December

Figure 12: Interception in Million Litres

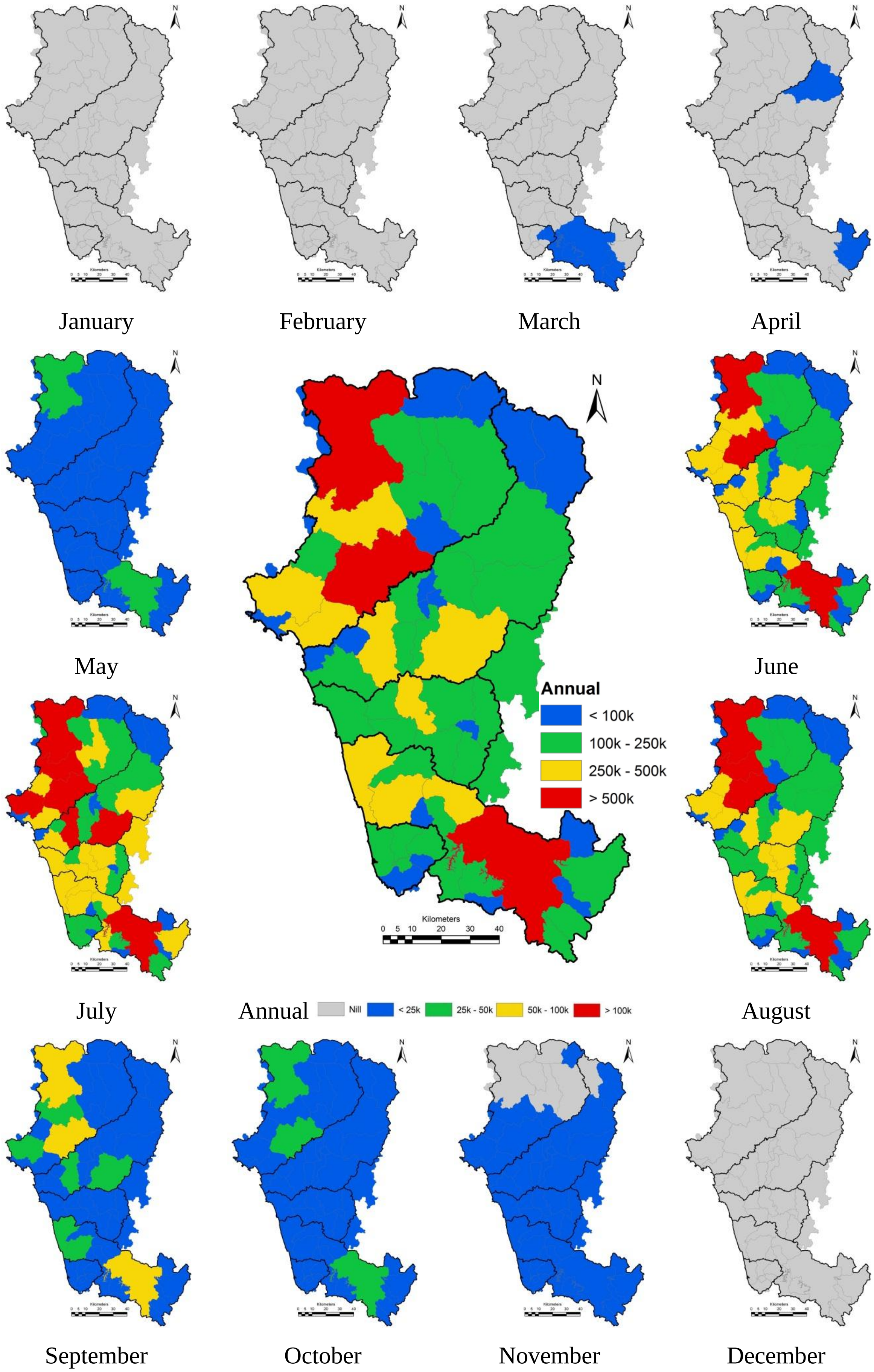
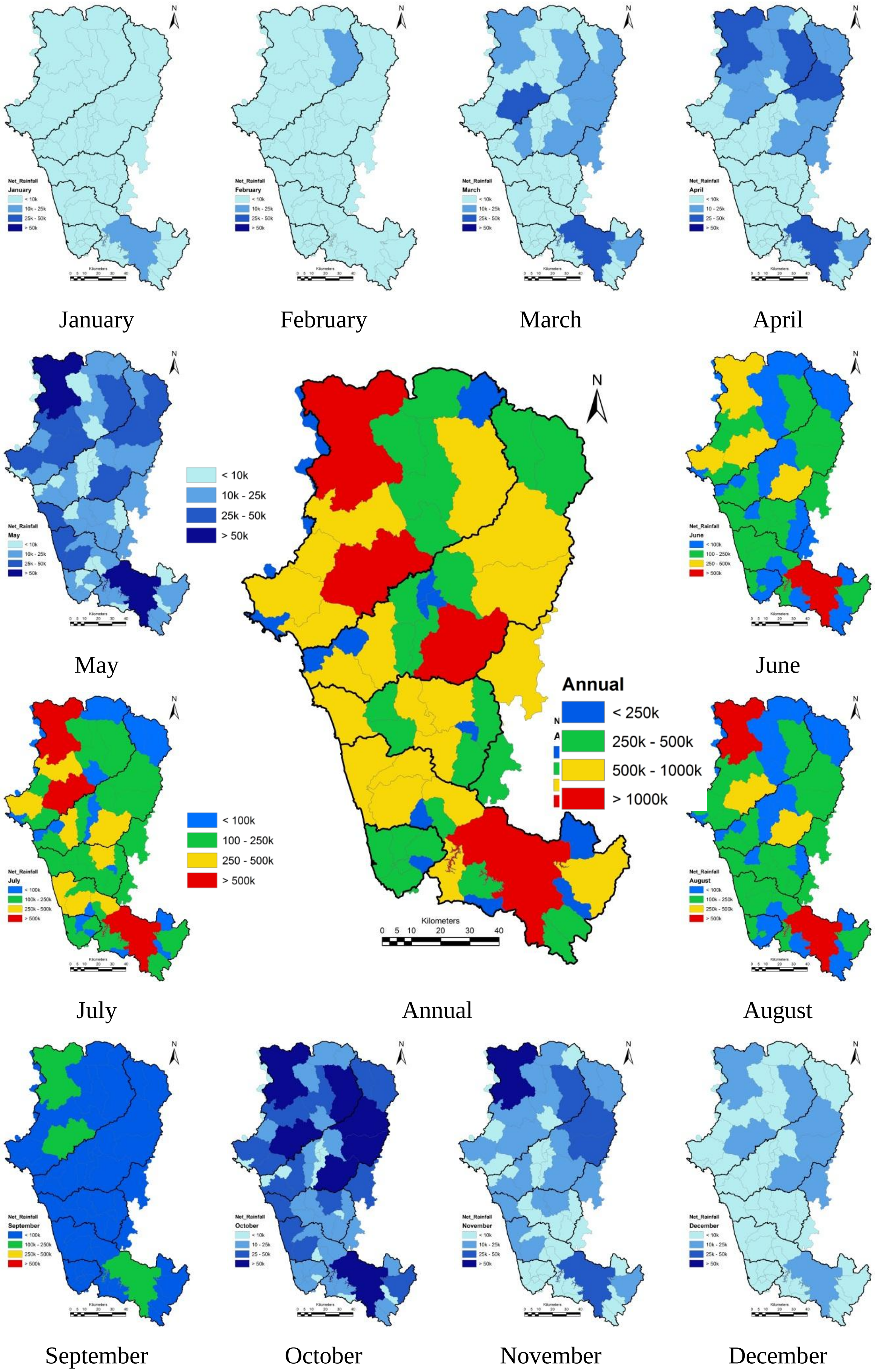


Figure 13: Net Rainfall Yield in Million Litres



Runoff**:** Runoff assessment was carried out using the empirical equation as a function of land use, precipitation (more than 50 mm/month) and area of sub basin. Monthly runoff is given in figure 14. Runoff in the basins begins in May (at coast of Uttara Kannada and Ghats of Shimoga) and continues till October. Runoff is high in the streams towards the plains (in the north east) due to no/low vegetation cover. Basins with thick vegetation have less runoff coefficients and higher water holding capabilities (as in Ghats). Despite high rainfall, runoff is moderate due to thick vegetation cover. Dam sites also indicate higher runoff during monsoon (annual). Runoff is one of the major causes for flow in streams during monsoon and along the downstream during post monsoon when stored in reservoirs.

Infiltration**:** Infiltration in each of the river sub-basins were assessed as function of net rainfall and runoff and is depicted in figure 15. Basins with higher vegetation cover show higher infiltration capacity compared to open areas and buildups. Higher infiltration / percolation is due to soil being porous due to organic matter and associated microbial action. Also, catchment with good vegetation cover have higher stream density compared to catchment with open area (sparse stream density).

Base flow**:** Base flow in each basin indicated is as indicated in figure 16, is assessed as function of infiltration. Base flow is very high in basins with reservoirs, as the ground water table is high and soil layers are over saturated, allowing larger amount of water to drain through the soil stratum into the streams.

Sub-surface flow**:** Sub-surface flow happens when adequate water is stored in vadose zone during rainfall. Figure 17 shows the water recharge capacity into the vadose zone. Apart from the basins with major reservoir's, the Ghats have higher water holding capacity of soils since they receive higher amount of rainfall, as these regions also have higher vegetation covered with diverse endemic and non-endemic floral species.

Ground Water Recharge**:** Ground water recharge potential for different river sub basins, month wise is given in figure 18, based on soil and lithology with rainfall of over 100 mm per month. The Ghats receive highest rainfall resulting higher ground water recharge potential, followed by coasts.

Figure 14: Runoff in Million Litres

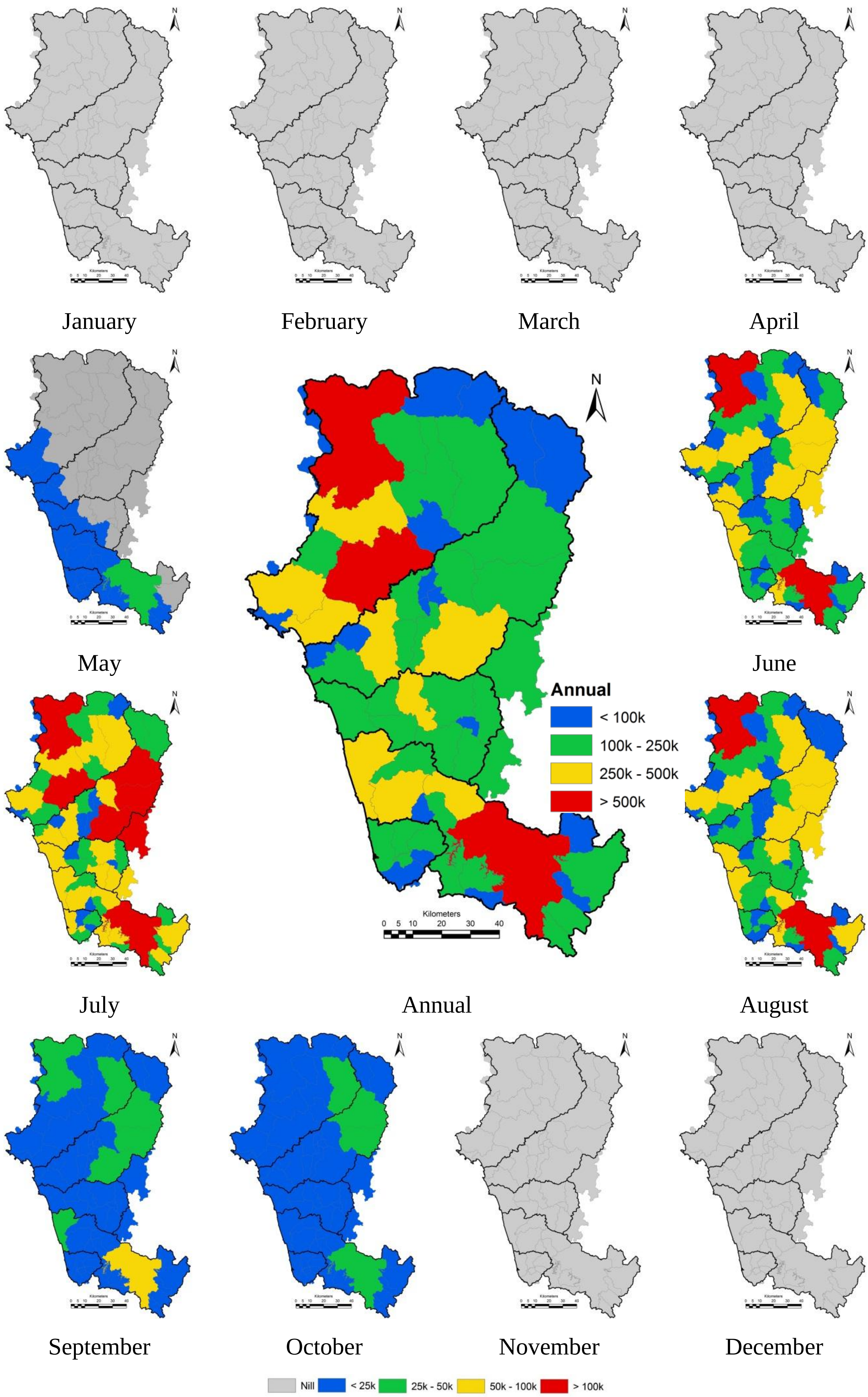


Figure 15: Infiltration in Million Litres

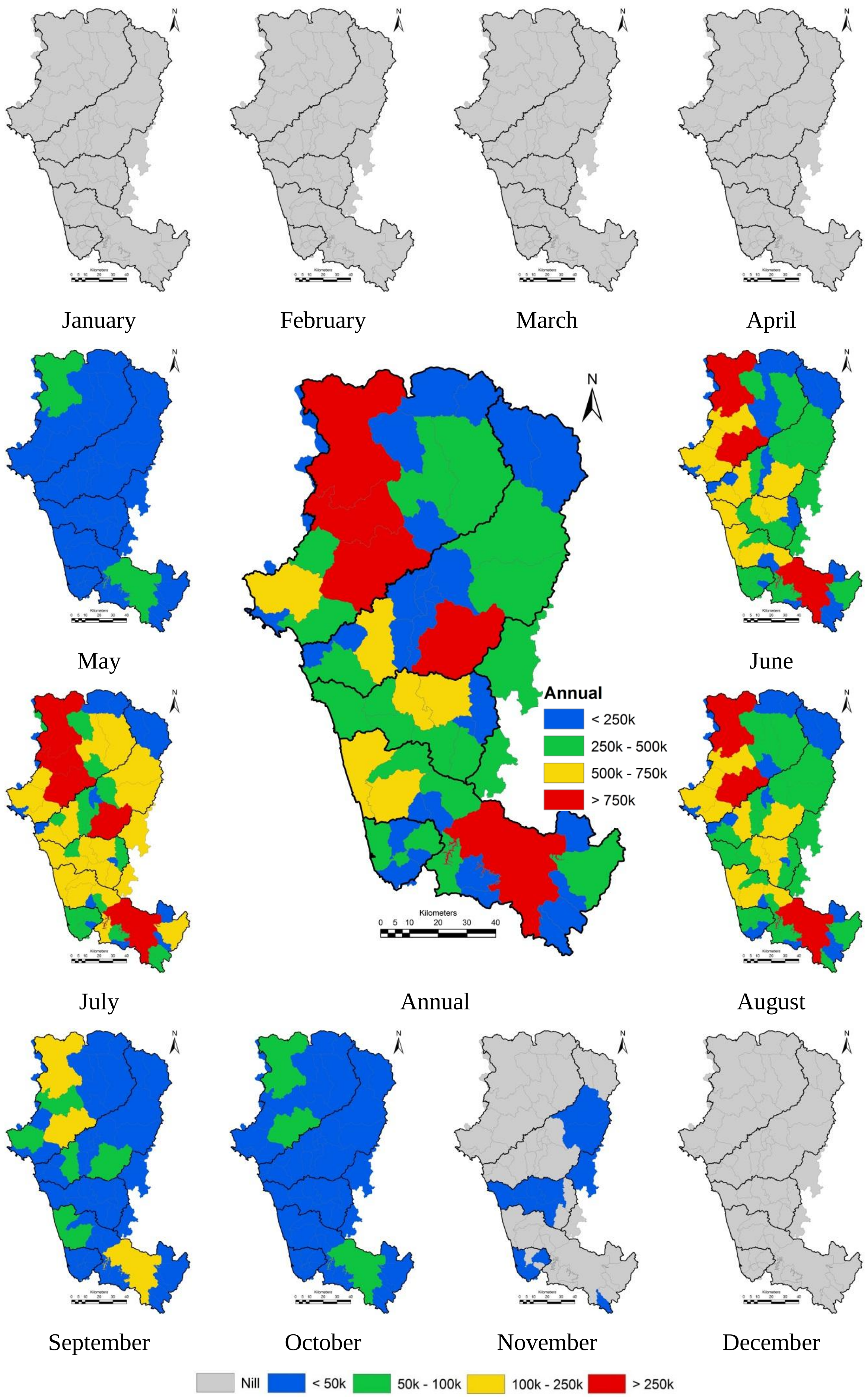


Figure 16 : Base flow in Million Litres

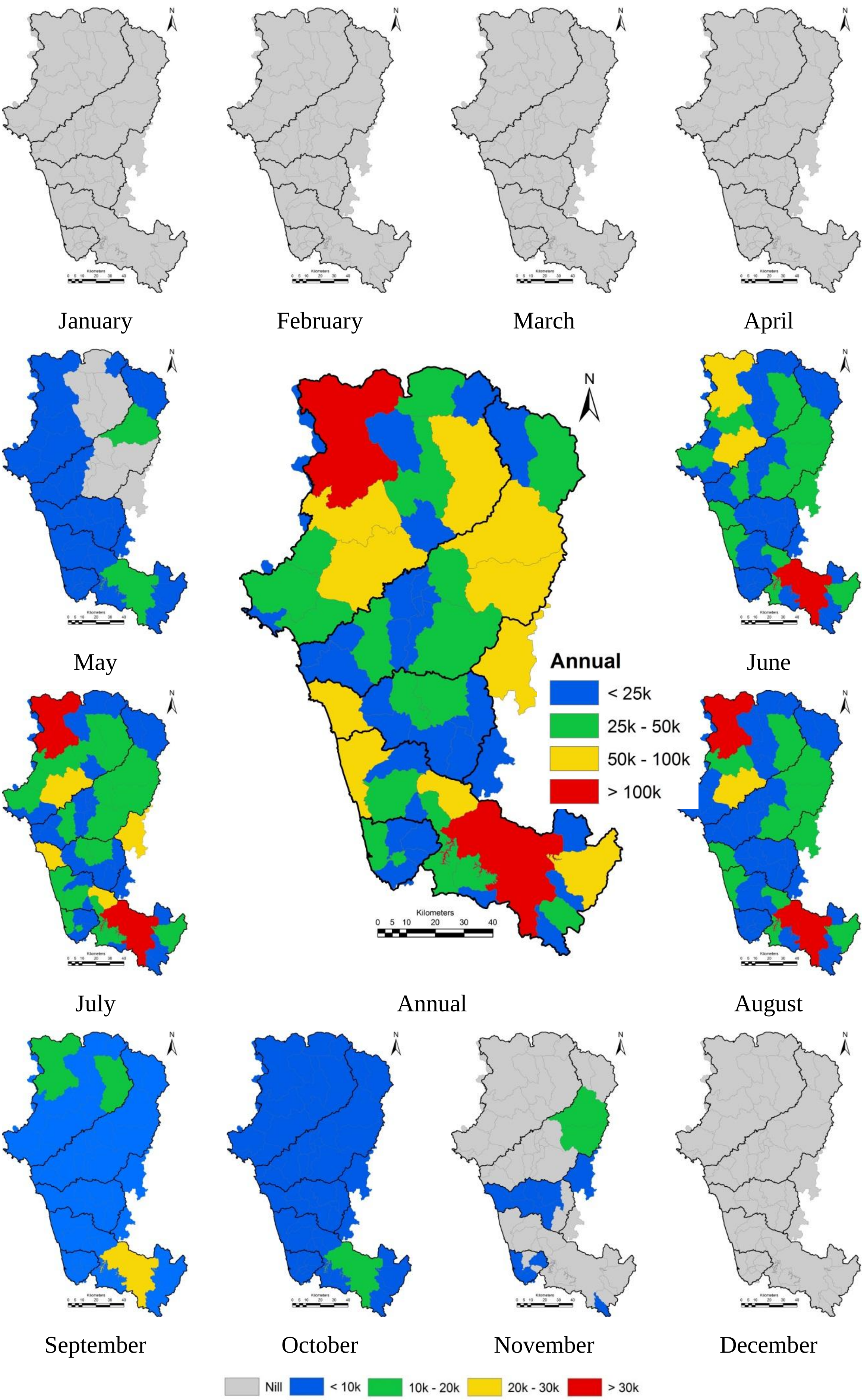


Figure 17: Water recharged to Vadose Zone (in Million Litres)

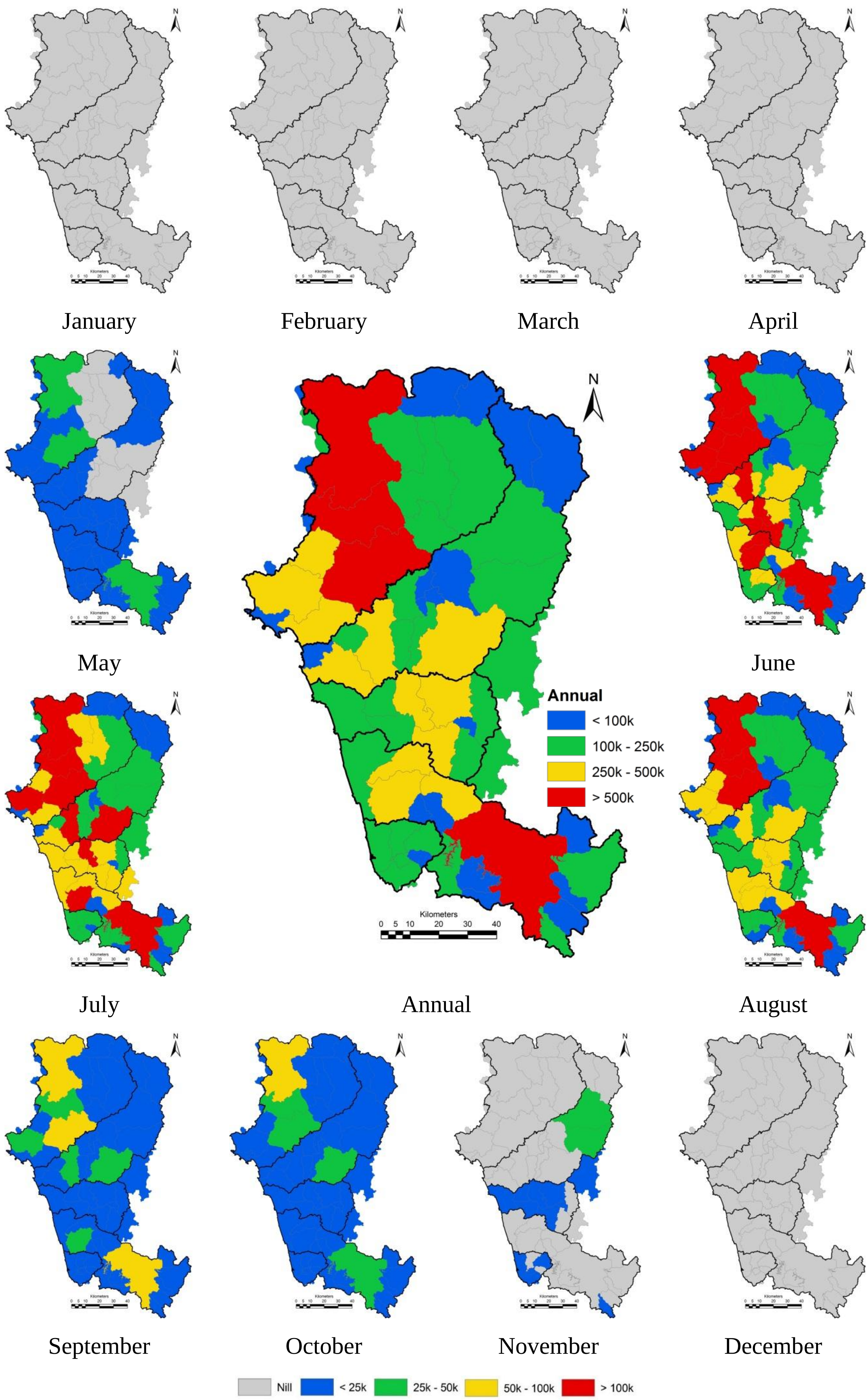
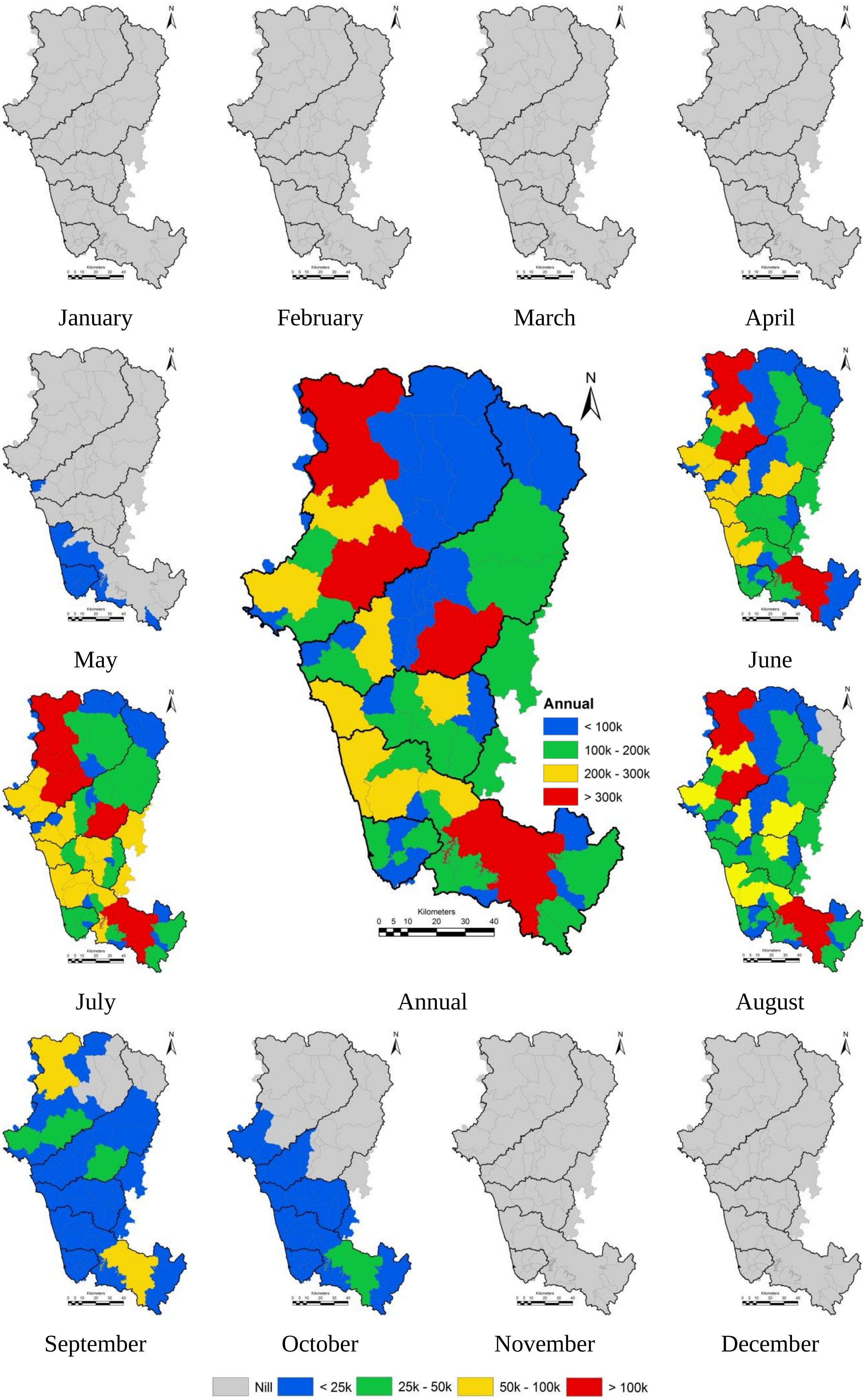


Figure 18: Ground Water Recharge (in Million Litres)


January
February
March
April
May
June
N
Annual
< 100k
100k - 200k
200k - 300k
> 300k
Kilometers
0 5 10 20 30 40
July
Annual
August
September
October
November
December
Nill
< 25k
25k - 50k
50k - 100k
> 100k

4.2 Water Demand

Crop water requirement**:** Sub-basin wise irrigation crop water requirement is computed and presented in figure 19. Sub-basins in Ghats indicate lesser irrigation and horticulture water requirement. Rain fed paddy is grown in this region. Sub basins with two season rice crops indicate higher water requirement. In sub basin toward Hubli-Dharwad district, cash crops are grown indicating higher water requirement. The crop water requirement is high in the north and north east in the plains, followed by coast, followed by the Ghats.

Domestic water requirement**:** the water requirement is function of population, and water requirement per person in the particular season. Population in the basin for the year 2013 was estimated using the earlier census for each river sub basin. Figure 20 indicates the population density (persons per square kilometer). Table 12 indicate the increase in population density since 1991.

Table 12: Population density variation in each sub basins

Basin	**1991**	**2001**	**2011**	**2013**
Kali	84.58	144.11	153.92	155.91
Gangavali	124.92	170.47	193.79	198.77
Aghanashini	103.95	130.51	143.44	146.10
Sharavathi	78.80	91.70	101.42	100.82
Venkatapura	***222.99***	***263.79***	***302.13***	***309.84***
Other	48.66	63.61	70.20	71.56

Of the five river basins, Venkatapura basin has the highest population density of about 309.84 persons per square kilometer followed by Gangavali (198.77), Kali (155.91), Aghanashini (146.10) and Sharavathi (108.92) basins. Domestic water requirement of each sub basin is given in figure 21. Coast and the plains show higher domestic water requirement due to higher population, whereas the Ghats indicate low domestic water requirement due to lower population.

Livestock Water Requirement**:** Livestock population density for each of the basins and for different livestock categories as shown in figure 22. The plains in the north east have higher sheep and goat population density as these basins have longer dry months with less rainfall. Whereas the coasts (Bhatkal taluk) of venkatapura river basin have higher cattle and buffalo density. Similar to domestic water requirement, livestock water requirement is computed and given in figure 22. Due to higher animal population, larger livestock water is required in the plains along the north east, east, followed by the coast in the west and Ghats in the north of the study area.

Figure 19: Crop Water Requirement (in Million Litres)

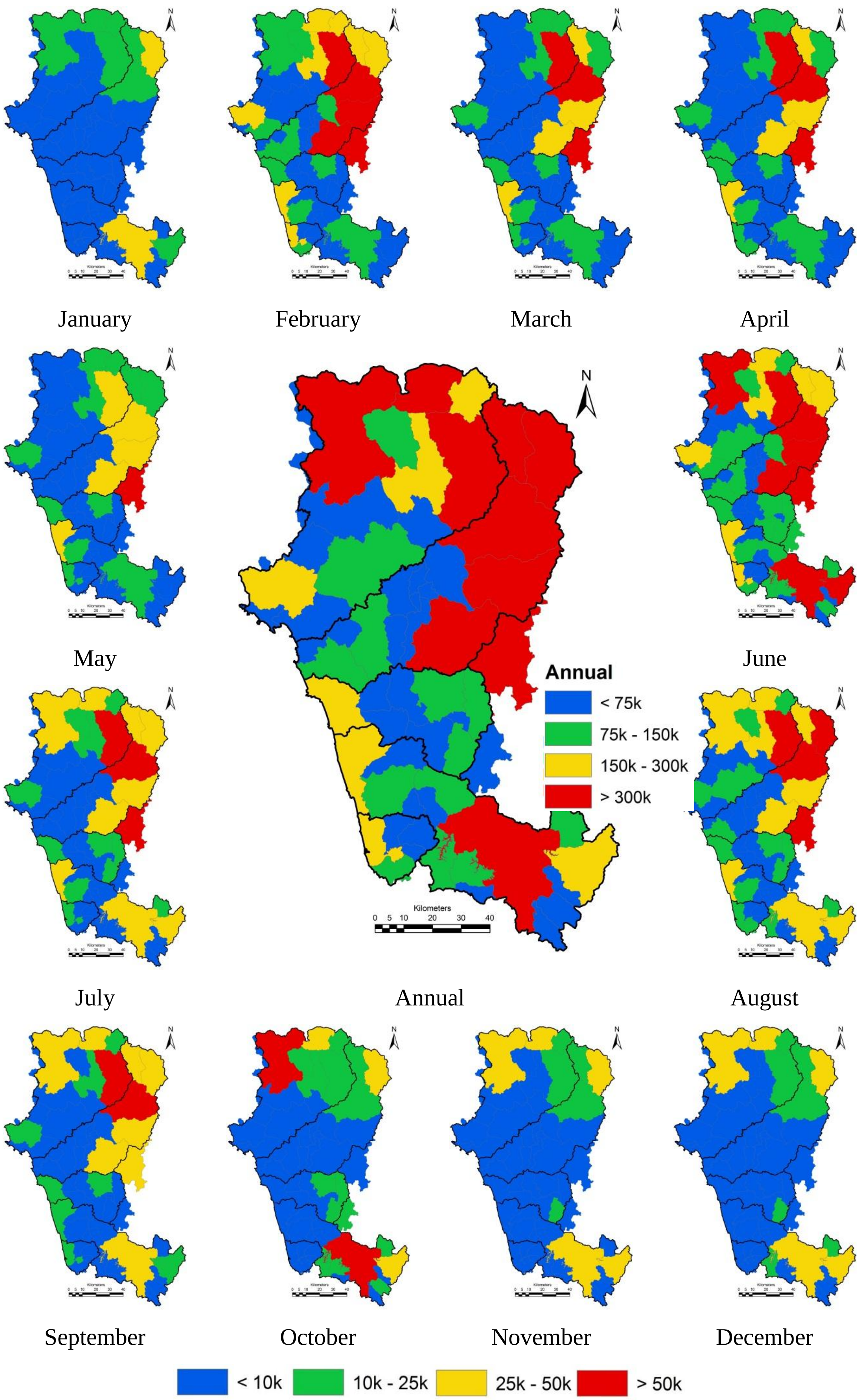

January
February
March
April
May
June
July
Annual
August
September
October
November
December
Annual
< 75k
75k - 150k
150k - 300k
> 300k
Kilometers
0 5 10 20 30 40
N
< 10k
10k - 25k
25k - 50k
> 50k

Figure 20: Population Density as persons per square kilometer

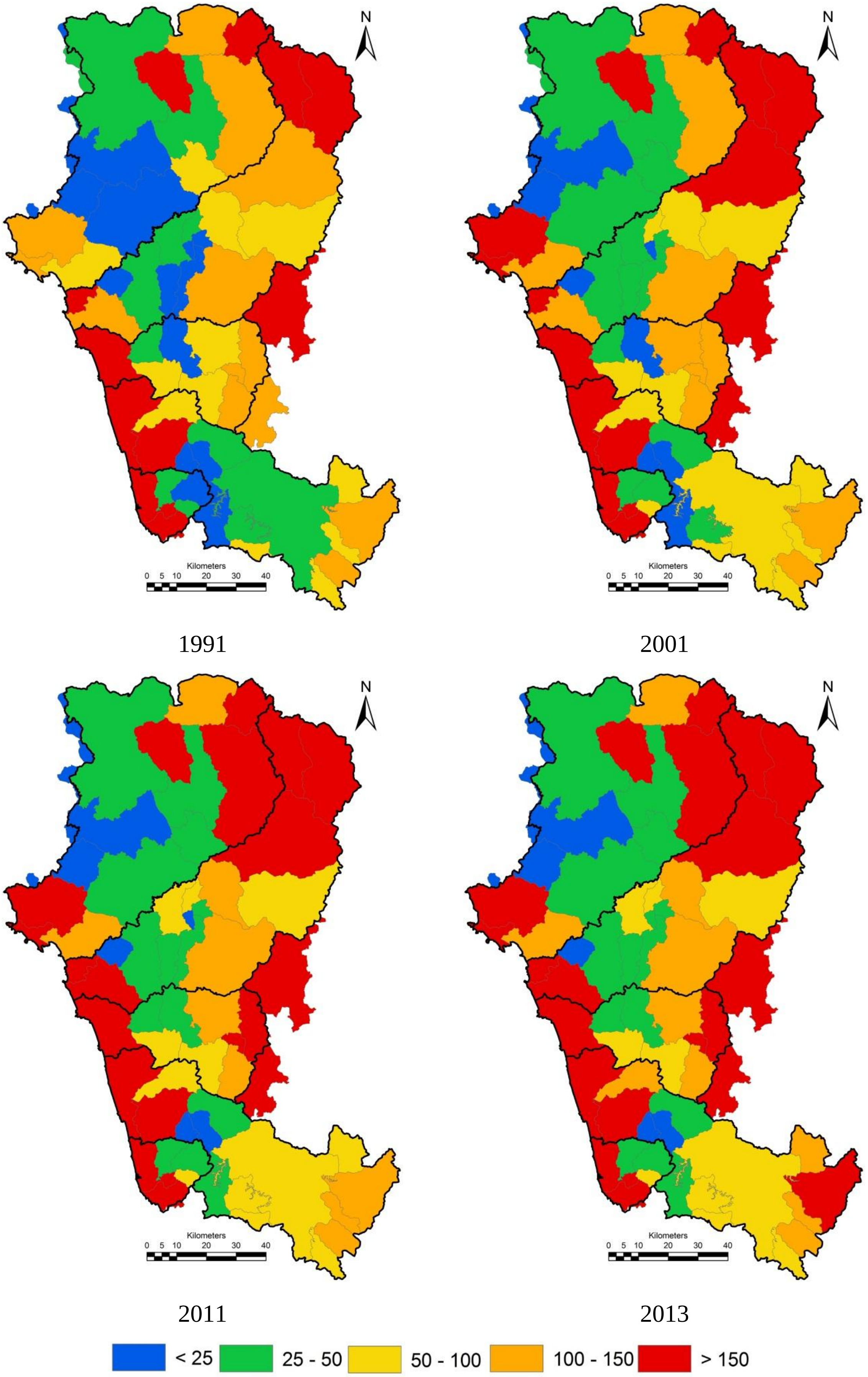
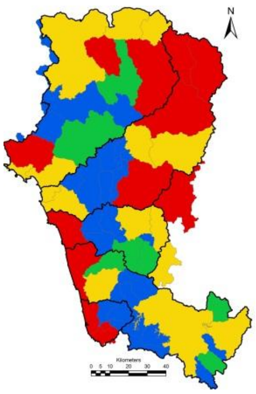
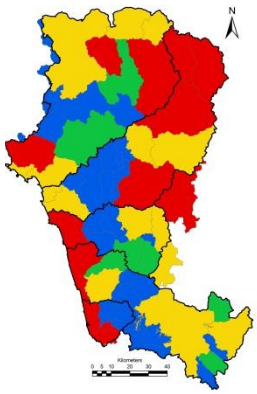


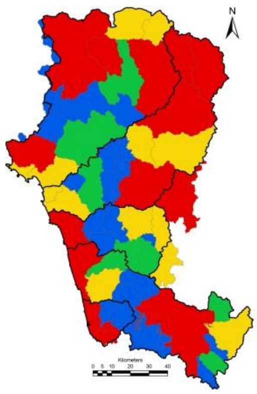
Figure 21: Domestic Water requirement (in Million Litres)



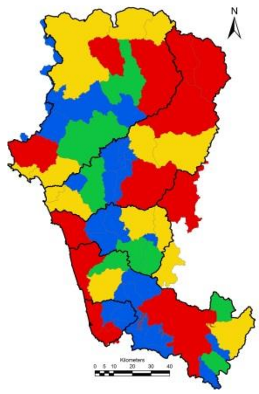
January



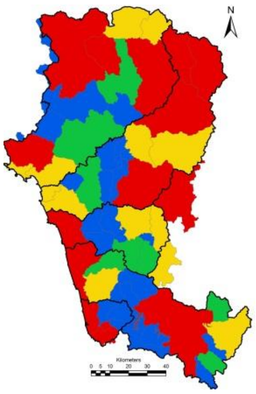
February



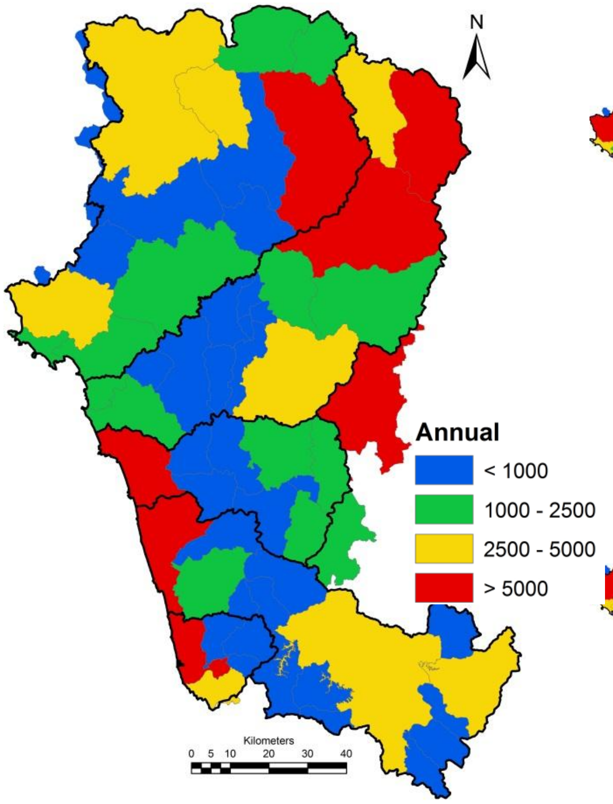
March

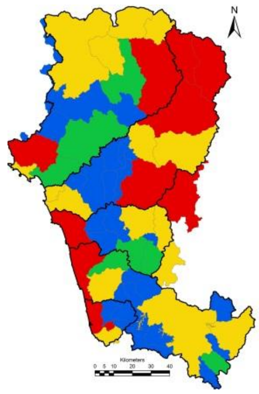


April

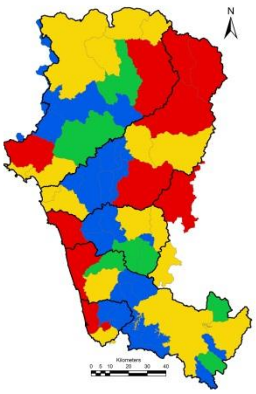


May



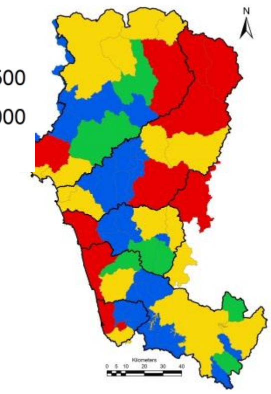


June

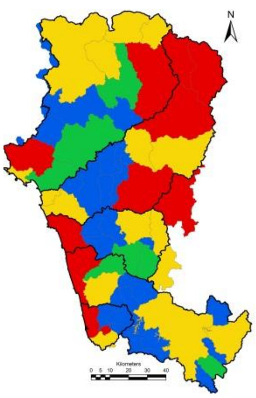


July

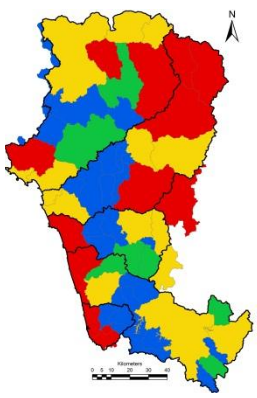
Annual



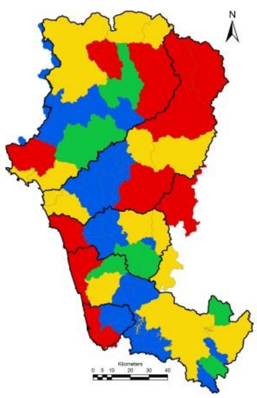
August



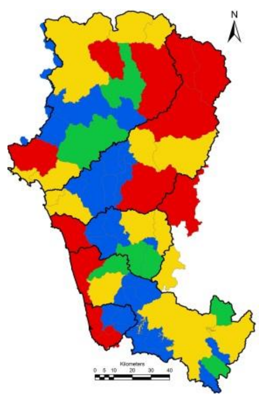
September



October



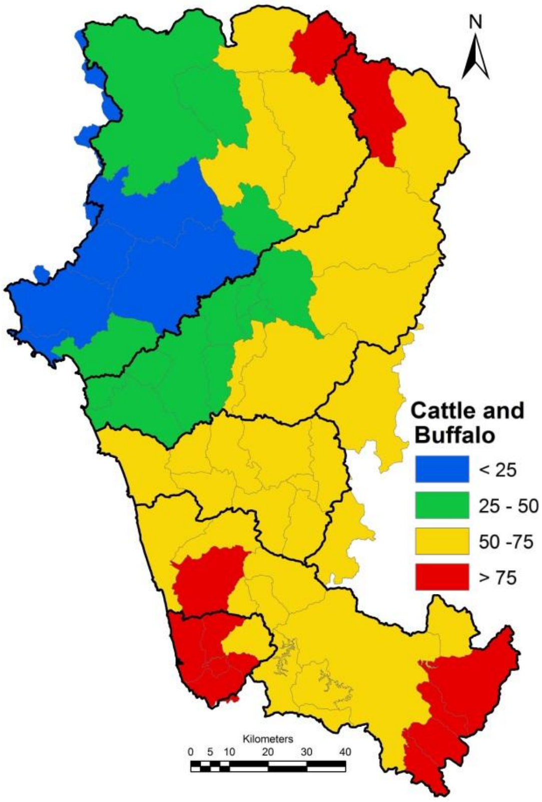
November



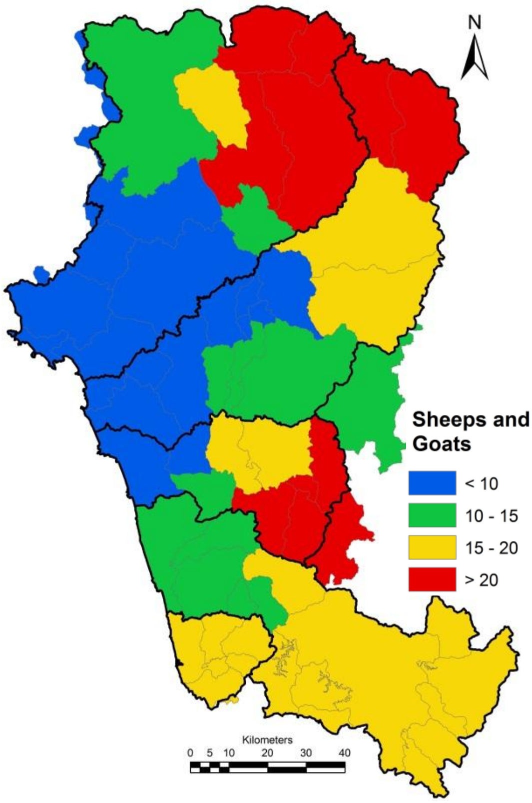
December

< 50 | 50 - 100 | 100 - 250 | > 250

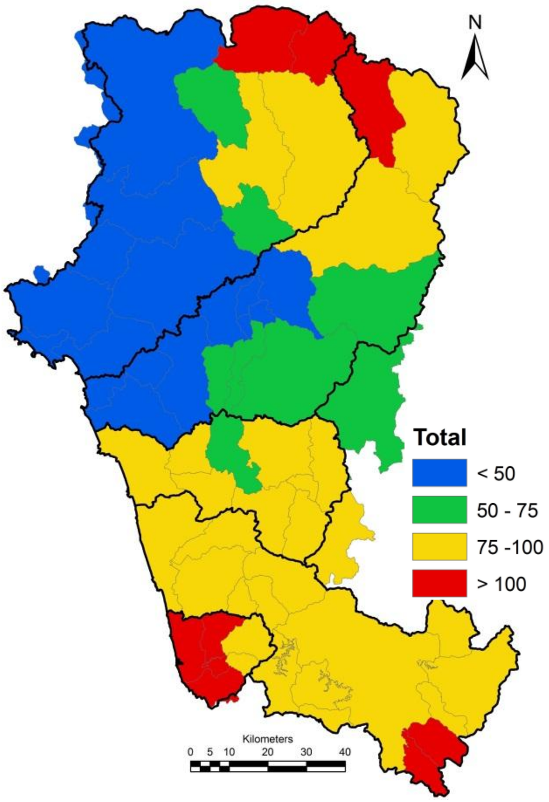
Figure 22: Livestock density (animals per square kilometer)



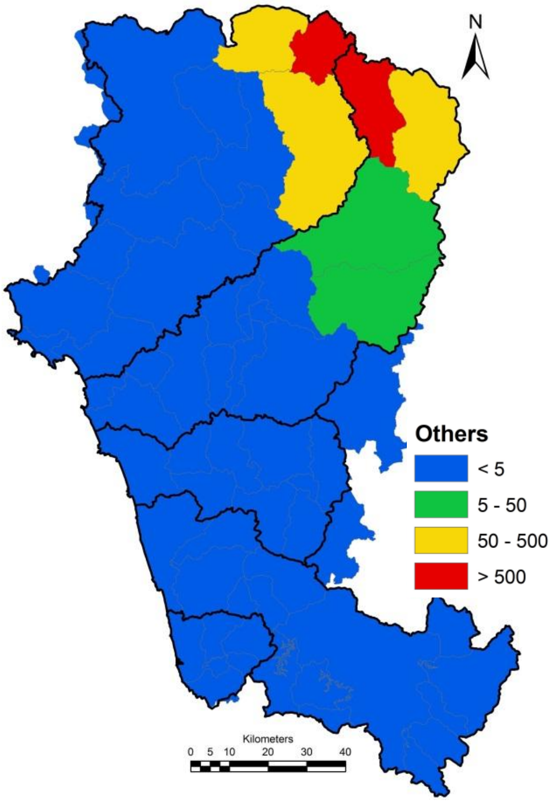
Cattle and Buffalo



Sheep and Goat

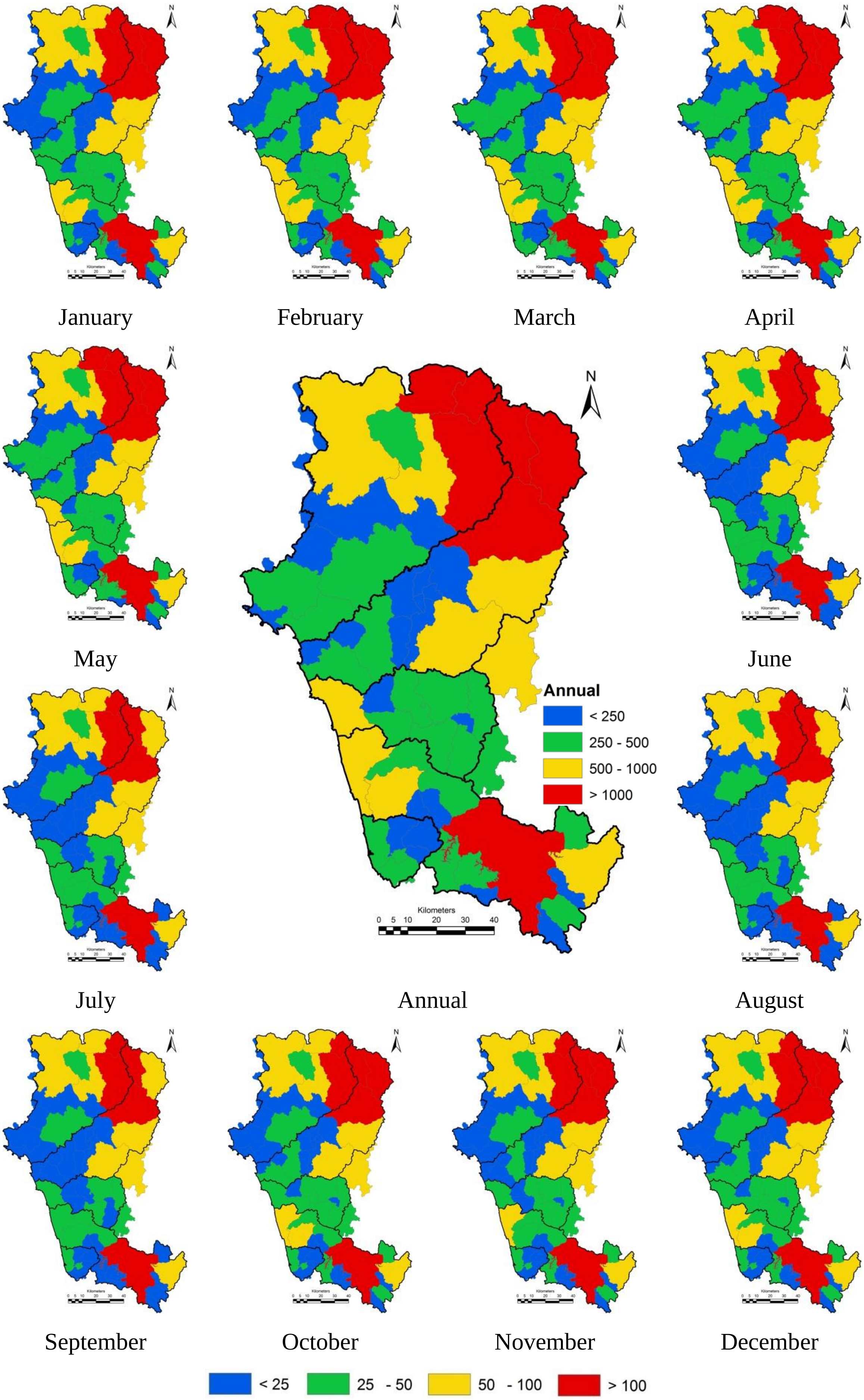


Total (Cattle, Buffalo, Sheep and Goat)



Others

Figure 23: Livestock Water required (in Million Litres)


January
February
March
April
May
June
Annual
< 250
250 - 500
500 - 1000
> 1000
Kilometers
0 5 10 20 30 40
N
July
Annual
August
September
October
November
December
< 25
25 - 50
50 - 100
> 100

***Potential Evapotranspiration*:** Potential evapotranspiration was estimated using Hargreaves method. Figure 24 depicts month-wise PET variations, which ranges from 5.6 mm/day (May) to 2.8 mm/day (July). Supplementary data to estimate PET are temperature (figure 25) (www.worldclim.org) and extraterrestrial solar radiation data (figure 26). Temperature in the basin on an average varies from as low as 15.4 °C (January) to 35.62 °C (April). Extraterrestrial solar irradiation depends upon the locations (latitude and longitude), and its position above or below the equator. It varies from 28.12 KJ/m^2/day (December) to about 38.63 KJ/m^2/day (May).

Figure 24: Month-wise Potential Evapotranspiration (mm/day)

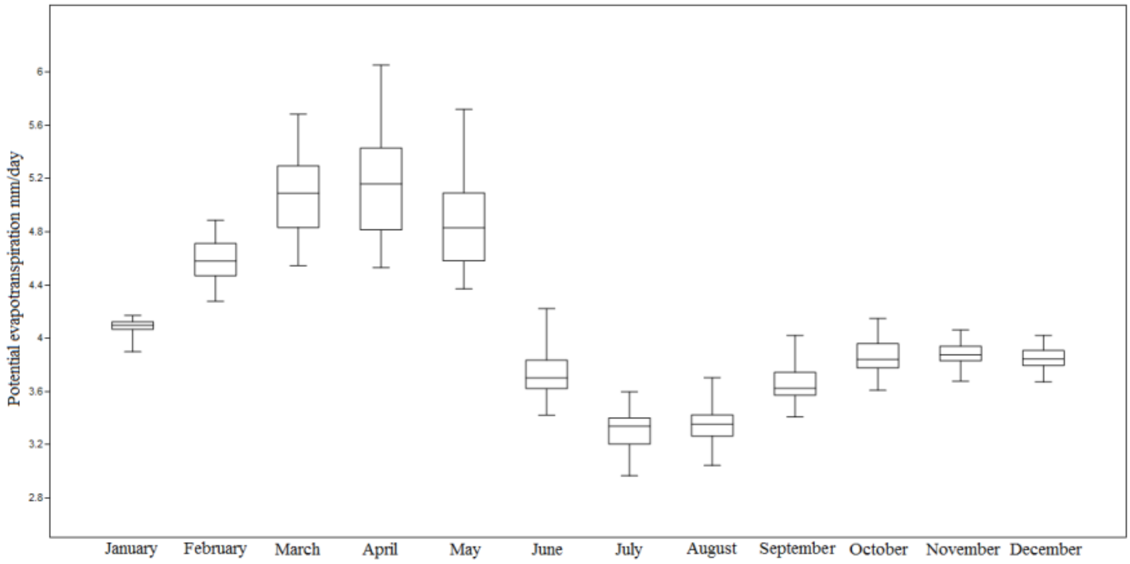


Figure 25: Month-wise Temperature (°C)

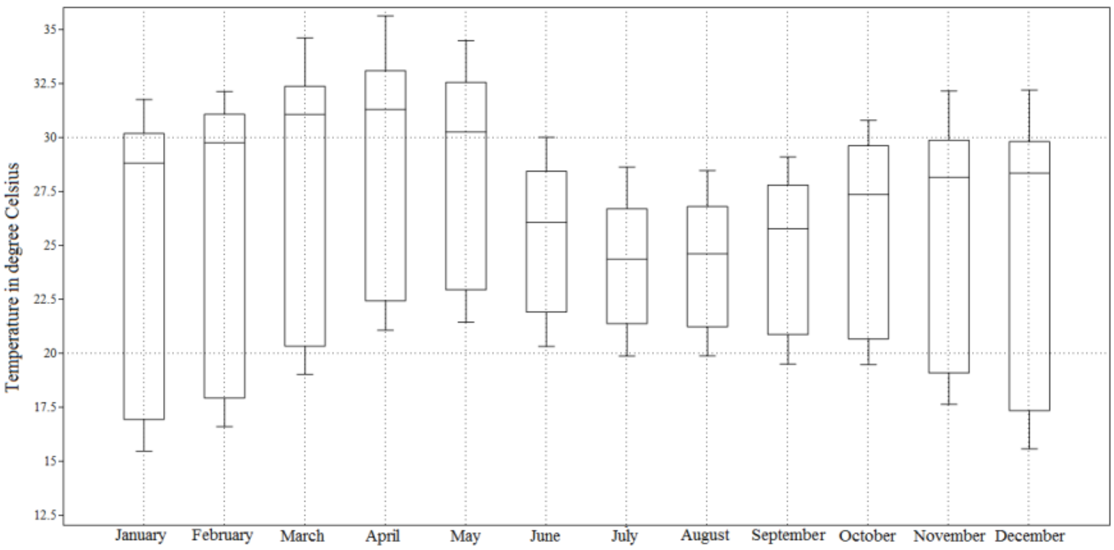


Figure 26: Extraterrestrial solar radiation (KJ/m^2/day)

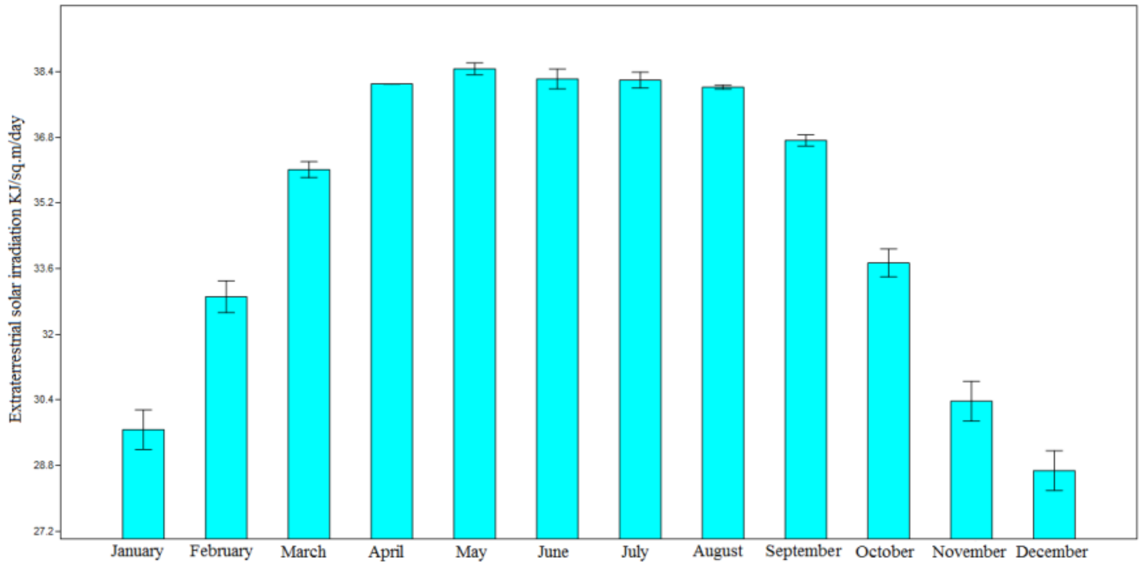
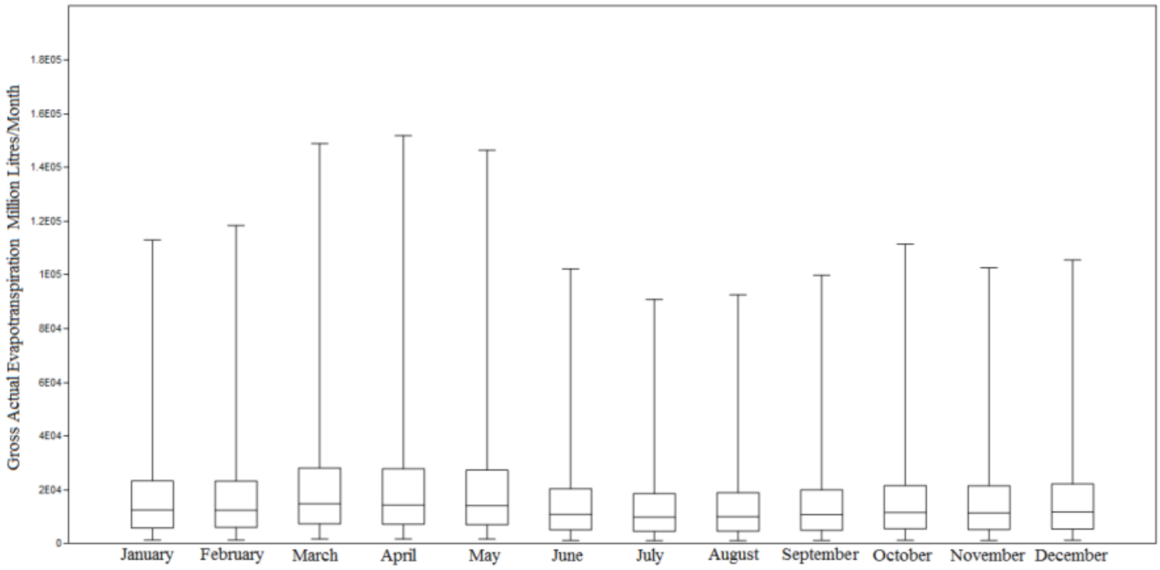


Figure 27: Gross AET Million Litres



Gross Actual evapotranspiration is derived as product of evapotranspiration coefficient and PET, is depicted in figure 27, indicating higher values during April, and lower values during July. Net Evapotranspiration is derived as difference between gross actual evapotranspiration and interception, as interception losses account to evapotranspiration and is as shown in figure 28. The evapotranspiration losses during monsoon is due to the process of interception of water. Higher forest cover in the Ghats contribute more to evapotranspiration loss. Sub basins with large water bodies contribute to a higher evapotranspiration followed by basins covered with dense forests.

Total Water Demand**:** Total water demand is the combination of crop water requirement, domestic and livestock water demand, and evapotranspiration. The total water demand given in figure 29, indicates of higher demand during dry seasons. The Northeastern part of the study area in the basins of Kali and Gangavali has a higher water demand, whereas the demand is comparatively less in Ghats, and regions dominant with natural vegetation cover.

Water Availability**:** Water supplied to cater the demand varies with the water available as runoff, vadose water and ground water discharge. Figure 30 shows the season wise water availability. During, December to May in some of the river sub basins of Kali, Gangavali and Sharavathi, water availability falls to zero indicating non-availability of naturally available water sources in the sub basin.

5.0 Water Budget and Stream flow assessment: Figure 31 indicates the hydrological status highlighting the basins with the water availability as either surplus or deficit (scarce). If the ratio of availability to demand falls below 1, sub-basin indicates the scarcity of water. Figure 31 also highlight the water availability as number of months in a year. The Ghats and some part of coast (with good forest cover) show water availability during all 12 months, whereas some sub-basins towards the plains and the rest of the coast the surplus is available between 6 to 11 months and the plains has the water available for less than 6 months

Streams were graded as A, B, C and D depending on the perennial, intermittent or seasonal water availability (which are comparable to field measurements, table 9). Figure 32 highlights the hydrological status of all rivers in Uttara Kannada district.

Figure 33 shows the Gram panchayat wise hydrological status. Most Gram panchayats of Karwar and Bhatkal taluks, the Ghats of Supa, Ankola, Kumta, Honnawara, Siddapura, Sirsi and Yellapura have water for all 12 months (perennial). Gram panchayath in the coasts of Honnavara, Kumta and Ankola along with the Ghats of Siddapura, Sirsi, Yellapura and Supa towards the plains have water for 10 – 11 months, the plain regions of Haliyal and Mundgod taluks with part of Yellapura and Sirsi taluks show water availability for less than 9 months (intermittent and seasonal). Table 13 below shows the forest cover in each of the Gram panchyayat's along with the water availability as surplus in months.

Figure 28: Net Evapotranspiration in Million Litres

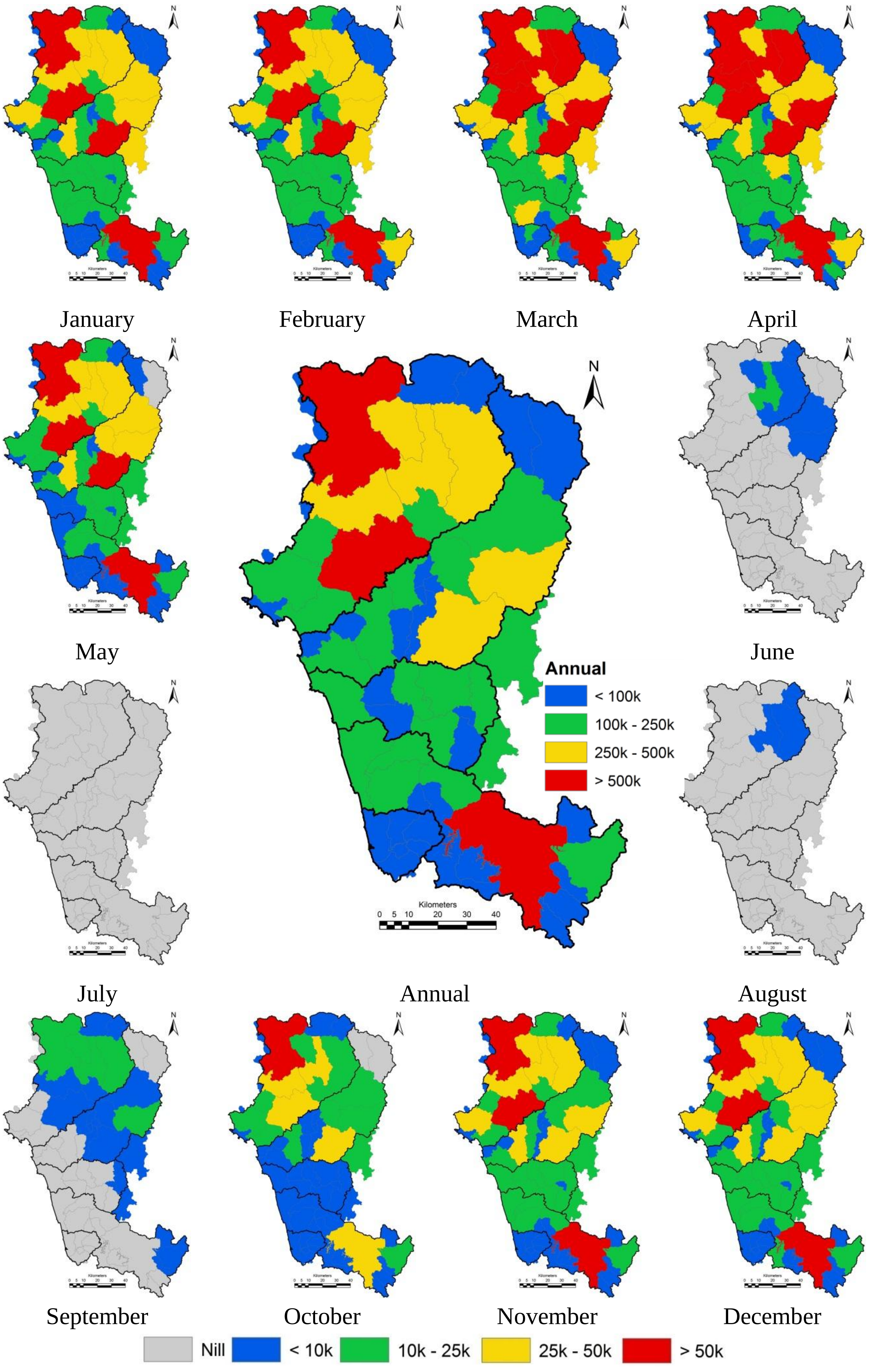


Figure 29: Water Demand (Agriculture, Domestic, Livestock & Evapotranspiration)

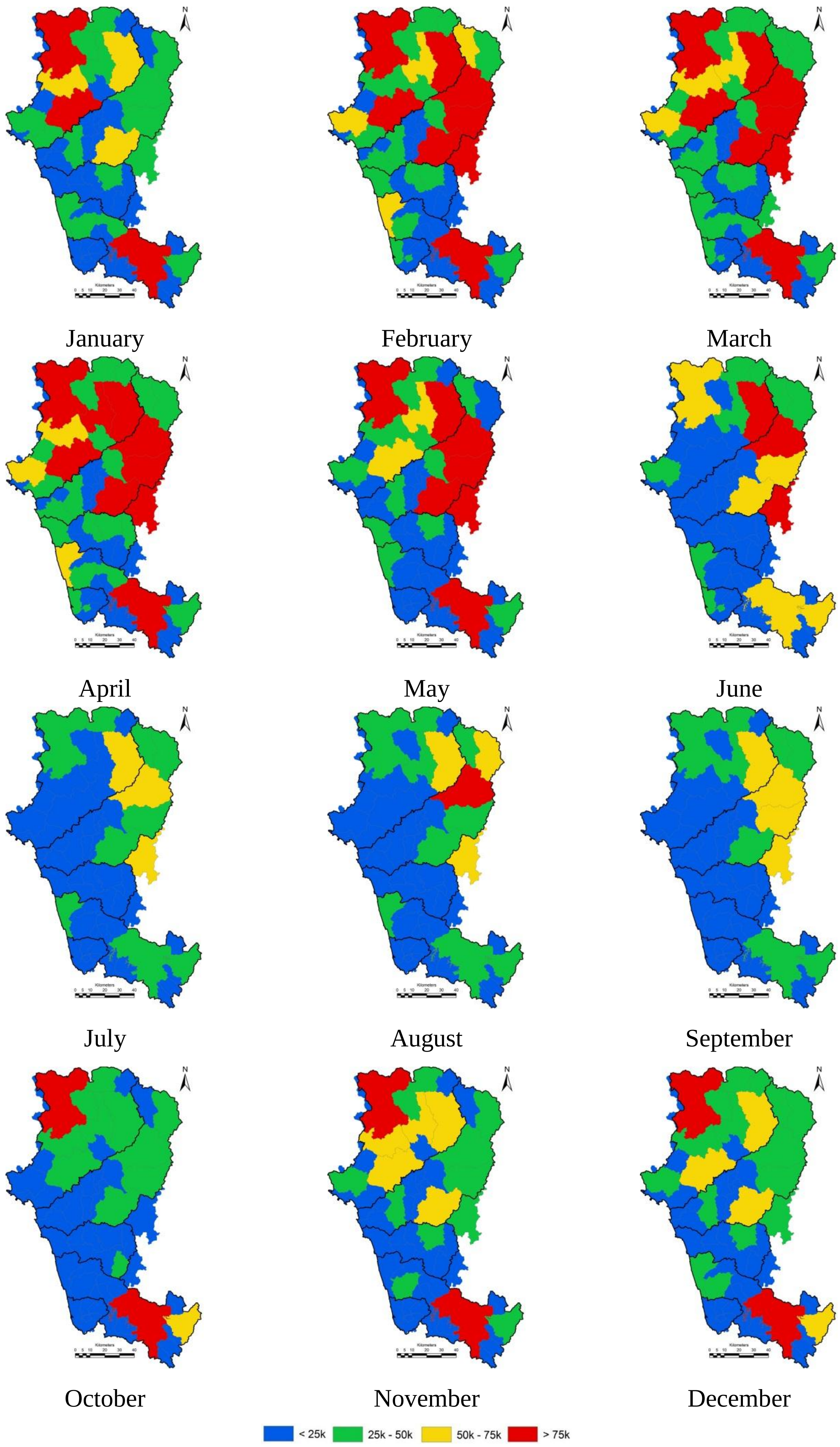
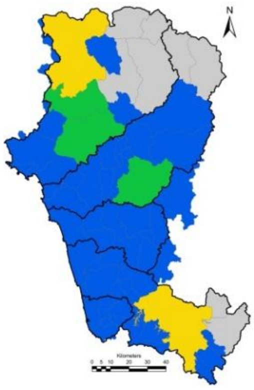
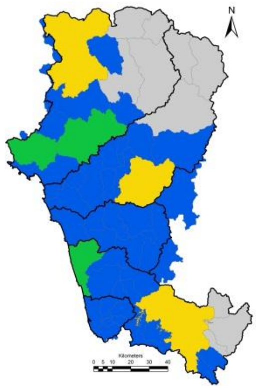


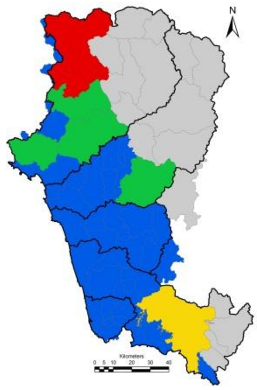
Figure 30: Water availability (in Million Litres)



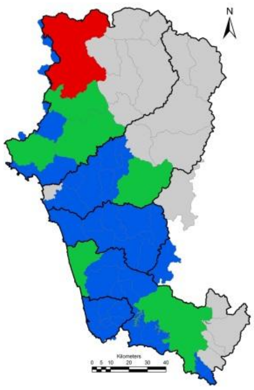
January



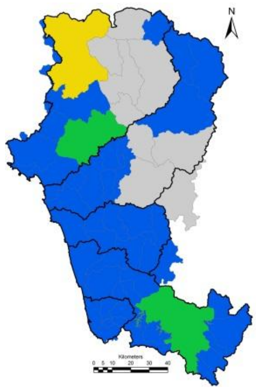
February



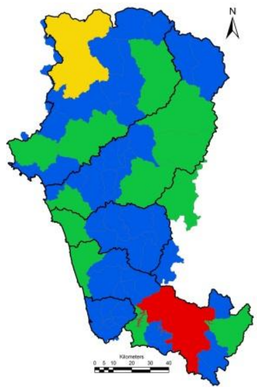
March



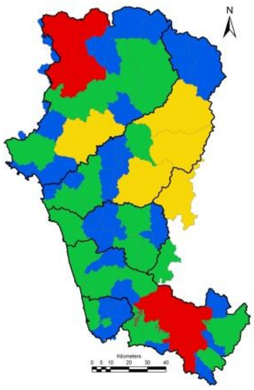
April



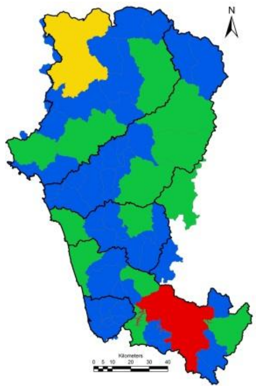
May



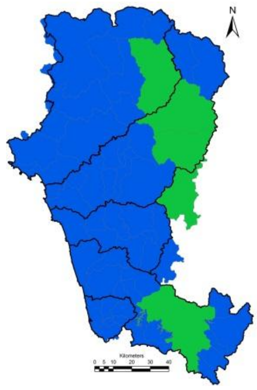
June



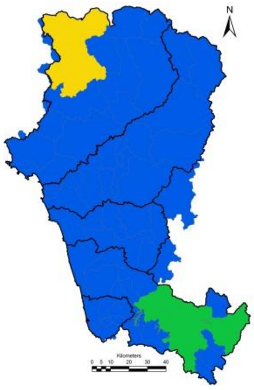
July



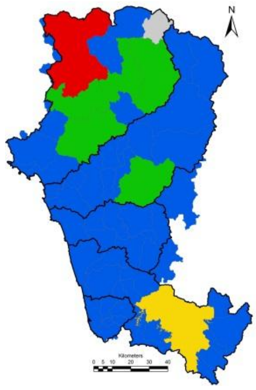
August



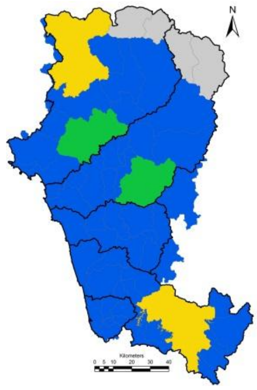
September



October



November



December

Nill | < 50k | 50k - 100k | 100k - 150k | > 150k

Figure 31: Hydrological Status (ratio of supply to demand)

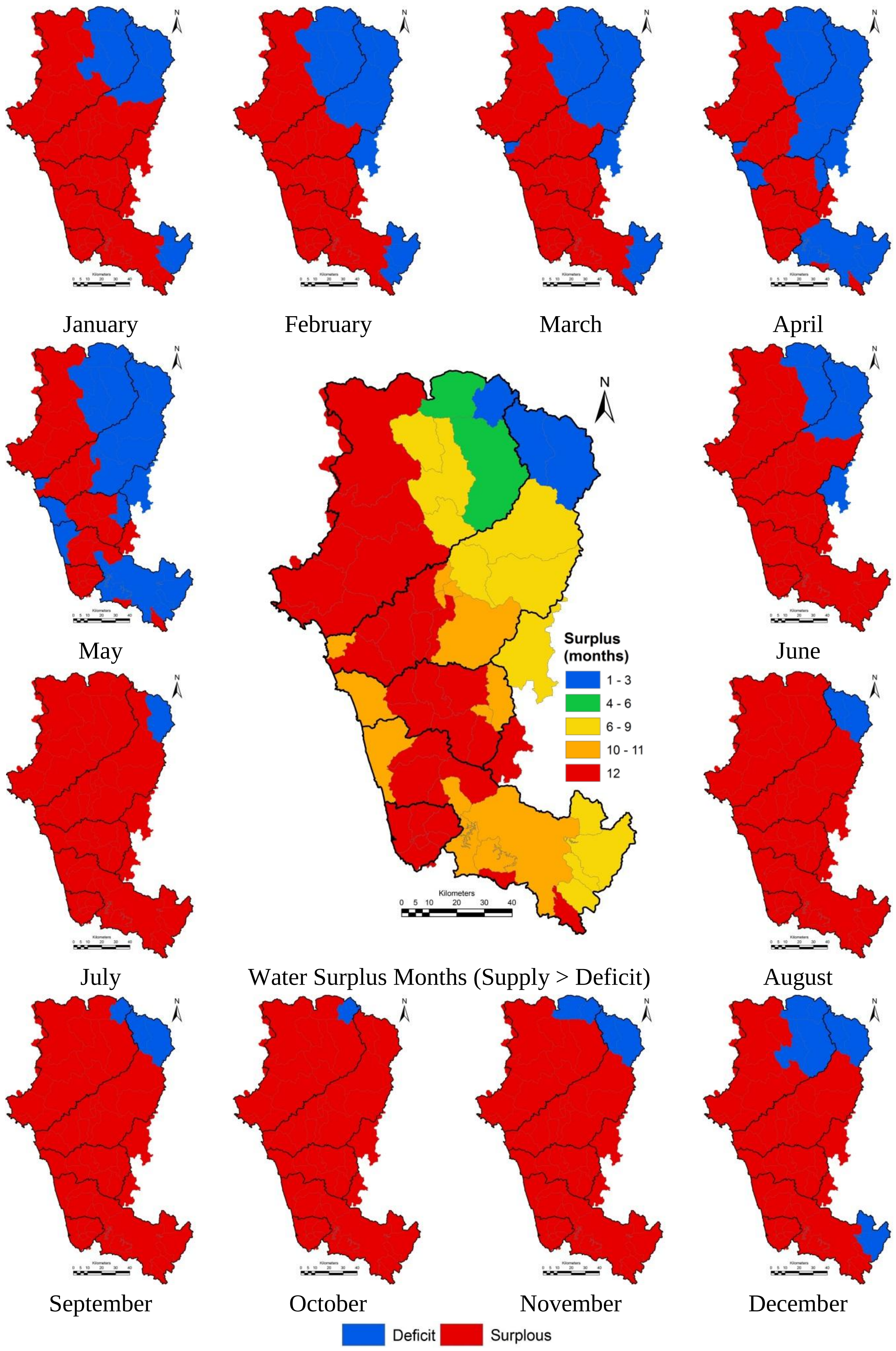
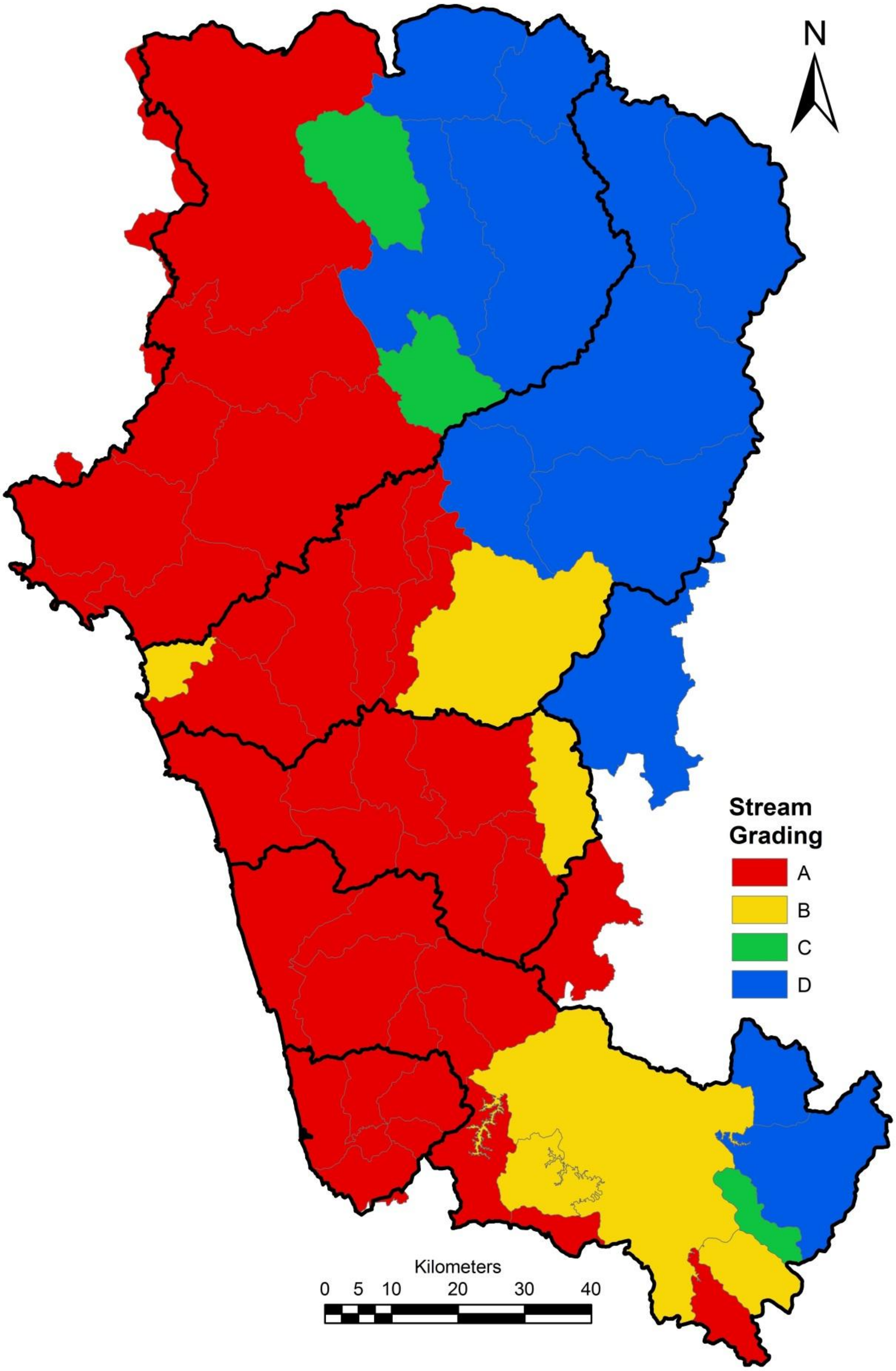


Figure 32: Stream Grading based on field measurements



Stream Grading	A	B	C	D
Flow Months	12	9	6	3

Figure 33: Gram Panchayat wise hydrologic status

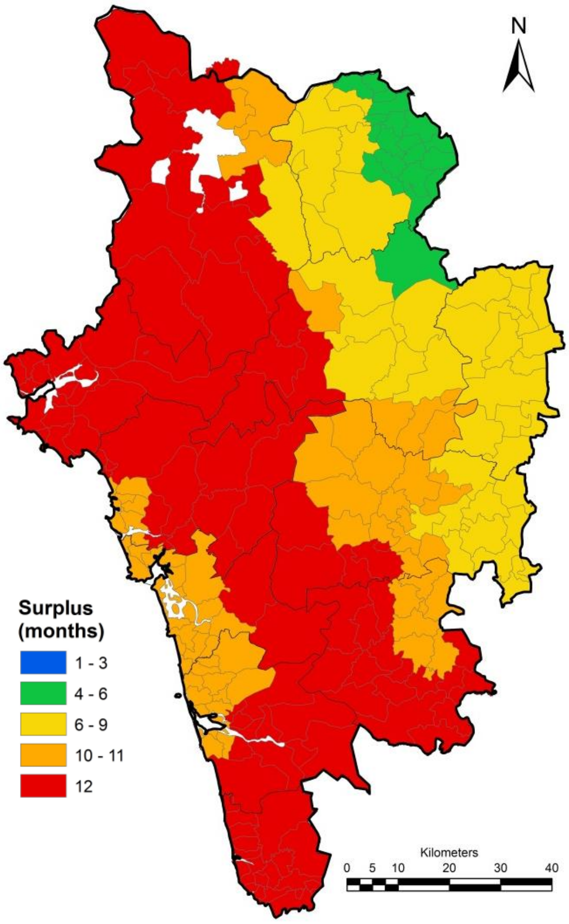


Table 13: Water supply(months) and forest area under each Gram Panchayat

Taluk	Gram Panchayat name	Gram Panchayat area in Hectares	Forest Area in Ha	% forest	Surplus months
Ankola	Harwada	605.87	128.72	21.25%	12
Ankola	Aversa	301.58	67.69	22.45%	12
Ankola	Belekeri	308.53	49.96	16.19%	12
Ankola	Hattikeri	21095.86	17219.88	81.63%	12
Ankola	Sunksal	14996.68	11690.31	77.95%	12
Ankola	Dongri	12756.13	10366.02	81.26%	12
Ankola	Achave	7639.13	6575.80	86.08%	12
Ankola	Mogta	6042.47	4617.36	76.42%	12
Ankola	Hillur	6484.69	5311.19	81.90%	12
Ankola	Agsur	10256.99	7168.81	69.89%	12
Ankola	Belse	2922.55	1186.21	40.59%	12
Ankola	Sagadgeri	1115.10	231.52	20.76%	12
Yellapur	Dehalli	5573.13	4875.16	87.48%	12

Yellapur	Mavinamane	10756.60	9145.16	85.02%	12
Yellapur	Idgundi	9754.23	6926.67	71.01%	12
Yellapur	Vajralli	8121.10	6466.25	79.62%	12
Karwar	Arga	618.54	284.89	46.06%	12
Karwar	Kadwad	601.08	390.75	65.01%	12
Karwar	Kinnar	794.25	385.44	48.53%	12
Karwar	Majali	1340.38	297.77	22.22%	12
Karwar		25.00	13.86	55.45%	12
Karwar	Gotegali	12673.15	10385.56	81.95%	12
Karwar	Kadra	8428.13	6157.95	73.06%	12
Karwar	Mallapur	14342.36	10579.09	73.76%	12
Karwar	Devalmakki	9390.69	7685.40	81.84%	12
Karwar	Kerwadi	1018.86	577.98	56.73%	12
Karwar	Ghadsai	1382.97	396.87	28.70%	12
Karwar	Hankon	4865.84	3186.50	65.49%	12
Karwar	Wailwada	1298.49	827.50	63.73%	12
Karwar	Amdalli	3624.59	2538.58	70.04%	12
Karwar	Shirwad	2117.15	1647.80	77.83%	12
Karwar	Asnoti	1268.45	526.40	41.50%	12
Karwar	Chitakula	899.42	197.67	21.98%	12
Karwar	Mudgeri	1546.39	648.10	41.91%	12
Karwar	Chendiye	2403.43	1591.27	66.21%	12
Karwar		2982.74	1433.74	48.07%	12
Supa	Ramanagar	2017.08	689.15	34.17%	12
Supa	Kalambuli	2574.48	2192.74	85.17%	12
Supa	Asu	9777.73	7880.19	80.59%	12
Supa	Bazarkunang	18218.55	14510.72	79.65%	12
Supa	Samjoida	13786.03	10016.68	72.66%	12
Supa	Kateli	18739.19	16468.35	87.88%	12
Supa	Joida	11026.22	9185.85	83.31%	12
Supa	Anshi	19799.60	18698.45	94.44%	12
Supa	Ulvi	22399.61	19451.51	86.84%	12
Supa	Nandigadde	9060.89	7753.27	85.57%	12
Supa	Akheti	17058.05	12315.37	72.20%	12

Kumta	Santeguli	15016.68	10321.47	68.73%	12
Kumta	Alkod	12862.25	10603.30	82.44%	12
Honnavar	Nagarabastikeri	10332.49	7381.34	71.44%	12
Honnavar	Kudrige	1717.56	1086.38	63.25%	12
Honnavar	Hadinbal	694.09	78.13	11.26%	12
Honnavar	Kharwa	999.12	200.82	20.10%	12
Honnavar	Balkur	1596.98	657.46	41.17%	12
Honnavar	Jalavalli	1149.91	288.68	25.10%	12
Honnavar	Herangadi	1778.16	946.68	53.24%	12
Honnavar	Chikkankod	8090.55	5867.93	72.53%	12
Honnavar	Upponi	8884.66	6585.52	74.12%	12
Honnavar	Kodani	4622.36	3031.94	65.59%	12
Honnavar	Manki	10544.40	6529.62	61.93%	12
Bhatkal	Bailur	946.81	176.97	18.69%	12
Bhatkal	Mavalli	1619.29	407.31	25.15%	12
Bhatkal	Kaikini	1440.34	547.83	38.03%	12
Bhatkal	Bengre	1364.96	394.35	28.89%	12
Bhatkal	Shirali	924.92	72.73	7.86%	12
Bhatkal	Heble	777.93	67.15	8.63%	12
Bhatkal		620.99	55.00	8.86%	12
Bhatkal	Koppa	9464.25	7456.50	78.79%	12
Bhatkal	Joli	1388.02	168.42	12.13%	12
Bhatkal	Mavinkurve	383.87	39.97	10.41%	12
Bhatkal	Mundalli	477.79	41.59	8.70%	12
Bhatkal	Marukeri	1536.73	691.76	45.01%	12
Bhatkal	Muttalli	1283.06	270.67	21.10%	12
Bhatkal	Hadvalli	6751.42	5287.88	78.32%	12
Bhatkal	Konar	1964.10	1154.16	58.76%	12
Bhatkal	Yelavadikavoor	1240.04	358.62	28.92%	12
Bhatkal	Belke	2668.32	1236.61	46.34%	12
Siddapur	Analebail	3884.75	2161.15	55.63%	12
Siddapur	Heggarni	3249.17	1884.81	58.01%	12
Siddapur	Sovinkoppa	3266.47	1698.84	52.01%	12
Siddapur	Kyadgi	3102.56	1844.03	59.44%	12

Siddapur	Dodmane	6413.47	4834.48	75.38%	12
Siddapur	Nilkunda	9195.44	6213.67	67.57%	12
Siddapur	Kangod	3151.43	1500.26	47.61%	12
Siddapur		1778.00	542.42	30.51%	12
Siddapur	Bedkani	2300.49	791.67	34.41%	12
Siddapur	Bilgi	1426.23	768.90	53.91%	12
Siddapur	Itagi	2968.70	1633.49	55.02%	12
Siddapur	Wajagod	5277.37	3488.41	66.10%	12
Siddapur	Halgeri	9074.57	5329.01	58.72%	12
Siddapur	Kavanchur	2948.15	745.77	25.30%	12
Siddapur	Shiralgi	2934.32	900.23	30.68%	12
Siddapur	Manmane	4556.14	1834.49	40.26%	12
Sirsi	Devanalli	11734.42	9426.64	80.33%	12
Sirsi	Neggu	4618.71	2400.50	51.97%	12
Sirsi	Janmane	3762.24	1980.85	52.65%	12
Sirsi	Bandal	12904.58	11316.21	87.69%	12
Ankola	Agragone	666.12	136.55	20.50%	11
Ankola	Shetgeri	1358.22	161.85	11.92%	11
Supa	Aveda	6692.99	4247.23	63.46%	11
Kumta	Kujalli	931.71	281.65	30.23%	11
Kumta	Kalbhag	583.10	26.37	4.52%	11
Kumta	Devgiri	835.37	94.51	11.31%	11
Kumta	Valgalli	1422.37	175.80	12.36%	11
Kumta	Mur00r	2741.52	1458.77	53.21%	11
Kumta	Mirjan	7409.42	4837.72	65.29%	11
Kumta	Nadumaskeri	647.32	140.24	21.66%	11
Honnavar	Salkod	4260.24	2829.05	66.41%	11
Honnavar	Haldipur	1147.79	109.01	9.50%	11
Honnavar		611.53	70.75	11.57%	11
Honnavar	Hosakuli	624.70	135.11	21.63%	11
Honnavar	Chandavar	5752.90	3895.45	67.71%	11
Honnavar	Kadtoka	791.17	182.19	23.03%	11
Honnavar	Kelginoor	1602.38	278.77	17.40%	11
Honnavar	Kasarkod	515.43	35.65	6.92%	11

Honnavar	Navilgone	962.74	229.00	23.79%	11
Honnavar	Kadle	1853.74	536.39	28.94%	11
Honnavar	Karki	1532.26	114.77	7.49%	11
Honnavar	Mugwa	1111.49	114.23	10.28%	11
Honnavar	Mavinkurve	458.87	17.82	3.88%	11
Honnavar	Melin-idgunji	1096.59	343.76	31.35%	11
Siddapur	Hasargod	3107.54	1857.80	59.78%	11
Siddapur	Harshikatta	3559.60	1814.41	50.97%	11
Siddapur	Kolsirsi	3141.23	1168.29	37.19%	11
Siddapur	Bidarkan	4069.91	1880.93	46.22%	11
Sirsi	Kodnagadden	7485.24	6080.72	81.24%	11
Sirsi	Vanalli	9434.85	7381.61	78.24%	11
Sirsi	Kanagod	2057.68	1026.43	49.88%	11
Sirsi	Shivalli	4281.13	1793.35	41.89%	11
Sirsi	Yedalli	2092.09	1002.67	47.93%	11
Ankola	Belember	1047.07	237.37	22.67%	10
Yellapur	Angod	7380.59	5148.81	69.76%	10
Supa	Jagalbet	2980.64	2416.16	81.06%	10
Kumta		1563.05	178.14	11.40%	10
Kumta	Gokarn	1645.55	342.32	20.80%	10
Kumta	Holanagadde	903.75	51.13	5.66%	10
Kumta	Divgi	2214.12	564.39	25.49%	10
Kumta	Bargi	1341.22	191.73	14.30%	10
Kumta	Kodkani	521.10	19.26	3.70%	10
Kumta	Kagal	746.26	98.93	13.26%	10
Kumta	Baad	268.03	36.73	13.70%	10
Kumta	Hiregutti	1465.31	306.05	20.89%	10
Kumta	Hegde	957.54	47.98	5.01%	10
Gonehalli	Torke	916.45	87.04	9.50%	10
Bankikodla	Hanehalli	867.96	138.98	16.01%	10
Siddapur	Tyagali	3753.37	2365.12	63.01%	10
Siddapur	Tarehalli-kansu	3470.47	1976.98	56.97%	10
Sirsi	Hulekal	7325.23	4259.65	58.15%	10
Sirsi	Bhairumbe	5801.68	2296.17	39.58%	10

Sirsi	Itguli	2710.91	828.13	30.55%	10
Sirsi	Kulve	2590.18	1355.88	52.35%	10
Sirsi	Hunsekoppa	2260.53	879.53	38.91%	10
Sirsi	Hutgar	1019.78	345.02	33.83%	10
Sirsi	Salkani	9091.42	5057.62	55.63%	10
Ankola	Bhavikeri	440.84	34.21	7.76%	9
Ankola		560.98	62.02	11.06%	9
Ankola	Algeri	2006.46	541.25	26.98%	9
Ankola	Vandige	1259.02	133.13	10.57%	9
Ankola	Bobruwada	395.68	36.82	9.30%	9
Yellapur	Hitlalli	5323.27	3530.17	66.32%	9
Yellapur	Shigemaneummach	5153.60	2483.85	48.20%	9
Yellapur	Kundargi	6691.84	2616.80	39.10%	9
Supa	Shingargaon	9509.44	8334.32	87.64%	9
Sirsi	Isloor	3693.94	1723.32	46.65%	9
Yellapur		7236.92	1893.81	26.17%	8
Yellapur	Kannigeri	13191.66	6993.56	53.01%	8
Yellapur	Nandolli	12797.34	7481.07	58.46%	8
Yellapur	Kampli	5735.73	2322.00	40.48%	8
Yellapur	Hasangi	10199.13	2229.92	21.86%	8
Supa	Pradhani	14772.88	11456.99	77.55%	8
Haliyal		1019.21	490.94	48.17%	8
Sirsi		2509.88	648.46	25.84%	8
Sirsi	Bisalkoppa	6806.57	3329.35	48.91%	8
Mundgod	Salgaon	3652.01	1434.91	39.29%	8
Mundgod	Chigalli	2281.96	495.62	21.72%	8
Mundgod	Katur	10919.96	1970.32	18.04%	8
Mundgod	Bedsgaon	7042.36	3239.79	46.00%	8
Mundgod	Kodambi	2918.20	608.59	20.85%	8
Haliyal	Yedoga	7122.18	3768.71	52.92%	7
Haliyal	Alur	13076.93	8750.36	66.91%	7
Haliyal	Abikanagar	5202.10	2892.06	55.59%	7
Sirsi	Badanagod	3935.81	152.57	3.88%	7
Sirsi	Andgi	2648.37	104.06	3.93%	7

Sirsi	Bankanal	3803.41	1100.42	28.93%	7
Sirsi	Doddanalli	3024.75	1060.10	35.05%	7
Sirsi	Bhasi	3035.69	879.44	28.97%	7
Sirsi	Banavasi	953.61	123.59	12.96%	7
Sirsi	Sugavi	5411.25	994.75	18.38%	7
Sirsi	Unchalli	3653.44	1027.87	28.13%	7
Sirsi	Gudnapur	3523.52	361.68	10.26%	7
Mundgod	Hungunda	2395.54	151.67	6.33%	7
Mundgod	Nandikatta	6407.15	650.98	10.16%	7
Mundgod	Bachanki	3868.37	917.42	23.72%	7
Mundgod		1216.88	164.37	13.51%	7
Mundgod	Indoor	1921.44	101.90	5.30%	7
Mundgod	Gunjavati	12133.68	543.96	4.48%	7
Mundgod	Chavadalli	4831.44	525.41	10.87%	7
Mundgod	Pala	3083.38	617.95	20.04%	7
Mundgod	Malgi	4865.24	773.31	15.89%	7
Yellapur	Madnur	10300.71	678.71	6.59%	6
Haliyal	Mangalwad	2617.46	1069.10	40.84%	6
Haliyal	Kesrolli	5098.29	1681.91	32.99%	6
Haliyal	Bhagwati	19189.19	4626.27	24.11%	6
Yellapur	Kirwatti	12867.23	1324.74	10.30%	5
Haliyal	Tergaon	852.99	7.74	0.91%	5
Haliyal		710.40	38.80	5.46%	5
Haliyal	Madnalli	1407.32	54.19	3.85%	5
Haliyal	Arlwad	2165.10	521.54	24.09%	5
Haliyal	Havgi	2373.78	410.82	17.31%	5
Haliyal	Tatwani	2696.16	413.97	15.35%	5
Haliyal	Belwatgi	2391.95	757.92	31.69%	5
Haliyal	Nagshettikoppa	2674.21	279.67	10.46%	5
Haliyal	Buzruk kanchana	2150.39	86.23	4.01%	5
Haliyal	Murkwad	1204.34	64.00	5.31%	5
Haliyal	Kawalwad	1792.02	185.52	10.35%	5
Haliyal	Jamge	2709.78	49.42	1.82%	5
Haliyal	Gundolli	2003.24	107.48	5.37%	5
Haliyal	Sambrani	5118.61	370.95	7.25%	5
Haliyal	Chibbalgeri	1952.82	196.41	10.06%	5

4.5: Relationship between flow regime and the parameters affecting the flow

Step wise multiple regression analysis was carried out to find the probable relationship between various parameters that would contribute to the flow of water in the rivers (Table 14).

Flow regime Fl = f(Rainfall, Runoff, Slope, land use, base flow, pipe flow, etc) … 21

The flow regime is a physical phenomenon that is dependent upon basic aspects such as the slope, land use, drainage density, and rainfall; and derived aspects such as runoff, pipe flow, Pipe Flow, forest cover and type of forest such as interior forests, perforated forests, patch forests, edge forests, and transitional forests

Table 14: Probable relationship between flow regime and environmental variables

Dependent Variable	**Independent Variable**	**Equation**	**R^2**	**Eq.**
Flow Regime	Forest	$Fl = 27.535*F^3 - 59.075*F^2 + 43.256*F + 0.8118$	0.75	22
Flow Regime	Slope	$Fl = -308.17*S^2 + 135.91*S - 2.9707$	0.674	23
Flow Regime	Rainfall	$Fl = 2*10-5*Pnet^3 - 0.0057*Pnet^2 + 0.4319*Pnet + 0.6367$	0.844	24
Flow Regime	Drainage Density	$Fl = 4*10^{-5}*Dd^2 + 0.0303*Dd + 8.4879$	0.074	25
Flow Regime	Agriculture and Horticulture	$Fl = 3*10^{-5}*AH^3 - 0.0046*AH^2 + 0.0956*AH + 10.985$	0.666	26
Flow Regime	Runoff	$Fl = -0.0015*R2 + 0.1663*R + 7.0053$	0.199	27
Flow Regime	Perforated Forest	$Fl = -1852.8*Pef^2 + 243.68*Pef + 3.0594$	0.203	28
Flow Regime	Patch Forest	$Fl = -43385*Pa^2 + 533.61*Pa + 8.6308$	0.012	29
Flow Regime	Interior forest	$Fl = 31.697*If^3 - 65.008*If^2 + 45.283*If + 0.8906$	0.725	30
Flow Regime	Transitional forest	$Fl = -24377*Tf^2 + 914.06*Tf + 2.9516$	0.445	31
Flow Regime	Elevation	$Fl = 9*10^{-9}*E^3 – 4*10^{-5}*E^2 + 0.0156*E + 10.458$	0.348	32
Flow Regime	Interior forest, Perforated forest	$Fl = 9.33*If + 53.26*Pef + 2.71$	0.669	33
Flow Regime	Interior forest, Perforated forest, Transitional Forest, Patch forest	$Fl = 10.99*If + 51.38*Pef -77.63*Tf+228.305*Paf + 1.96$	0.678	34
Flow Regime	Interior forest, Perforated forest, Patch forest	$Fl = 10.33 * If + 25.90 *Pef + 260.38*Paf + 2.33$	0.674	35
Flow Regime	Forest, Forest Plantation, Agriculture Plantation, Agriculture	$Fl = -0.576 * F -10.583 * FP + 6.314 *AP -12.227 * A + 13.63$	0.805	36
Flow Regime	Interior forest, Perforated forest, Patch forest, Slope	$Fl = 7.186*If + 28.011*Pef + 179.412*Paf + 14.201*S + 1.808$	0.698	37
Flow Regime	Rainfall, Runoff, Vadose, Pipe Flow,	$Fl = 0.0005*Pnet + 0.0004*R + 0.0006*V - 0.024*Pf - 0.021*Gwd + 2.214$	0.803	38

	Ground water discharge			
Flow Regime	Runoff, Baseflow, Ground water discharge	Fl = 0.0028*R + 0.0032*Pf + 0.0257*Gwd + 4.581	0.665	39
Flow Regime	Runoff, Vadose	Fl = 0.0022 * R + 0.0038 * V + 2.821	0.742	40
Flow Regime	Runoff, Ground Water discharge, Interior forest, Perforated Forest, Patch Forest	Fl = 0.0037 * R + 0.0092 * Gwd + 8.081*If + 18.865 * Pef + 12.9112 * Paf - 3.147*S + 1.836	0.803	41
Flow Regime	Runoff, Ground Water discharge, Interior forest, Perforated Forest	**Fl = 0.0034 * R + 0.0086 * Gwd + 7.571 * If + 20.092 *Pef + 1.740**	**0.802**	**42**
Flow Regime	Rainfall, Interior forest, Perforated forest, Slope	Fl = 0.00166 * Pnet + 6.627 * If + 2.035 * Pef -1.4 * S + 1.58	0.812	43
Flow Regime	Rainfall, Interior forest, Perforated forest	Fl = 0.00162 * Pnet + 6.404 * If + 22 * Pef + 1.542	0.812	44

Fl: Flow regime in months; Pnet: Net Rainfall in mm; **R : Runoff in mm**; V : Vadose in mm; Pf: Pipe flow in mm; Gwd: Ground water discharge in mm; S: Slope as percentage; E: Elevation in meters; Dd: Drainage density as per meter; AH: Combined Agriculture and Horticulture as percentage; FP: Forest plantation as percentage; AP: Agriculture plantation as percentage; F: Total forest as percentage; **If: Interior forest as percentage**; Pef: Perforated forest as percentage; Paf: Patch forest as percentage; Ef: Edge forest as percentage; Tf: Transition forest as percentage;

The significance value for all the above relationships were less than 0.05, indicating good confidence level of 95 % of the relationships. The relation between runoff, ground water discharge, interior forest and perforated forest provides significant results with coefficient of determination as **0.802**. i.e.,

$$Fl = 0.0034 * R + 0.0086 * Gwd + 7.571 * If + 20.092 * Pef + 1.740 \quad \ldots..42$$

The equation indicates that the presence of interior forest has higher importance over the flow regime, as forests hold higher water in vadose and ground water zones and releases water during lean season to streams as pipe flow or base flow.

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6.0: Silt Yield in Uttara Kannada District

6.1 Summary:

Soil erosion is the result of complex processes involving alteration of landscape structure due to denudation and transportation of surface soils, the process of frosting and thawing action of rocks, which is controlled by climatic, topographic, geologic, geomorphic, and land use characteristics. Anthropogenic activities leading to deforestation and agricultural intensification influence the rate of erosion and sedimentation. This section quantifies the silt yield based on land use of sub –basin and suggest measures to regulate unsustainable extraction of sand in this region.

Keywords: Silt yield, sedimentation

6.2 Introduction:

Soil erosion is a major environmental problem worldwide (Guobin et al 2006) where the sediment is detached from the soil surface both by raindrop impact and by the shearing force of flowing water (Manoj and Kothyari, 2001) and a major hazard threatening the productivity of agriculture (Julien and Simons 1985). Soil erosion is the result of complex processes of land denudation (CS/AR-22/1999-2000 NIH Roorkee; Bishop et al, 2002) involving the process of frosting and thawing action of rocks, denudation and transportation of surface soils, which is controlled by climatic, topographic, geologic, geomorphic, and land use characteristics (Chanarmohan et al 2002). Anthropogenic activities such as deforestation, urbanization and agricultural intensification influence the rate of erosion and sedimentation (Rabin and Dushmanta 2005). Climatic factors that affect the process of erosion include precipitation, temperature and wind (CS/AR-22/1999-2000 NIH Roorkee). Removal of vegetation cover and high intensity rainfall in Sharavathi river catchment has contributed to the transportation of silt corresponding to top layer of soil in the upstream (Ramachandra et al., 2007). Removal of top productive layer of soil has led to the reduction in soil productivity. This forced the farmers to switch over to inorganic fertilisers and pesticides. Consumption of fertilizer and pesticide is prevalent in the eastern part compared to other parts. This has contributed to pollution of water in the streams (Ramachandra et al., 2007). Based on the intensity of rainfall in the catchment associated with the land use and the soil characteristics, the exposed surface soil and weathered rock particles is carried along the water bodies and deposited along the stream/river beds, along the estuaries Varying temperatures causes the effect of expansion and shrinkage of rock surfaces, evaporation and transpiration, in the process the combined surface particles isolates.

The soil particles that get transported through water get deposited in the bed and banks of dams, rivers, streams, canals, estuaries, and so on. Common types of water erosion are Ril and Interrill erosion (Fernandez et al 2003).Winds changes the velocity and angle of impact of raindrops, in the absence of rain, the winds carry the dust particles and displace to other locations.

The sediment deposition is a major problem that determines the reservoir life. It results in storage capacity losses, damage to valves and conduits and changes in water quality. The problem of sedimentation is taken care by providing sufficient dead storage. The rate of sedimentation is largely determined by the watershed characteristics. The amount of silt deposited in Linganamakki reservoir is estimated to be 130.08 Mm^3 in the last forty years of reservoir operation. This estimation takes into account only the contribution from the Linganamakki catchment. Other contributions may be due to the destabilization of huge landmasses leading to slides, bank erosion of the reservoir due to turbulent motion of water within the reservoir (Ramachandra et al., 2007). The field observations made by the central water commission (2000) revealed that about 171.83 Mm^3 of silt is deposited over a period of 36 years. The total life of the reservoir is estimated to be 68 years. Sedimentation has reduced the reservoir active life and the estimates indicate the life of the reservoir is reduced by 32 years considering the present siltation rate in the catchment.. Thus undulating terrain of Western Ghats with numerous drainages are prone to soil erosion in the absence of vegetation cover and can be regarded as highly sensitive zones to any land-use changes. Conversion of forests to other types of land-uses has also reduced the water holding capacity of the soil, which is evident from the soil analysis. Reduction of reservoir life, decreased productivity and water holding capacity of soil are the consequences of improper land-use practices. This emphasizes the requirement of appropriate catchment treatment measures, which can increase the life of the reservoir (Ramachandra et al., 2007). The deposition of coarse sediments reduces the reservoir storage and channel conveyance for water supply, irrigation and navigation, and causes extensive damage to streams, while the suspended sediment reduces the water clarity and sunlight penetration thereby affecting the biotic/ aquatic ecosystem (Reetesh et al 2006, Zarris et al 2002). Sediments deposition in the streams/river beds and banks has caused widening of the flood plain during floods (Kothyari et al 2002).

Numerous studies have attempted to estimate/measure sedimentation rate in river basins in India (Kothyari et al 2002; Bishop et al 2002; Kothyari 2007; Vipin and Jayappa 2011, Aswathanarayana 2012) and across the globe (Walling and Webb 1996, Zarris et al 2002, Chao-

Yuan et al 2002, Bagherzadeh and Daneshva, 2010) aided by Remote Sensing and GIS technologies (Ramachandra et al., 2007). Topographic elevation data resulting from the process of remote sensing through sensors such as ASTER, SRTM (http://glovis.usgs.gov, www.usgs.gov), Cartosat (http://www.nrsc.gov.in, http://www.isro.org), defines the effect of gravity on the movement of water and sediments in a catchment, and play a considerable role in hydrologic simulation, soil-erosion and landscape-evolution modeling (Zhang et al 1993). For modeling of hydrological and soil erosion process, parameters such as slope, direction of slope i.e., aspect are derived from DEM (Zhang and Montgomery 1994, Montgomery and Foufoula 1993). Temporal change analysis of land use and land cover characteristics along with the elevation database plays an important role in deciding the quantity of hydrological discharge as runoff into streams and erosion of soils. Land use is derived from temporal remote sensing data considering the characteristics of different land use as the spectral signature.

The information upon the sediment yield at the mouth of the river basin and along the river course would provide information about the rate of soil erosion in the upstream of the watershed that can be associated with land use and its dynamics, and also for the assessment of rate soil erosion as to how fast soil is being eroded which would be helpful in planning conservation work, developing policies and prioritizing water sheds, controlling the de-silting activities from the rivers.

The process of removal of silt i.e., de-silting is necessary to mitigate the problems caused due to settling of sediments in the river basin as they tend to increase the flood plains during floods (Kothyari et al 2002), decrease the storage capacity of reservoirs, displacement of mouth of estuaries, causing meanders and oxbows etc. in turn affecting the regional ecosystem. Generally silt is extracted from the river beds which are used for construction purposes, but due to illegal sand mining activities (Figure 1), this resource is being over exploited, and exported outside the administration boundary or overseas by the sand mafia involving various profile of people by violating the laws paved down by the authorities that has been reported in various location along river coarse and near the coasts, in Karnataka, Andhra Pradesh, Maharashtra, Kerala and Tamilnadu respectively.

Figure 1: Sand Mining at Ulippu along Kumaradhara River, Dakshina kannada, date: 5/12/2013

Mining from, within or near a riverbed has a direct impact on the stream's physical characteristics, such as channel geometry, bed elevation, substratum composition and stability, in stream roughness of the bed, flow velocity, discharge capacity, sediment transportation capacity, turbidity, temperature, etc. Alteration or modification of the above attributes may cause hazardous impact on ecological equilibrium of riverine regime. This may also cause adverse impact on in stream biota and riparian habitats. This disturbance may also cause changes in channel configuration and flow-paths. The major hazards caused due to mining of sand/gravel include the following ***(***Geological Survey of India, http://www.portal.gsi.gov.in***)***:

i. ***Stream habitat***: Mining results in an increase of river gradient, suspended load, sediment transport, sediment deposition, turbidity, change in temperature, etc. Excessive sediment deposition for replenishment/ refilling of the pits affect turbidity, prevent the penetration of the light required for photosynthesis of micro and macro flora which in turn reduces food availability for aquatic fauna. Increase in river gradient may cause excessive erosion causing adverse effect on the biota in stream habitats.

ii. ***Riparian habitat:*** This includes vegetation cover on and adjacent to the river banks, which controls erosion, provide nutrient inputs into the stream and prevents intrusion of pollutant in the stream through runoff. Bank erosion and change of morphology of the river can destroy the riparian vegetation cover.

iii. ***Degradation of Land:*** Mining pits are responsible for river channel shifting as well as degradation of land, causing loss of properties and degradation of landscape.

iv. ***Lowering of groundwater table in the floodplain area:*** Mining may cause lowering of riverbed level as well as river water level resulting in lowering of groundwater table due to excessive extraction and draining out of groundwater from the adjacent areas. This may cause shortage of water for the vegetation and human settlements in the vicinity.

v. ***Depletion of groundwater:*** Excessive sand mining especially in abandoned channels generally result in depletion of groundwater resources causing severe scarcity, which affects irrigation and potable water availability. In extreme cases, it may also result in creation of ground fissures and land subsidence in adjacent areas.

vi. ***Polluting groundwater:*** In case the river is recharging the groundwater, excessive mining will reduce the thickness of the natural filter materials (sediments), infiltration through which the ground water is recharged. The pollutants due to mining, such as washing of mining materials, wastes disposal, diesel and vehicular oil lubricants and other human activities may pollute the ground water.

vii. ***Choking of filter materials for ingress of ground water from river:*** Dumping of final material, compaction of filter zone due to movement heavy machineries and vehicles for mining purposes may reduce the permeability and porosity of the filter material through which the groundwater is recharging, thus resulting in steady decrease of ground water resources. The riverbed mining may be allowed considering minimization of the above mentioned deleterious impacts. The guidelines of National Water Policy of India should also be followed which states that watershed management through extensive soil conservation, catchment area treatment, preservation of forest, increasing of forest cover and construction of check dams should be promoted. Efforts shall be made to conserve the water in the catchments.

Objectives: Objective of this study is to estimate the silt yield in river basins of Uttara Kannada district.

6.3 Method:

The estimation of sediments using the empirical equation is as depicted in figure 2. The DEM and topographic maps of 1: 50000 were used to delineate the sub basin, followed by estimation of slope and drainage density.

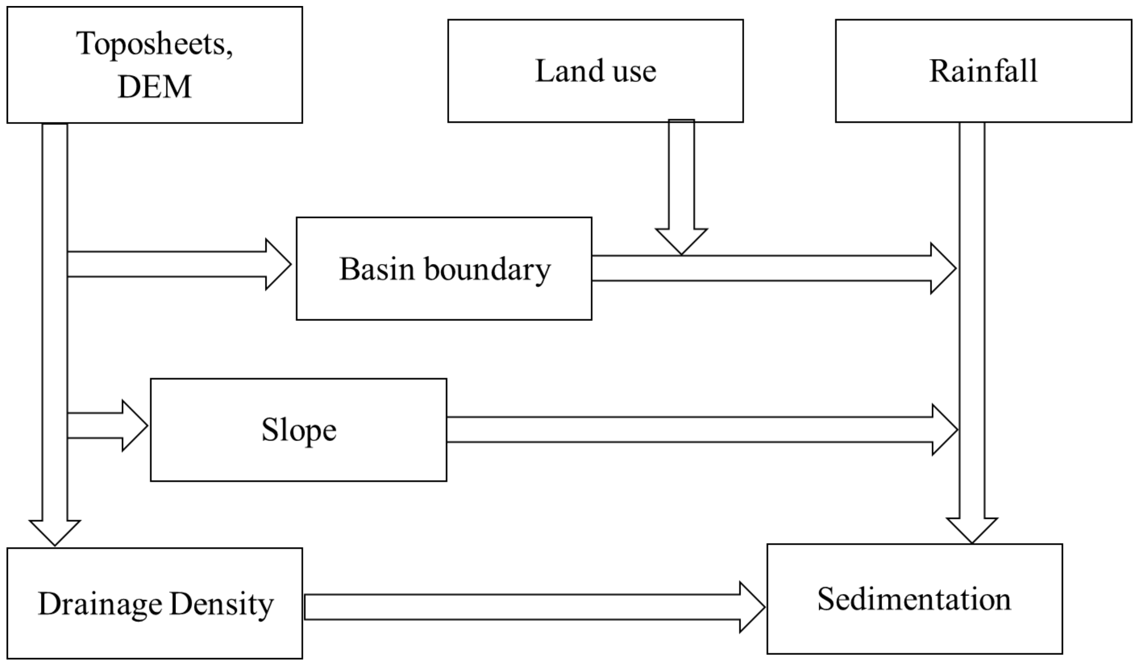

Figure 2: Method to quantify silt yield

Slope function of elevations of surrounding 8 pixels (as in figure 3) and is estimated using Horn's equation, as

A	B	C
D	E	F
G	H	I

Figure 3: Kernel for deriving slope

$$\text{Slope} = \left[\left(\frac{\delta z}{\delta x}\right)^2 + \left(\frac{\delta z}{\delta y}\right)^2\right]^{0.5} \qquad \text{........1}$$

Where

$\delta z/\delta x$: Slope along x axis = [(C + 2F + I) – (A + 2D + G)]/(8*Cell size) …… 2

$\delta z/\delta y$: Slope along y axis = [(G + 2H + I) – (A + 2B + C)]/(8*Cell size) ……. 3

The drainage density in every sub basin is estimated as the ratio of drainage length per hectare based on the drainages delineated from the Topographic maps and DEM.

The annual sedimentation in the rive brains is estimated using the following empirical formulae

1) Khoslas Equation
2) Dhruva and Narayan Babu's equation
3) Garde and Kothyaris equation
4) Average of all the three

Khoslas equation considers the total area under the river basin (A) and an erosion factor (K_e) to determine the annual rate of siltation (V_s).

$$V_s = K_e * A^{0.72} \qquad \ldots\ldots\ldots\ldots 4$$

Where, A is in sq.km

K_e = 0.00232

Dhruva Narayan and Babu used the data from 18 river basins in India, and obtained relation between annual sedimentation rate (V_s) and runoff in the river (R)

$$V_s = 14.25 * R^{0.84} \qquad \ldots\ldots\ldots\ldots 5$$

R is in Million Hectare meters or 10 Mega cubic meters.

Garde and Kothyari used the data from 50 small and large catchments of Indian rivers along with the hydro-meteorological, geological, physiographical, topographical characteristics to determine the sedimentation yield. The factors such rainfall (P), slope(S), drainage density (D_d), erosion factor (K_e) that is dependent upon the land use characteristics play an important role in determining the sedimentation (V_s).

$$V_s = 0.02 * P^{0.6} * K_e^{1.7} * S^{-0.25} * D_d * \left(\frac{P_{max}}{P}\right)^{0.19} \qquad \ldots\ldots\ldots\ldots\ldots 6$$

Where P is the average annual rainfall; P_{max} is the average maximum monthly rainfall.

6.4 Results:

Silt yield per hectare computed as discussed in Methods section (based on 4 scenarios) is depicted in figure 4. Quantification of silt yield based on equation 6 (Garde and Kothyari) indicated lower silt yield in the Sahyadri with good vegetation cover of thick forests, forest plantations, etc. The plains due to the higher lands under irrigation and are open lands, the silt yield is comparatively higher than that of other topographic regions. Figure 5 gives the total silt yield in each sub-basin of the district. Sand mining at Chandewadi forest area (Figure 6) upstream of Supa dam of Kali river basin, as per government records is 360 kilo cubic metres per annum, whereas the estimated silt yield at Chandewadi is about 228 kilo (table1) cubic metres indicating that quantity of sand mined is more than silt yield in the respective basin. Over exploitation of sand has led to loosening of top soil along the river banks. Reports indicate that around 1100 hectare of forest land of Chandewadi is under threat due to the mining activity, that would lead to instability in soil would affect the dam (Supa). The change in land use over time has led by conversion of forest to agriculture and horticulture fields have also led to increase in silt yield, as at Magod (Figure 6) of Gangavali river basin. The silt yield at Magod in 2001 was estimated as 830 kilo cubic meters per annum (Ramachandra et al, 2001), which has increased to 1536 kilo cubic metres per annum (table 1), in 2010 due to removal of vegetation cover/forests in Bedthi basin.

Table1: Silt yield using empherical equations

Silt Yeild in kilo cum/ annum	Chandewadi	Magod
Khoslas	249.2	1293.6
Dhruva Narayan and Babu	226.5	1014.5
Garde and Kotyari	209.7	2300.2
Average	228.4	1536.1

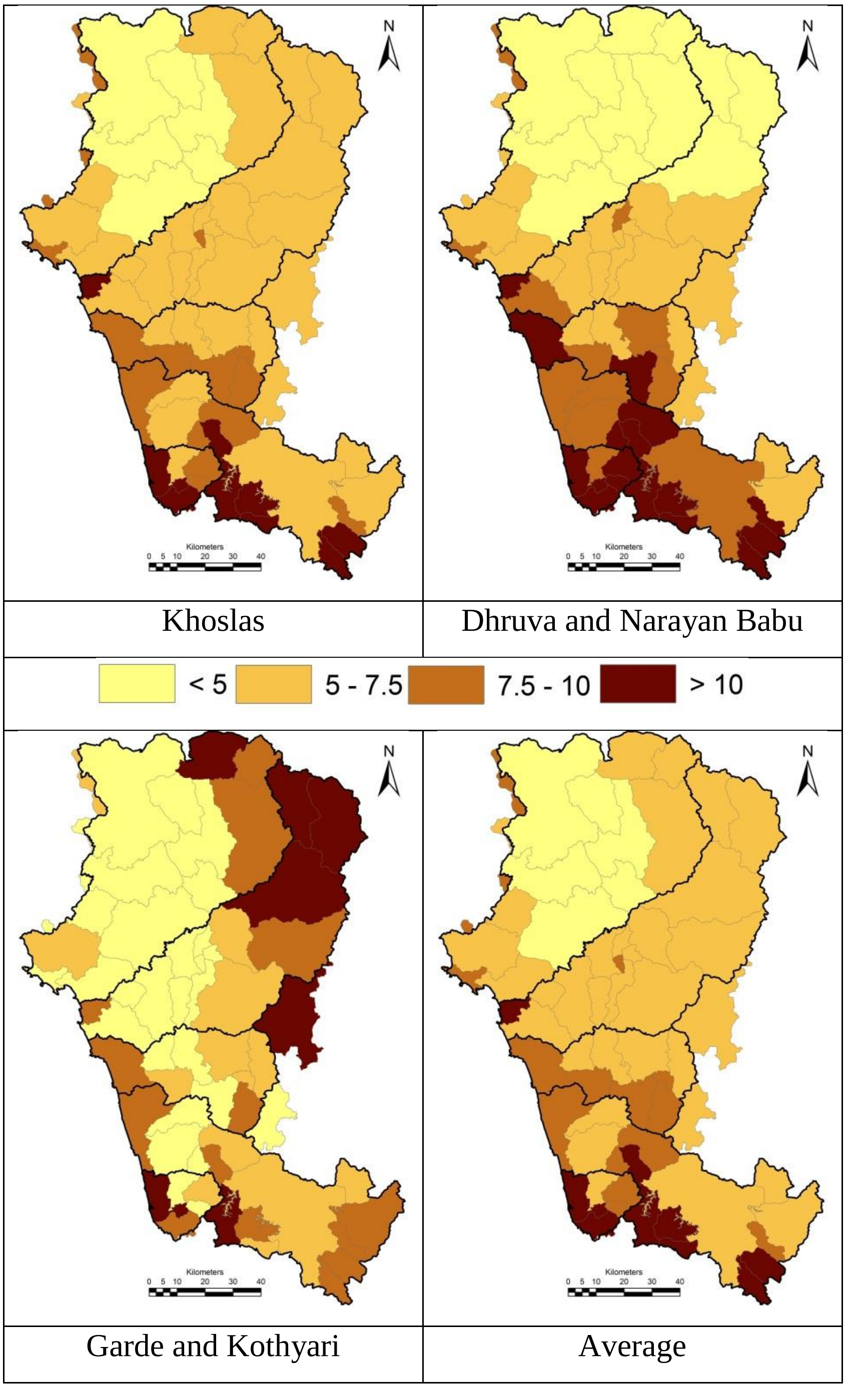

Figure 4: Silt Yeild in cubic metre per hectare per annum

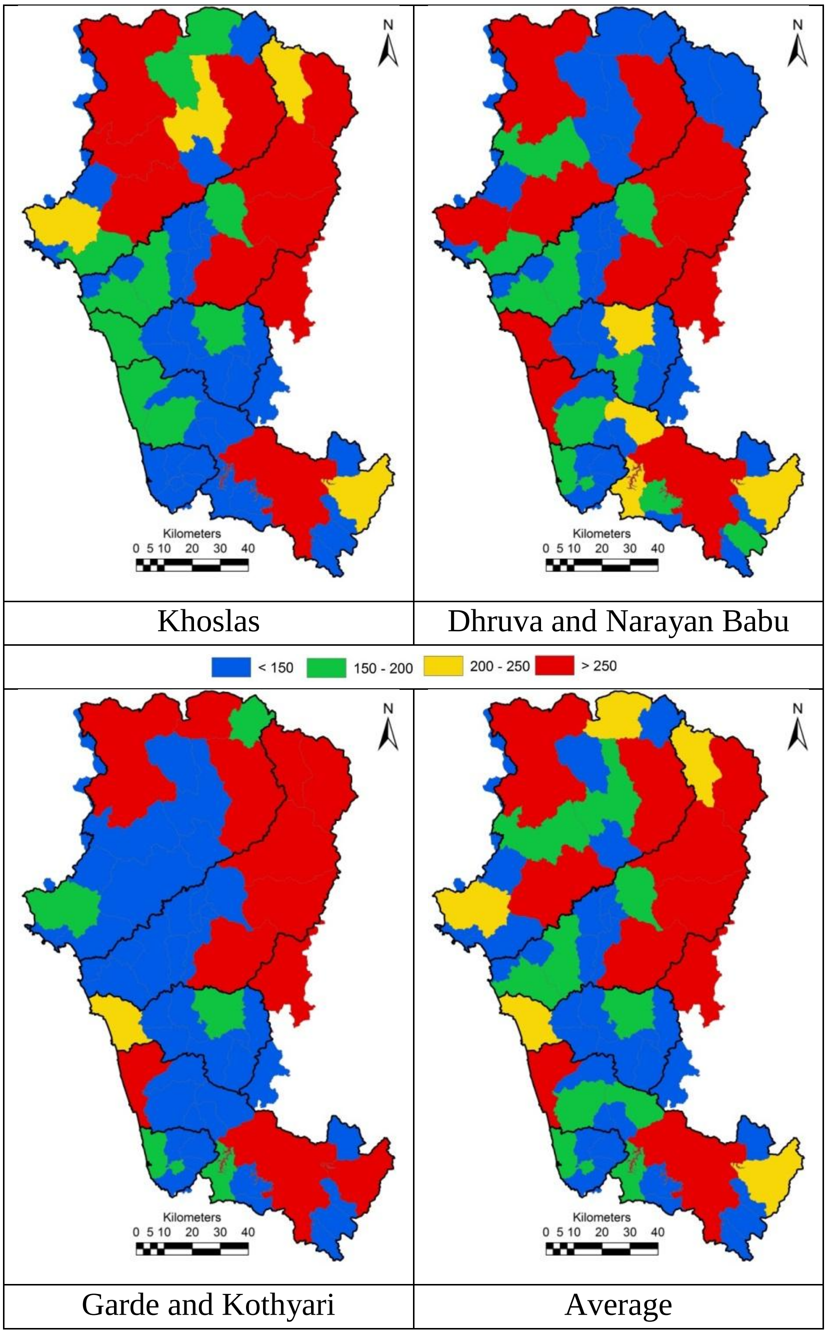

Figure 5: Sedimentation in kilo cubic meter per annum

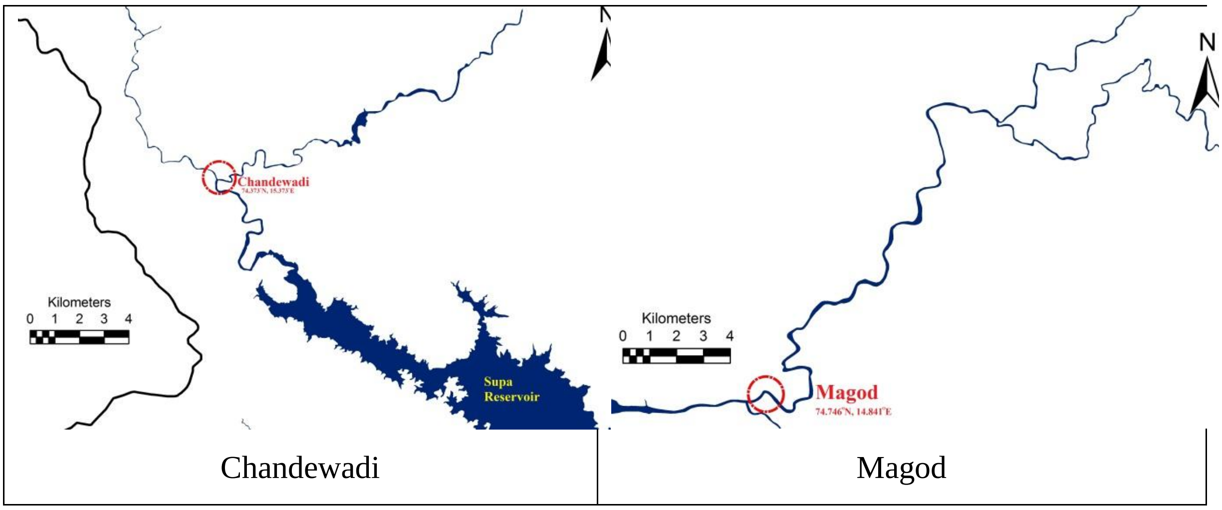

Figure 6: Locations where intense sand mining were reported

At the mouth of the river basins, the estimated silt yield is as in table 2. The sediment yield in basins such Gangavali, Sharavathi and Venkatapura, is very high with more than 6m^3/Ha/year, the annual silt yield is very high in Gangavlai river basin of 2500 x 10^3 m^3/year, Agnashini and Venkatapura are the lowest with less than 1000 x 10^3 m^3/year.

Table 2: Sedimentation at mouth of the river basins

River Basin	Area Ha	Annual Silt Yield	
		10^3 m^3	m^3/ha
Kali	508593	2345	4.61
Gangavali	393573	3056	7.76
Agnashini	144877	900	6.21
Sharavathi	304271	2180	7.16
Venkatapura	45969	360	7.83

Impacts of Sand Mining: Sand mining has an adverse and destructive impact, at the same time it has some positive impacts also, if the amount extracted is less than the quantity of silt yield per annum. Field assessment reveals that the removal of sand from the riverbeds has exceeded the natural replenishment, making it unsustainable.

Taking into consideration the places of occurrences of the adverse environmental impacts of river sand mining, Kitetu and Rowan (1997) classified the impacts broadly into two categories namely Offsite impacts and Onsite impacts. The offsite impacts are, primarily, transport related, whereas, the onsite impacts are generally channel related. The Onsite impacts are classified into Excavation impacts and water supply impacts. The impacts associated with excavation are channel bed lowering, migration of excavated pits and undermining of structures, bank collapse, caving, bank erosion and valley widening and channel instability. The impacts on water supply are reduced ground water recharge to local aquifers, reduction in storage of water for people and livestock especially during drought periods, contamination of water by oil, gasoline and conflicts between miners and local communities. The depletion of sand in the streambed of coastal region, which has caused deepening of rivers and estuaries, and the enlargement of river mouths and coastal inlets, leading to saline-water intrusion. Thus, sand mining results in the destruction of aquatic and riparian habitat through large changes in the channel morphology. Impacts include bed degradation, bed coarsening, lowered water tables near the streambed, and channel instability. In a recent study it is reported that sand mining from the Achankovil River over the past few decades has caused notable changes in the eco-biology of benthic communities (Sunil Kumar, 2002). It is well understood that mining changes the physical characteristics of the river basin, disturbs the closely linked flora and fauna, and alters the local hydrology, soil structure as well as the socioeconomic condition of the basin in general (UNEP 1990, Kundolf 1994a 1997, Padmalal 2001, Sunil Kumar 2002 and Padmalal et.al., 2003). Kundolf(1993) reported that sand mining in streams have resulted in channel degradation and erosion, head cutting, increased turbidity, stream bank erosion and sedimentation of riffle areas. All these changes adversely affect fish and other aquatic organisms either directly by damage to organisms or through habitat degradation or indirectly through disruption of food web. Effect of excessive sand and shell mining are evident from the reports of:

1) Weakening of Piers of the Konkan Railway bridge across Kali River (http://www.thehindu.com/todays-paper/tp-national/tp-karnataka/illegal-sand-mining-is-posing-a-threat-to-rail-bridge-across-kali/article4008219.ece)
2) At Tamilnadu, Karnataka , depletion of groundwater, lesser availability of water for industrial, agricultural and drinking purposes, destruction of agricultural land, loss of employment to farm workers, threat to livelihoods, human rights violations, and damage to roads and bridges (http://www.narmada.org/related.issues/kali/workshop/sand.mining.dossier.doc.).
3) This illegal sand mining is leading to a loss of revenue to the tune of at least Rs. 10 crores (www.narmada.com).
4) Endangered the estuary area: Sea erosion has intensified in Shiriya Kadappura area due to the sand mining and even the sea walls are being engulfed by the sea. (http://thecanaratimes.com/epaper/index.php/archives/10779).
5) Illegal sand mining has contaminated well waters and has turned them saline, contaminating agriculture fields. (http://thecanaratimes.com/epaper/index.php/archives/12628).
6) Coastal ecosystem is under threat losing its endemic fishes and breeding grounds, bivalves…etc.(Ramachandra et al ETR 48)

To overcome the excessive sand mining along the river basins polices are need to be maintained, framed, and revised to restore the balance and so on. Some of the polices on sand mining includes:

1) Sand mining policy of Tamilnadu
2) Sand mining policy of Kerala

3) Sand mining policy of Maharashtra.
4) MoEF policy on minerals

   And many more

Similar framework needs to be incorporated in the Western Ghats scenario to protect the ecosystem against excessive sand mining. Locations are to be identified in consultation with the hydrologists and geologists suitable for sand extraction from the river bed through the non-mechanized process. Different zonation's with respect to the stream type and characteristics, specifying the time during which the mining is allowed followed by the strict monitoring of sediment extraction. Table 3 lists the strategies to overcome the excessive silt extraction or sand mining.

Table 3: Strategies to regulate excess sand extraction

Slno	Strategy	Discretion
1	Creation of No Development Zones (NDZ)	Industries needs to be classified based on their type, and polices shall be amended upon which between 500 m to 10 km either sides of the river as listed in Table 4 and CRZ 1 (Coastal Regulation Zone 1)
2	Fixing of time for silt removal	Removal of sand be permitted between 7 AM and 4 PM
3	Fixing of sand removal location and quantity	Based on category of river, sand removal shall be allowed only from the river bed, and no sand removal operation be allowed within 10 m of the river bank. No sand removal is allowed within 500 m from any bridge, irrigation project, pumping stations, retaining wall structures, religious places, etc. Quantity of sand extracted at particular location shall not exceed the quantity of silt yield per annum. Weighing bridges are to be fixed at identified locations to regulate the quantity of sand extracted during a year.
4	Fixing vehicle loading points	Vehicles shall be parked at least 25 to 50 m away from the river banks, no vehicles shall be brought near the river bank.

		Erecting of pillars to demarcate vehicle restriction regions, beyond which vehicle should not be allowed
5	Restriction on mechanized removal	No pole scooping or any method shall be carried out in sand removal operation
6	Restriction or ban on sand removal	Sand shall not be removed from likely places where saline waters mixes with fresh water Sand removal quantity per year based on scientific assessment and approval of on expert committee of district Sustainable harvesting of sand considering the yield at point of extraction Regions such as breeding habitat of fishes and other aquatic organisms, endemic species of riparian vegetation, and basins where ground water extraction is prevalent, are to be identified in the river basins for restricting sand mining District collector may ban sand removal in any river or river stream during monsoons, based on Expert Committee. Based on the acts, rules and orders made by the GOI/ state the expert committee shall prepare river development plans for protection of river to keep up the biophysical environment along the river banks
7	Liability of District Collector	Fifty percent of the amount collected by the local authorities shall be contributed as river management fund and shall be maintained by the district collector.
8	No construction between 500 m to 1 km from flood plain	To protect life and property damages in cases of flash floods
9	Different stretch of rivers different regulations	Rivers are dynamic, they come across different geomorphic, climatic, sociopolitical settings. Due to this different stretches of rivers faces different issues. Rivers where rivers originate, they are at the

		highest purity level which needs to be maintained as it is the source contributor for the downstream.
10	Flood Plain protection	To protect against the damage that affects the floral and faunal diversity, intern maintaining the aesthetical and economic value of the river basins No chemical based agriculture or fertilizers shall be used in the agricultural fields that affect the river channel polluting and affecting the ecosystem
11	Creating awareness among the stake holders	Very essential in order to protect the riparian vegetation, stake holders includes fishermen, dhobi's, cattle heard's, manufacturer's, entrepreneurs, environmentalists etc… all of those shall be made aware of impact of their activities on the environment/ rivers
12	Afforestation	To prevent the erosion of soil To prevent landslides along the banks of rivers

Table 4: Class of Rivers and Allowable developments

Class of stream	NDZ for any type of Industry	Only Green and Orange category of industries with pollution control devices	Any category of industries with pollution control devices
I	3 km on either sides of river w.r.t HFL	3 km to 8 km from the HFL on either sides	Beyond 8 km from HFL
II	1 km on either sides of river w.r.t HFL	1 km to 2 km from the HFL on either sides	Beyond 2 km from HFL
III	1/2 km on either sides of river w.r.t HFL	1/2 km to 1 km from the HFL on either sides	Beyond 1 km from HFL
IV	1/2 km on either sides of river w.r.t HFL	1/2 km to 1 km from the HFL on either sides	Beyond 1 km from HFL

Industries based on type and scale are classified as red, orange and green

Table 5 compares the policy guidelines of national and international agencies. Geo scientific considerations suggested to be taken into account for sand/ gravel mining ***in India are*** *(http://www.portal.gsi.gov.in/gsiDoc/pub/riverbed_mining_guidelines.pdf* **Geographical Survey of India***)*:-

1. Abandoned stream channels on terrace and inactive floodplains may be preferred rather than active channels and their deltas and floodplains. Replenishment of ground water has to be ensured if excessive pumping out of water is required during mining.
2. Stream should not be diverted to form inactive channel,
3. Mining below subterranean water level should be avoided as a safeguard against environmental contamination and over exploitation of resources,
4. Large rivers and streams whose periodic sediment replenishment capacity are larger, may be preferred than smaller rivers,
5. Segments of braided river system should be used preferably falling within the lateral migration area of the river regime that enhances the feasibility of sediment replenishment,
6. Mining at the concave side of the river channel should be avoided to prevent bank erosion. Similarly meandering segment of a river should be selected for mining in such a way as to avoid natural eroding banks and to promote mining on naturally building (aggrading) meander components,
7. Scraping of sediment bars above the water flow level in the lean period may be preferred for sustainable mining,
8. It is to be noted that the environmental issues related to mining of minerals including riverbed sand mining should clearly state the size of mine leasehold area, mine lease period, mine plan and mine closure plan, along with mine reclamation and rehabilitation strategies, depth of mining and period of mining operations, particularly in case of river bed mining.
9. The Piedmont Zone (Bhabbar area) particularly in the Himalayan foothills, where riverbed material is mined. This sandy- gravelly track constitutes excellent conduits and holds the greater potential for ground water recharge. Mining in such areas should be preferred in locations selected away from the channel bank stretches. Areas where channel banks are not well defined, particularly in the braided river system, midstream areas should be selected for mining of riverbed materials for minimizing adverse effects on flow regime and in stream habitat.
10. Mining of gravelly sand from the riverbed should be restricted to a maximum depth of 3m from the surface. For surface mining operations beyond this depth of 3m (10 feet), it is imperative to adopt quarrying in a systematic bench- like disposition, which is generally not feasible in riverbed mining. Hence, for safety and sustainability restriction of mining of riverbed material to maximum depth of 3m.is recommended,
11. Mining of riverbed material should also take cognizance of the location of the active channel bank. It should be located sufficiently away, preferably more than 3m away

(inwards), from such river banks to minimize effects on river bank erosion and avoid consequent channel migration,

12. Continued riverbed material mining in a given segment of the river will induce seasonal scouring and intensify the erosion activity within the channel. This will have an adverse effect not only within the mining area but also both in upstream and downstream of the river course. Hazardous effects of such scouring and enhanced erosion due to riverbed mining should be evaluated periodically and avoided for sustainable mining activities.
13. Mineral processing in case of riverbed mining of the sandy gravelly material may consist of simple washing to remove clay and silty area. It may involve crushing, grinding and separation of valueless rock fragments from the desirable material. The volume of such waste material may range from 10 to 90%. Therefore, such huge quantities of mine wastes should be dumped into artificially created/ mined - out pits. Where such tailings / waste materials are very fine grained, they may act as a source of dust when dry. Therefore, such disposal of wastes should be properly stabilized and vegetated to prevent their erosion by winds,
14. Identification of river stretches and their demarcation for mining must be completed prior to mining for sustainable development
15. The mined out pits should be backfilled where warranted and area should be suitably landscaped to prevent environmental degradation.
16. Mining generally has a huge impact on the irrigation and drinking water resources. These attributes should be clearly evaluated for short-term as well as long-term remediation.

Ministry of Environment & Forests (MoEF: *http://e*nvfor.nic.in/content/report-*moef-sand-mining)* also stipulates the following recommendations on mining of minor minerals/ construction materials:

1. Mining Lease (ML) area should be demarcated on the ground with Pucca Pillars.
2. For river sand mining, area should be clearly specified for mining operations in the region. The area should be properly surveyed and mapped with the help of GPS to assign geo coordinates and accordingly erect boundary pillars so as to avoid illegal unscientific mining.
3. Within the ML area, if any forest land is existing, it should be distinctly shown on the map along with coordinates.

4. While considering the sanction of ML area, due attention should be paid to the presence of any National Park/Sanctuary/Ecologically Sensitive landscape. In such cases order of the Hon'ble Supreme Court in .W.P (C) No. 337/1995) should be strictly followed.
5. For mining lease within 10 km of the National Park/Sanctuary, recommendation/ permission of National Board of Wild Life (NBWL) have to be obtained as per the Hon'ble Supreme Court order in I.A. No. 460/2004.
6. Site-specific plans with eco-restoration should be considered/ implemented.

As per the ***Ministry of natural resources and environment department of irrigation and drainage Malaysia***, the following policies should be taken into consideration before approving sand and gravel mining permits:-

1) Ensure conservation of the river equilibrium and its natural environment.
2) Avoid aggradation at the downstream reach especially those with hydraulic structures such as jetties, water intakes etc.
3) Ensure the rivers are protected from bank and bed erosion beyond its stable profile.
4) Avoid interfering the river maintenance work by Department of Irrigation and Drainage (DID) or other agencies.
5) No obstruction to the river flow and water transport.
6) Avoid pollution of river water leading to water quality deterioration.

Table 5 gives the summary of the policies deployed/ needs to be followed:

Slno	Description	Govt of Kerala	Govt of Maharhastra	MoEF	GSI	Scientific Basis	Govt of Malaysia
1	Creation of No Development Zones (NDZ)		Y	Y		Y	
2	Fixing of time for silt removal	Y					Y
3	Fixing of sand removal location	Y	Y	Y	Y		Y
4	Fixing vehicle loading points	Y					
5	Restriction on mechanized removal	Y					Y
6	Restriction or ban on sand removal	Y			Y		Y
7	Different stretch of rivers different regulations and extractions based on yield		Y		Y	Y	Y
8	Flood Plain protection				Y	Y	Y
9	Creating awareness among the stake holders					Y	Y
10	Afforestation/Maintain the vegetation cover	Y	Y	Y		Y	Y
11	Monitoring	Y	Y	Y		Y	Y

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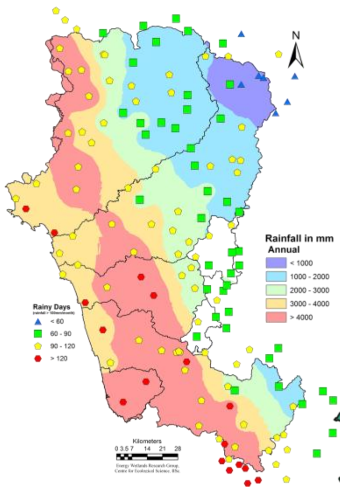

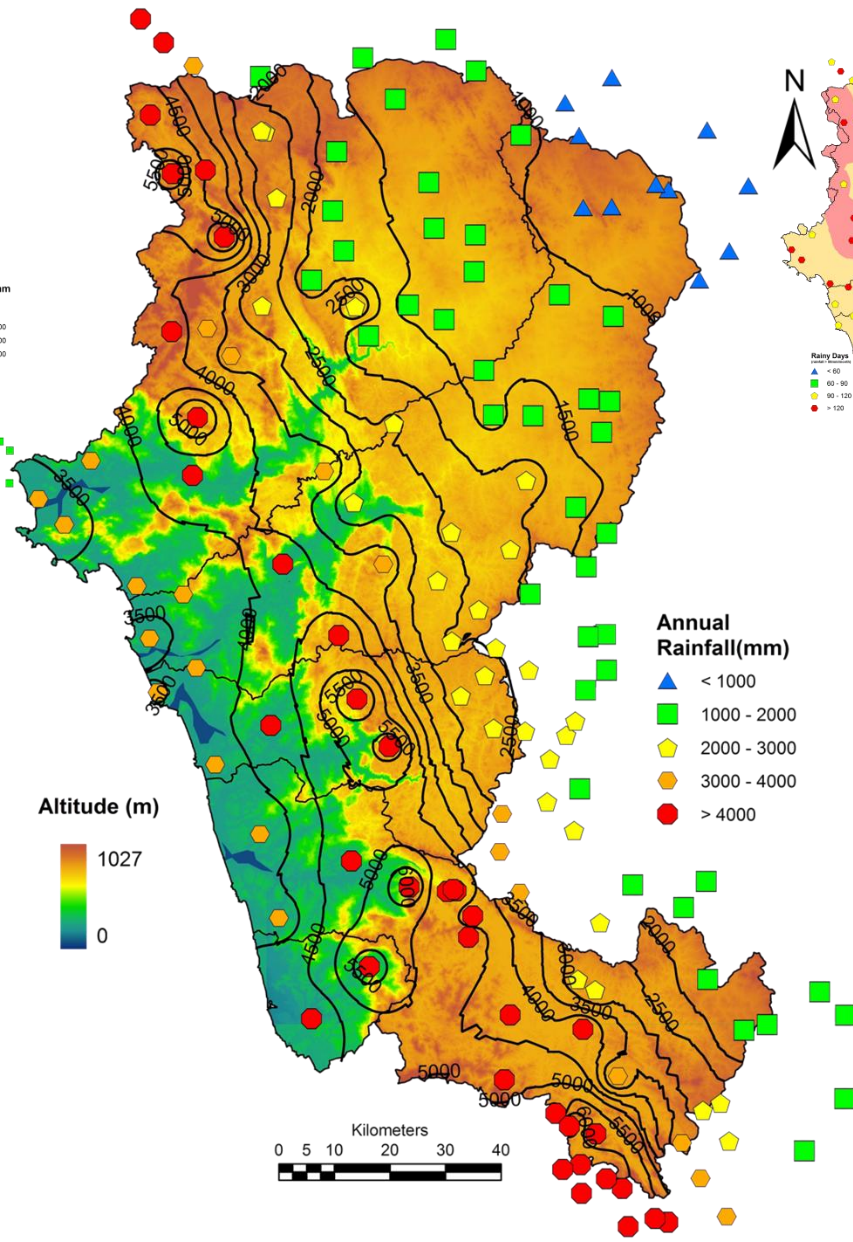

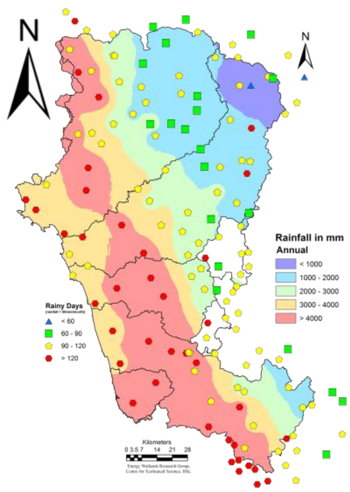

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