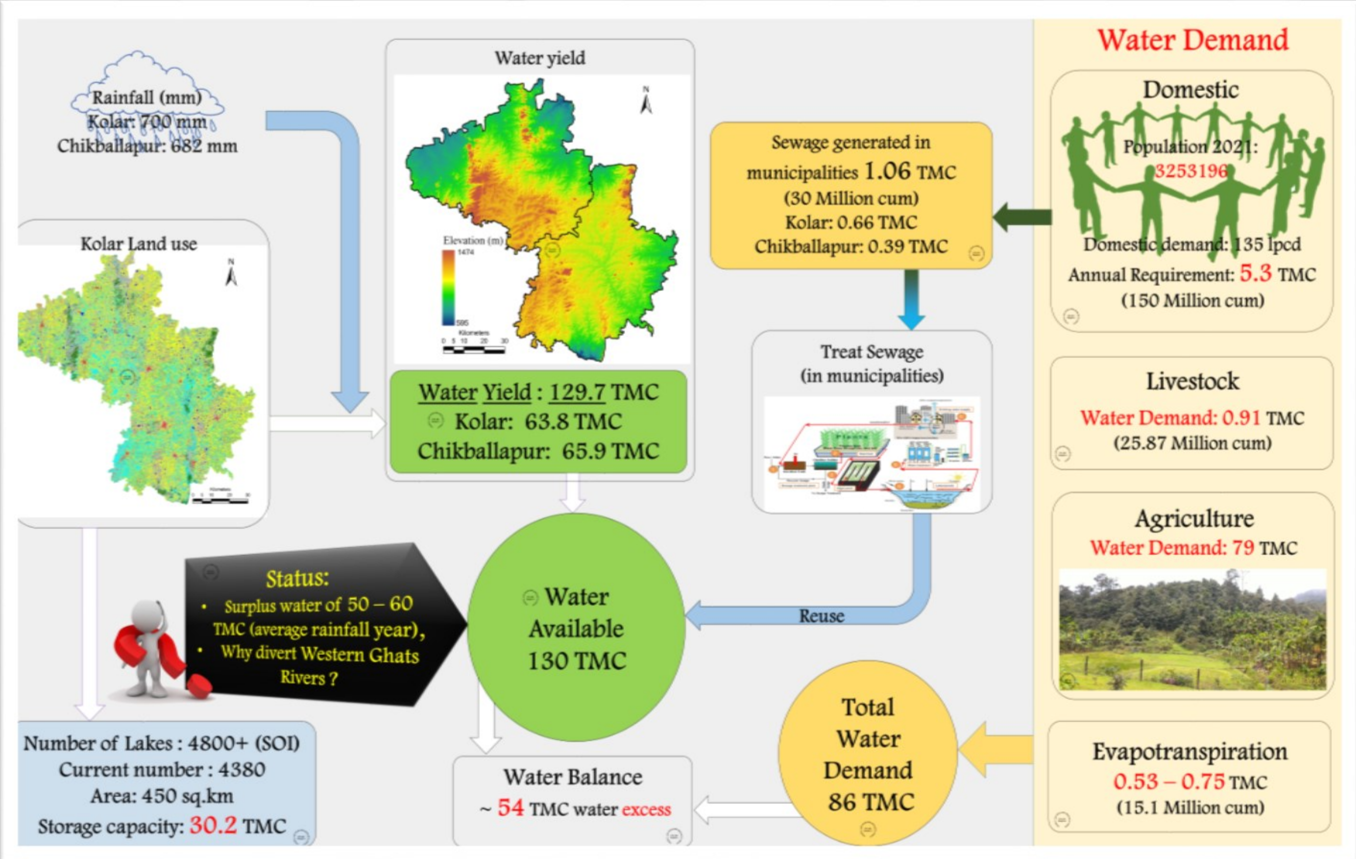
INTEGRATED WATERSHED MANAGEMENT FOR WATER & FOOD SECURITY IN KOLAR AND CHIKBALLAPUR DISTRICTS, KARNATAKA

RAMACHANDRA T. V.   VINAY S.   BHARGAVI R.   BHARATH H. AITHAL



Gautam and Vasantha Jagadisan Endowment– Lake Rejuvenation
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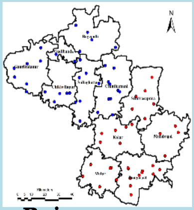
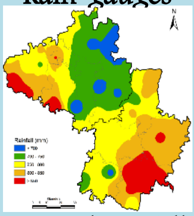
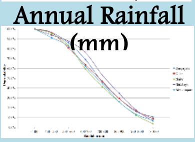
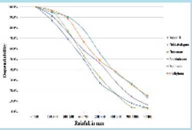


Rain-gauges

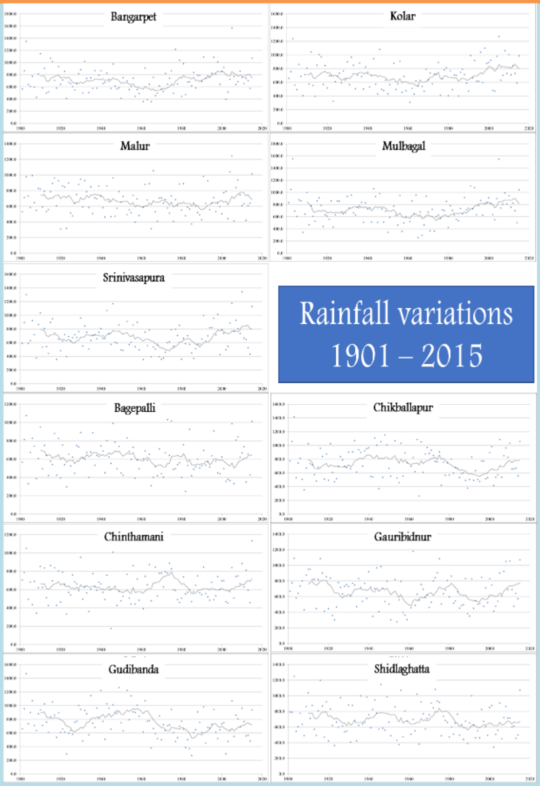


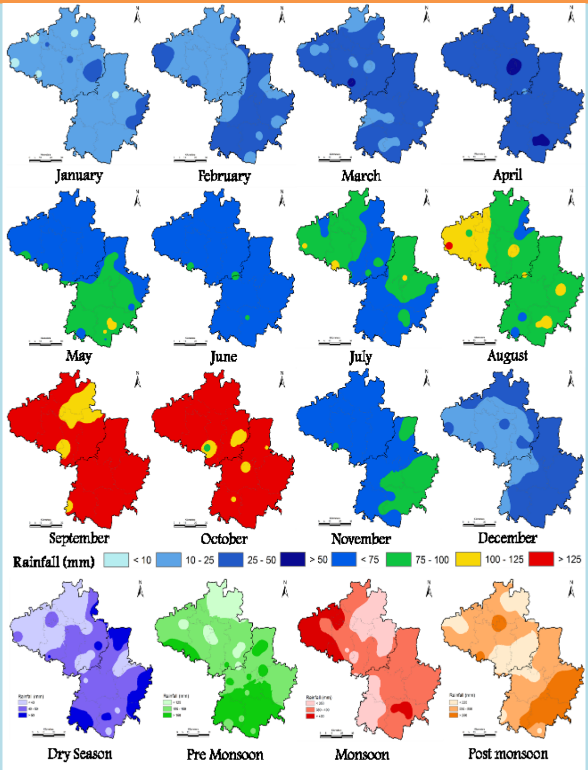
Annual Rainfall (mm)



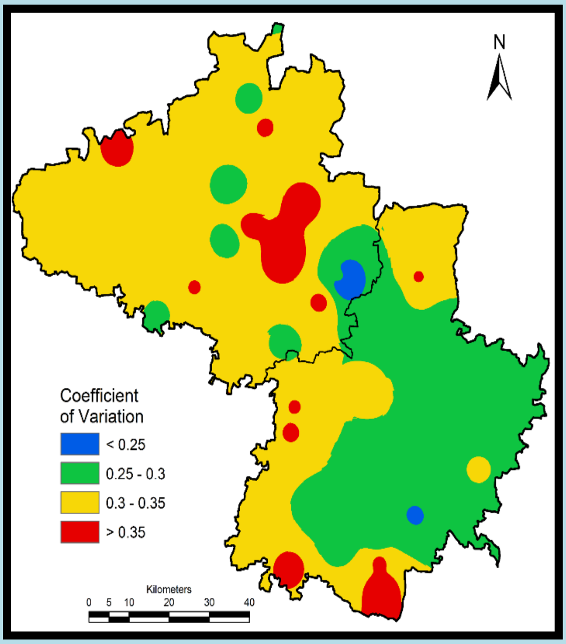


Rainfall Dependability - Kolar, Chikballapur





District	Taluk	Mean (mm)	SD# (mm)	COV*
Kolar	Bangarpet	716	209	0.29
	Kolar	703	211	0.3
	Malur	675	186	0.28
	Mulbagal	723	215	0.3
	Srinivasapura	686	206	0.3
Chikballapur	Bagepalli	610	182	0.3
	Chikballapur	734	217	0.3
	Chinthamani	639	167	0.26
	Gouribidnur	666	205	0.31
	Gudibanda	751	218	0.29
	Shidlighatta	694	202	0.29



COV (1901 – 2015)

KOLAR & CHIKBALLAPUR: NO DECLINE IN RAINFALL

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Highlights:

- Kolar and Chikaballapur districts are located in the south eastern part of Karnataka State, between 12°44'N to 13°45'N latitude and 77°12'E to 78°35'E longitude. Spatial extent of is 8213 sq.km (Chikaballapur: 4244 sq.km, Kolar: 3969 sq.km).
- Kolar and Chikballapur districts are located in the semi arid climatic zone, with average rainfall of 690 ± 201 mm/yr, temperature between 14.4°C (January) to 35.7°C (April).
- Terrain Topography varies between 595 m to 1474 m above Mean Sea Level. Slope is gentle across the plains and steep across the hill ranges. Kolar and Chikballapur together had over 4800 lakes (SOI 1:50000 topographic sheets 1970's) encompassing an area of 45085 hectares with current water holding capacity of ~**15 TMC** (with silt accumulation).
- Population has increased from 24,45,586 (2001 census) to 28,21,506(2011 census) at a decadal rate of 15.3%. Population at the year 2021 is projected to be 32,53,196 persons. Considering domestic demand is about 135 lpcd, annual demand by 2021 would be **~5.27 TMC** (~150 Million cubic meters).
- Temporal analyses of rainfall trends (based on the data of 1901 to 2015) reveals COV of 0.3 (ranges from 0.26 (Chintamani) to 0.31 (Bagepalli)).
- Spatio temporal analyses of rainfall trends based on 113 years of rainfall data from 70 rain gauges well distributed in these districts do not show any significant decline or increase in rainfall contrary to the claim by bureaucrats to push large scale projects (of diversions – Yettinholé, and such senseless plans) and COV (Coefficient of Variation – spatial and temporal is < 0.3)
- Annual water yield in Kolar is about 63.8 TMC and Chikballapur is about 65.9 TMC (Total is 129.9 TMC)
- Water Demand (Kolar + Chikballapur districts): 86 TMC (excess water: 54 TMC)
- Number of water bodies: 4380 (Kolar and Chikballapur) and majority are silted.
- Wasteland (unproductive barren land): 38% (higher compared to any other districts in Karnataka)
- **Solutions to water crisis**: Harvest Rainwater, Rejuvenate lakes, Watershed management, plant native samplings in the catchment, de-siltation of water bodies, good governance involving all sensible stake holders and minimize mismanagement.
- The sustainable option to meet the water requirements of arid regions in Karnataka is through (i) decentralized water harvesting (through tanks, ponds, lakes, etc.), (ii) rejuvenation or restoration of existing lakes/ponds, (iii) reuse of waste water, (iv) recharging groundwater resources, (v) planting native species of grasses and tree species in the catchment (to enhance percolation of water in the catchment), (vi) implementation of soil and water conservation through micro-watershed approaches. Implementation of these location specific approaches would cost much less compared

to the proposed project, which if implemented would help the section of the society involved in decision making, construction and implementation of the project.

Recommendations

- Decentralized rain water harvesting through lakes, recharge pits, etc.;
- Constructed wetlands integration with lakes to prevent water contamination (with agriculture run off, sewage inflow, etc.);
- Catchment/watershed management for effective soil and water conservation;
- Rejuvenation of existing lakes
  - De-silting to enhance the storage capacity as well as groundwater recharge;
  - Reestablish inter-connectivity among lakes;
  - Removal of all encroachments (lake bed, natural drains);
  - Maintaining at least 33% green cover (of native species) in the catchment;
  - catchment treatment (through planting native saplings)
- Restrictions on any construction activity in the buffer zone of a lake (75 m).
- Maintaining aquatic macrophytes in the buffer zone of each lake, which helps in bioremediation.
- Incentive to create farm ponds in all agricultural fields (this helps in ground water recharge, and also helps in fish rearing and hence local livelihood)
- Phasing out monoculture plantations of exotic species (such as eucalyptus, etc. which sucks groundwater) with native species on priority.
- Appropriate cropping pattern and restriction on crops that are water intensive.
- Allowing only dry land crops;
- Incentives to farmers growing crops suitable for semi-arid region;
- Greening/afforestation in the catchments of water bodies (lakes, rivers, etc.) with native species, ensure that at least 33% is maintained with native trees and grasses to enhance water retaining capacity of Catchment/watershed;
- Inclusions of concepts - watershed, environment, afforestation, reforestation in the education curriculum (Schools and Colleges);
- Management of water bodies involving all stakeholders, and constitution of joint environment management committee at each village level to address the issue of forest as well as water bodies;
- Restriction on sand mining beyond sustainable yield;
- Restrictions on bore wells and regulation of number of wells in a region (to mitigate overexploitation)
- Kolar has distinction of having highest barren area (un-productive land) and is heralding towards desertification (next to Rajasthan). This requires immediate afforestation in the catchment through CAMPA. Auditing of these activities through independent and unbiased academic institutions.
- Environment education / awareness programmes to sensitize farmers, youth and school children.

1.0 Introduction

Freshwater ecosystems are aquatic systems include lakes and ponds, rivers and streams, wetlands and groundwater. They provide the majority of our nation's drinking water resources, water resources for agriculture, industry, sanitation, as well as food including fish. They also provide recreational opportunities and a means of transportation. In addition, freshwater ecosystems are home to numerous organisms (e.g., fish, amphibians, aquatic plants, and invertebrates). It has been estimated that 40% of all known fish species on Earth come from freshwater ecosystems. We obtain freshwater from surface water and groundwater. These make up only a small quantity of the world's water. Freshwater may be present as: Groundwater, Wetlands, Lakes and Ponds, Rivers and streams, etc.

1.1 Wetlands: A wetland is a place where water is the primary factor controlling the immediate environment. Wetlands can be as small as a pool or as large as a lake. Wetlands generally occur where land and water meet and underground water is at or near the surface, or where land is covered with water less than six feet deep. The water level in a wetland rises and falls. This shift may depend on location, weather, climate, or surrounding ecosystems. The area may be temporarily saturated, then dry up until another watery inundation. Meanwhile, a wetland provides a rich home to many animals and plants. What we call the rivers, lakes etc. comes under the category of wetlands. Wetlands are important for so many reasons:

i). Wetlands aid in remediation and act as 'kidneys of a landscape';

ii). Wetlands prevent flooding by holding water much like a sponge. By doing so, wetlands help in keeping river levels normal and filter and purify the surface water.

iii). Wetlands accept water during storms and whenever water levels are high. When water levels are low, wetlands slowly release water.

iv). Wetlands also release vegetative matter into rivers, which helps feed fish in the rivers. Wetlands help to counter balance the human effect on rivers by rejuvenating them and surrounding ecosystems.

v). Many animals that live in other habitats use wetlands for migration or reproduction. For example, herons nest in large old trees, but need shallow areas in order to wade for fish and aquatic life. Amphibians often forage in upland areas but return to the water to mate and reproduce.

vi). While wetlands are truly unique, they must not be thought of as isolated and independent habitat. To the contrary, wetlands are vital to the health of all other biomes and to wildlife and humans everywhere.

vii). Unlike most other habitats, wetlands directly improve other ecosystems.

viii). Looking at pictures of deltas one can tell that rivers deposit a lot of sediment into the ocean. The sediment is the top soil that has been eroded and washed away.

ix). Emergent plants firmly rooted in the muddy bottom but with stalks that rise high above the water surface) are able to radically slow the flow of water. As a result, they counter the erosive forces of moving water along lakes and rivers, and in rolling agricultural landscapes. Erosion control efforts in aquatic areas often include the planting of wetlands plants.

x). Wetlands and Water Purification: Wetlands also clean the water by filtering out sedimentation, decomposing vegetative matter and converting chemicals into useable form.

xi). Supports local livelihood: Valuation of goods and services from a relatively pristine wetland in Bangalore shows the value of Rs. 10,435/ha/day (much higher than global coastal wetland ecosystems with a total annual of US$ 14,785/ha), while the polluted wetland shows the value of Rs.20/ha/day (Ramachandra et al., 2005) and sewage fed Varthur wetland has a value of Rs.119/ha/day (Ramachandra et al., 2011).

xii). Anthropogenic activities particularly, indiscriminate disposal of industrial effluents and sewage wastes, agricultural runoff have altered the physical, chemical as well as biological integrity of the ecosystem. This has resulted in the ecological degradation, which is evident from the current ecosystem valuation of wetlands.

The ability of wetlands to recycle nutrients makes them critical in the overall functioning of earth. No other ecosystem is as productive, nor as unique in this conversion process. In some places artificial wetlands were developed solely for the purpose of water purification.

1.2 Rivers and Streams: Although there are many rivers and streams, these sources of running water account for a very small portion of the earth's total surface, just 0.3%. Rivers and streams describe natural and man-made bodies of moving water. These systems consist of numerous tributaries joined together to form a main channel. Rivers may sometimes be ephemeral, carry water only during and immediately after a rain, they may be intermittent, flow part of the year, or they may be perennial, flow all the year round. The tributaries (streams) are identified by their stream order, denoted by its position in the system (Table 1.1, Figure 1.1).

Table 1.1: Stream Orders and their Characteristics

Stream Order	Characteristics
First Order	Not connected to any other tributary
Second Order	Connected to one other stream/tributary
Third Order	Joining of two second order streams

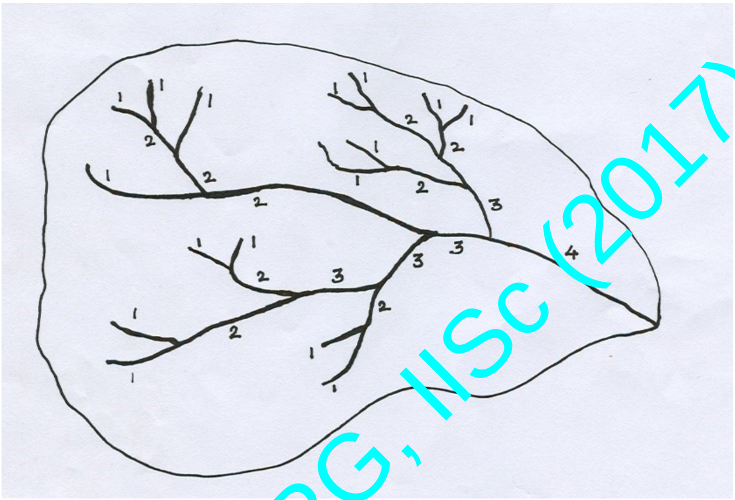
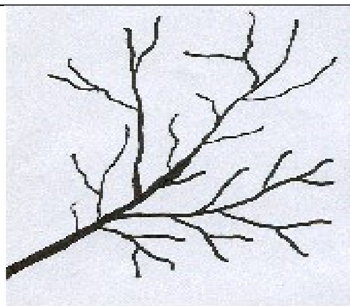
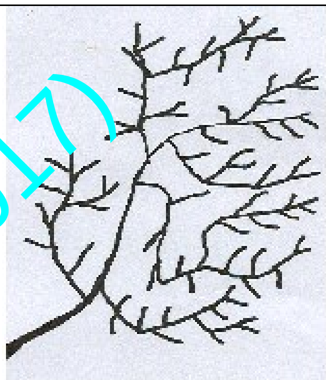
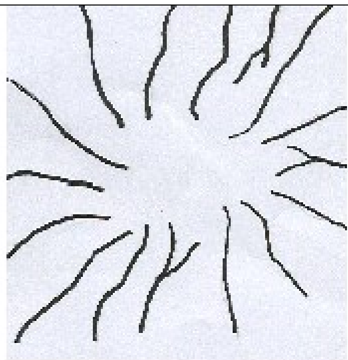
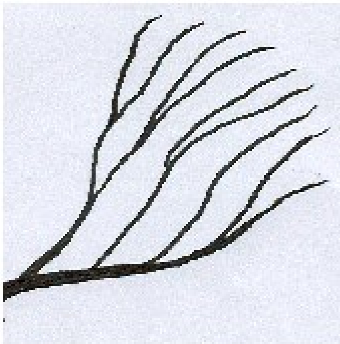
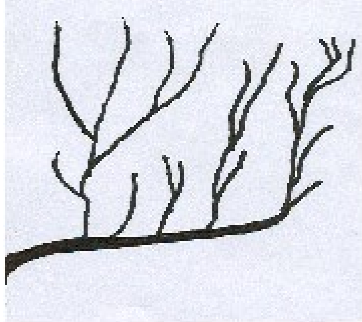
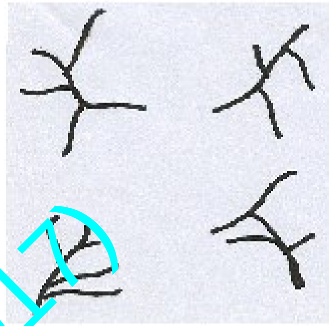
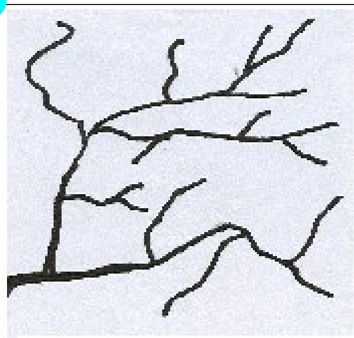
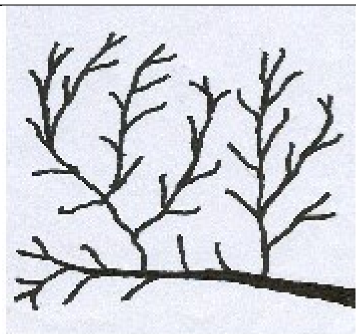


Figure 1.1: Catchment / watershed with streams (first, second, etc.)

Where gradients (slopes) are steep and near the source of the river or stream, water travels in a straight channel, velocity is high and much sediment is carried. Upon reaching ground-level, velocity decreases and sediments are dropped in the form of silt, mud, and sand. As a river or stream channel builds up or erodes the surrounding floodplain, it meanders, creating loops of varying sizes in the channel. When meanders become extremely distorted they can be severed, becoming independent oxbow lakes. The combined effects of climate and geology on the topography yield an erosion pattern, which is characterized by a network of streams. Some of the frequently observed stream patterns are given in the Table 1.2.

Table 1.2: stream patterns

Type of stream pattern	Description	Illustration
Dentric	When a region is homogenous offering no variation in the resistance to the flow of water, the resulting streams run in all directions without definite preference to any one particular region.	
Trellis	This pattern develops when the underlying rock is strongly folded or sharply dipping. The longer streams will have preference to one particular orientation and the other tributaries will have an orientation and the tributaries will have an orientation at right angles to this.	
Radial	The drainage pattern from dome Mountains and volcanoes is of radial type where the streams emanate from a central focus and flow radially outward.	
Parallel	The internal geological structure of the land, sometimes the parallel and sub parallel patterns are formed. The most of the streams run in the same direction is the main characteristic feature	

Sub parallel	The internal geological structure of the land, sometimes the parallel and sub parallel patterns are formed. The most of the streams run in the same direction is the main characteristic feature	
Annular	The streams, which form in the weaker strata of the dome mountain, indicate approximately circular or annular pattern. The annular pattern may be treated as a special form of trellis pattern.	
Rectangular	A region consisting of many rectangular joints and faults may produce a rectangular drainage pattern with streams meeting at the right angle.	
Pinnate	In pinnate stream pattern, all the main streams run in one direction with the tributaries joining them at an oblique angle.	

Collectively the network of rivers and streams forms a watershed (Figure 1). Thus, river, pond, wetlands, lake or estuary is an ultimate destination of all water running downhill through an area of land, which is referred as watershed.

1.3 **WATERSHED:** A watershed describes an area of land that contains a common set of streams and rivers that all drain into a single body of water such as a tributary, river, a lake or an ocean. It represents a catchment basin bounded by topographic features, such as ridge tops and performs primary functions of the ecosystem with biotic and abiotic components. The word watershed is sometimes used interchangeably with drainage basin or catchment. Ridges and hills that separate two watersheds are called the drainage divide. The watershed consists of surface water--lakes, streams, reservoirs, and wetlands--and all the underlying ground water.

A watershed can cover a small or large land area. All the streams flowing into small rivers, larger rivers, and eventually into the ocean, form an interconnecting network of waterways as shown in Figure 1.2. In a large watershed, water from precipitation will interact and leach minerals from the soil before being discharged into the lake or river. Lakes with small watersheds, maintained primarily by groundwater flow, are known as seepage lakes. Whereas, lakes fed by inflowing streams or rivers are known as drainage lakes.

Not only does water run into the streams and rivers from the surface of a watershed, but water also filters through the soil, and some of this water eventually drains into the same streams and rivers. There can be sub watersheds within a watershed like a tributary to a river having its own watershed, which is a part of the larger total drainage area to the river. The network of streams and rivers that drain our watershed, ultimately empty into larger bodies of water, such as lakes and oceans.

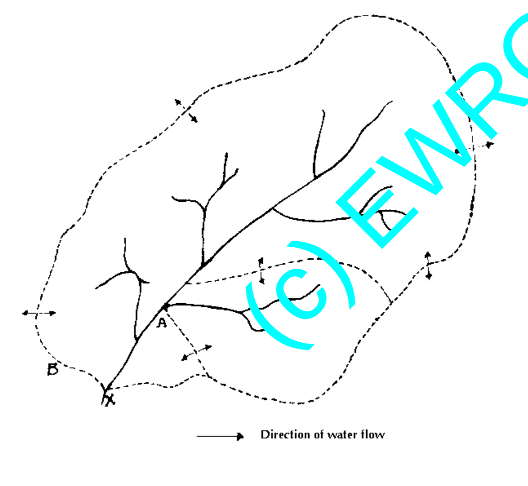


Figure 1.2: A Typical Watershed

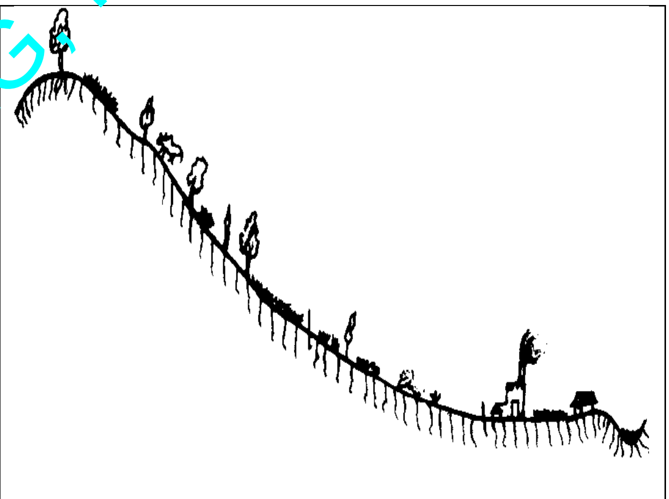


Figure 1.3: A Typical Watershed Transect (macro-perspective)

Watershed plays a critical role in the natural functioning of the ecosystem (Ramachandra, 2002) such as:

- Hydrologically, watersheds integrate the surface water run-off of an entire drainage basin. It captures water from the atmosphere. Ideally, all moisture received from the atmosphere, whether in liquid or solid form, has the maximum opportunity to enter the ground where it falls. The water infiltrates the soil and percolates downward. Several factors affect the infiltration rate, including soil type, topography, climate, and vegetative cover. Percolation is also aided by the activity of burrowing animals, insects, and earthworms.

- It stores rainwater once it filters through the soil. Once the watershed's soils are saturated, water will either percolate deeper, or runoff the surface. This can result in freshwater aquifers and springs. The type and amount of vegetation, and the plant community structure, can greatly influence the storage capacity in any one watershed. The root mass associated with healthy vegetative cover keeps soil more permeable and allows the moisture to percolate deep into the soil for storage. Vegetation in the riparian zone affects both the quantity and quality of water moving through the soil (Figure 1.3).
- Finally, water moves through the soil to seeps and springs, and is ultimately released into streams, rivers, and the ocean. Slow release rates are preferable to rapid release rates, which result in short and severe peaks in stream flow. Storm events which generate large amounts of run-off can lead to flooding, soil erosion and siltation of streams.
- Ultimately, the moisture will return to the atmosphere by way of evaporation. The hydrologic cycle (the capture, storage, release, and eventual evaporation of water) forms the basis of watershed function. Economically, they play a critical role as sources of water, food, hydropower, recreational amenities, and transportation routes.
- Ecologically, watersheds constitute a critical link between land and sea; they provide habitat -- within wetlands, rivers, and lakes - for 40 percent of the world's fish species, some of which migrate between marine and freshwater systems.
- Watersheds also provide habitat within the terrestrial ecosystems such as forests and grasslands - for most terrestrial plant and animal species; and they provide a host of other ecosystem services -- from water purification and retention to flood control to nutrient recycling and restoration of soil fertility -- vital to human civilizations.

Humans alter a watershed by paving over land and constructing buildings. This will affect how water flows over the land and may cause harmful materials to flow directly into the water. This will affect the organisms that depend on the water for survival. For example, polluted water may cause these organisms to die leaving the fish with no food.

Soil types and their susceptibility to erosion is another important component of the watershed. The type and abundance of vegetation determines the extent of erosion. Areas with native undisturbed vegetation like forests are less prone to erosion than areas with disturbed vegetation like agricultural lands. Factors influencing watershed operations are:

a) Size: Both run-off volume and rate increases with increase in watershed size. However, both rate and volume per unit of watershed area decreases as the area increases. The size or area of watershed is an important parameter in determining the peak rate of run-off. Based on the size, watershed is classified as micro (0-10 ha), small (10-40), mini (40-200), sub-watershed (200-400) and macro (400-1000 ha)

b) Shape: Long and narrow watersheds have longer times of concentration resulting in lower runoff-rates than more square watersheds of similar size, which have a number of tributaries discharging into the main channel. This type of concentration also affects the amount of water infiltrating into the soil in the watershed. The longer time it takes to leave the watershed, the greater is its seepage into the soil.

c) Land-slope: Slope has major implications on land-use. The speed and extent of run-off depend on the slope of the land. Greater the slope, greater is the velocity of flow of run-off water. If velocity is doubled, energy and consequently erosion also increases. The degree of slope sets limits on land use for annual crops, plantation and land reclamation, depending on soil depth.

d) Drainage pattern: Drainage pattern of an area depends on the course of the streams and their tributaries. Land-slope, lithology and structure influence the drainage pattern. In general, coarser the drainage texture, higher is the conductivity. Finer drainage texture results in heavier soil type. Drainage patterns act as guidelines to locate vulnerable areas requiring different kinds and degrees of soil conservation measures.

e) Soil and geology: Soil and geology of the watershed also determine the amount of water percolating into the ground. Soil character also determines the amount of silt that will be washed down into water harvesting structures.

f) Vegetative cover: The type and quality of vegetative cover of the watershed influence run-off, infiltration rates, erosion, sediment production and evapotranspiration rate. Dense native vegetation reduces erosion and also increases infiltratration.

g) Precipitation: Amount and nature of precipitation is an important factor determining the rate of run-off into the water body. Rainfall distributed evenly throughout the year has a different impact than a sudden sharp seasonal rainfall.

Watershed management is a term used to describe the process of implementing land use practices with soil conservation and water management practices to protect and improve the quality of the soil, water and other natural resources within a watershed by managing the use of those land and water resources in a comprehensive manner. Watershed management implies an effective conservation of soil and water resources for sustainable production with minimum external inputs. It involves management of land surface and vegetation so as to conserve the soil and water for immediate and long term benefits to the farmers, community and society as a whole. Objectives of the watershed management are (i) sustenance of natural resources, (ii) production of food, fodder, fuel, etc., (iii) pollution control, (iv) water storage, flood control, arresting sedimentation. (v) Wild life preservation, (vi) erosion control and prevention of soil, degradation and conservation of soil and water, (vii) employment generation through industrial development dairy fishery production, (viii) recharging of ground water to provide regular water supply for domestic and agriculture use and(ix) recreational facility.

The various measures adopted under watershed management are (a) vegetative barriers; (b) building of contour bunds along contours for erosion; (c) furrow/ and ridges method of cultivation across the slope; (d) irrigation water management through water efficient drip and sprinkler methods, and (e) planting of horticultural contour species on bunds. Thus, watershed management recognizes the judicious management of basic natural resources - soil water and vegetation, on watershed basis, for achieving sustainable livelihood of dependent people. It includes treatment of land through biological as well as engineering measures.

Integrated Watershed Management (IWM) is the process of managing human activities and natural resources on a watershed basis. This approach allows us to protect important water resources, while at the same time addressing critical issues such as the current and future impacts of rapid growth and climate change. Watershed planning entails (i) preparation of base maps, (ii) reconnaissance survey of the watershed, (iii) assessing rainfall characteristics, (iv) Preparation of soil maps and classification of lands for different uses according to capability classification for agriculture, forestry, pasture, horticulture, etc., (v) land use analyses and temporal land cover dynamics, (vi) appraisal of agricultural production patterns and potentials, (vii) carrying out topographic and hydrologic surveys, (viii) geo-hydrological survey to identify regions for groundwater development, (ix) formulation of an integrated time-bound plan for land and moisture conservation, ground water. recharge, development of productive afforestation of native specis, agriculture production, grasslands and horticulture and (x) assessment of the social costs and benefit with participatory approaches in the management.

Objectives: Objectives of the current research are (i) land use analysis of Kolar (kolar and Chikballapur districts), (ii) rainfall trend analyses, (ii) assessment of hydrological status and (iv) investigation of a typical watershed (case study)

2.0 Materials and Method

Kolar and Chikaballapur districts are located in the south eastern part of Karnataka State, between 12°44'N to 13°45'N latitude and 77°12'E to 78°35'E longitude (Figure 2.1). Spatial extent of is 8213 sq.km (Chikaballapur: 4244 sq.km, Kolar: 3969 sq.km). Kolar and Chikballapur districts are located in the semi arid climatic zone, with average rainfall of 690 ± 201 mm/yr, temperature between 14.4°C (January) to 35.7°C (April). Terrain Topography varies between 595 m to 1474 m above Mean Sea Level (Figure 2.2). Slope is gentle across the plains and steep across the hill ranges. Kolar and Chikballapur together had over 4800 lakes (SOI 1:50000 topographic sheets 1970's) encompassing an area of 45085 hectares with current water holding capacity of ~**15 TMC** (with silt accumulation). Population has increased from 24,45,586 (2001 census) to 28,21,506 (2011 census) at a decadal rate of 15.3%. Population at the year 2021 is projected to be 32,53,196 persons (Figure 2.3). Considering domestic demand is about 135 lpcd, annual demand by 2021 would be **~5.27 TMC** (~150 Million cubic meters).

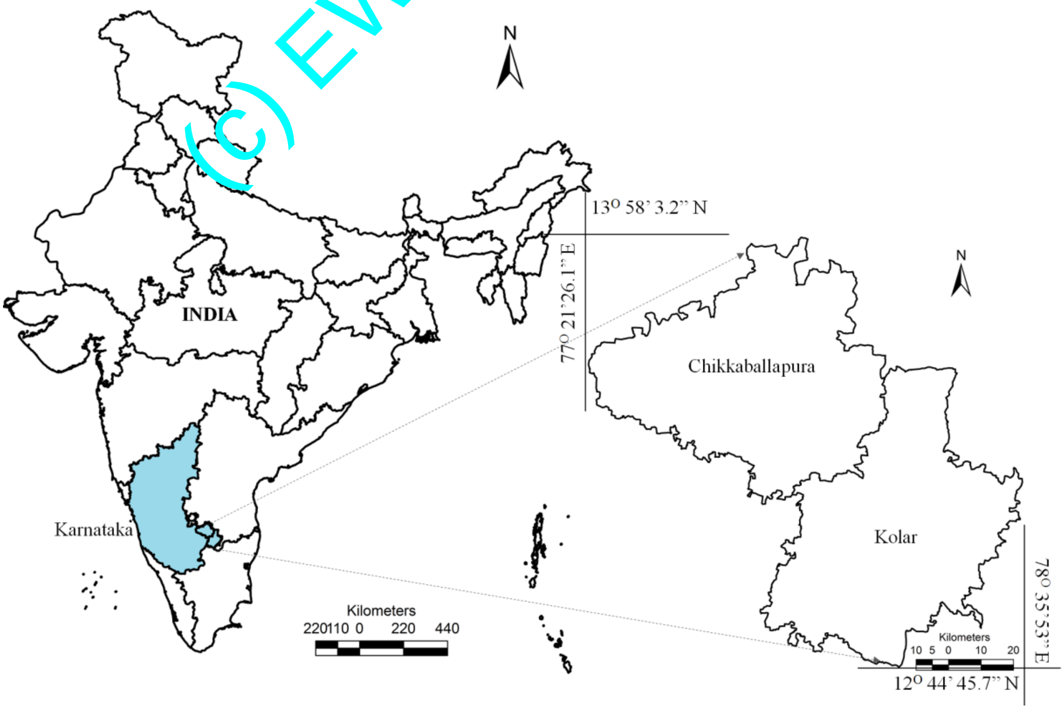


Figure 2.1: Study Area (Kolar and Chikballapur districts, Karnataka)

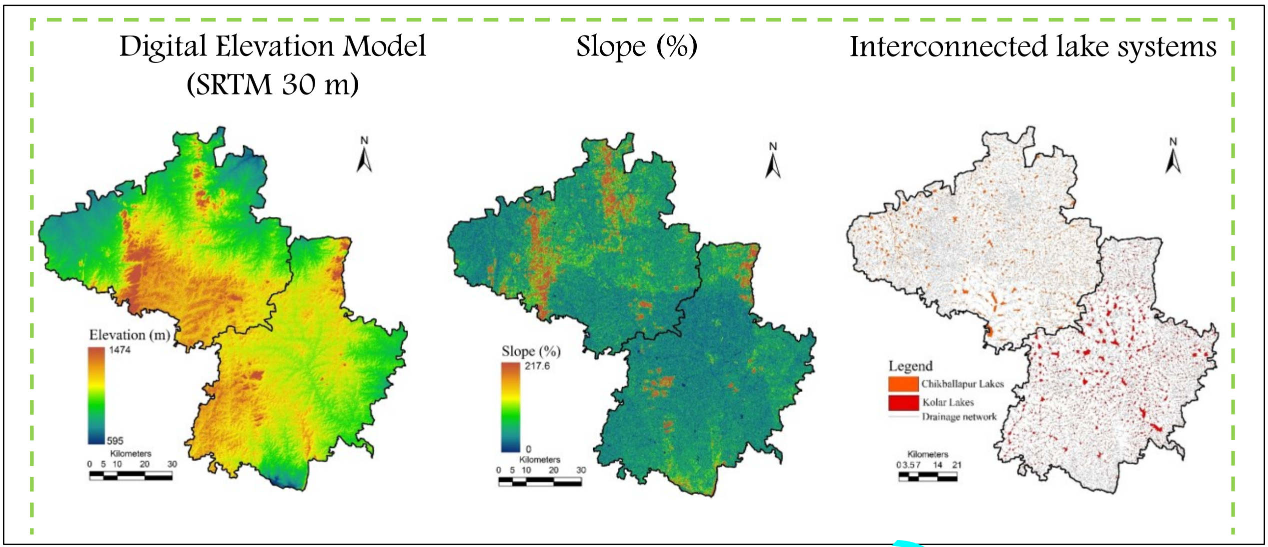


Figure 2.2: Terrain topography and water bodies in Kolar (Kolar and Chikballapur districts)

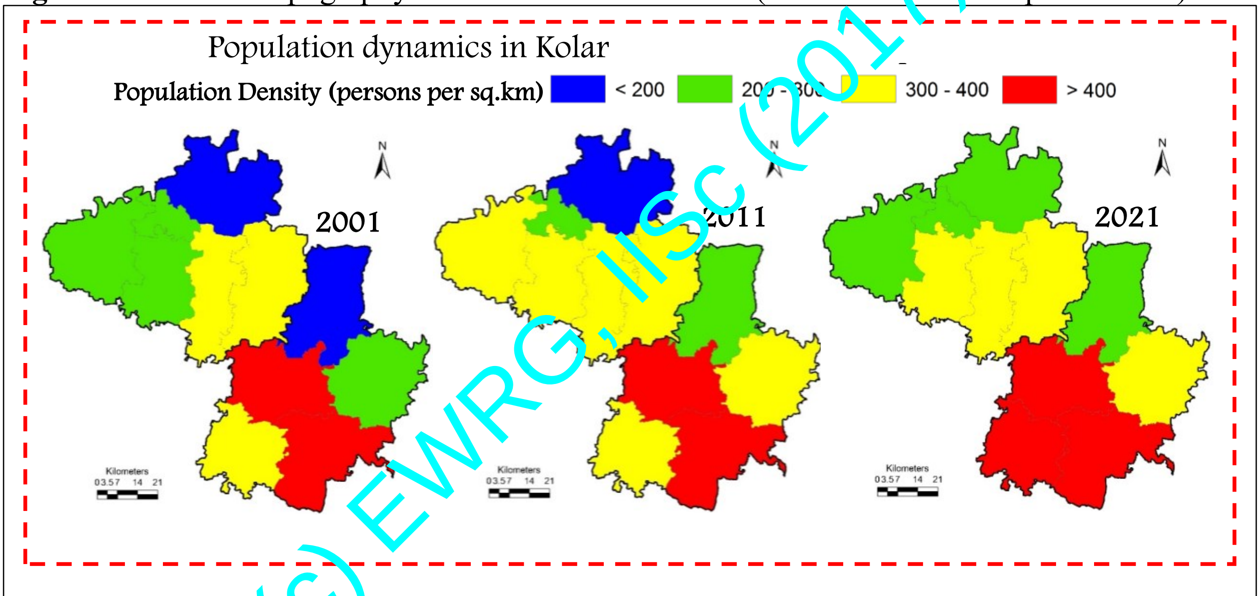


Figure 2.3: Population Dynamics in Kolar and Chikballapur districts

2.1 DATA: Data required for hydrological and spatial analyses were compiled from multiple agencies. Table 2.1 describes the various data used for assessment of the hydrological regime across the catchments. Data used include satellite remote sensing data acquired through Landsat 8 series of 2016. Rainfall data was acquired from Bureau of Economics and Statistics, Karnataka, Temperature data was sourced from worldclim of 1km resolution. Census data from government of India, state and district census departments. This data was supplemented with secondary data from various sources as tabulated in table 2.1. Data inventory was also done through field investigations and feedback from public.

Table 2.1: Data used for land use and assessment of hydrologic regime

Data	Source	Description
Remote sensing data – spatial data	Landsat 8 Satellite, 2016 from USGS earth explorer (http://landsat.usgs.gov, *http:// glcf.umd.edu/data/landsat/, http:// landsat.gsfc.nasa.gov/, http:// www.landsat.org/*	Remote sensing data of 30m spatial resolution and 16 bit radiometric resolution were used to analyse the land use at catchment level
Rainfall	Rain gauge station wise – compiled from Directorate of Economics and Statistics – Karnataka (http://*des.kar.nic.in/*), India Meteorological Department (IMD), Pune (http://imdpune.gov.in).	Daily rainfall data for 110 year between 1901 and 2015. Used to assess the rainfall distribution over the basin
Crop Calendar	Agriculture Department of Karnataka, (http://*raitamitra.**kar**.nic.in/), iKisan (http:// www.**ikisan**.com),* National Food Security Mission *(http://www.**nfsm**.gov.in/.*	To understand when, where and which crops are grown which helps in understanding the crop water requirement based on the growth phases
Crop Coefficient	Food and Agriculture Organization- FAO (http://www.fao.org), Agriculture Department of Karnataka (http:// http://raitamitra.kar.nic.in/KAN/index.asp).	Each land use has its own evaporative coefficients, used to estimate the Actual Evapotranspiration.
Temperature (max, min, mean), Extra-terrestrial solar radiation	Worldclim (http://*www.worldclim.org/),* FAO (http://www.fao.org), http://www.cru.uea.ac.uk, *http:// climate.nasa.gov/, http:// data.giss.nasa.gov/gistemp/*	Temperature data of 1km spatial resolution, available for each month. Extra-terrestrial solar radiation, every 1^0 North latitude available across different hemispheres for various months. Used to estimate the Potential Evapotranspiration
Population Census	Census India (http://censusindia. gov.in) 1991, 2001 and 2011	Data available at village level, used to estimate the population for the year 2021, and estimate the water requirement for domestic use at sub basin level
Livestock Census	Kolar district at a glance 2010-2016 (http://www.kolar.nic.in)	Taluk level data was used to estimate the livestock population and estimate water requirement at each of the river basins.

Digital Elevation data	Cartosat DEM from NRSC-Bhuvan (http://bhuvan.nrsc.gov.in)	Carto-DEM of 30m resolution. Used to derive the catchment boundaries, stream networks in association with Google earth and Toposheets
Secondary Data	Google Earth (http://earth. google.com), Bhuvan (http://bhuvan.nrsc.gov.in), French Institute Maps (http://*www.ifpindia.org/.*), Western Ghats biodiversity portal (http:// thewesternghats.india*biodiversity.org/*), the Survey of India topographic maps (http://*www.surveyofindia.gov.in/*)	Supporting data in order to assist land use classification, delineation of streams/rivers/ Catchment, Geometric correction
Field data	GPS based field data, data form public (stratified random sampling of households)	Geometric Corrections, Land use classification, Crop water requirement, livestock water requirement estimate

2.2 METHOD: The method involved in evaluation of the hydrological status is as depicted in figure 2.4 and figure 2.5. Hydrologic assessment in the catchment involved 1) delineation of catchment boundary 2) land use analysis, 3) assessment of the hydro meteorological data, 4) analysis of population census data, 5) compilation of data through public interactions for assessing the water needs for livestock, agriculture/horticulture and cropping pattern, and 6) evaluation of hydrologic regime.

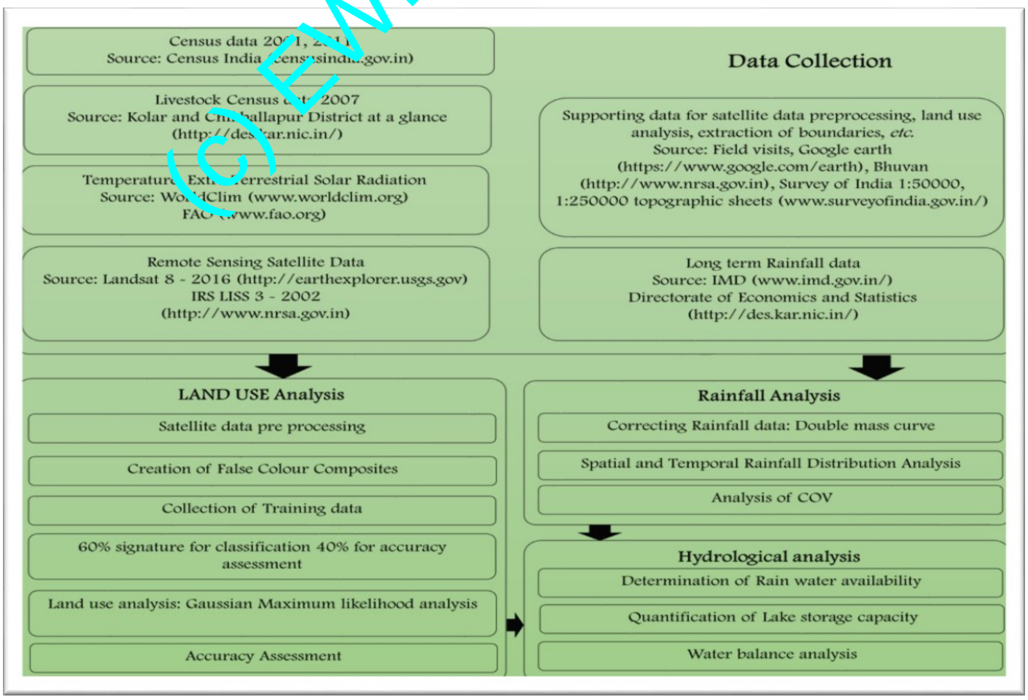


Figure 2.4: Protocol followed for hydrologic assessment

2.3 Delineation of catchment boundary: Catchment boundaries and the stream networks (Figure 1.1) considering the topography of the terrain based on CartoSat DEM were delineated using the hydrologic modeling tool in GRASS GIS. These catchment boundaries were overlaid on the extracted boundaries from the Survey of India topographic maps in order to check and correct the variations (if any due to errors in DEM), Corrected catchment boundaries were further overlaid on Google earth in order to visualize the terrain variations.

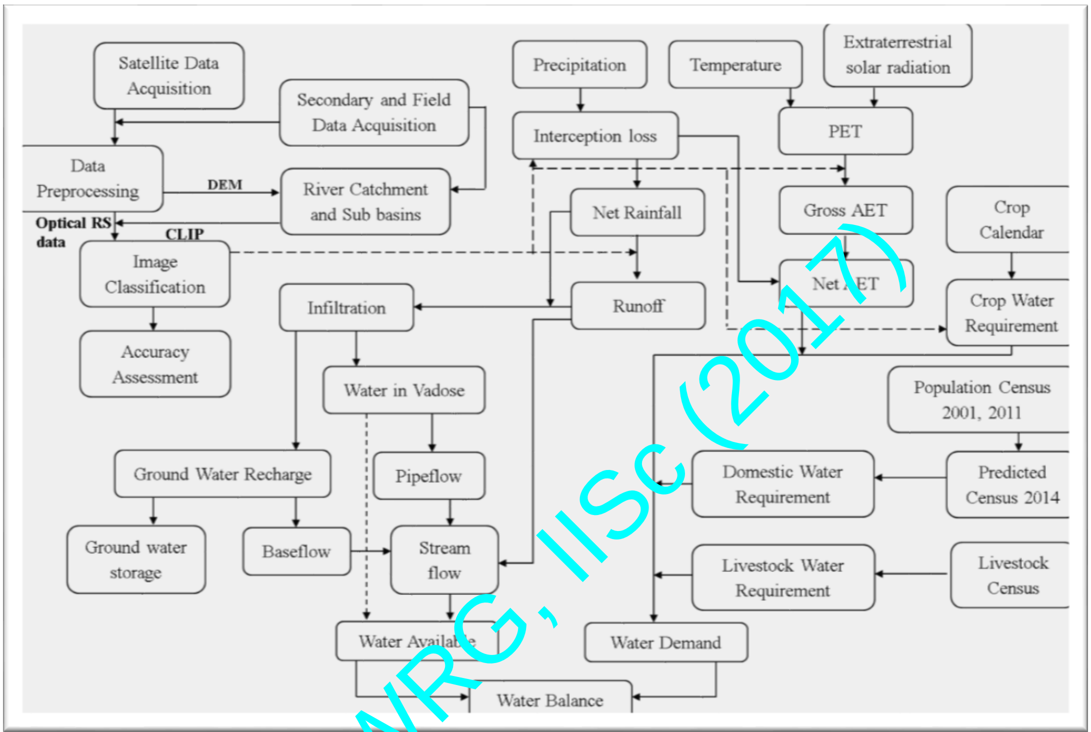


Figure 2.5: Component wise details of the method

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

Land use analysis involved i) generation of False Colour Composite (FCC) of remote sensing data (bands – green, red and NIR). This helped in locating heterogeneous patches in the landscape ii) selection of training polygons (these correspond to heterogeneous patches in FCC) 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. GPS helped in locating respective training polygons in the field, iv) supplementing this information with

Google Earth v) 65% of the training data has been used for classification, while the balance is used for validation or accuracy assessment. The process of assessing land use is as follows:

2.4.1 Satellite data acquisition: Satellite data sets for the whole world (earth) at different resolutions are available since 1972 (Landsat1) up to date. For the land use analysis, Landsat 8 (2013) data was obtained from the public domain (USGS: http://*earthexplorer.usgs.gov/). Survey of India (SOI) topo-sheets of 1:50000 and 1:250000 scales were used to generate base layers of catchment boundary, stream network, etc.*

2.4.2 Data pre-processing: The remote sensing data obtained were geo-referenced, rectified and cropped pertaining to the study area. Geo-registration of remote sensing data (Landsat data) has been done using ground control points collected from the field using pre calibrated GPS (Global Positioning System) and also from known points (such as road intersections, etc.) collected from geo-referenced topographic maps published by the Survey of India and from online BHUVAN portal (http://bhuvan.nrsc.gov.in).

3.0 Preparation of False Colour Composite: False colour composite is the representation of earth features in their non-original colours in order to identify the heterogeneity in various landscapes. FCC is prepared by combination of spectral bands NIR, GREEN and RED bands. Figure 2.4 depicts FCC of the catchments.

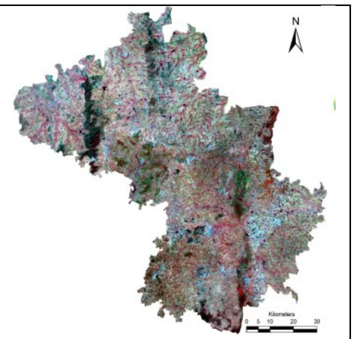
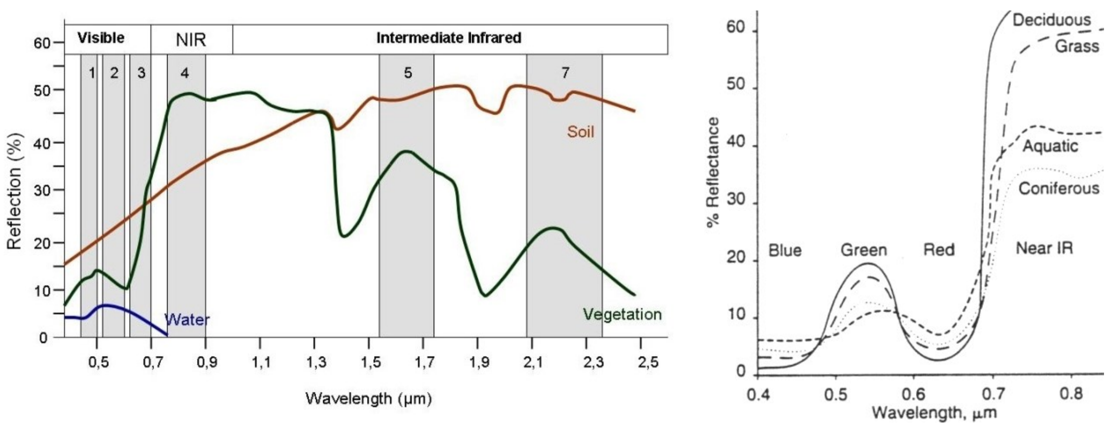


Figure 2.4: False Color Composite **(FCC)** – Kolar and Chikballapur districts

2.4.3 ***Preparation of signature data set:*** Signatures are the training datasets (training polygons) which are used to classify the satellite image into various land use classes based. Signatures were developed for various land use categories based on the site knowledge [Field data, Topographic maps (the Survey of India: http://surveyofindia.gov.in), Google earth (http://www.googleearth.com), Bhuvan (http://bhuvan.nrsc.gov.in), Western Ghats Biodiversity Portal (thewesternghats.indiabiodiversity.org/), French institute vegetation, geoclimate and soil maps (*www.ifpindia.org/.../data-paper-—high-resolution-**vegetation**-cover-data-southern-western-ghats-india*)] and based on spectral properties of landscape elements (Figure 2.5). Training data collected spread uniformly across the study area covering at least 15% of the total area.



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

Figure 2.5: Spectral properties of diverse landscape elements

2.4.4 ***Classification of Satellite image:*** Land use analysis was carried out using supervised pattern classifier - Gaussian maximum likelihood algorithm. The classifier computes the mean and variance of digital numbers under each training data set, based on which unknown pixel is categorized under a land use class. Recent remote sensing data (2016) was classified using the collected training samples. Statistical assessment of classifier performance based on the performance of spectral classification considering reference pixels is done which include computation of kappa (κ) statistics and overall (producer's and user's) accuracies. For earlier time data, training polygon along with attribute details were compiled from the historical published topographic maps, vegetation maps, revenue maps, etc. Of the overall signatures, 65% of the total signatures are considered in classification of the image and 35% of the pure signatures are used for assessing the accuracy. Land use was computed using the temporal data through open source program GRASS - Geographic Resource Analysis Support System (http://ces.iisc.ernet.in/grass). Land use categories include i) Water bodies (Lakes/tanks, rivers, streams, ii) Built up (buildings, roads or any paved surface, iii) Open Spaces iv) Evergreen forest (Evergreen and Semi Evergreen), v) Deciduous forest (Moist deciduous and dry deciduous) vi) Scrub land and grass land, vii) Agriculture Plantation (coconut, arecanut, rubber) viii) Forest plantations (Acacia, etc.)

2.4.5 ***Accuracy assessment:*** Accuracy is necessary in order to check if the classified remote sensing data agrees with the reference data. The reference data is based on the field data, or collateral data. Kappa is estimated as a measure of agreement between the reference map and the classified map.

2.5 Assessment of the hydro meteorological data: The method involved assessment of the rainfall data obtained from various sources such as TRMM (http://trmm.gsfc.nasa.gov/), data from local rain gauge stations (http://des.kar.nic.in) in and around the study site. Long term precipitation data helped in understanding the rainfall variability over decades. Iso-lines across the months were developed based on the spatial rainfall variation of rainfall w.r.t the rain gauge stations across the basin. Along with rainfall, temperature (minimum, maximum and average), extra-terrestrial solar radiation across the catchment were used to hydrological behaviors of the catchments which enables to understand the hydrological status.

2.5.1 *Rainfall:* Point based daily rainfall data from various rain gauge stations in and around the study area between 1901 and 2015 were considered for analysis of rainfall. The rainfall data used for the study were obtained from

i. Directorate of economics and statistics, Government of Karnataka (http://des.kar.nic.in)
ii. Indian metrological data (IMD), Government of India (http://imdpune.gov.in)
iii. Tropical rainfall Measuring Mission (TRMM), NASA (http://trmm.gsfc.nasa.gov/),

Some rain gauge stations had incomplete records with missing data for few months. Missing data's were computed based on neighboring stations and also through regression analysis. Rainfall trend analysis was done for select rain gauge stations to assess the variability of rainfall at different locations in the study area.

Long term daily rainfall data were used to compute the monthly and annual rainfall in each rain gauge station based on mean and standard deviation of select rain gauge stations in the study region. The average monthly and annual rainfall data were used to derive rainfall throughout the study area through the process of interpolation (isohyets). The interpolated rainfall data was used to derive the gross yield (R_G) in the basin (given in equation 1). Net yield (R_N) was quantified (equation 2) as the difference between gross rainfall and interception (In).

$$R_G = A * P \text{ ....(1)}$$

$$R_N = R_G - In \text{ ......(2)}$$

Where

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

2.5.2 *Runoff*: This is the portion of rainfall that flows in the streams after precipitation. Runoff can be typically divided into two categories 1) Surface runoff or direct runoff 2) sub surface runoff

Surface runoff: Portion of water that directly enters into the streams during rainfall, which is estimated based on the empirical equation 3.

$$Q = \Sigma(C_i * P_R * A_i) \;......(3)$$

Where Q: Runoff in cubic meters per month

C: Runoff Coefficient which is dependent upon various land uses (listed in table 2.2 based on land use type)

P_R: Net rainfall in mm (Gross rainfall – Interception)

i: Land use type

Table 2.2: Runoff Coefficients

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

2.5.3 Interception: During monsoons, portion of rainfall does not reach the surface of the earth, it remains on the canopy of trees, roof tops, etc. and gets evaporated. Field studies in Western Ghats show that, losses due to interception is about 15% to 30%, based on the land use. Table 2.3 shows the interception loss across various rainy months and land uses.

Table 2.3: Interception loss

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

2.5.4 Infiltration: Due to precipitation, the portion of water enters the subsurface of the earth (vadoze and groundwater zones). Only after saturation of sub surfaces, overland flow is noticed in streams. The water stored in sub-surfaces will flow laterally towards streams and contributes to stream flow during non-monsoon periods, which are referred as pipe flow (during post monsoon) and base flow (during summer).

$$\mathbf{Inf = R_N - Q} \;\ldots\ldots(4)$$

2.5.5 Ground water recharge: This is the portion of water that is percolated below the soil stratum (vadose) after soil gets saturated. Recharge is considered the fraction of infiltrated water that recharges the aquifer after satisfying available water capacity and pipe flow. Equation 5 (Krishna Rao equation, 1970) was used to determine the ground water recharge.

$$\mathbf{GWR = R_C * (P_R - C) * A} \;\ldots\ldots(5)$$

Where

GWR : Ground water recharge

R_C : Ground water recharge coefficient (listed in table 2.4)

C : Rainfall Coefficient

A : Area of the catchment

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

Table 2.4: Ground water recharge coefficients

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

2.5.6 Subsurface Flow (Pipe flow)**:** Part of the infiltrated effective rainfall circulates more or less horizontally (lateral flow) in the superior soil layer and appears at the surface through stream channels is referred as subsurface flow. The presence of a relatively impermeable shallow layer favours this flow. Subsurface flows in water bearing formations have a drainage capacity slower than superficial flows, but faster than groundwater flows. Pipe flow is considered to be the fraction of water that remains after infiltrated water satisfies the available water capacities under each soil. Pipe flow is estimated for all the basins as function of infiltration, ground water recharge and pipe flow coefficient, given by equation 6

$$\mathbf{P_F = (Inf - GWR) * K_P} \;\ldots\ldots(6)$$

Where

P_F : Pipeflow

Inf : Infiltration volume

K_P : Pipe flow coefficient

2.5.7 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. 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 after monsoon and pipeflow has receded. This water generally sustains flow in the rivers during the dry season.

$$\mathbf{GWD = GWR * Y_S} \text{ ...... (7)}$$

Where

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

2.6 Estimation of Water Demand

2.6.1 Evapotranspiration: Evaporation is a process where in water is transferred to atmosphere as vapour. Transpiration is the process by which water is released to the atmosphere from plants through leaves and other parts above ground. In the process of transpiration water is taken into the atmosphere from ground (soil) through the roots. On the other hand, evaporation continues throughout the day and night at different rates. The process of evaporation takes place on all different land uses. Evapotranspiration is the total water lost from different land use due to evaporation from soil, water and transpiration by vegetation. Some of the important factors that affect the rate of evapotranspiration are: (i) temperature, (ii) wind, (iii) light intensity, (iv) sunlight hours, (v) humidity, (vi) plant characteristics, (vii) land use type and (viii) soil moisture. If sufficient moisture is available to completely meet the needs of vegetation in the catchment, the resulting evapotranspiration is termed as potential evapotranspiration (PET). The real evapotranspiration occurring in specific situation is called as actual evapotranspiration (AET). These evapotranspiration rates from forests are more difficult to describe and estimate than for other vegetation types.

Potential evapotranspiration (PET) is determined using Hargreaves method (Hargreaves, 1972) an empirical based radiation based equation, which is shown to perform well in humid climates. PET is estimated as mm using the Hargreaves equation is given by equation 8.

$$\mathbf{PET = 0.0023 * (R_A/\lambda) * \sqrt{Tmax - Tmin} * \left(\frac{Tmax+Tmin}{2} + 17.8\right)} \text{ ...... (8)}$$

Where

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

Tmax = Maximum temperature

Tmin = Minimum temperature

λ = latent heat of vapourisation of water (2.501 MJ/kg)

Actual evapotranspiration is estimated as a product of Potential evapotranspiration (PET) and Evapotranspiration coefficient (K_C) (table 2.5), given in equation 9. The evapotranspiration coefficient is a function of land use varies with respect to different land use. Table 2.5 gives the evapotranspiration coefficients for different land use

$$AET = PET * K_C \quad ......(9)$$

Table 2.5: Evapotranspiration coefficient

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

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

2.6.2 Domestic water demand: Understanding the population dynamics in a region is necessary to quantify and also to predict the domestic water demand. Population census for villages during 2001 and 2011 were considered in order to compute the population of the basin level. Based on the rate of change of population (equation 10), the population for the year 2014 was predicted as given in equation 11.

$$r = (P_{2011}/P_{2001} - 1)/n \quad ......(10)$$

Where

P_{2001} and P_{2011} are population for the year 2001 and 2011 respectively

n is the number of decades which is equal to 1; r is the rate of change

$$P_{2021} = P_{2021} * (1 + n*r) \quad ......(11)$$

Where

P2021 is the population for the year 2021; n is the number of decades

Domestic water demand is assessed as the function of water requirement per person per day, population and season. Water required per person include water required for bathing, washing, drinking and other basic needs. Water requirements across various seasons are as depicted in table 2.6.

Table 2.6: Seasonal water requirement

Season	Water lpcd
Summer	150
Monsoon	125
Winter	135

2.6.3 Livestock water requirement: Household surveys were conducted with the structured questionnaires to understand the agricultural cropping pattern and water needed for various crops in the catchment. Livestock population details were obtained from the district statistics office and water requirement for different animals were quantified based on the interviews. Table 2.7 gives the water requirement for various animals.

Table 2.7: Livestock water requirement

	Water Requirement in Liters per animal							
Season\Animal	**Cattle**	**Buffalo**	**Sheep**	**Goat**	**Pigs**	**Rabbits**	**Dogs**	**Poultry**
Summer	100	105	20	22	30	2	10	0.35
Monsoon	70	75	15	15	20	1	6	0.25
Winter	85	90	18	20	25	1.5	8	0.3

2.6.4 Crop water requirement: The crop water requirement for various crops was estimated considering their growth phase and details of the cropping pattern in the catchment (based on the data compiled from household surveys and publications such as the district at a glance, department of agriculture). Land use information was used in order to estimate the cropping area under various crops. Figure 2.8 provides the information of various crop water requirements based on their growth phase as cubic meter per hectare.

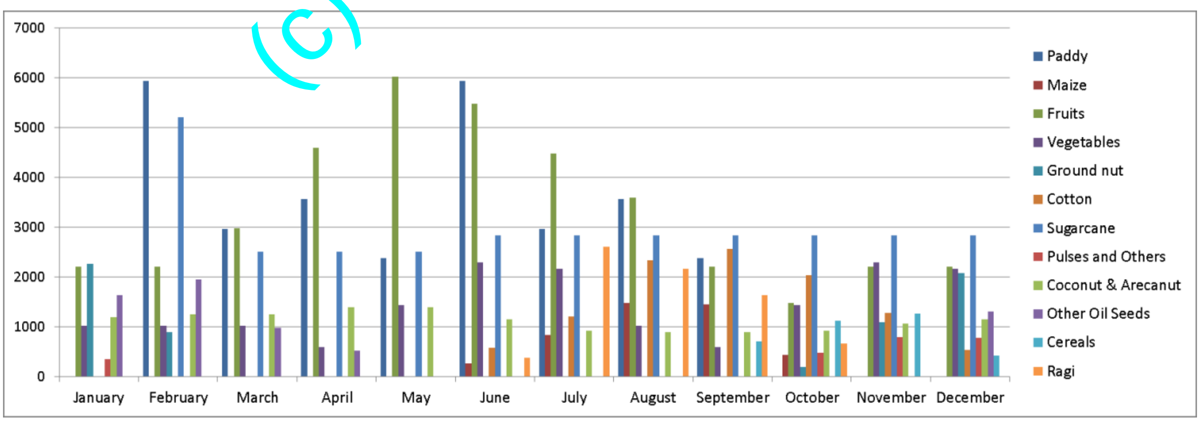


Figure 2.8: Crop water requirement (as cum per hectare per month)

2.7 Evaluating Hydrological Status: The hydrological status in the catchment is analysed for each month based on the water balance which take into account the water available to that of the demand. The water available in the catchment is function of water in the soil, run off (streams and river) and water available in the water bodies (Lentic water bodies such as lakes, etc.). Water demand in the catchment is estimated as the function of crop water demand, domestic and livestock demand and the evapotranspiration. The catchment is considered hydrological sufficient, if the water available caters the water demand completely else the deficit catchment, if the water demand is more than the water available in the system.

3.0 Results and Discussion

3.1 **Land use analysis:** Land use analysis was carried out using remote sensing data of 2016, and results are given in figure 3.1 and table 3.1. Major portion of the catchment is covered with degraded forest (6.5%), agriculture (33.9%), plantations (16.9%), etc. The accuracy of the land use classification is 87% with kappa of 0.82. Higher spatial extent of wastelands (38%) highlights the gross mismanagement of land resources in the region

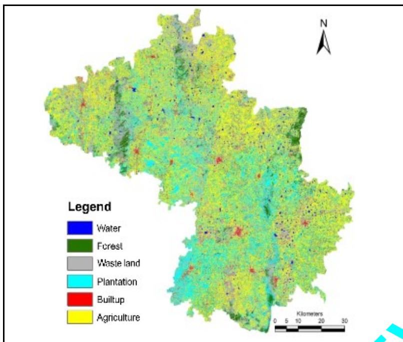


Fig 3.1: Land use (2016)

Land use - 2016	Area (%)
Water (Lakes, Rivers, Ponds)	1.8
Forest	6.5
Wastelands (Open/Quarries/Scrub lands)	38.0
Plantation (Horticulture/Forest plantations)	16.9
Built-up (Buildings, roads)	3.0
Agriculture (Fallow, Current sown)	33.9

Table 3.1: Land use statistics

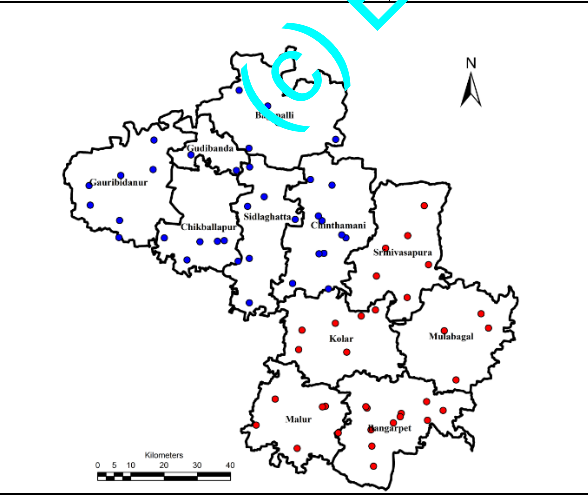
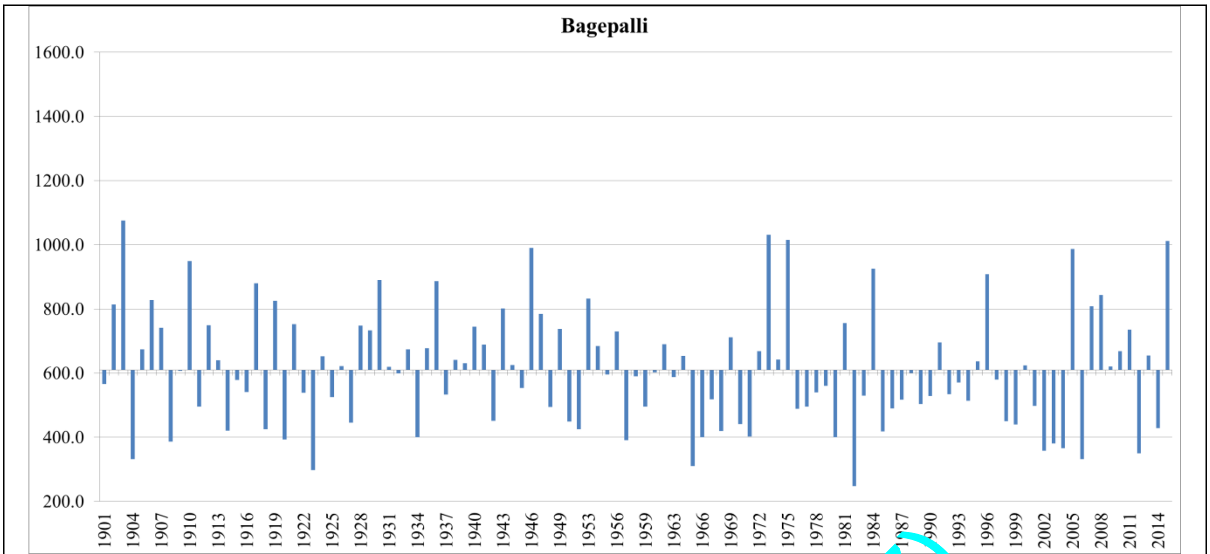


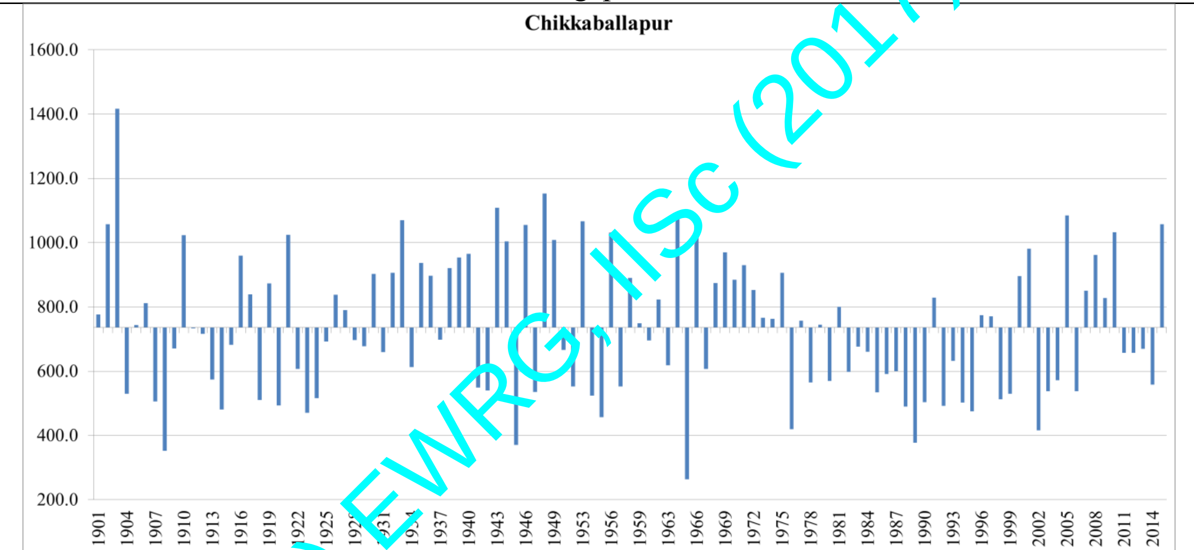
Fig 3.2: Spatial distribution of rain gauges

Variability of rainfall was assessed based on 70 rain gauge stations in the catchment (31 in Kolar and 39 are in Chikballapur) and the spatial distribution of these rain gauges are depicted in Figure 3.2. Talukwise temporal variations are depicted in Figure 3.3. Decadal variability is presented in Figure 3.4 (moving average, taluk wise). These analyses highlights of normal variability across the precipitation cycles and there is no significant decline in rainfall (as claimed by individuals with vested interests)

3.2 RAINFALL VARIATIONS ACROSS TIME AND SPACE



Bagepalli



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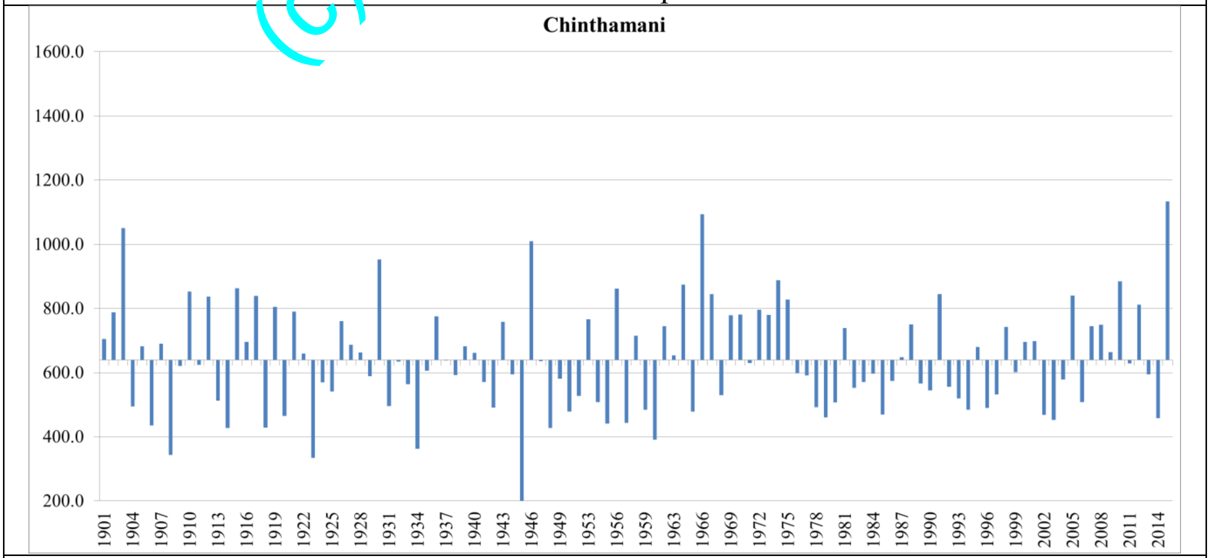

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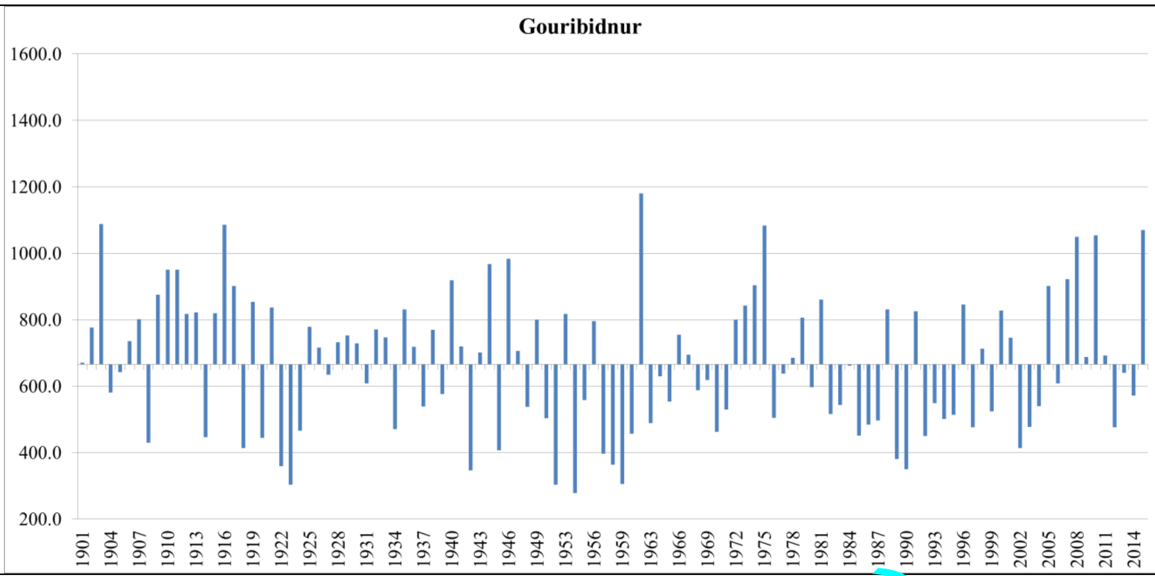

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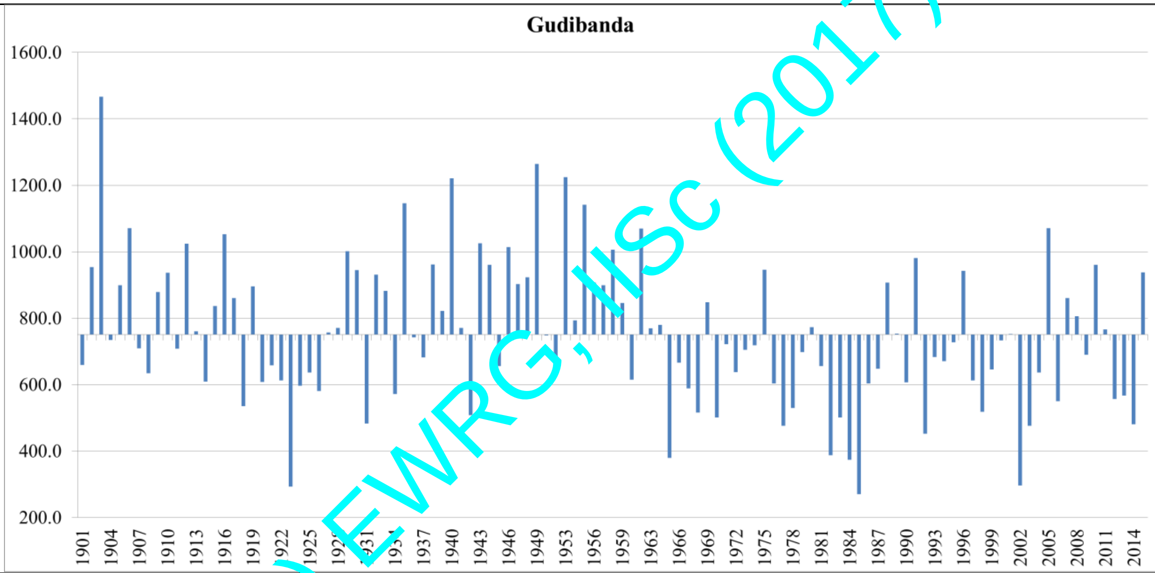

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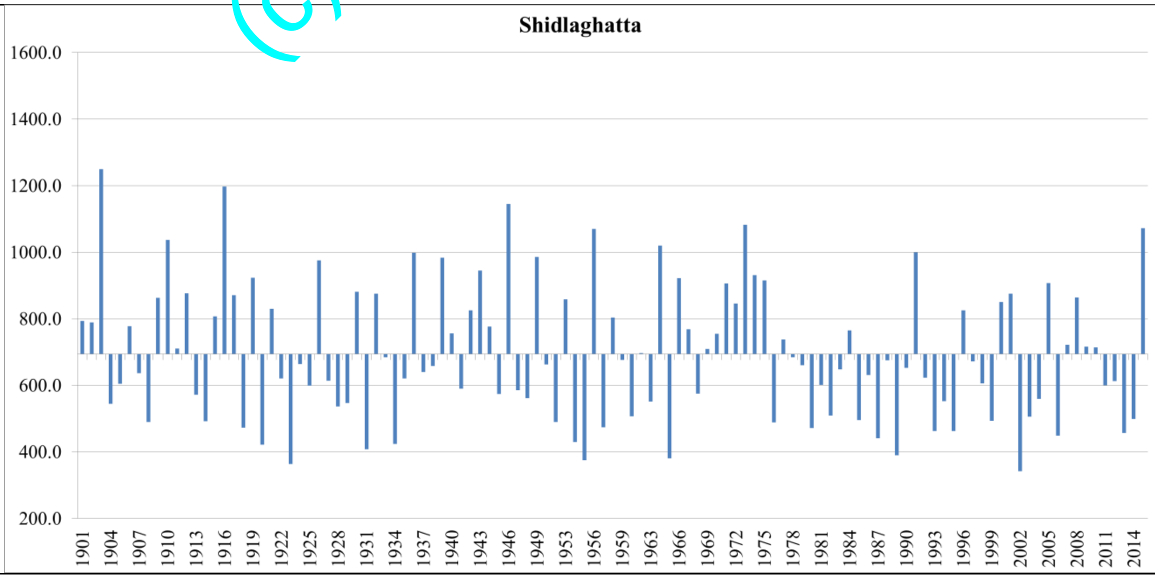

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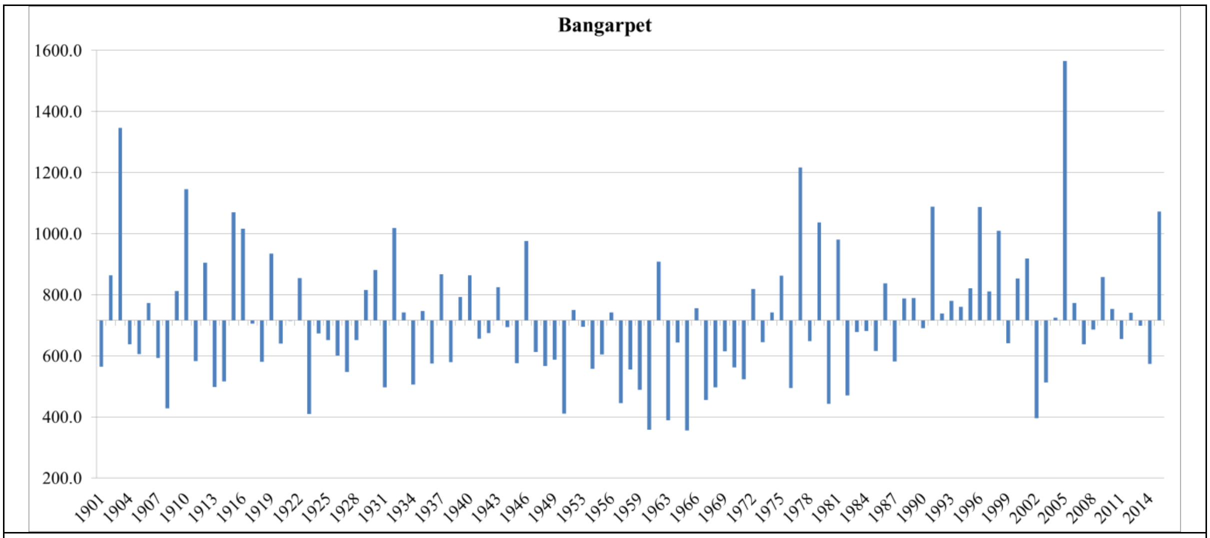

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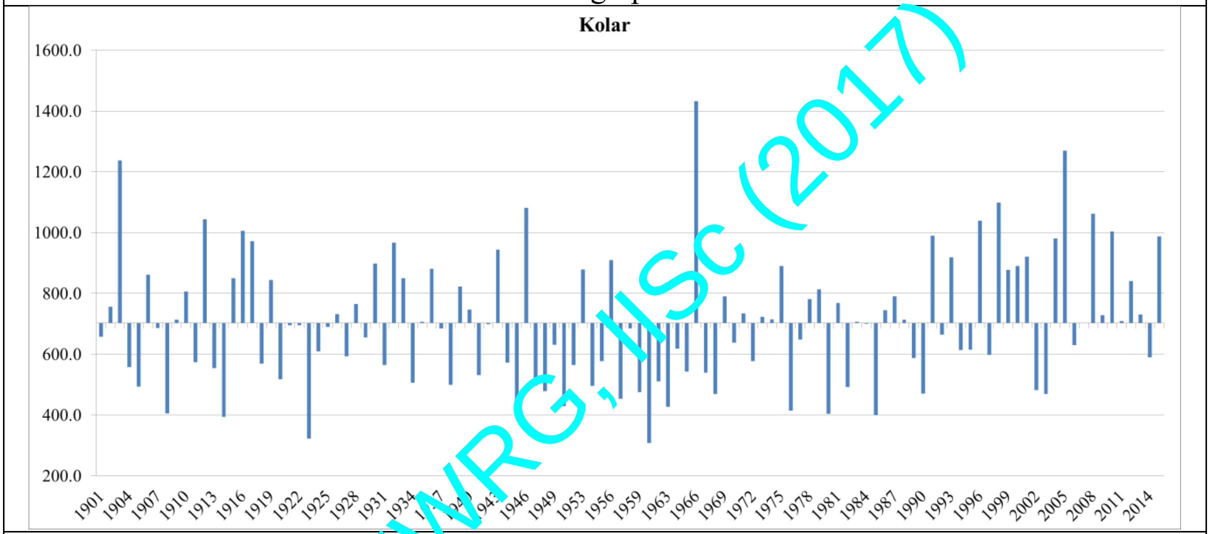
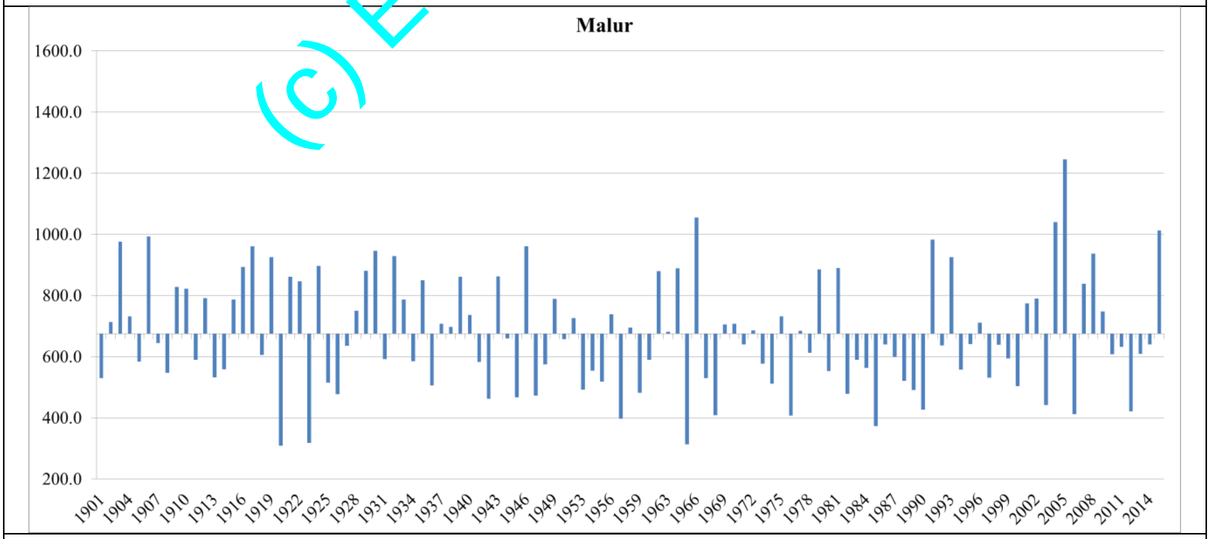
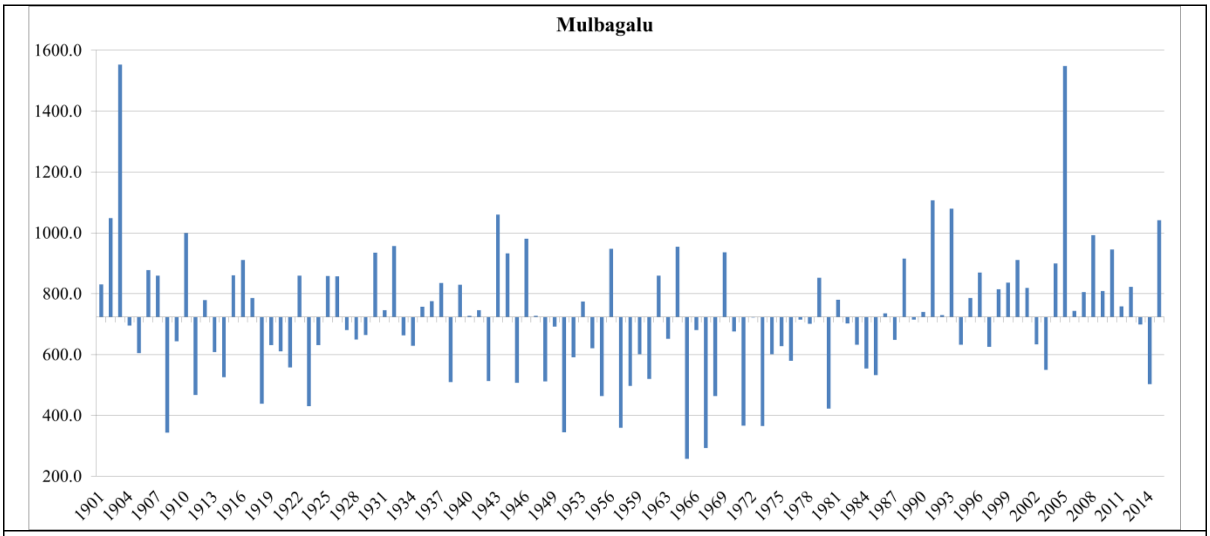


Kolar



Malur



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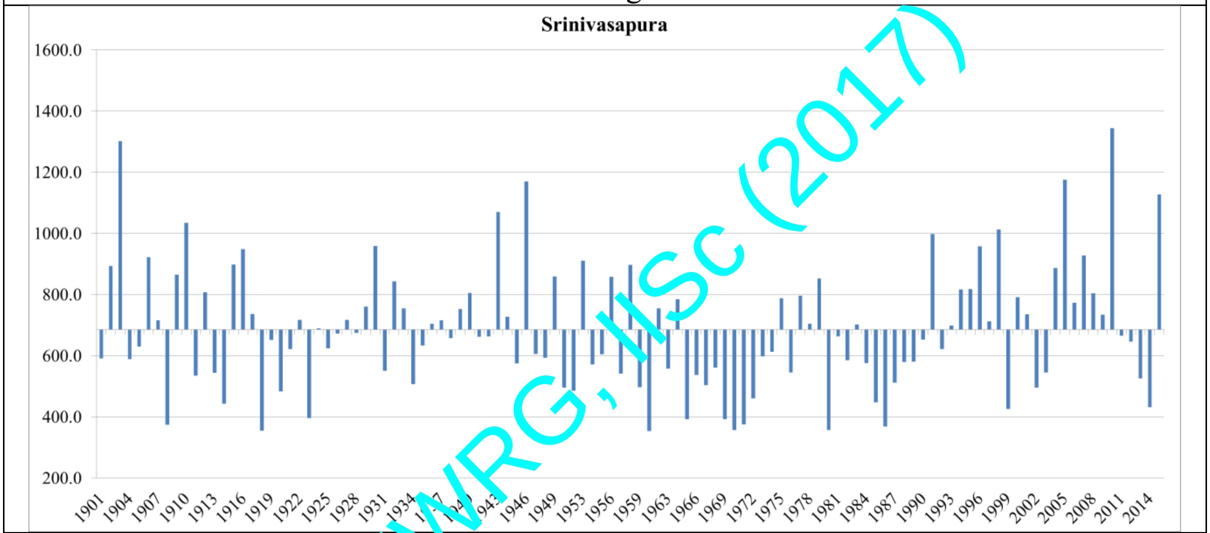
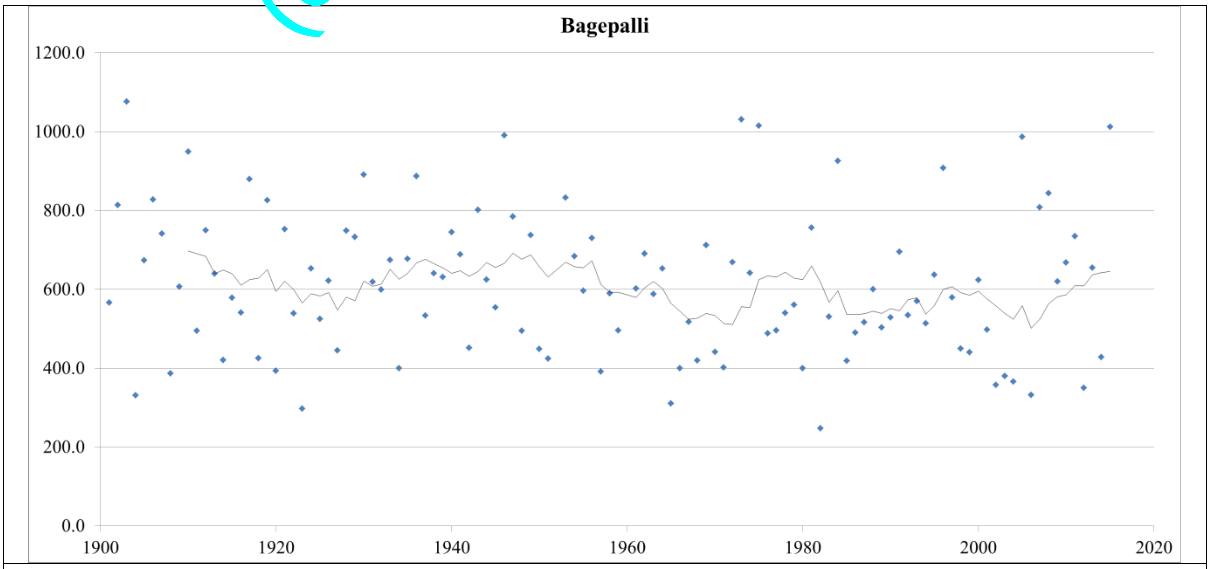
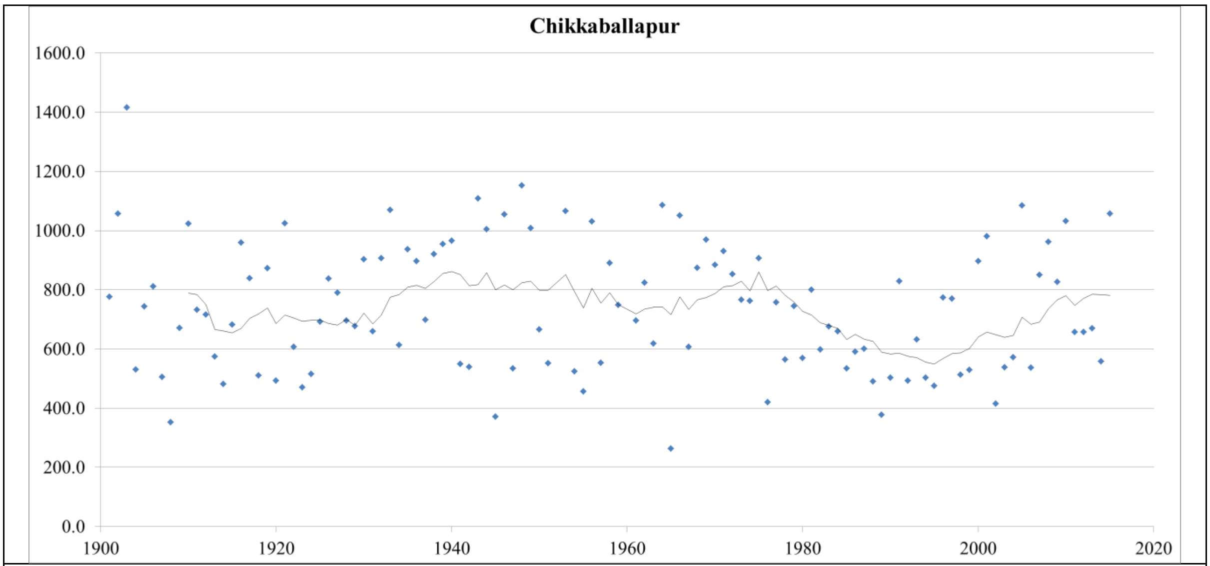


Srinivasapura

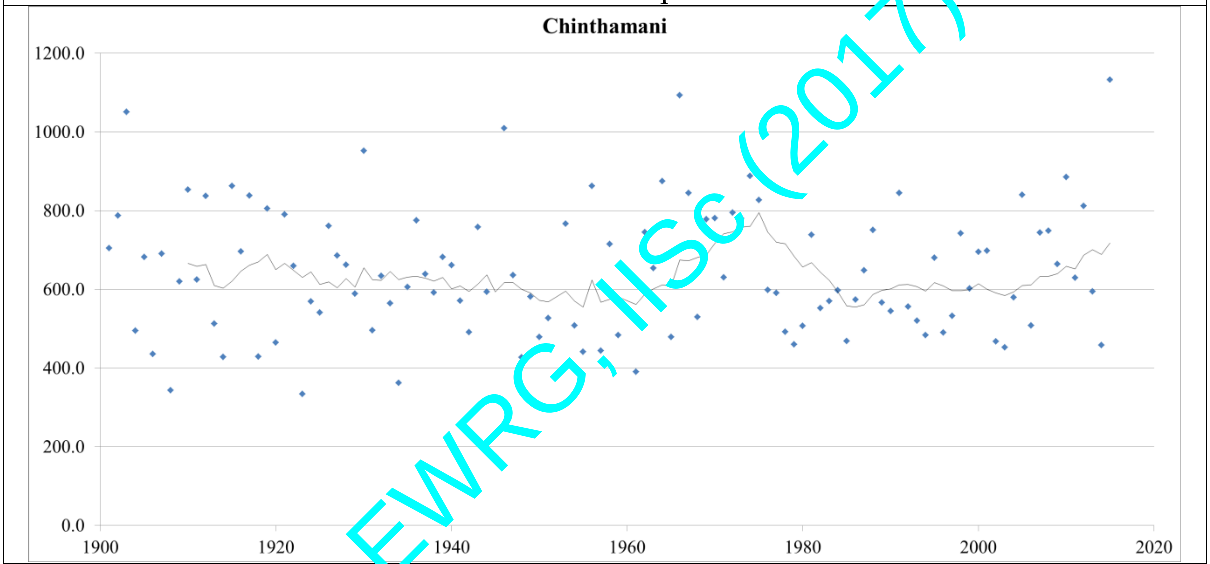
Figure 3.3: Rainfall distribution with respect to mean rainfall (X axis – years, Y axis – rainfall in mm)



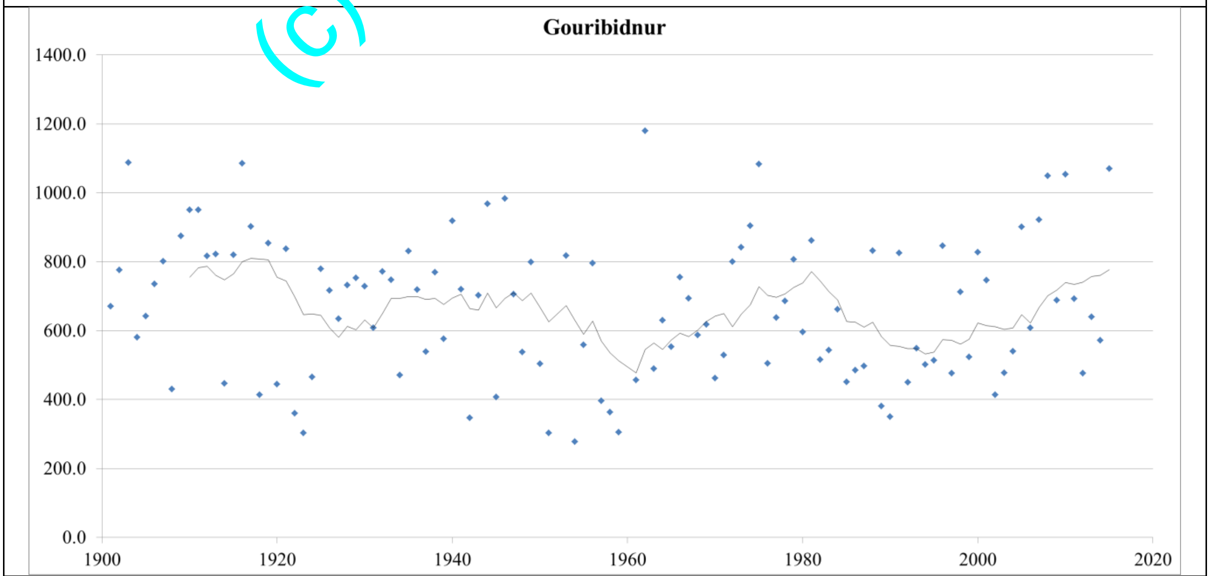
Bagepalli



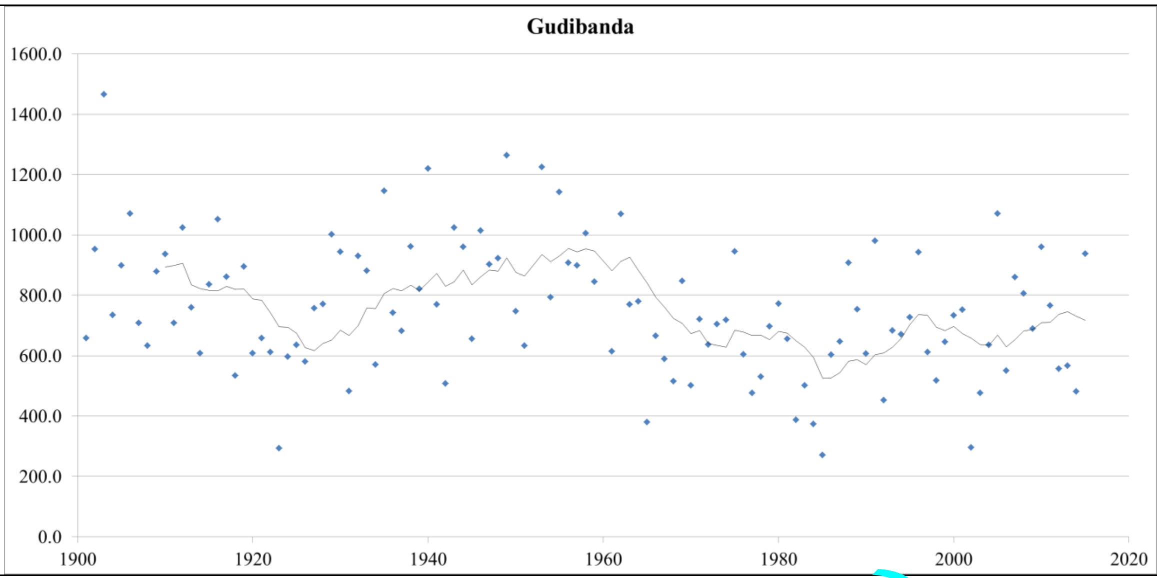
Chikkaballapur



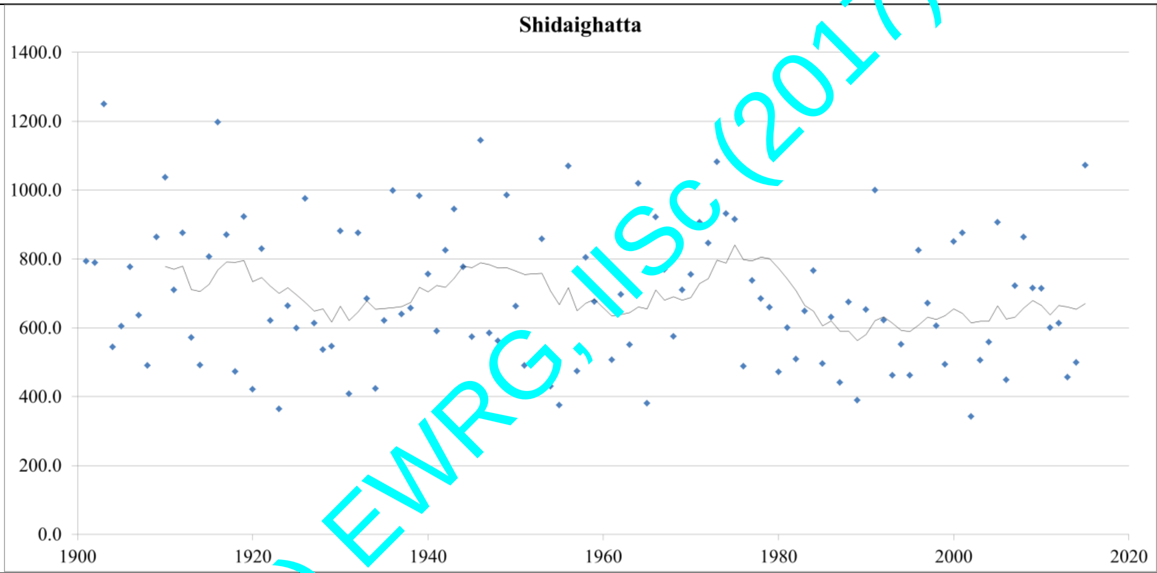
Chinthamani



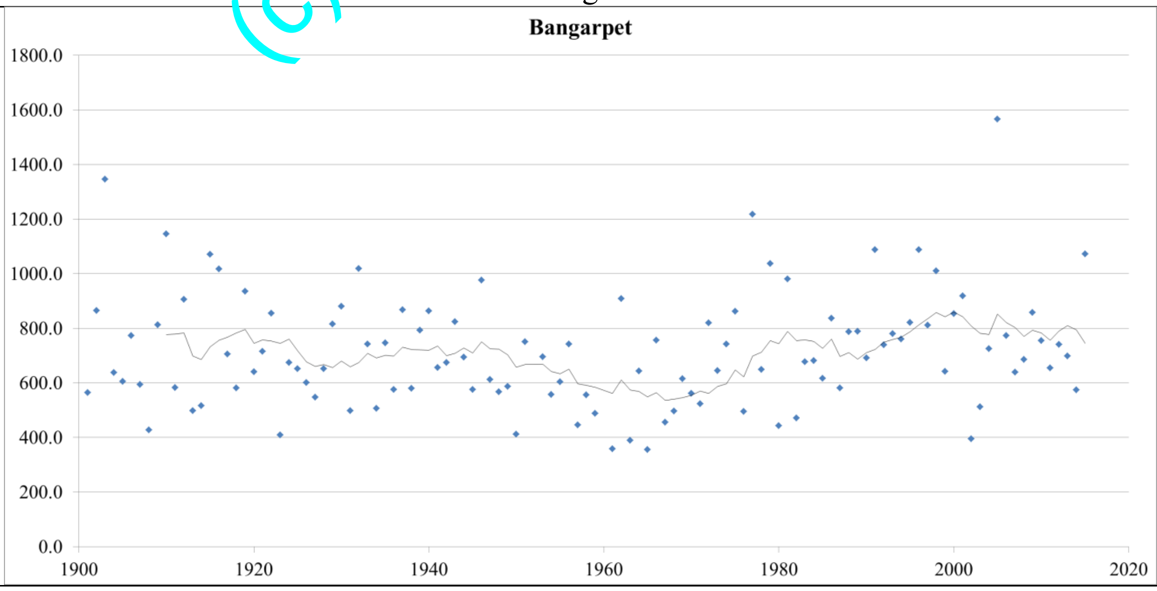
Gouribidnur



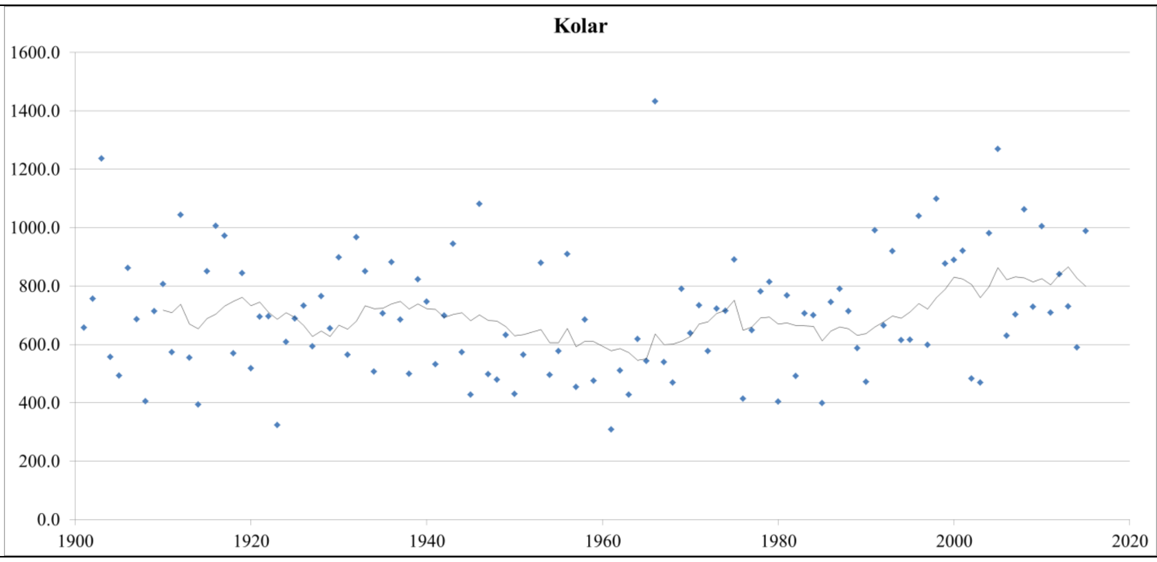
Gudibanda



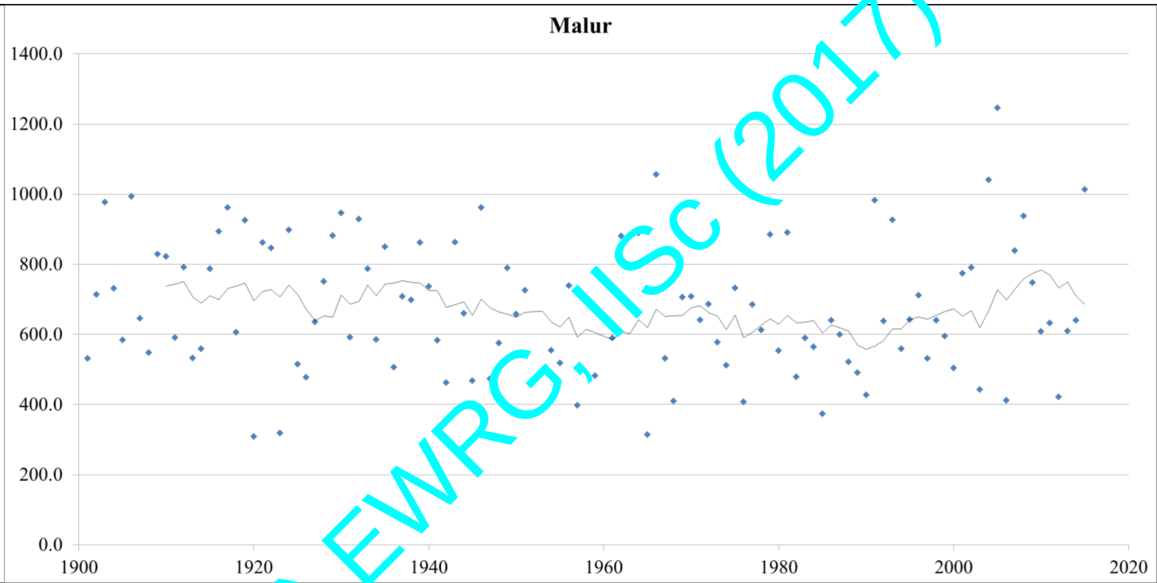
Shidlaghatta



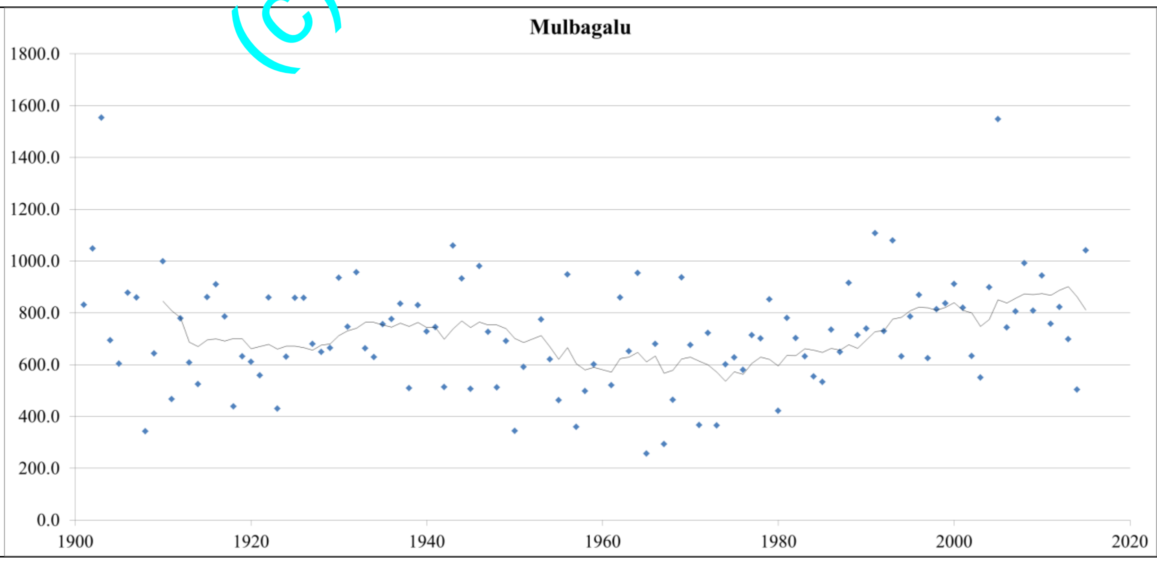
Bangarpet



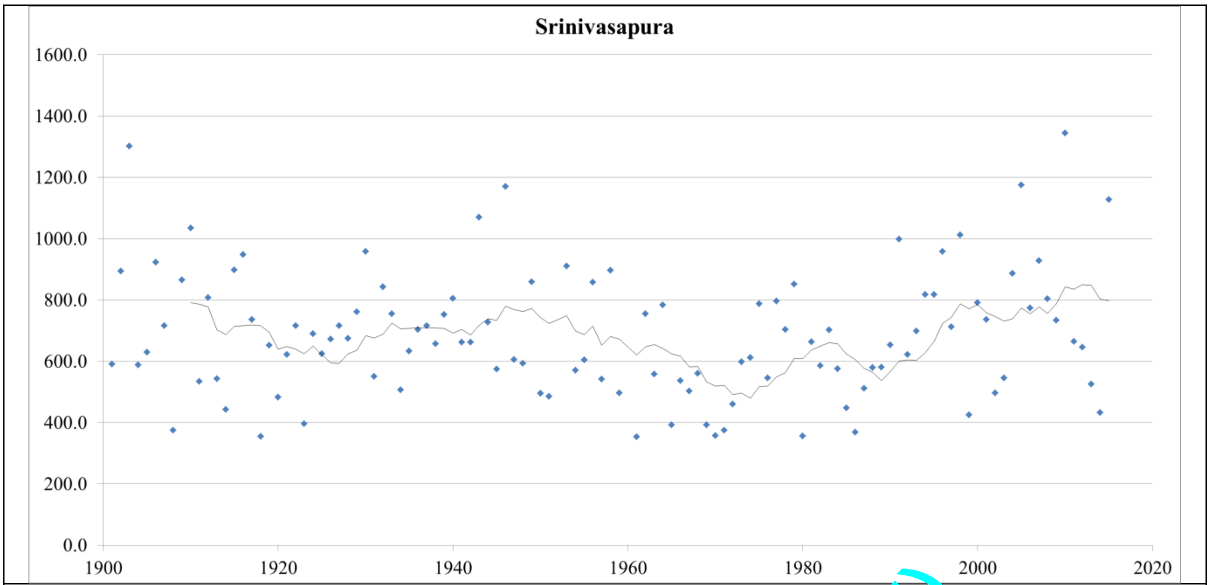
Kolar



Malur



Mulbaglu



Srinivasapura

Figure 3.4: Decadal rainfall moving average (X axis – Years, Y axis – Rainfall in mm)

Table 3.2: Rainfall frequency distribution, Kolar district (Rainfall in mm)

Frequency	Bangarpet	Kolar	Malur	Mulbaglu	Srinivasapura
< 400	4	4	5	7	10
400 - 500	12	**18**	14	7	10
500 - 600	**19**	**19**	**27**	13	**23**
600 - 700	**26**	**19**	**20**	**26**	**20**
700 - 800	**19**	**20**	**18**	**21**	**21**
800 - 900	15	14	15	**19**	14
900 - 1000	6	9	10	13	7
> 1000	12	10	4	7	8

Frequency of occurrences of rainfall (<400, 400-500, 500-600..), taluk wise for Kolar district is given in Table 3.2, which highlights Bangarpet has received in the region 600 -700 mm (23% years) and > 1000 mm during 12 years (of 113 years). Taluk wise rainfall dependability is given in Table 3.3 and Figure 3.5, which highlights that all taluks receives rainfall in the range 500-600 mm (>85% dependability). Rainfall range wise return period is computed and are listed in Table 3.4, which illustrates the return period of 6 years (for 500-600 mm) and 8 years (for 700-800 mm).

Table 3.3: Rainfall dependability, Kolar district(Rainfall in mm)

Dependability	Bangarpet	Kolar	Malur	Mulbaglu	Srinivasapura
< 400	100.0%	100.0%	100.0%	100.0%	100.0%
400 - 500	96.5%	96.5%	95.6%	93.8%	91.2%
500 - 600	85.8%	80.5%	83.2%	87.6%	82.3%
600 - 700	69.0%	63.7%	59.3%	76.1%	61.9%

700 - 800	46.0%	46.9%	41.6%	53.1%	44.2%
800 - 900	29.2%	29.2%	25.7%	34.5%	25.7%
900 - 1000	15.9%	16.8%	12.4%	17.7%	13.3%
> 1000	10.6%	8.8%	3.5%	6.2%	7.1%

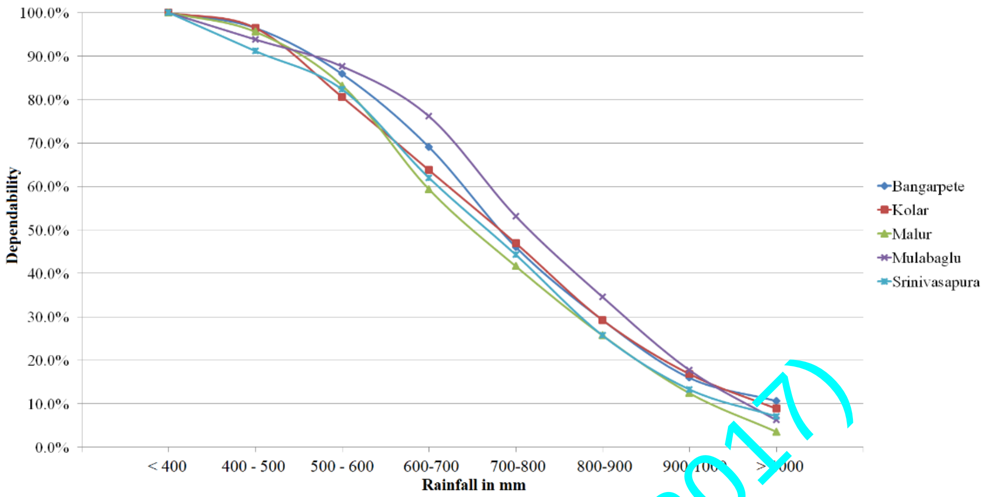


Figure 3.5: Rainfall dependability in Kolar District, Taluk wise

Table 3.4: Rainfall return period in years, Kolar district (Rainfall in mm)

Return Period	Bangarpet	Kolar	Malur	Mulbaglu	Srinivasapura
< 400	28	28	23	16	11
400 - 500	9	6	8	16	11
500 - 600	6	6	4	9	5
600 - 700	4	6	6	4	6
700 - 800	6	6	6	5	5
800 - 900	8	8	8	6	8
900 - 1000	10	13	11	9	16
> 1000	9	11	28	16	14

Frequency of occurrences of rainfall (<400, 400-500, 500-600..), taluk wise for Chikballapur district is given in Table 3.5, which highlights Chikballapur taluk has received in the region 600 -700 mm (23% years) and > 1000 mm during 17 years (of 113 years). Taluk wise rainfall dependability is given in Table 3.6 and Figure 3.6, which highlights that all taluks receives rainfall in the range 500-600 mm (>75% dependability). Rainfall range wise return period is computed and are listed in Table 3.7, which illustrates the return period of 6 years (for 500-600 mm) and 98 years (for 700-800 mm).

Month and season wise spatial variability is depicted in Figure 3.7. All taluks receives 75-100 mm rainfall during July-August and 100-125 mm during October-November. The region 700-750 mm during pre monsoon and 800-850 mm during north east monsoon. Similar analyses done for taluk is depicted in Figure 3.8.

Table 3.5: Rainfall frequency distribution, Chikkaballapura (Rainfall in mm)

Frequency	Bagepalli	Chikkaballapur	Chinthamani	Gouribidnur	Gudibanda	Shidlaghatta
< 400	15	4	5	10	6	5
400 - 500	**20**	9	**21**	**18**	5	19
500 - 600	**22**	**25**	**27**	**19**	14	17
600 - 700	**25**	**20**	**23**	14	**25**	**23**
700 - 800	12	12	18	**20**	**21**	14
800 - 900	10	14	14	16	12	15
900 - 1000	5	12	1	9	15	12
> 1000	4	17	4	7	15	8

Table 3.6: Rainfall dependability, Chikkaballapur district (Rainfall in mm)

Dependability	Bagepalli	Chikkaballapur	Chinthamani	Gouribidnur	Gudibanda	Shidlaghatta
< 400	100%	100%	100%	100%	100%	100%
400 – 500	87%	96%	96%	91%	95%	96%
500 – 600	69%	88%	77%	75%	90%	88%
600 – 700	50%	66%	53%	58%	78%	66%
700 – 800	27%	49%	33%	46%	56%	49%
800 – 900	17%	38%	17%	28%	37%	38%
900 – 1000	8%	26%	4%	14%	27%	26%
> 1000	4%	15%	4%	6%	13%	15%

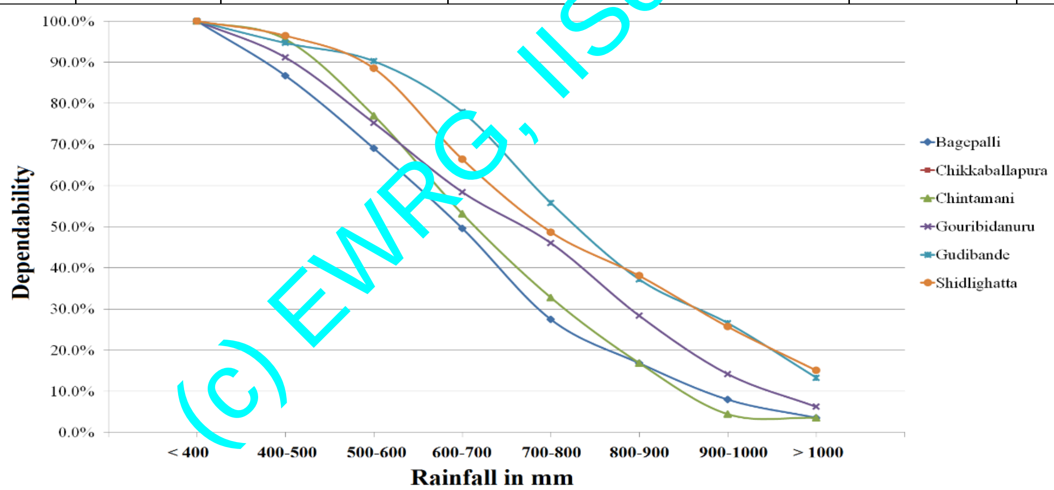


Figure 3.6: Rainfall dependability, Chikkaballapura District, Taluk wise

Table 3.7: Return Period in years, Chikkaballapura (Rainfall in mm)

Return period	Bagepalli	Chikkaballapur	Chinthamani	Gouribidnur	Gudibanda	Shidlaghatta
< 400	8	28	23	11	19	23
400 - 500	6	13	5	6	23	6
500 - 600	5	5	4	6	8	7
600 - 700	5	6	5	8	5	5
700 - 800	9	9	6	6	5	8
800 - 900	11	8	8	7	9	8
900 - 1000	23	9	113	13	8	9
> 1000	28	7	28	16	8	14

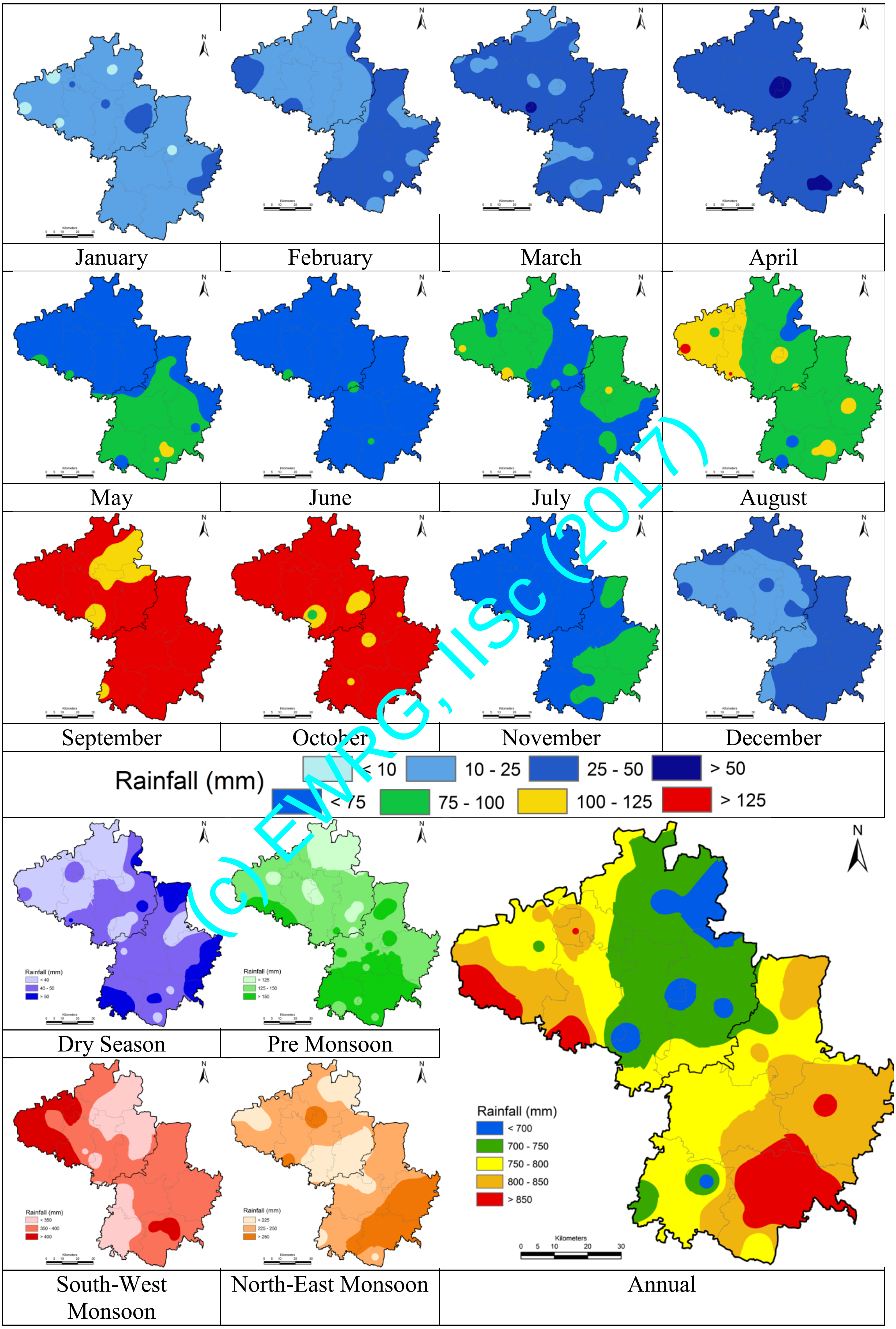


Figure 3.7: Rainfall distribution

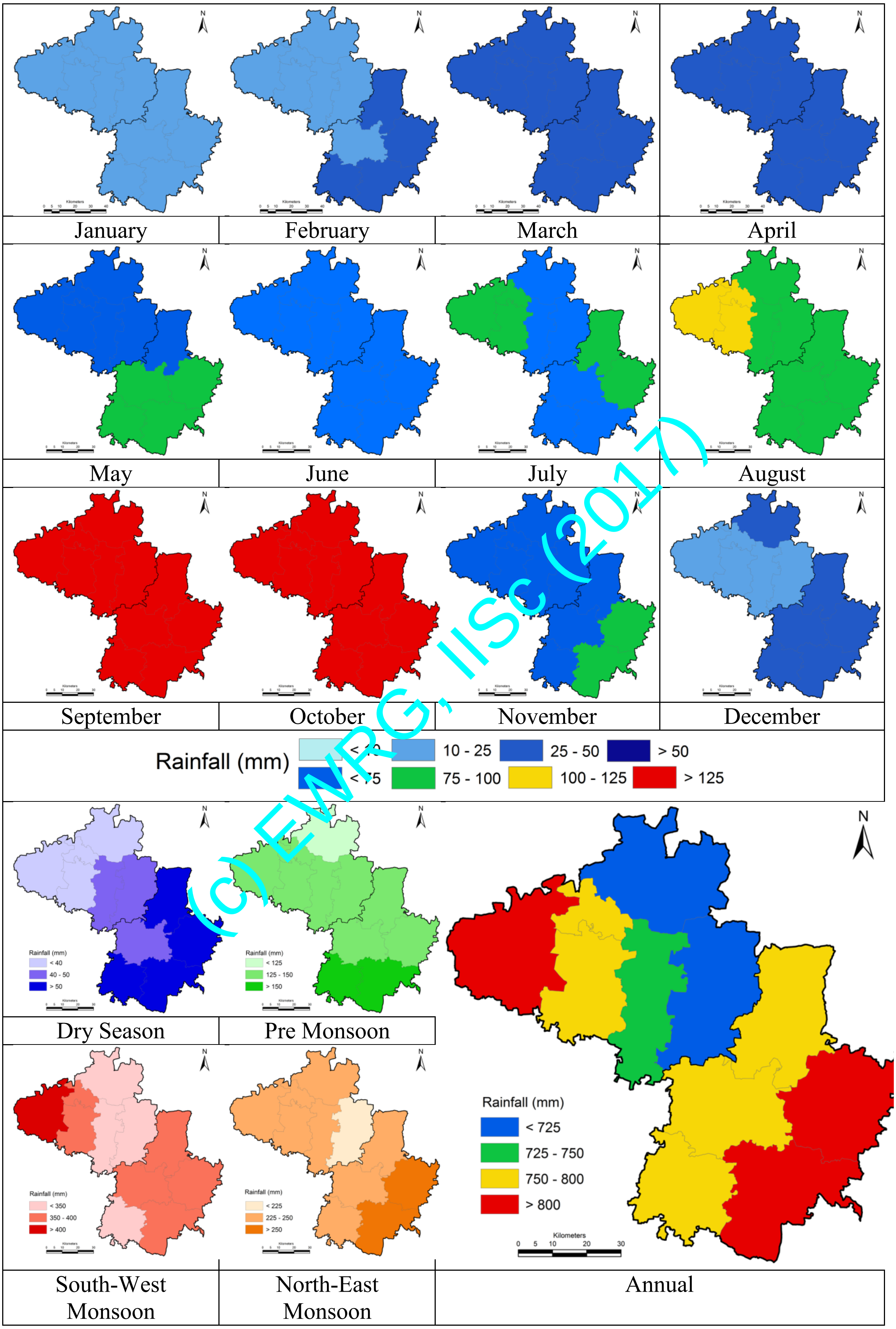
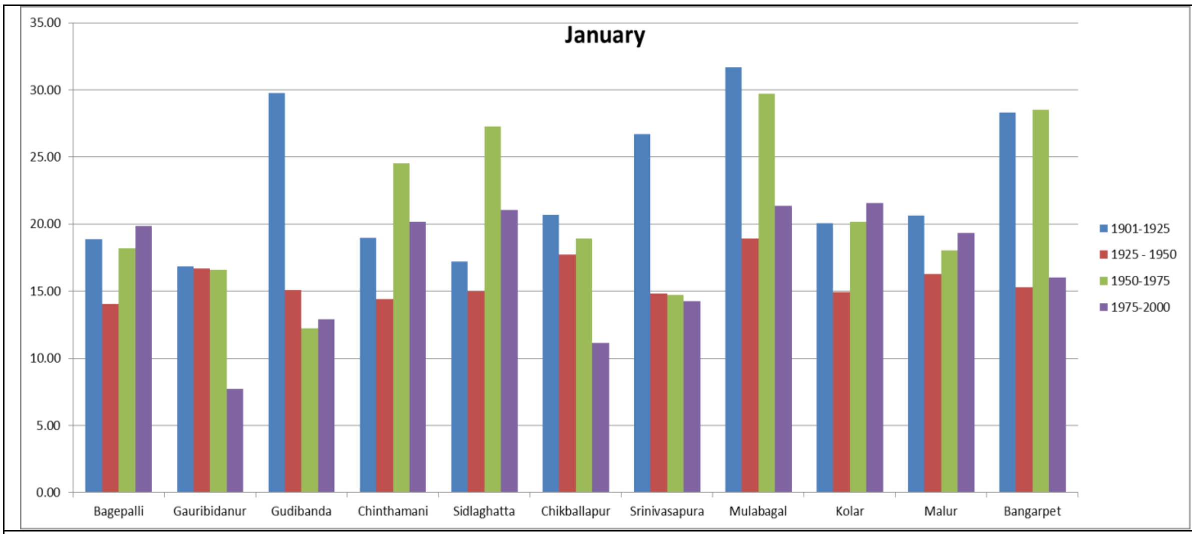


Figure 3.8: Taluk wise Rainfall distribution



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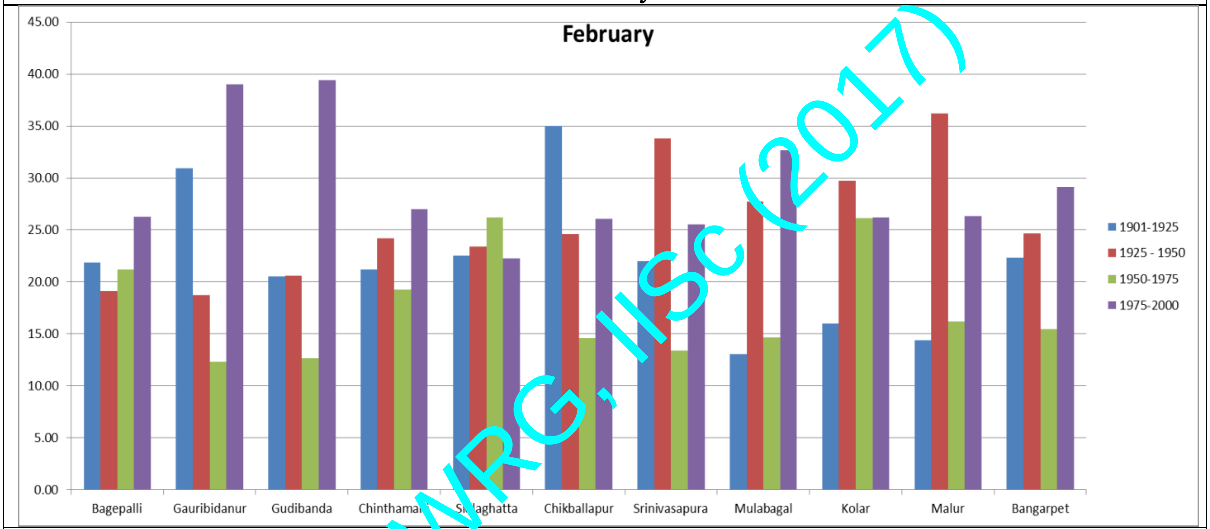

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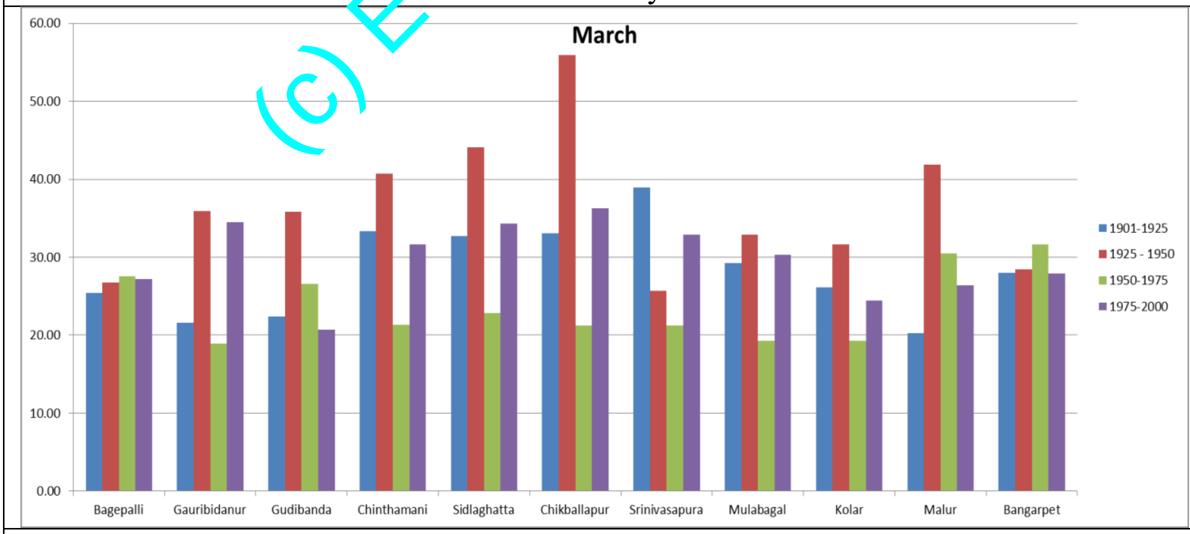

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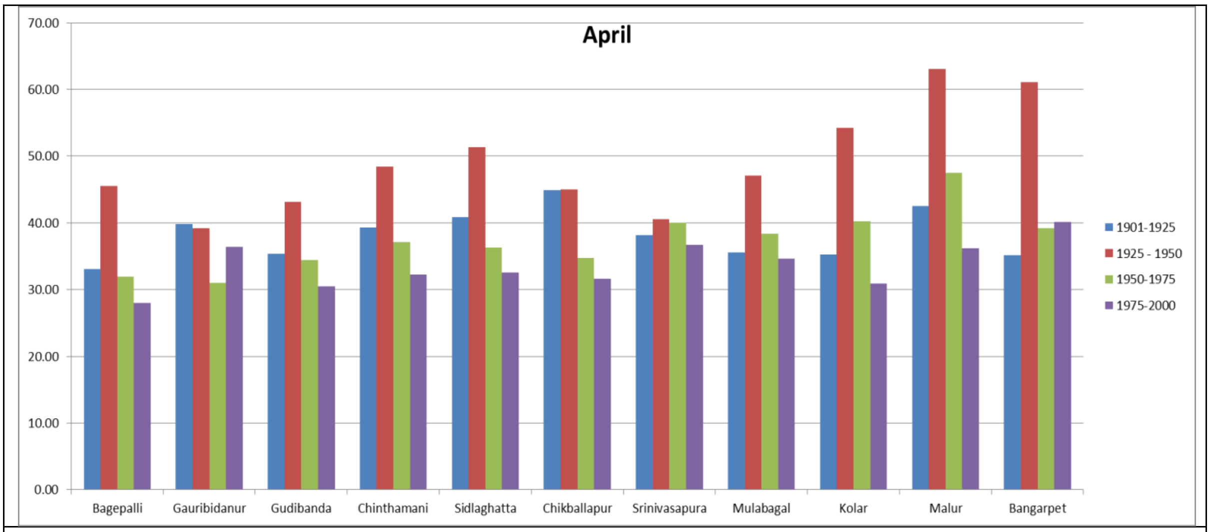
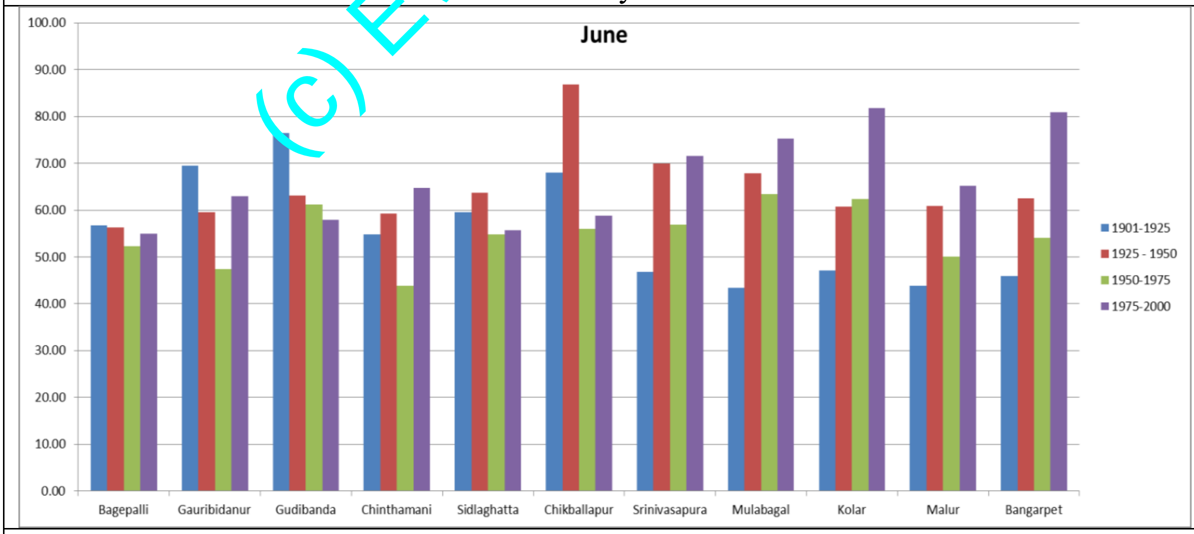


April

May



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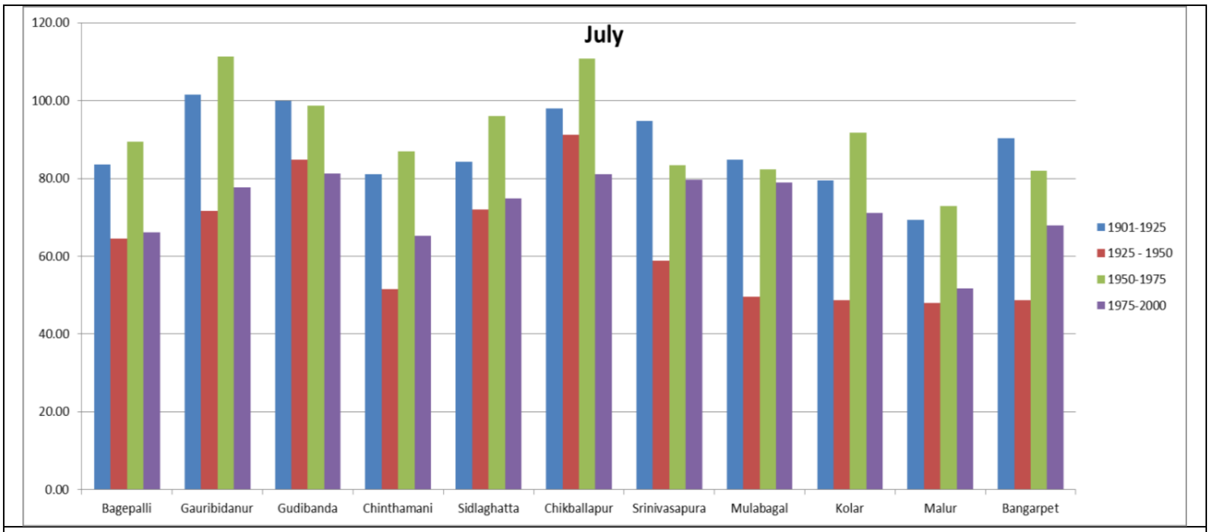

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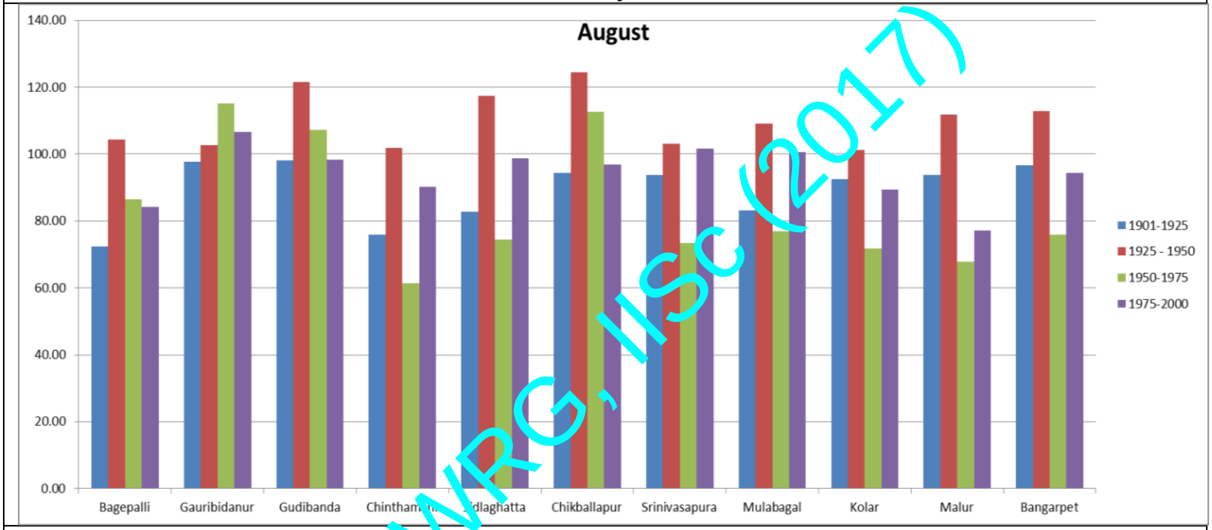

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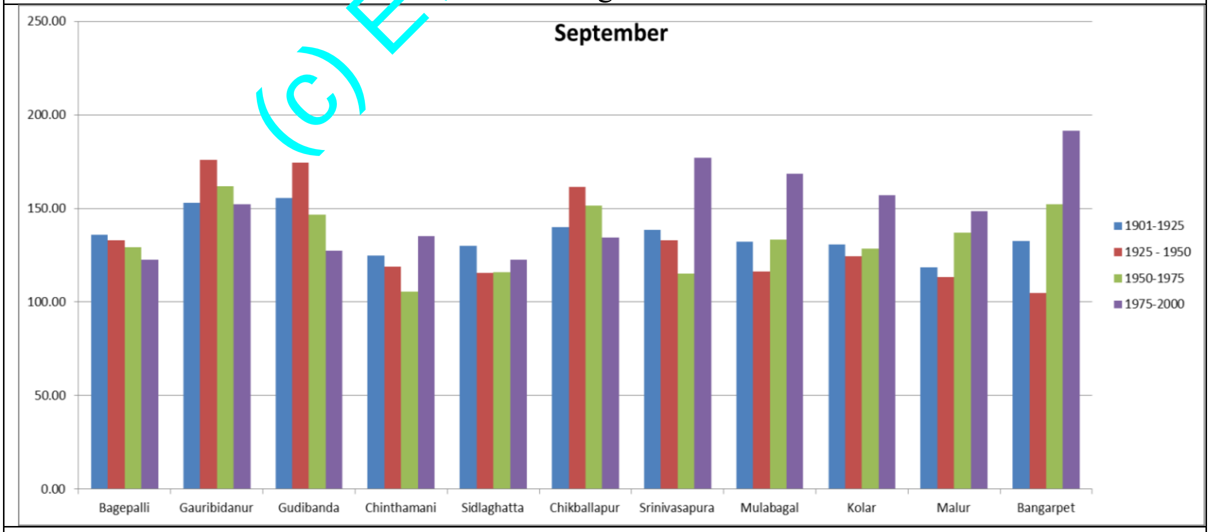
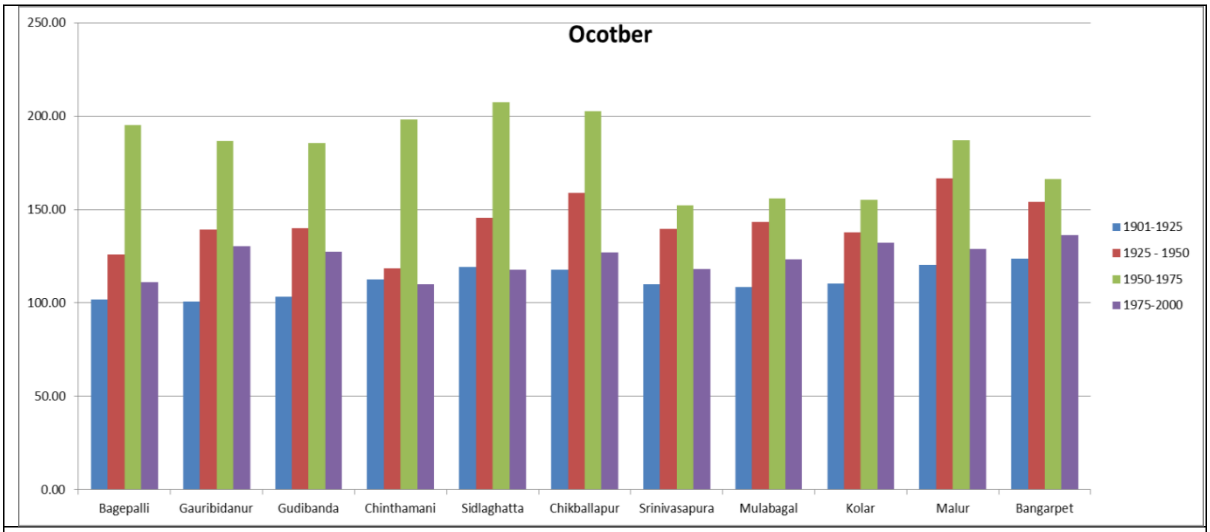
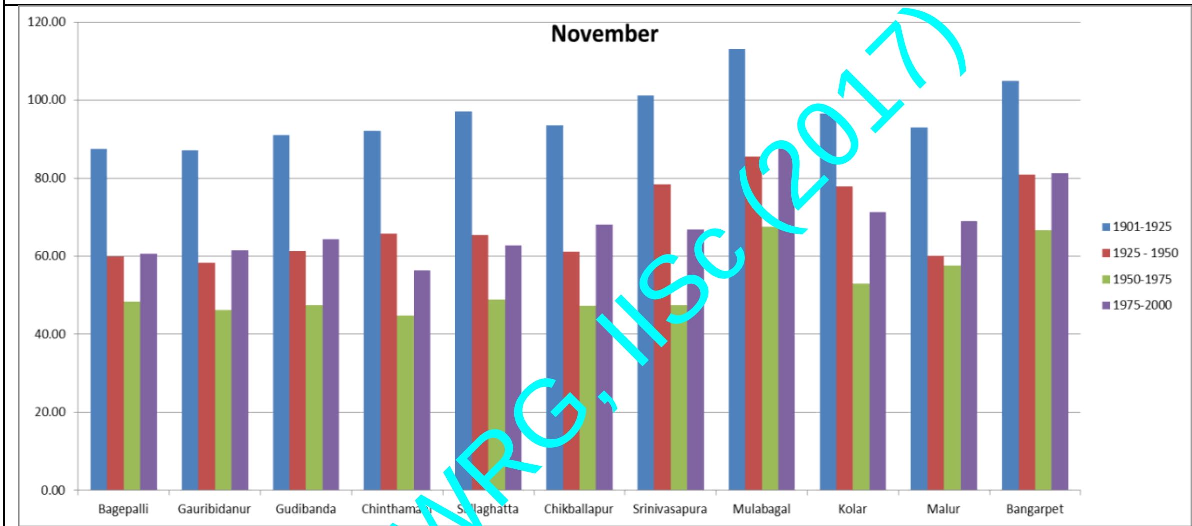


September



October



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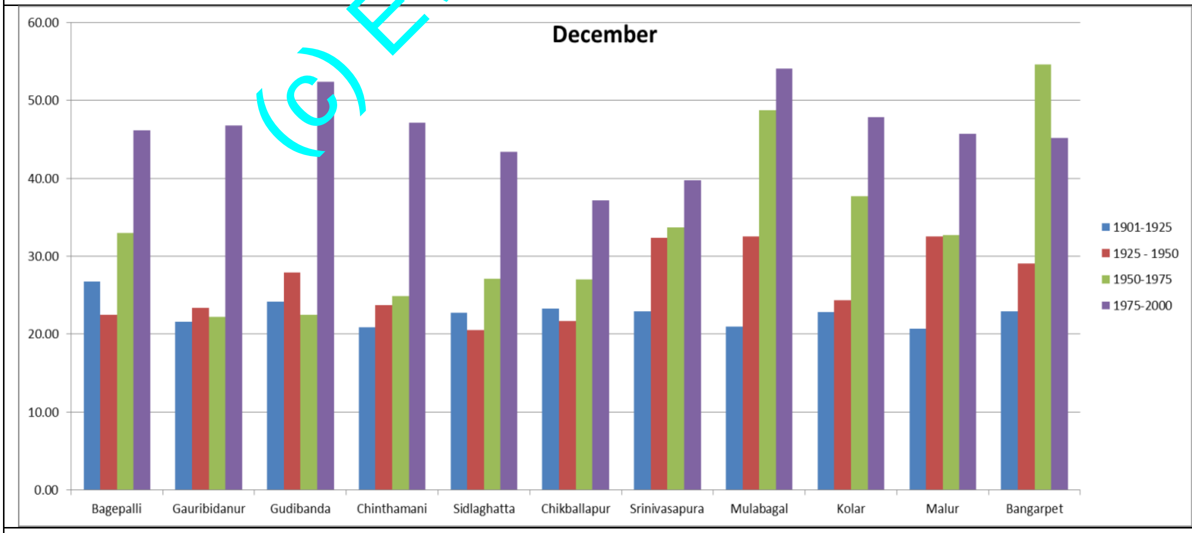

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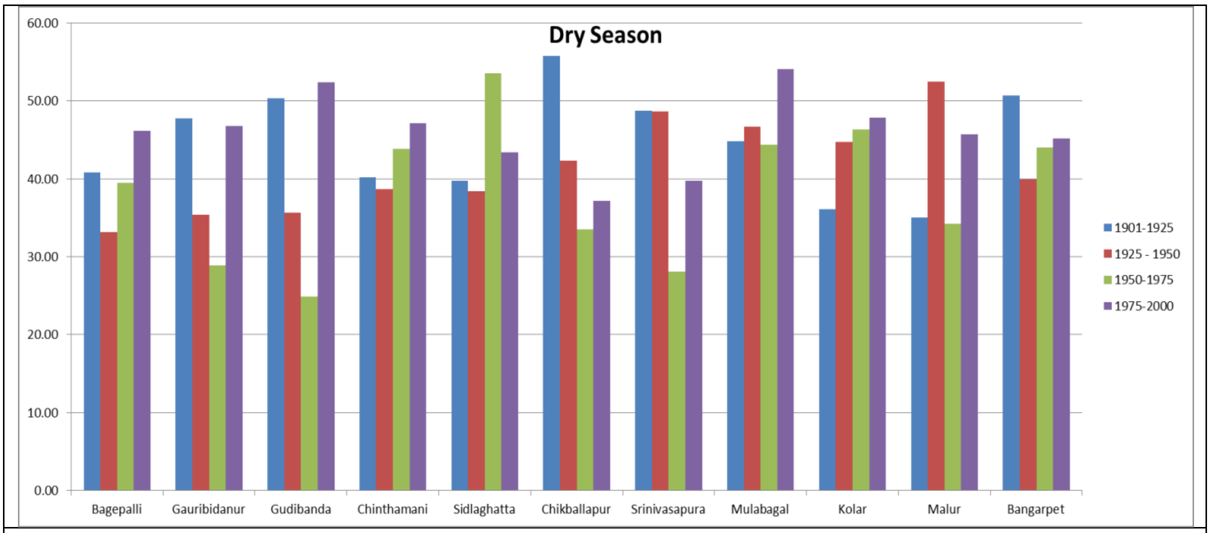

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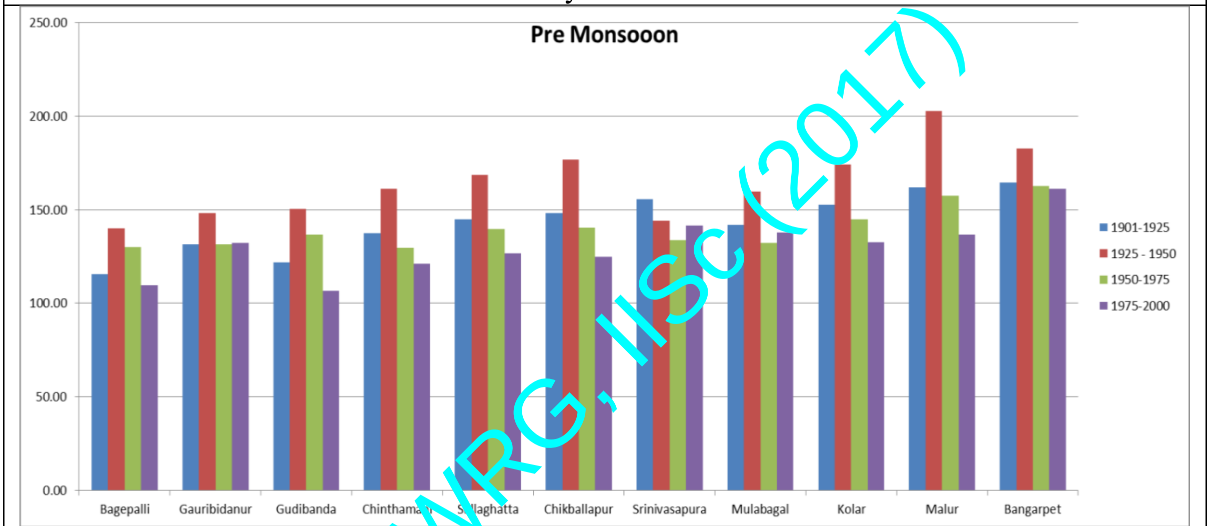
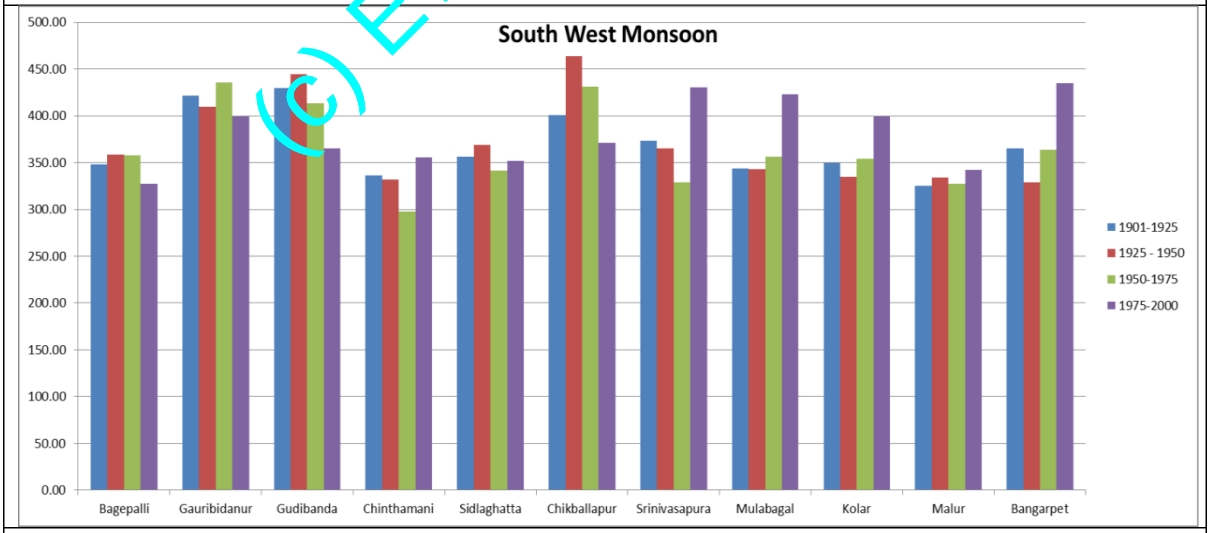


Pre Monsoon



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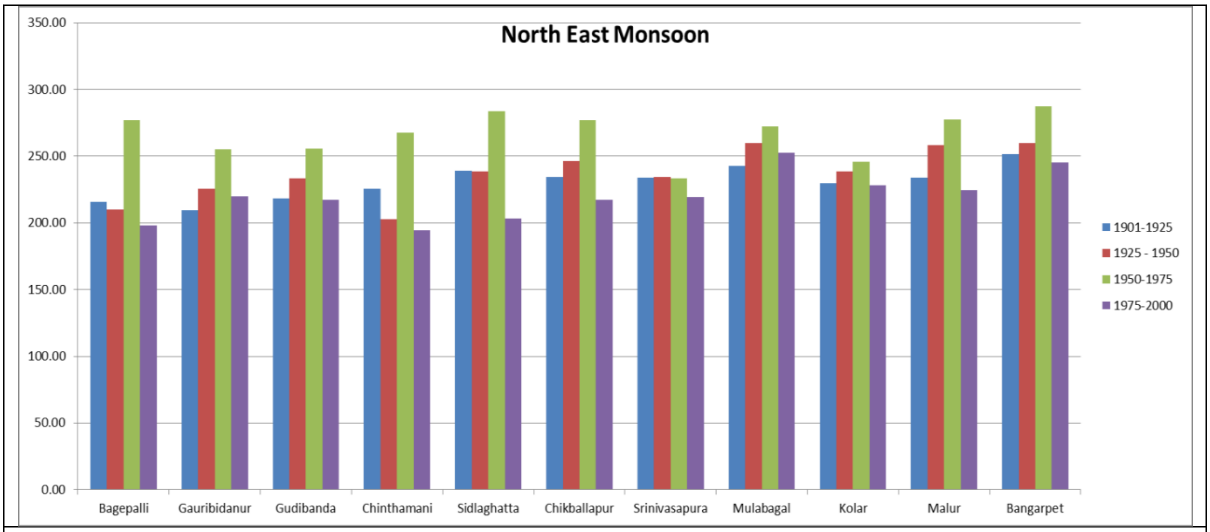


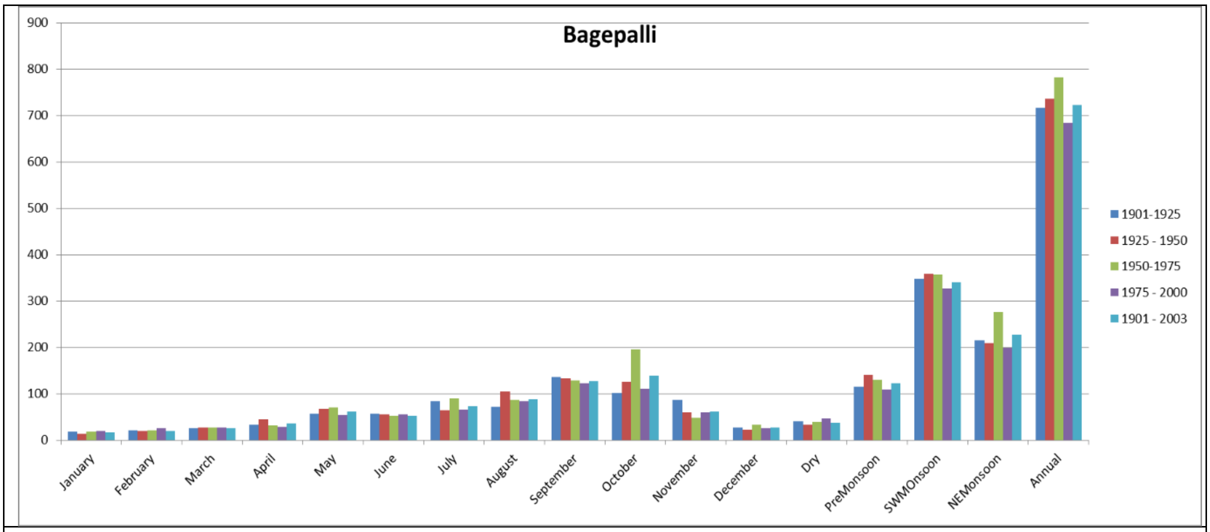
North East Monsoon

Annual

Figure 3.9: Month and Season wise rainfall dynamics

Figure 3.9 illustrates talukwise variation in the rainfall - month wise, season wise (mean rainfall for 25 years period). Temporal dynamics of annual rainfall highlights that all taluks have been receiving > 650 mm rainfall during 113 years.

Month-wise variability for each taluk is portrayed in Figure 3.10 further confirms of the availability of sufficient quantum of rainfall in the region (Kolar and Chikballapur districts)



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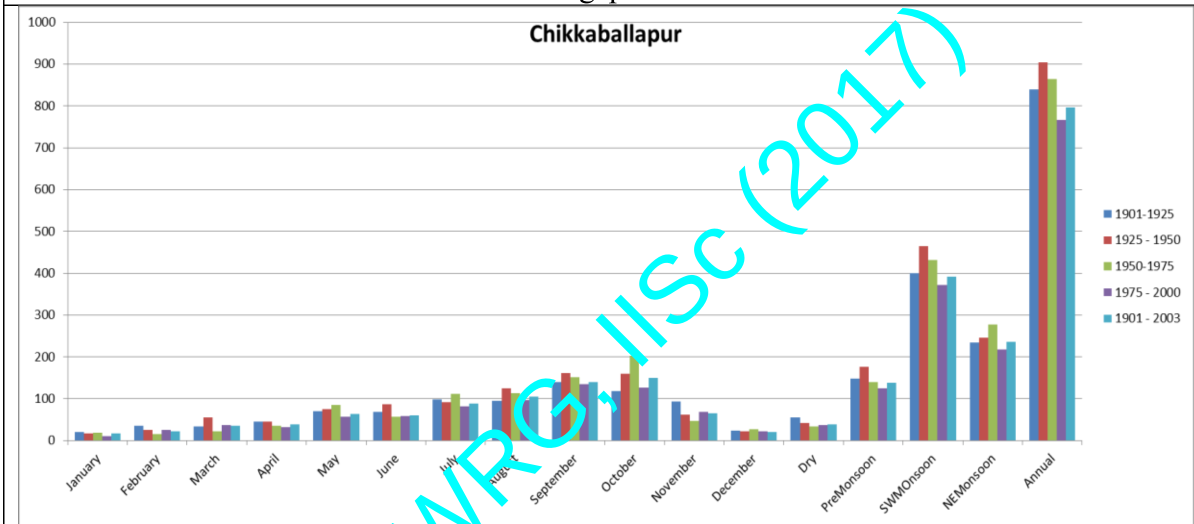
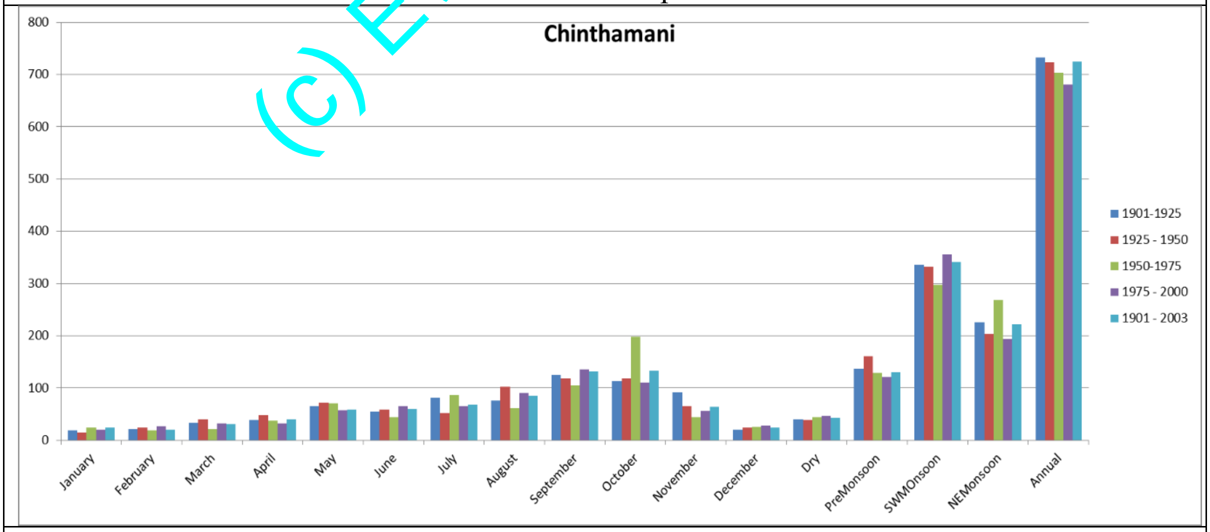
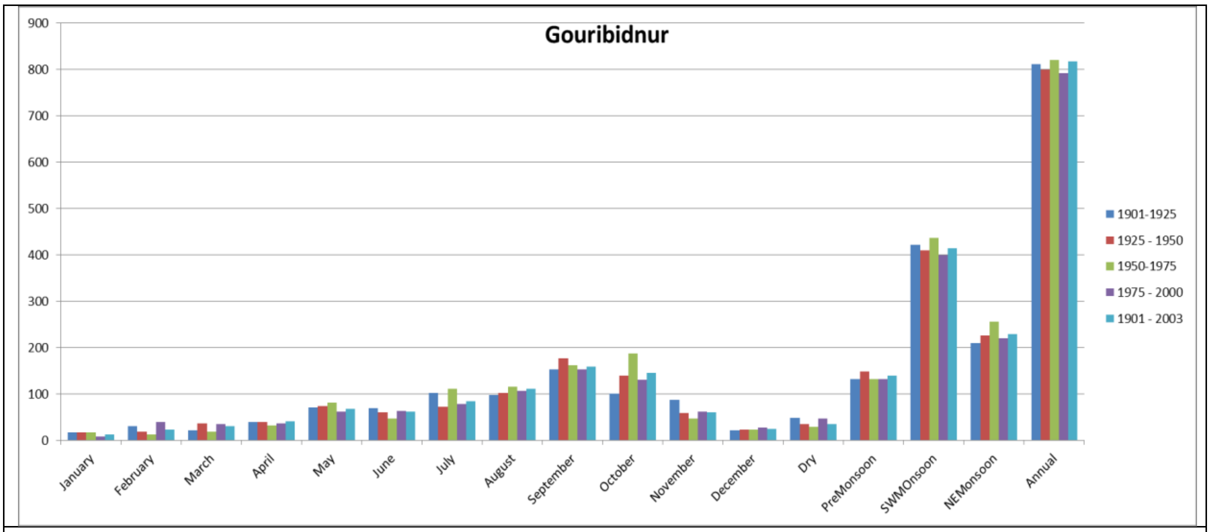


Chikkaballapur



Chinthamani



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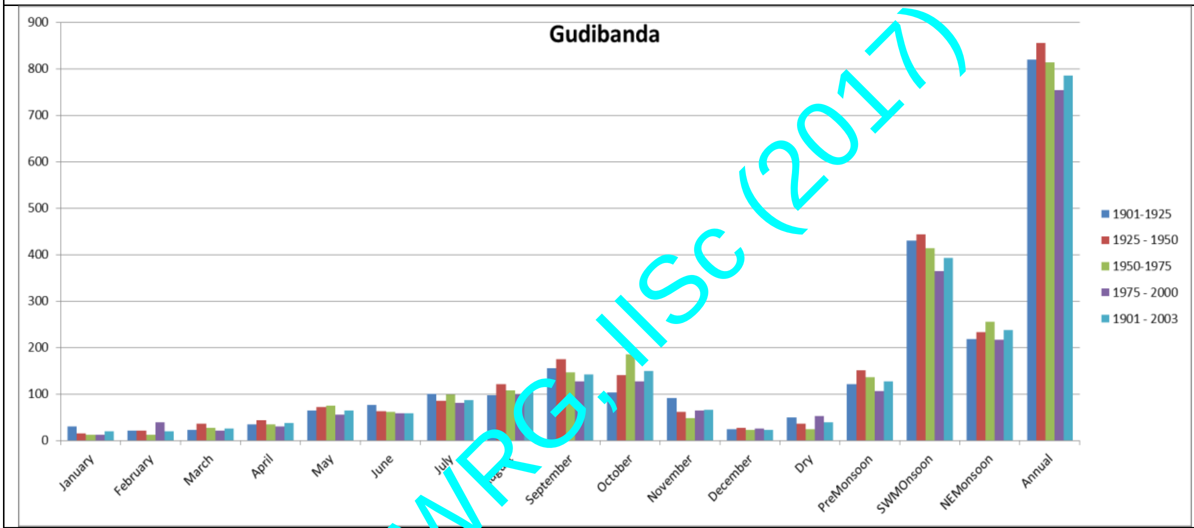
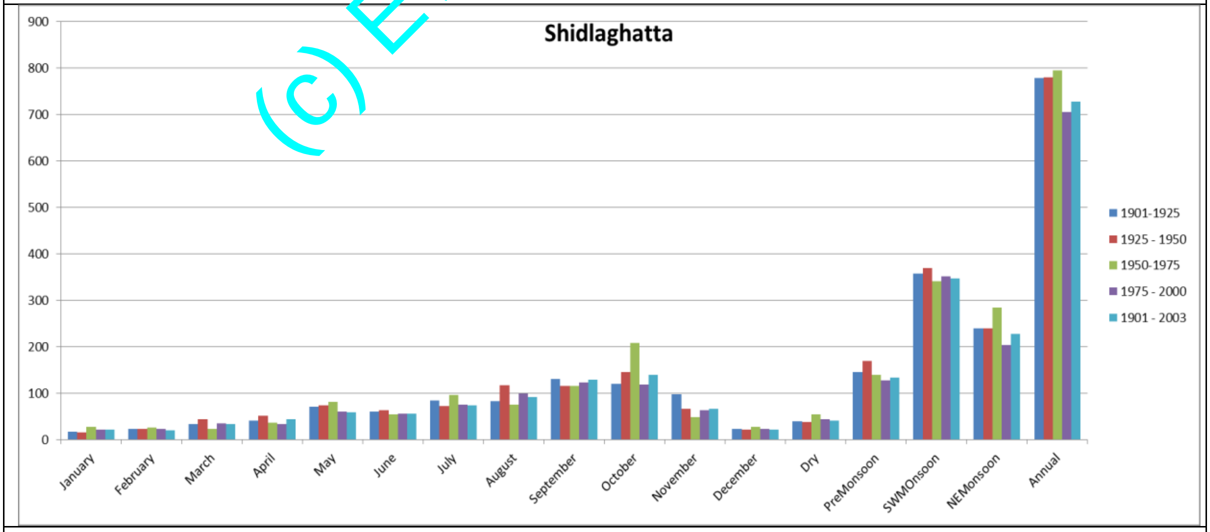
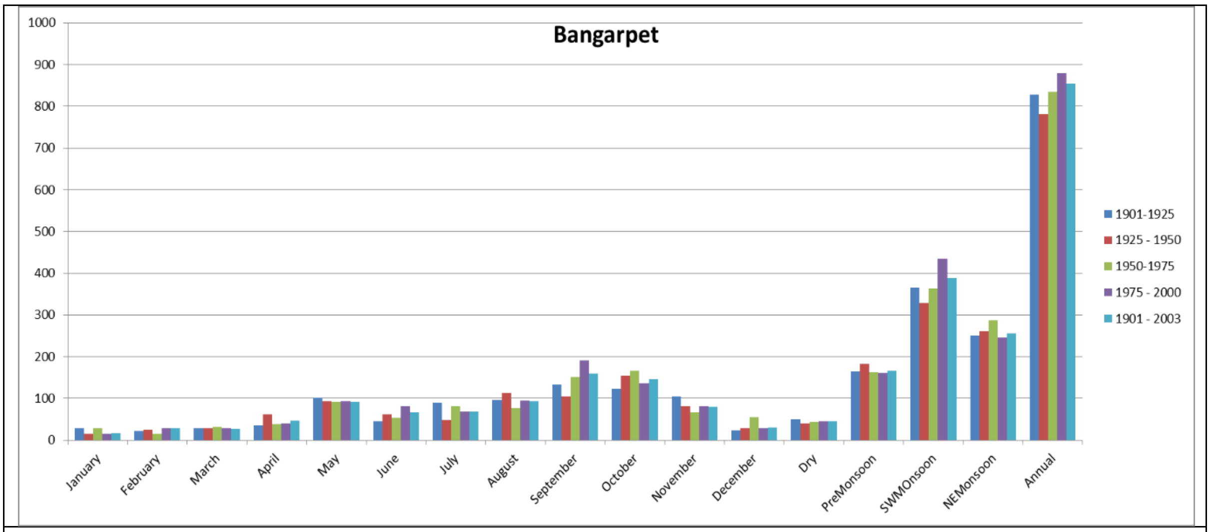


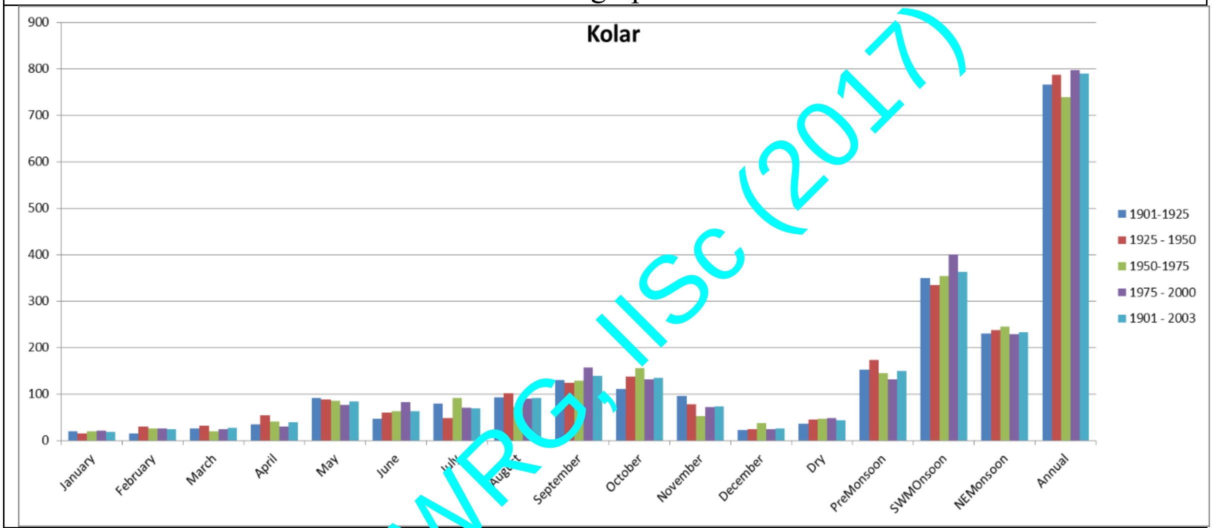
Gudibanda



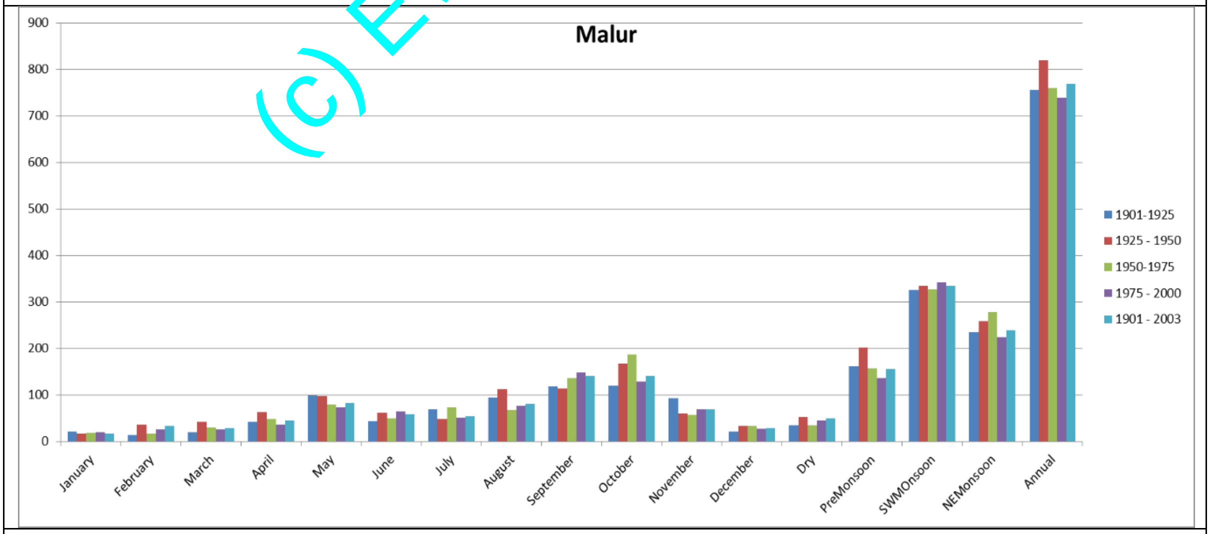
Shidlaghatta



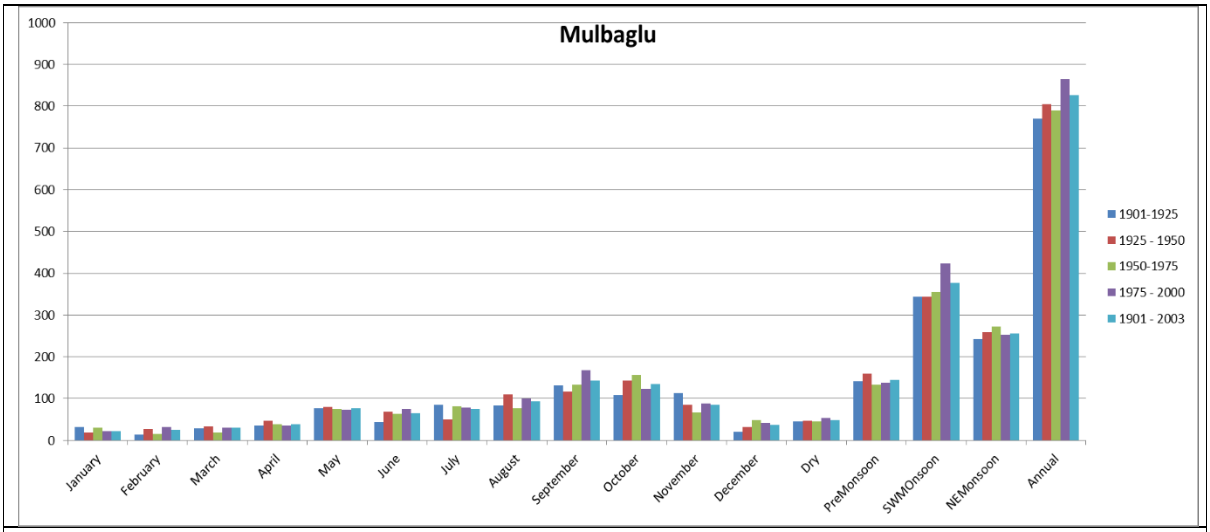
Bangarpet



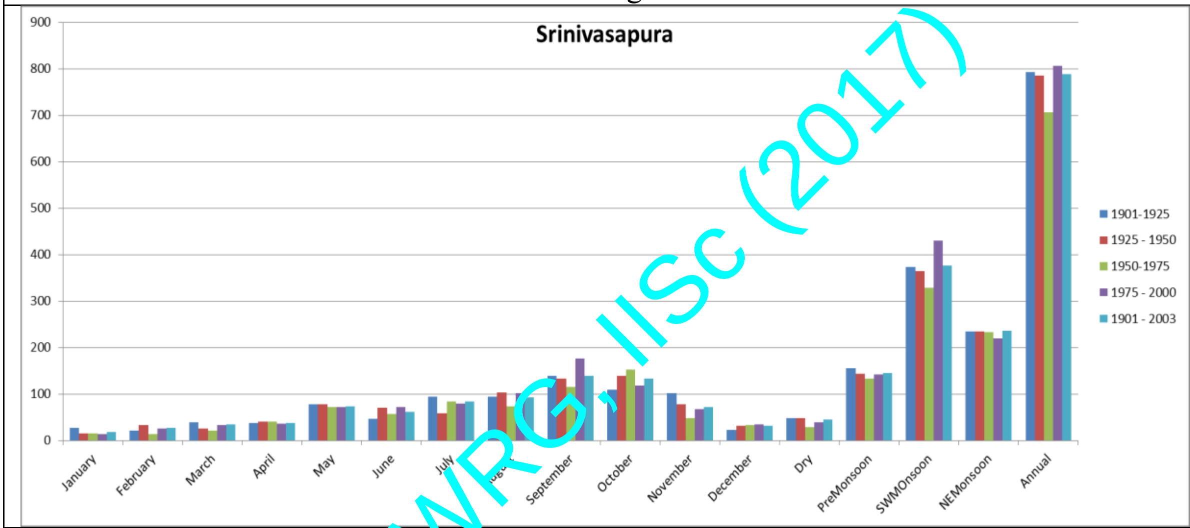
Kolar



Malur



Mulbaglu



Srinivasapura

Figure 3.10: Rainfall dynamics Taluk wise

COEFFICIENT OF VATIATION (COV) – SPATIAL VARIATION

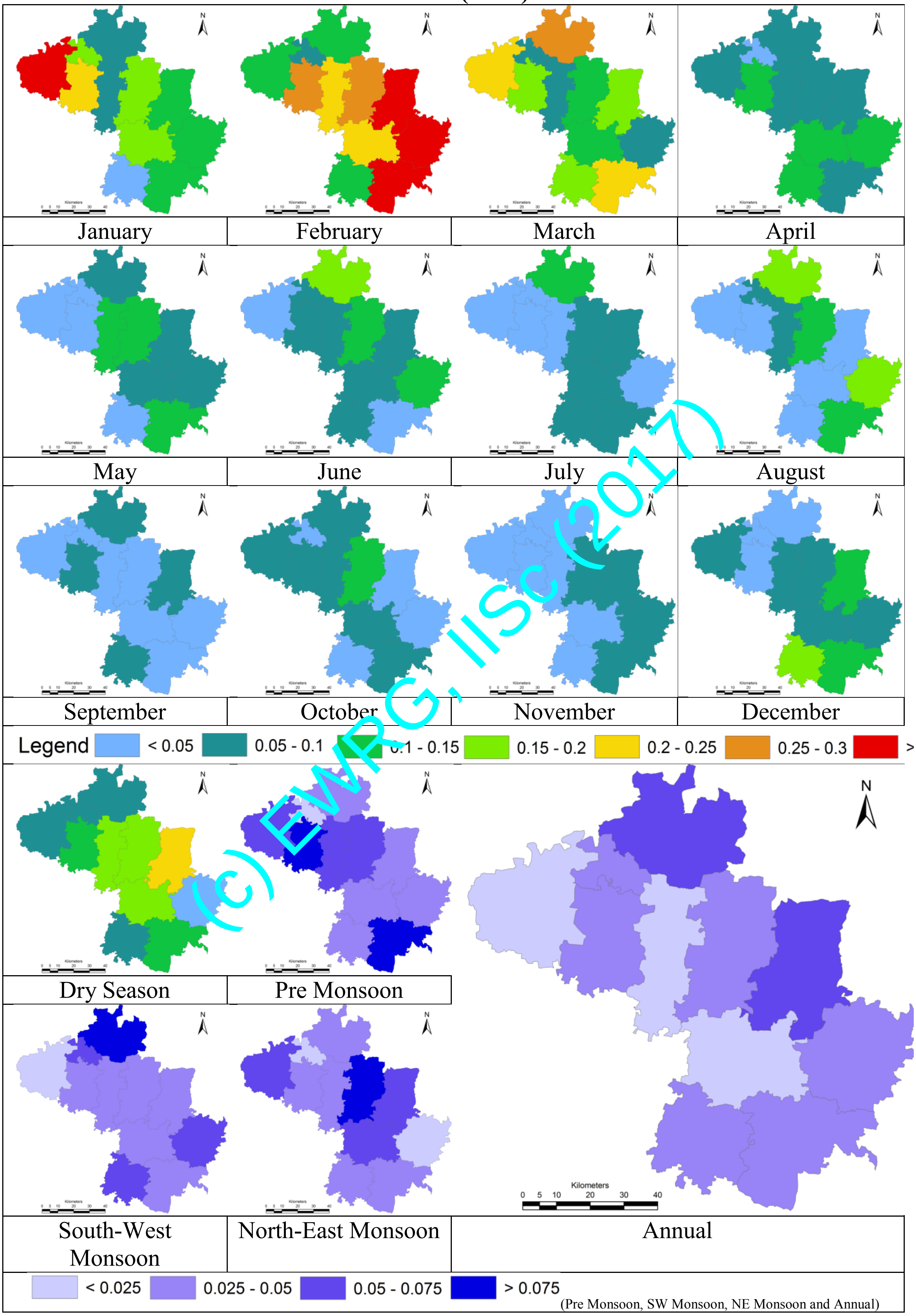


Figure 3.11.1: Coefficient of variation (Spatial) month wise 1901 – 1925

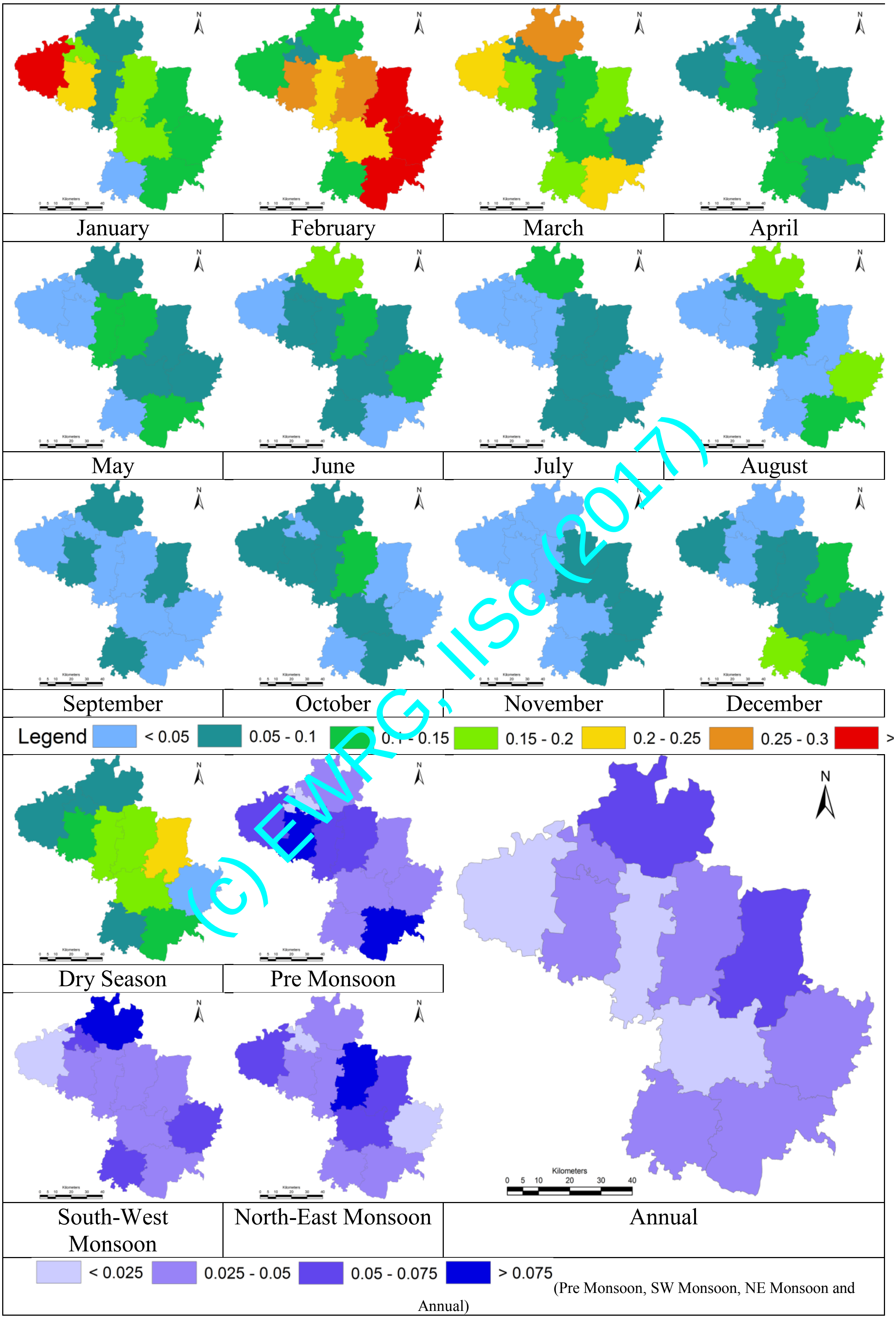


Figure 3.11.2: Coefficient of variation (Spatial) month wise 1926 – 1950

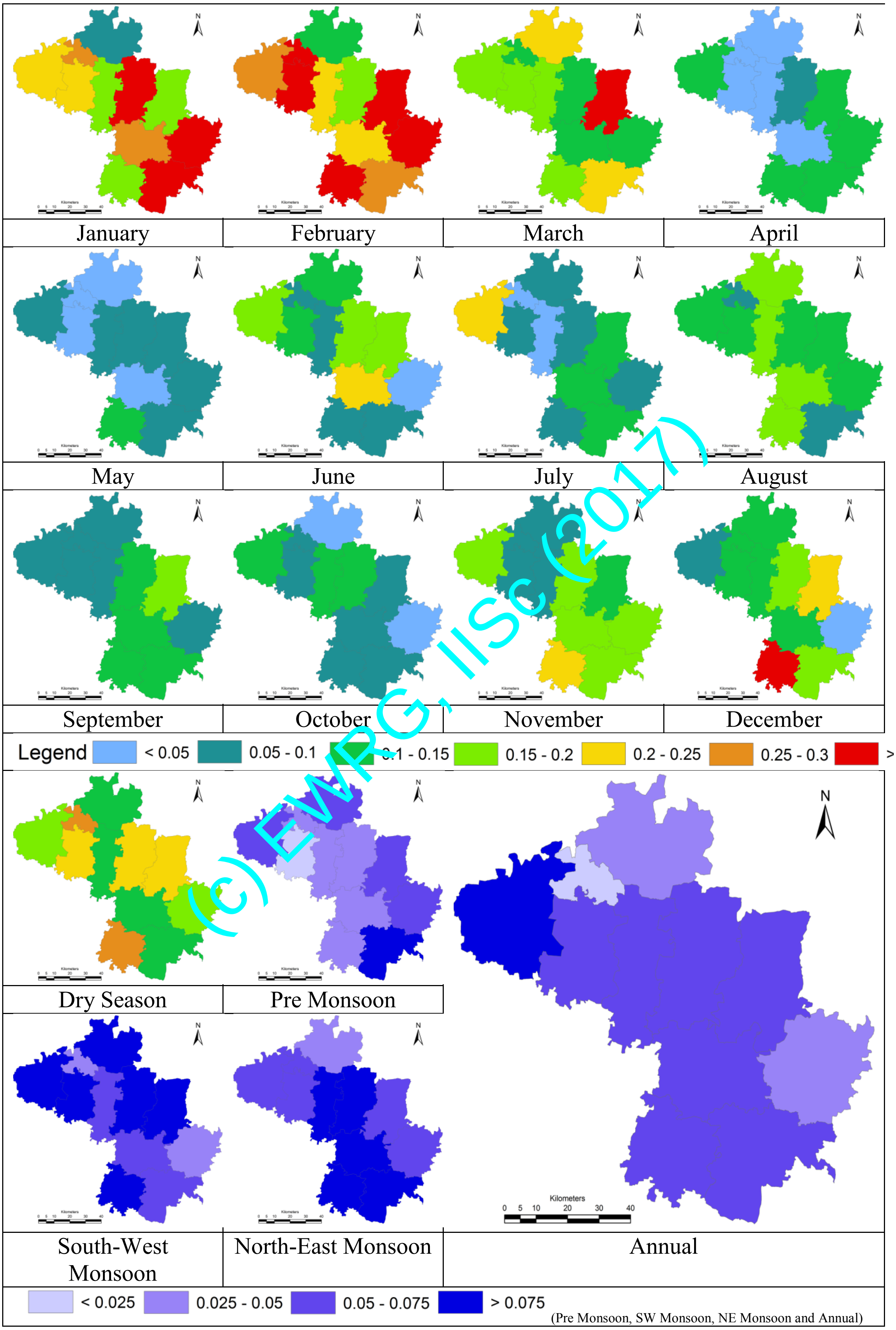


Figure 3.11.3: Coefficient of variation (Spatial) month wise 1951 – 1975

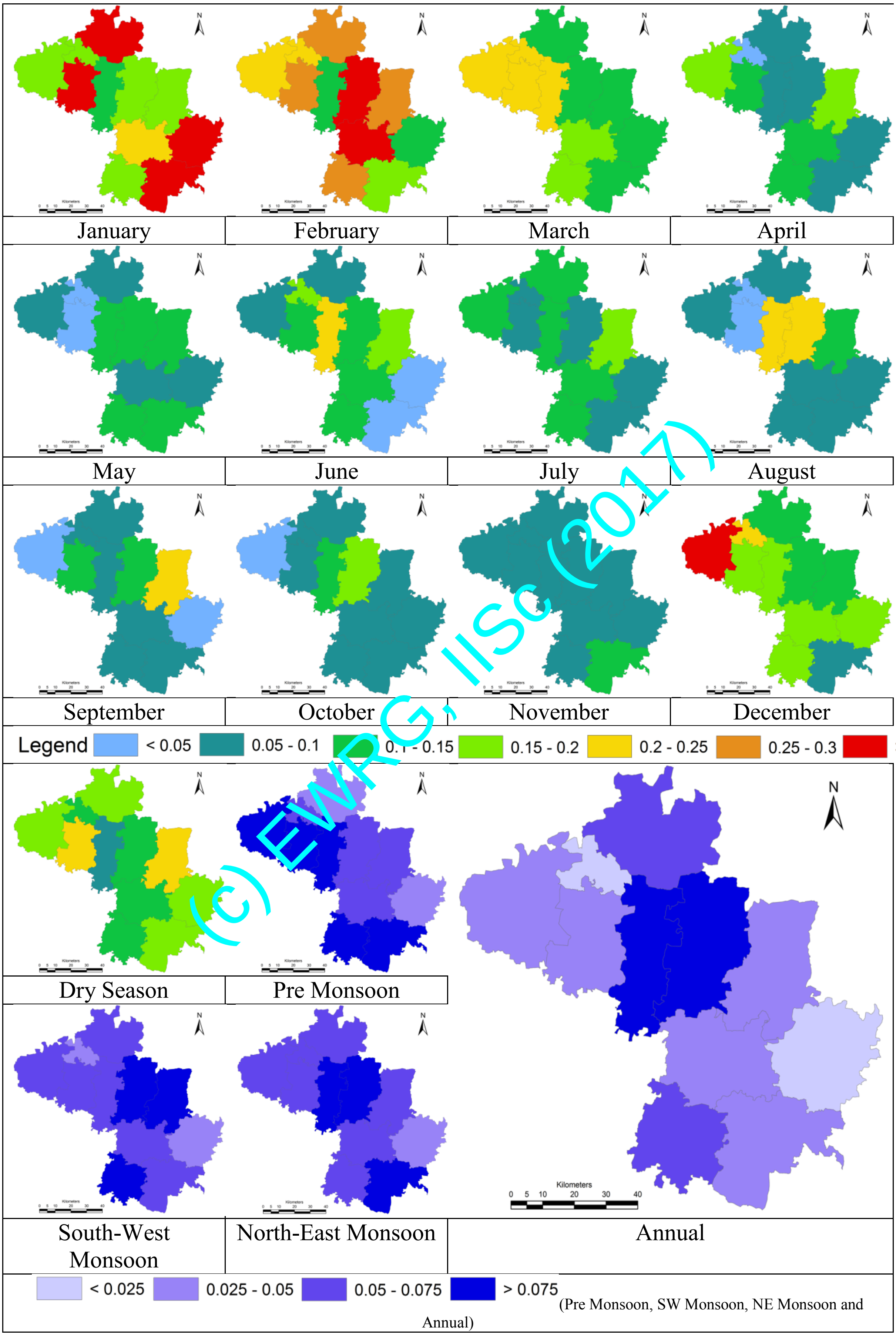
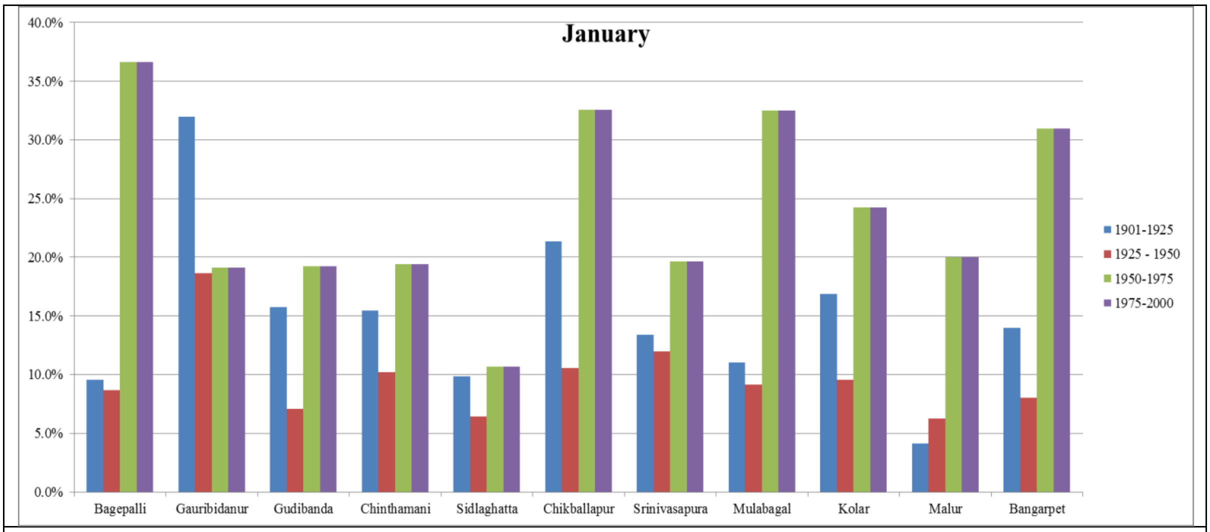
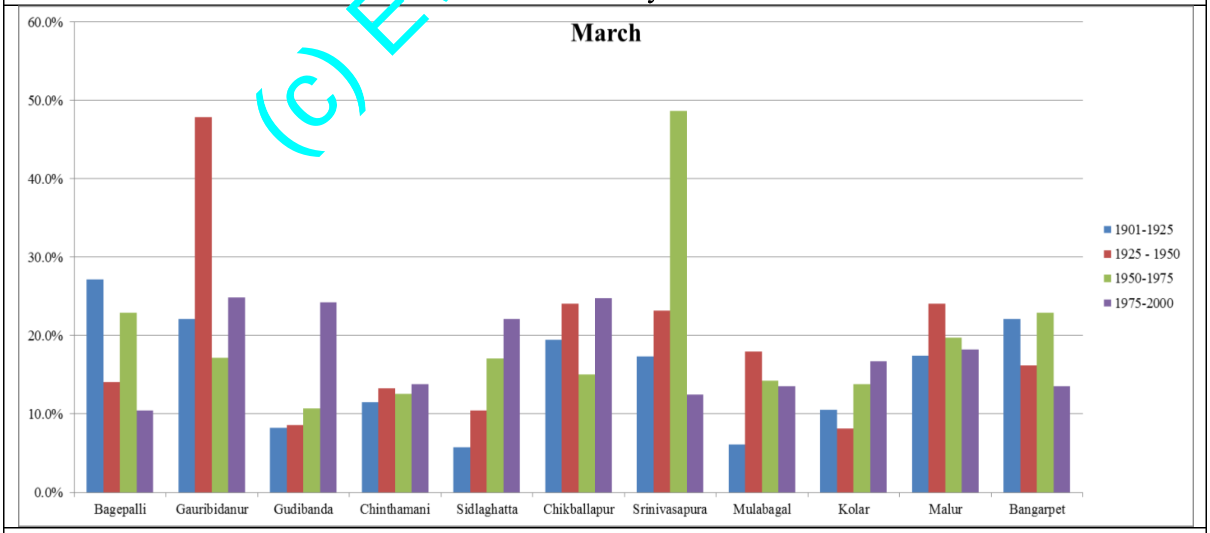


Figure 3.11.4: Coefficient of variation (Spatial) month wise 1976 – 2000



January

February



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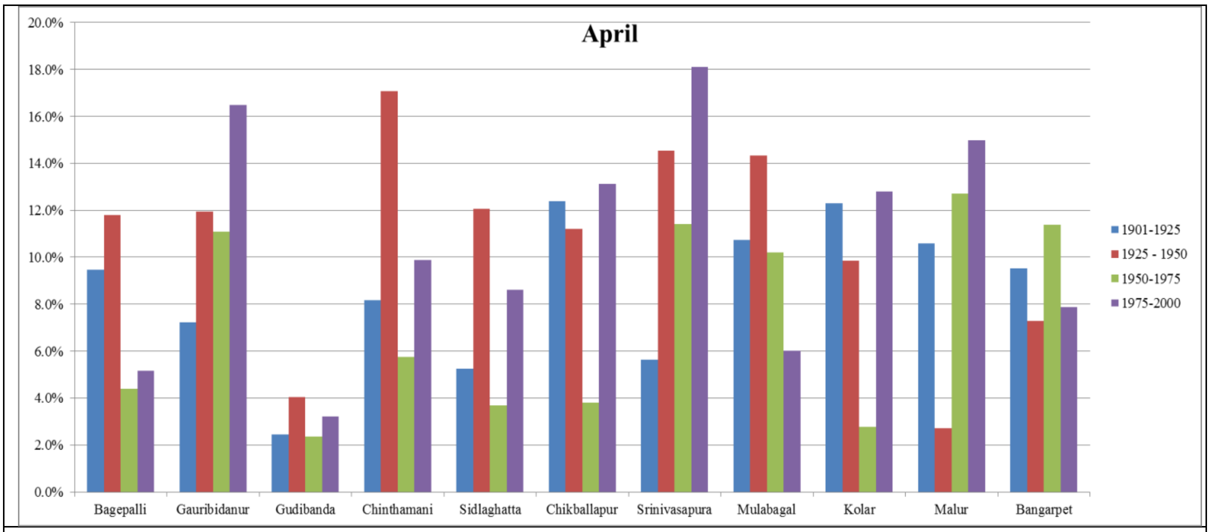

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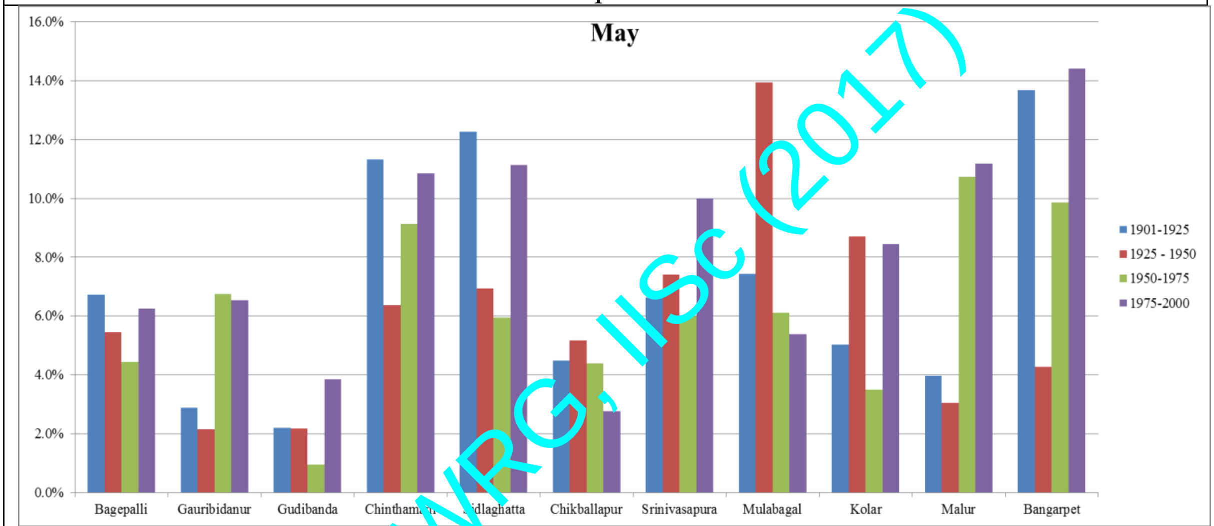

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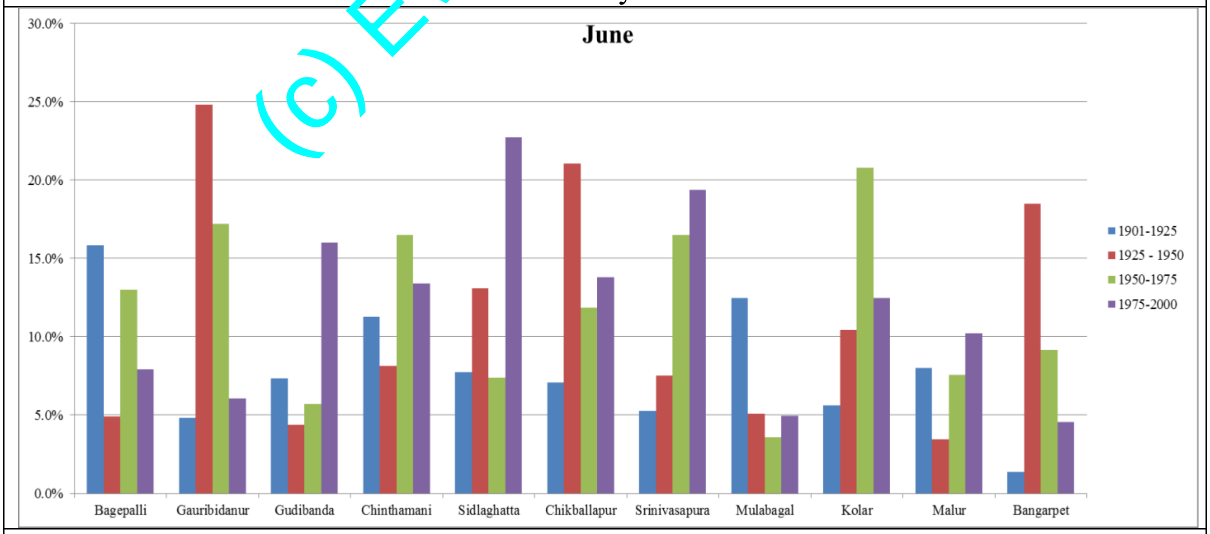

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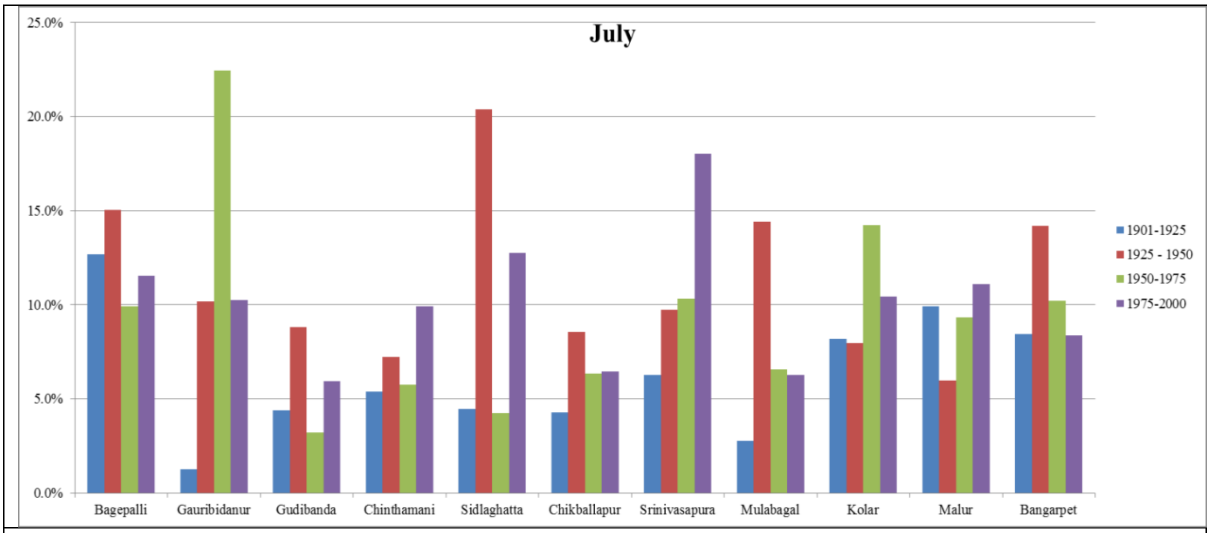

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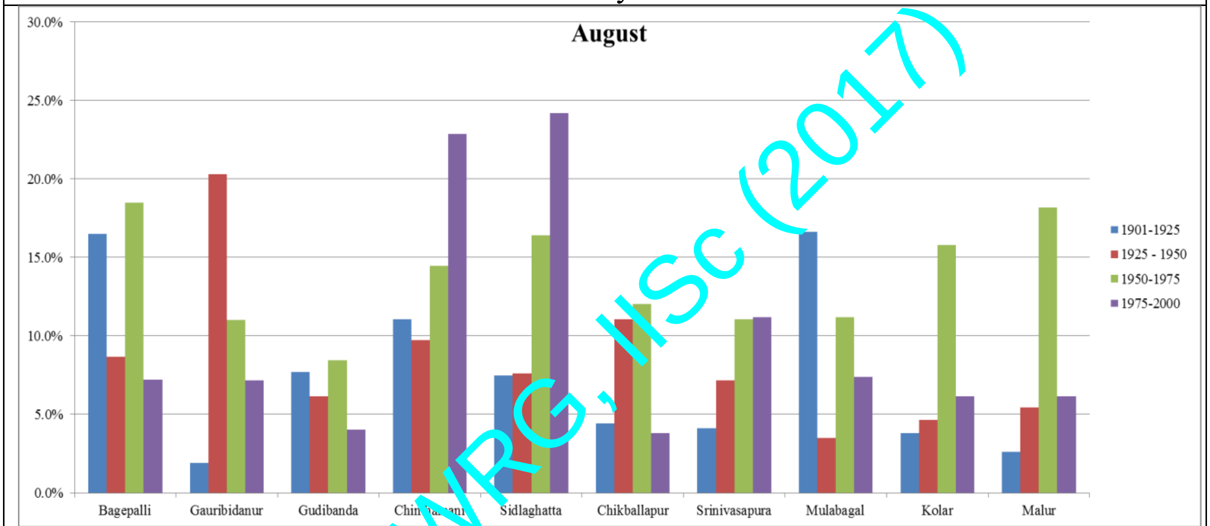

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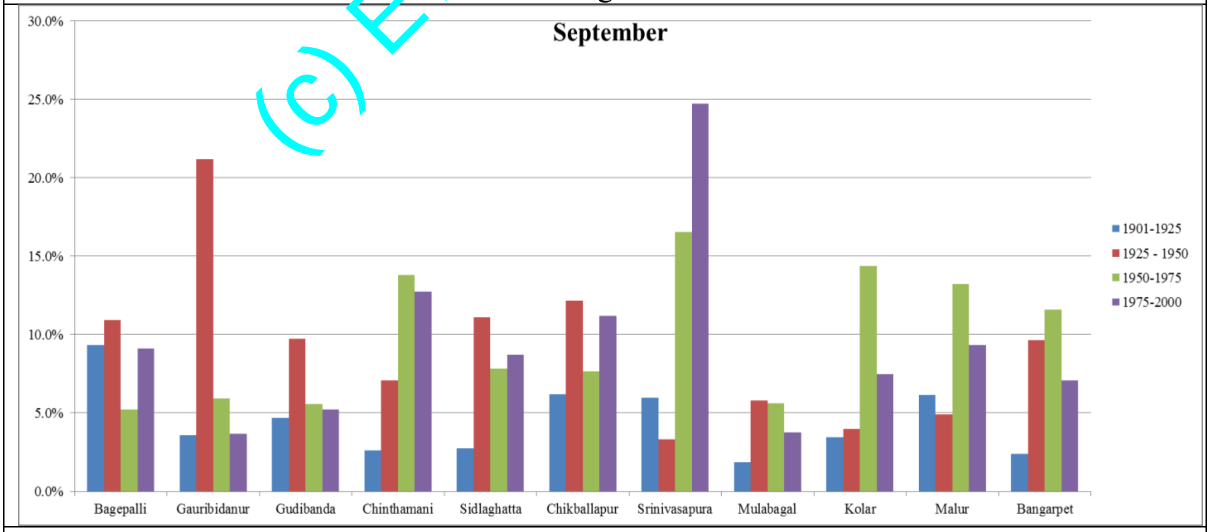

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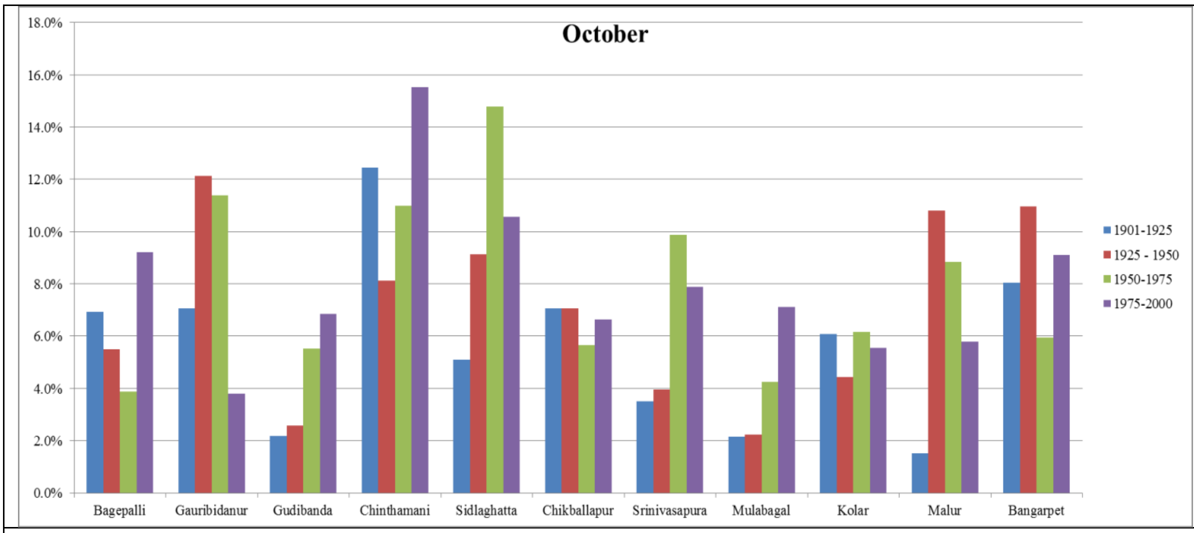

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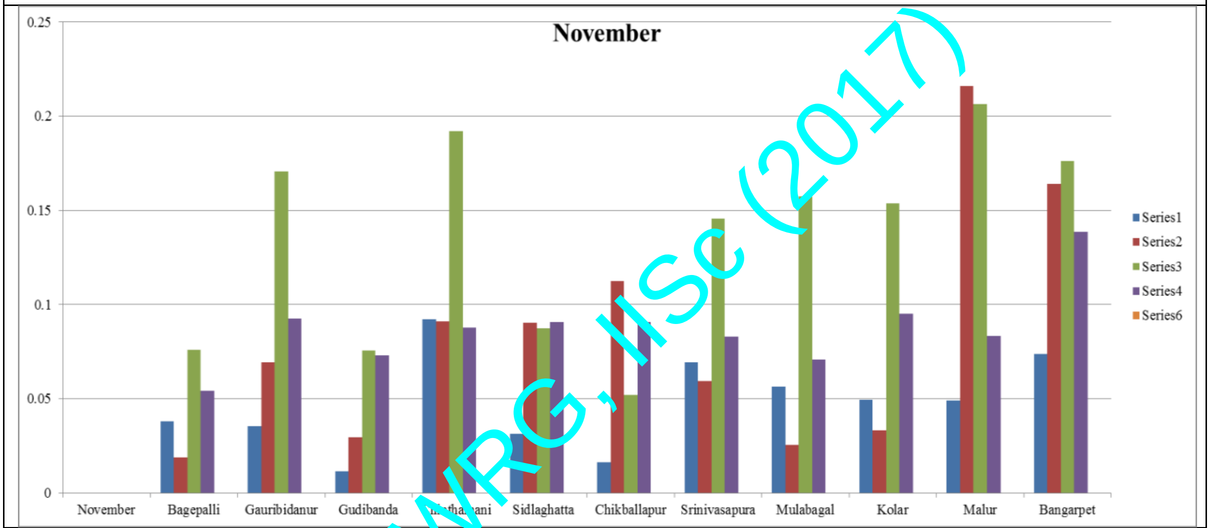

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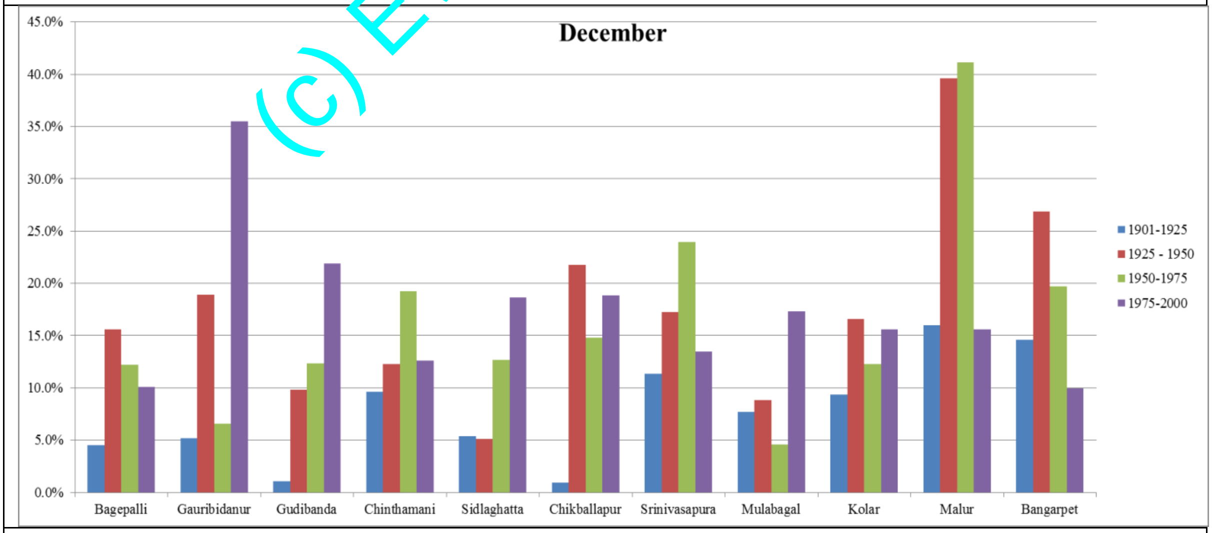

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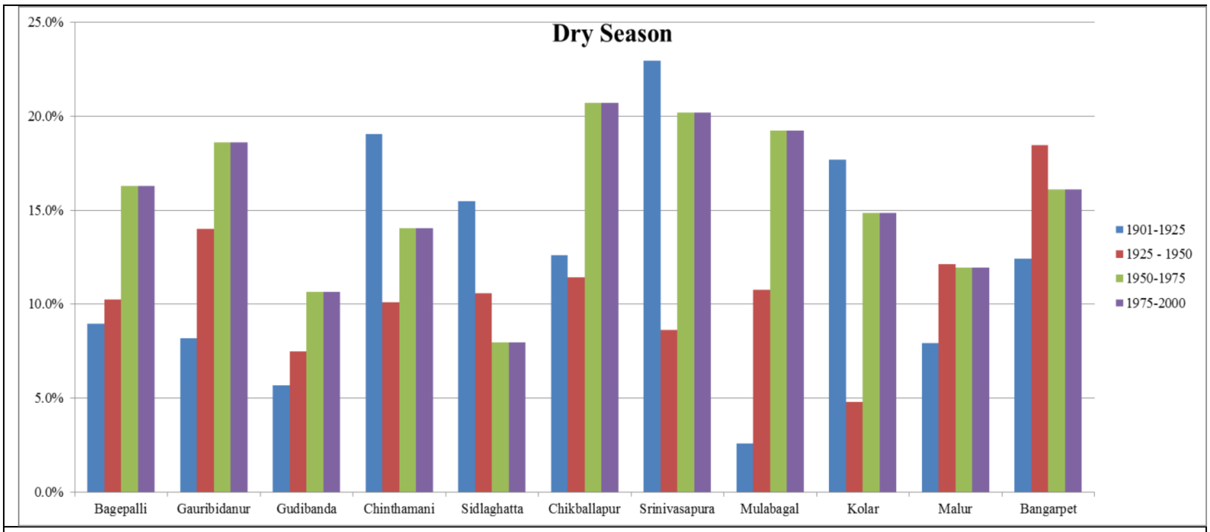
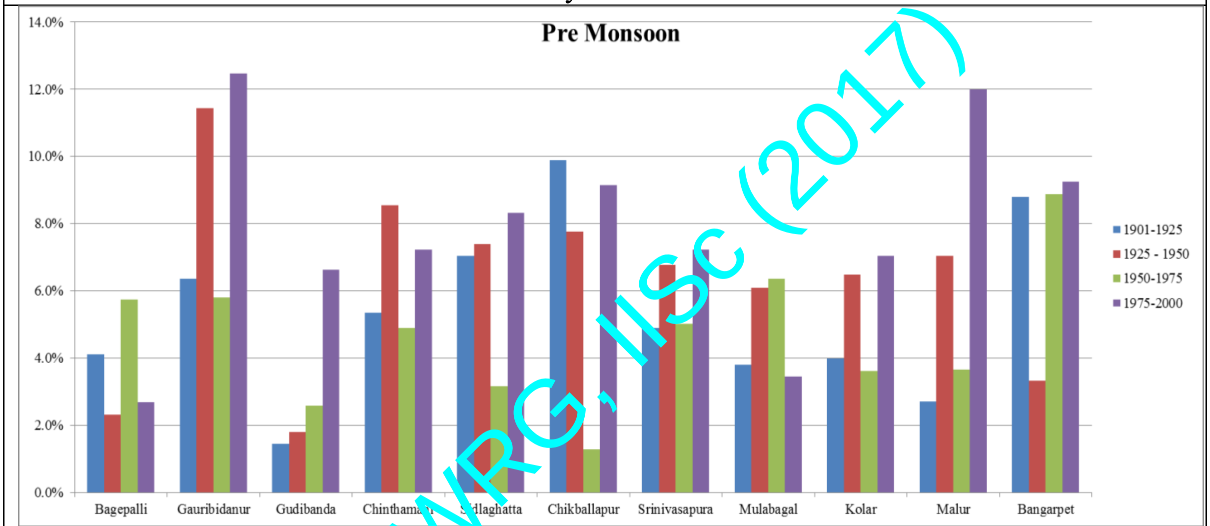
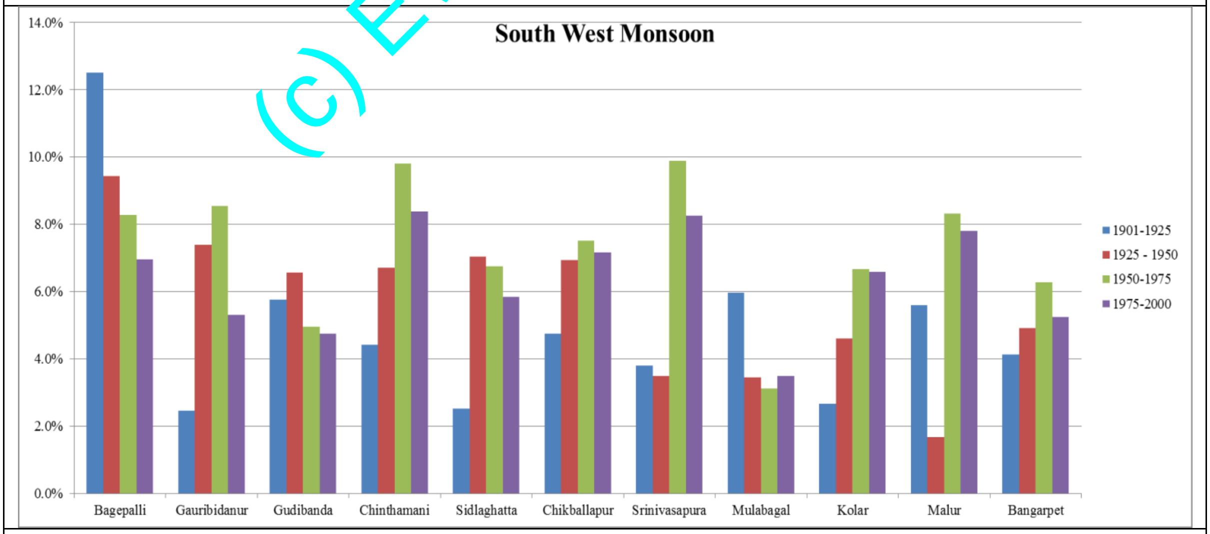


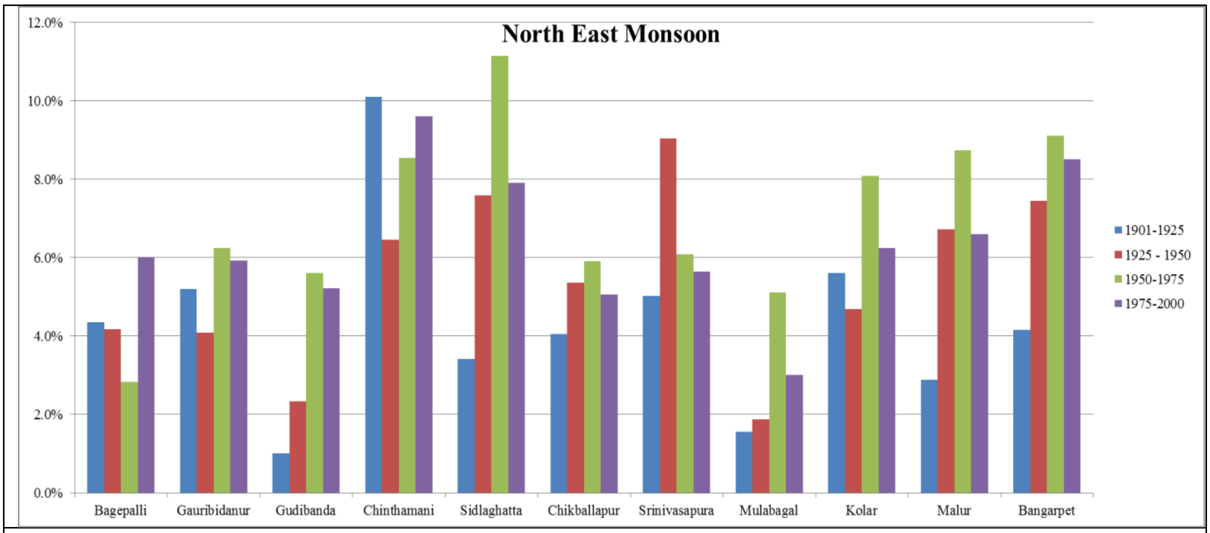
Dry Season



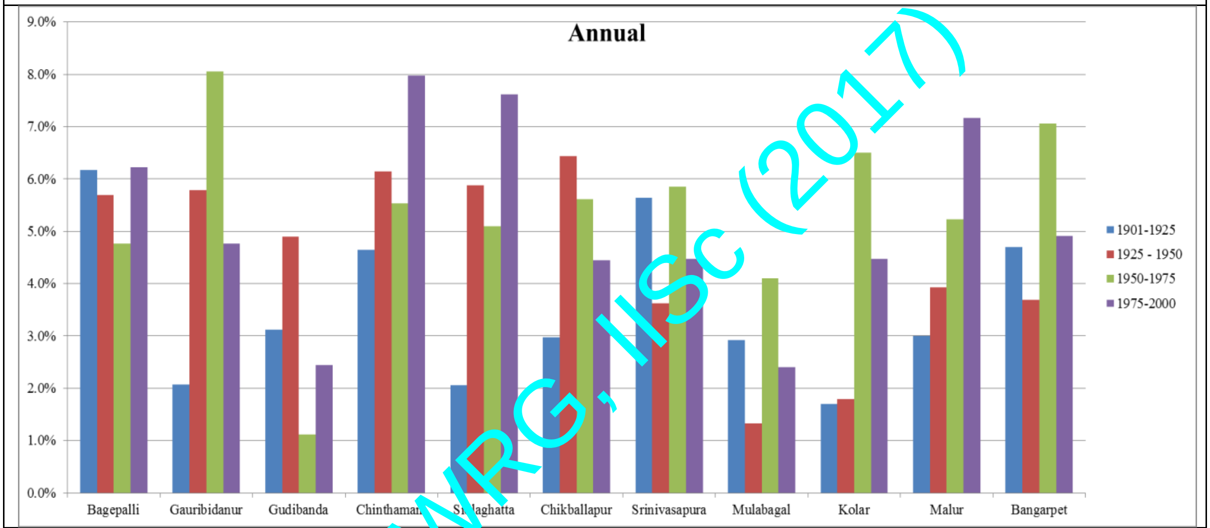
Pre Monsoon



South West Monsoon

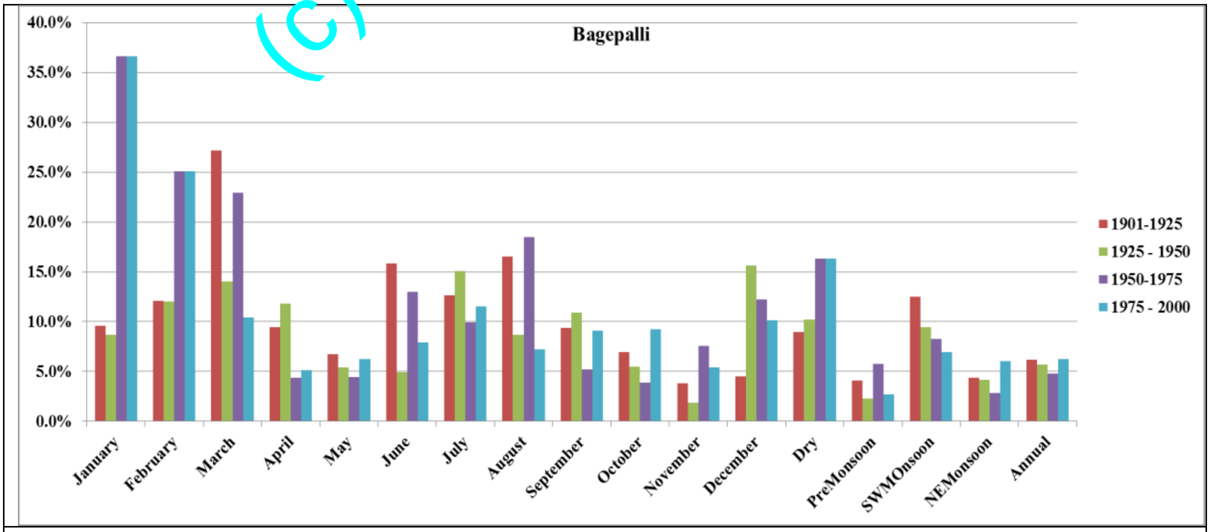


North East Monsoon

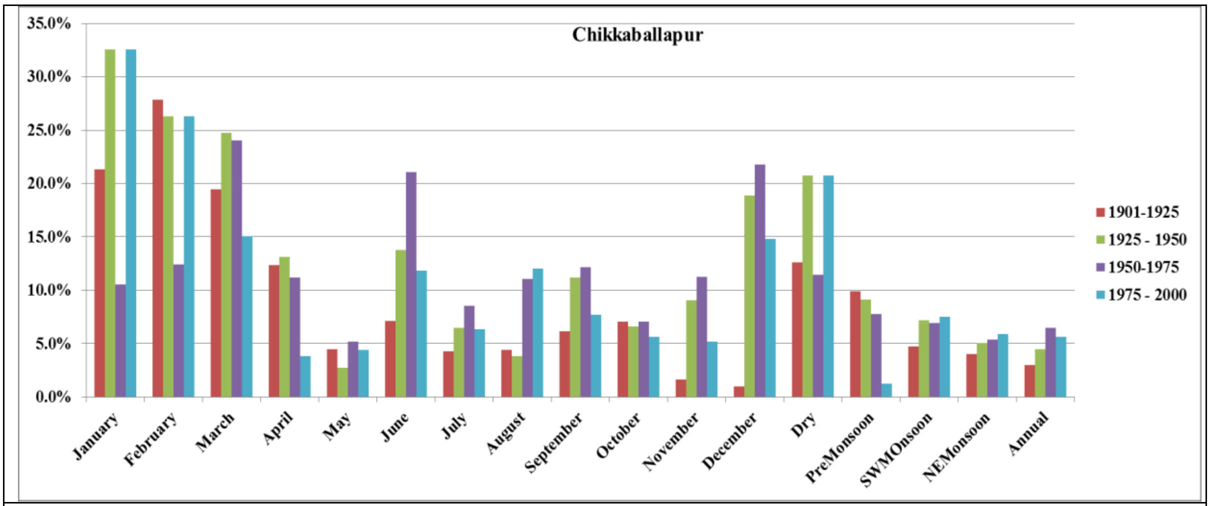


Annual

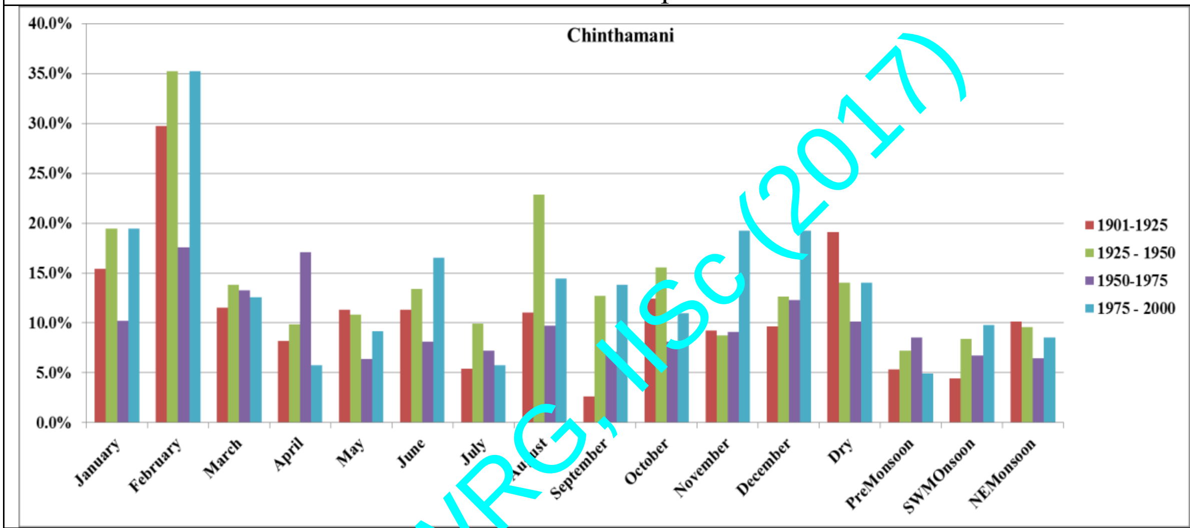
Figure 3.12: COV Month and Season wise (for 25 years rainfall data)



Bagepalli



Chikkaballapur



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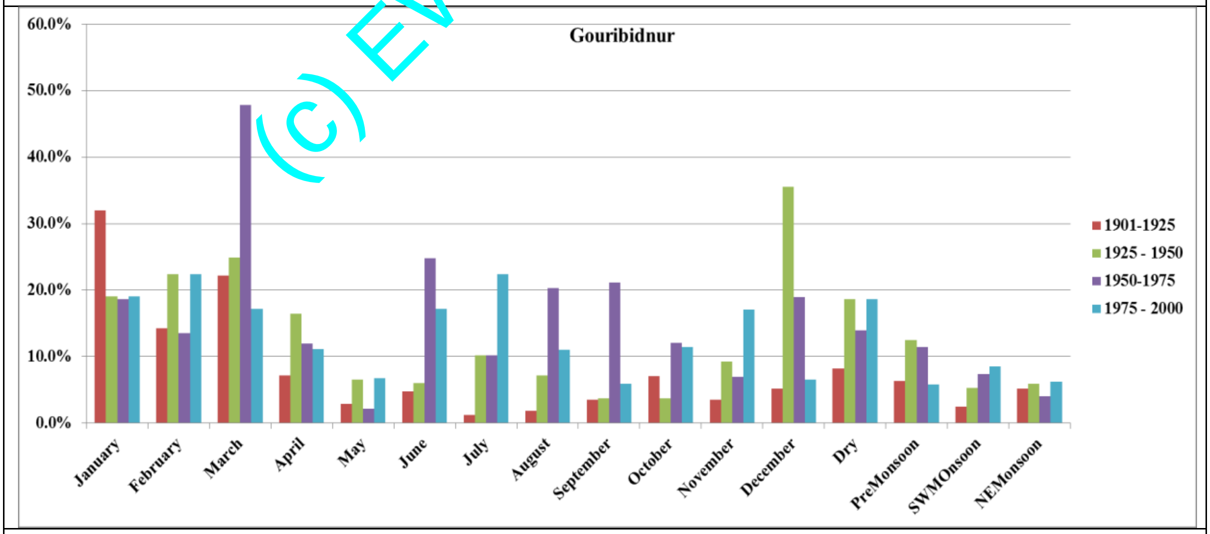
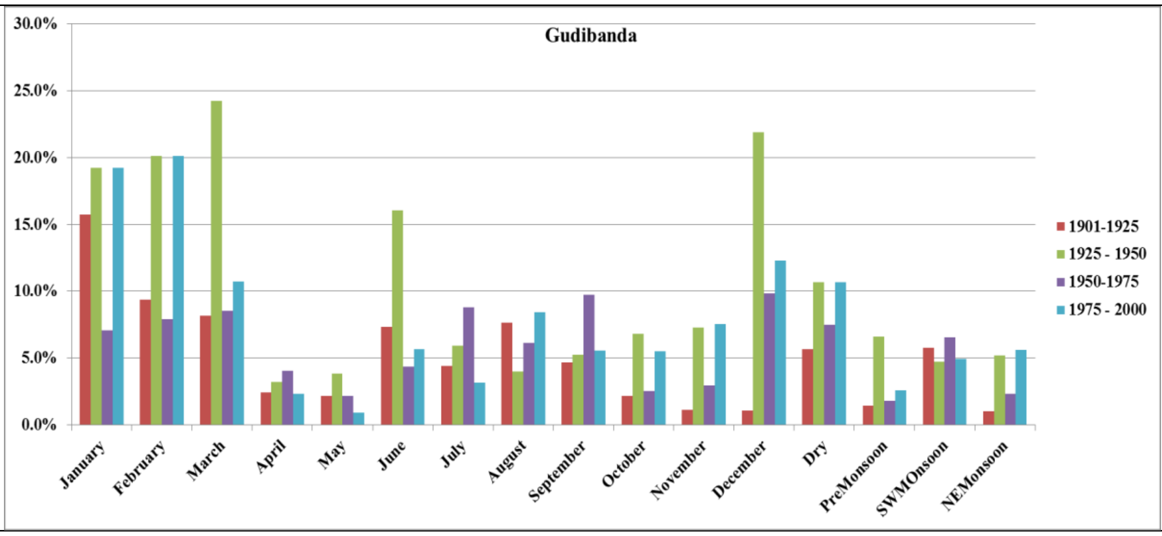
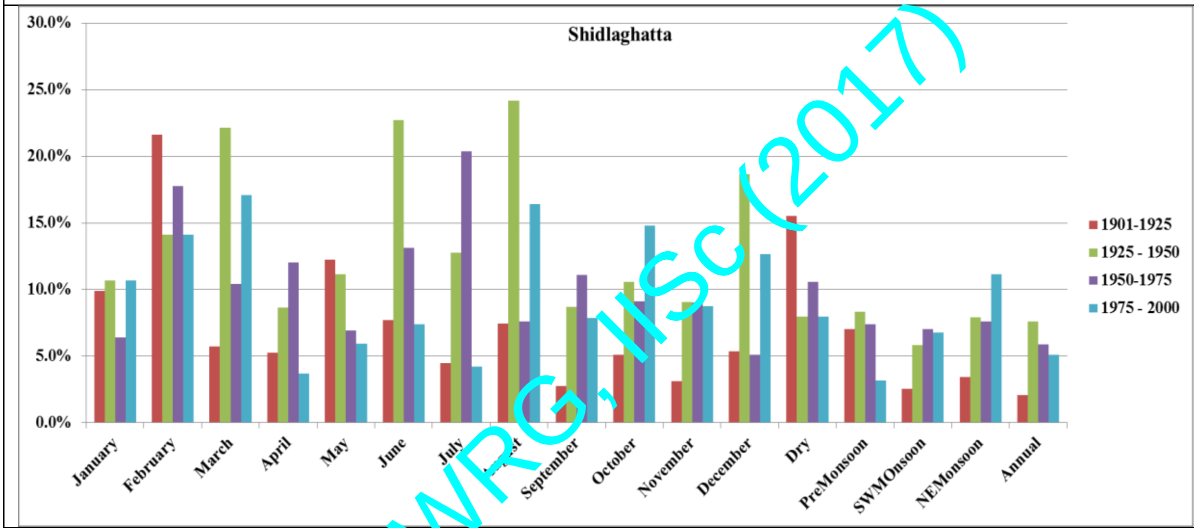


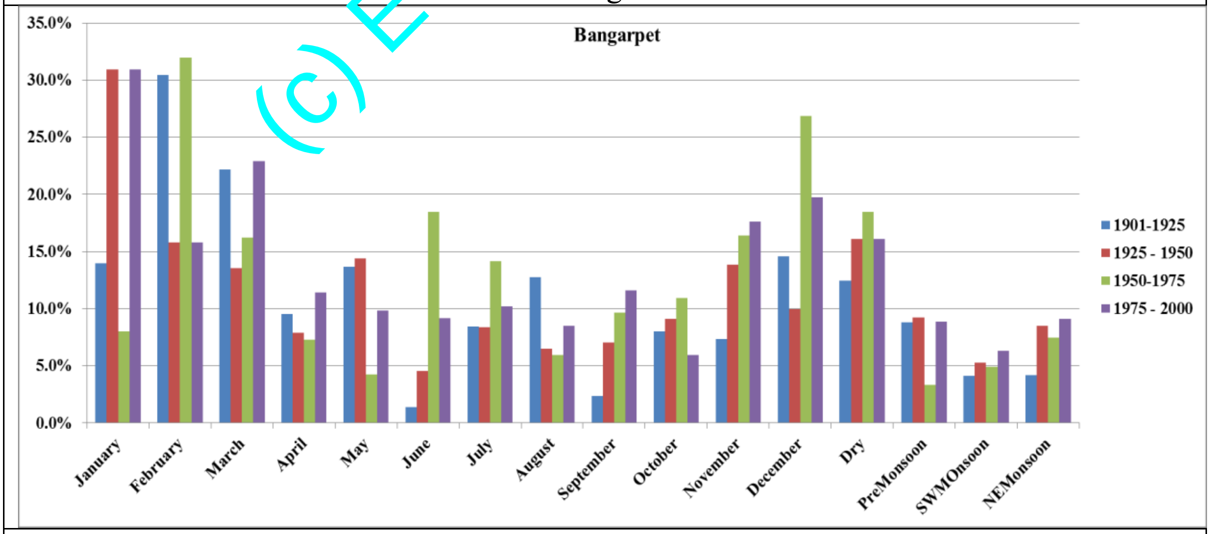
Gouribidnur



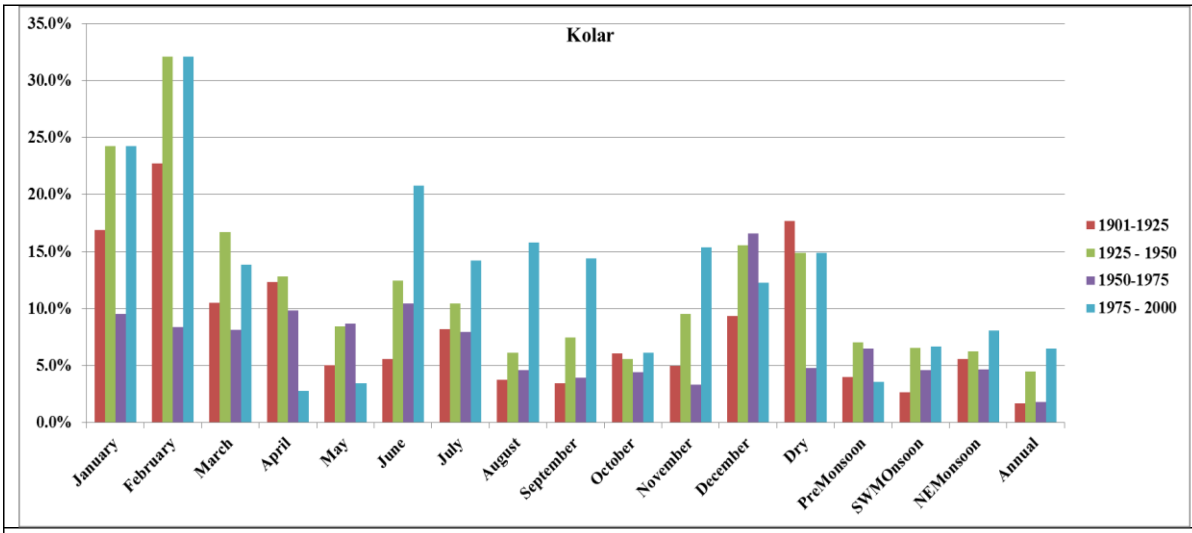
Gudibanda



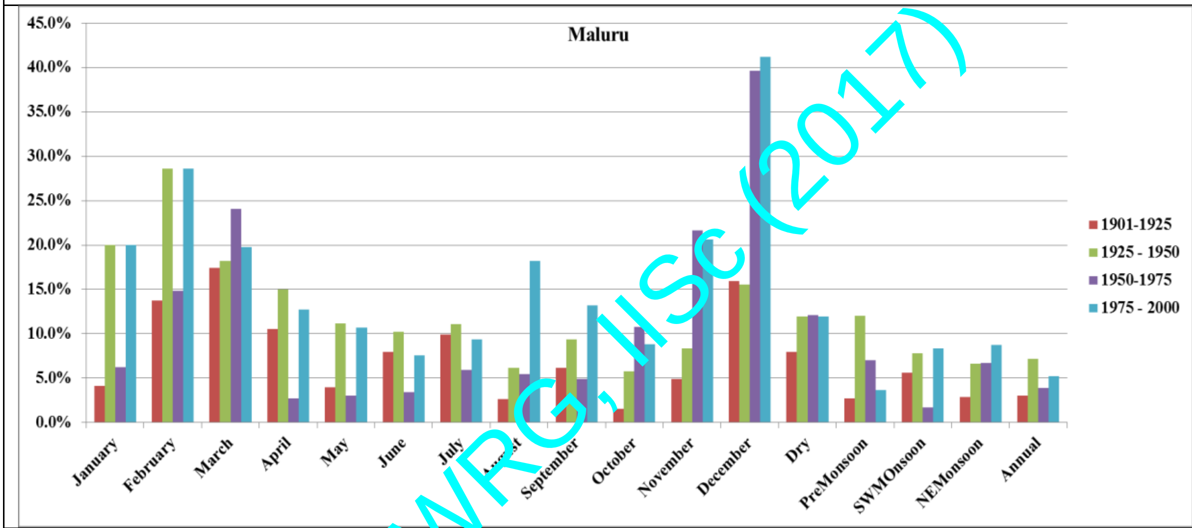
Shidlaghatta



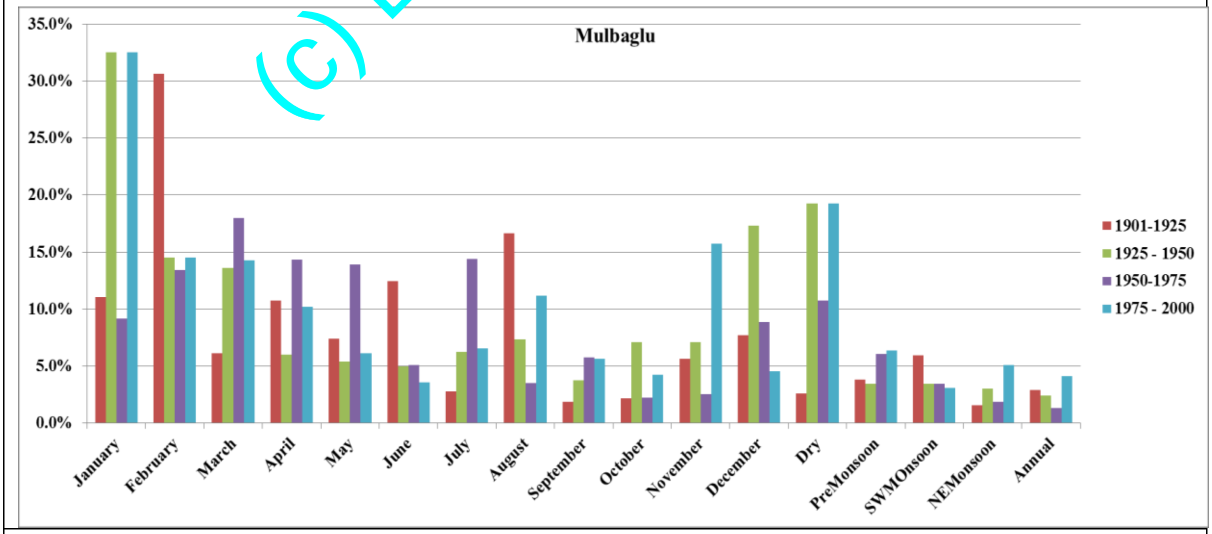
Bangarpet



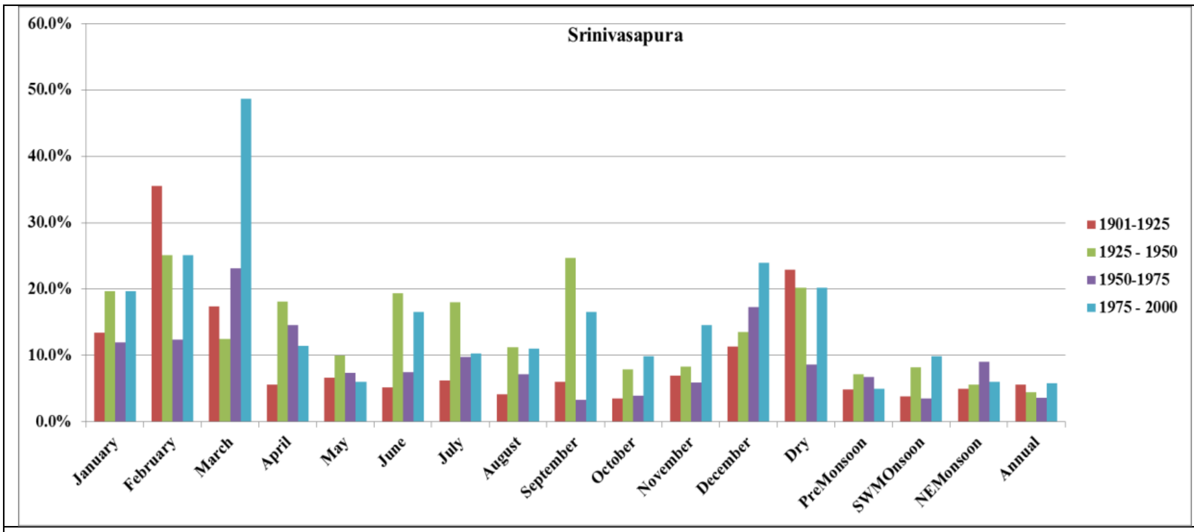
Kolar



Maluru



Mulbaglu



Srinivasapura

Figure 3.13: month wise COV - Taluk wise (for 25 years rainfall)

COV - TEMPORAL VARIATIONS

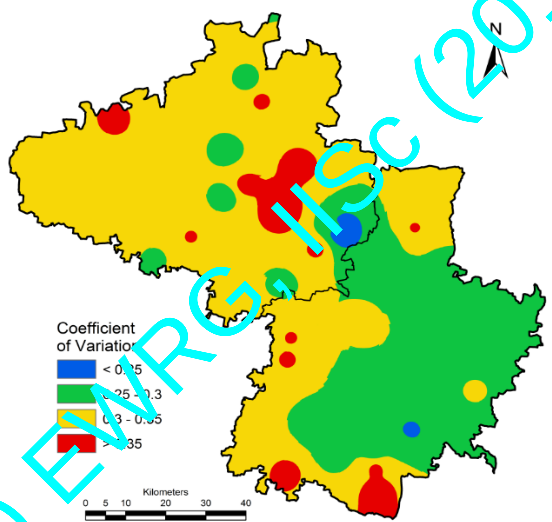
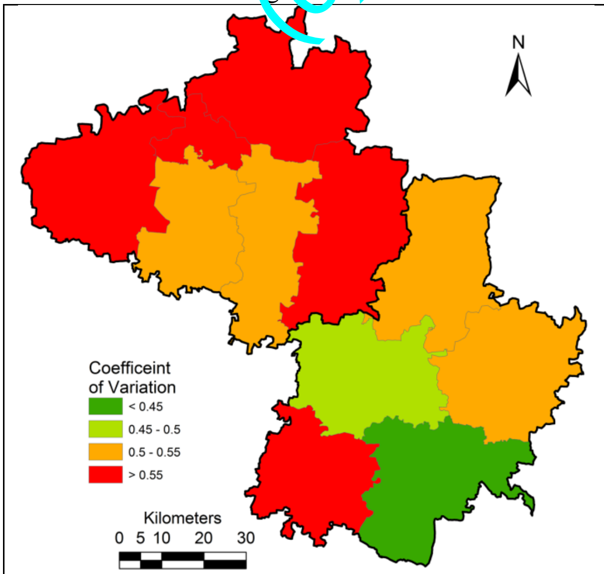
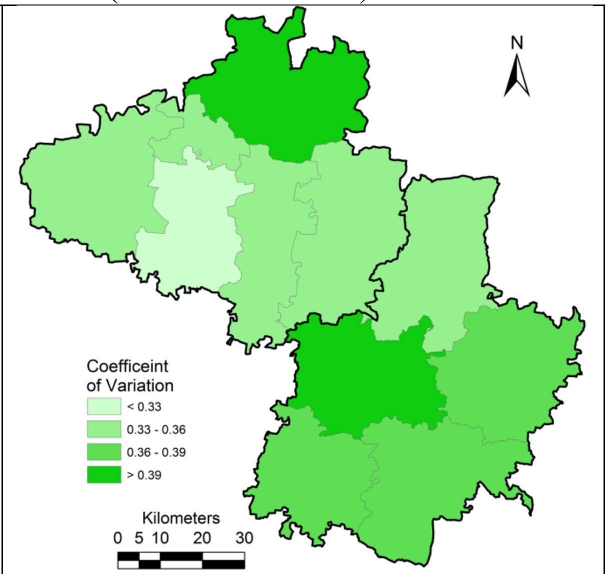


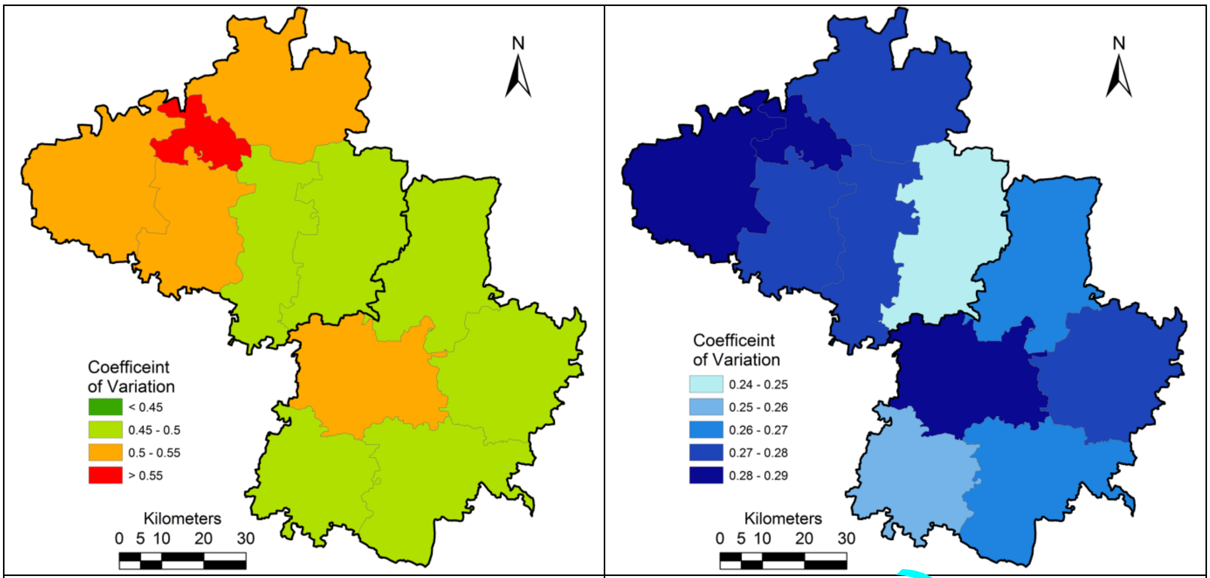
Figure 3.14: Coefficient of variation (1901-2015 Annual)



Pre Monsoon



South West Monsoon



North East Monsoon	Annual

Figure 3.15: Coefficient of Variation taluk and season wise

Table 3.8: Rainfall Statistics of Kolar District (1901 – 2015)

Taluk	Mean (mm)	SD (mm)	COV
Bangarpete	716	209	0.29
Kolar	703	211	0.30
Malur	675	186	0.28
Mulbaglu	723	215	0.30
Srinivasapura	686	206	0.30

Table 3.9: Rainfall Statistics of Chikkaballapur District (1901 – 2015)

Taluk	Mean (mm)	SD (mm)	COV
Bagepalli	610.01	182.48	0.30
Chikkaballapur	734.03	217.10	0.30
Chintamani	639.69	167.85	0.26
Goudribidanuru	666.45	205.09	0.31
Gudibande	751.96	218.74	0.29
Shidlighatta	694.61	202.66	0.29

Figure 3.11.1 to 3.11.4 illustrates coefficient of variation (Spatial) month wise and season wise based on the mean rainfall for the period 1901-1925, 1926-1950, 1951-1975 and 1976 – 2000. Similarly, Figure 3.12 presents month and season wise (for 25 years rainfall data) COV. Figure 3.13 provides month wise COV for each taluk based on 25 years rainfall data. Figure 3.14 depicts spatial variation of COV based on annual rainfall data of the period 1901-2015 Annual. COV lower than .30 further highlights that there is no significant variation in the rainfall. Figure 3.15 depicts COV taluk and season wise and these are summarised in Tables 3.8 and 3.9 respectively. The rainfall trend analyses based on the rainfall data of the period 1901-2005

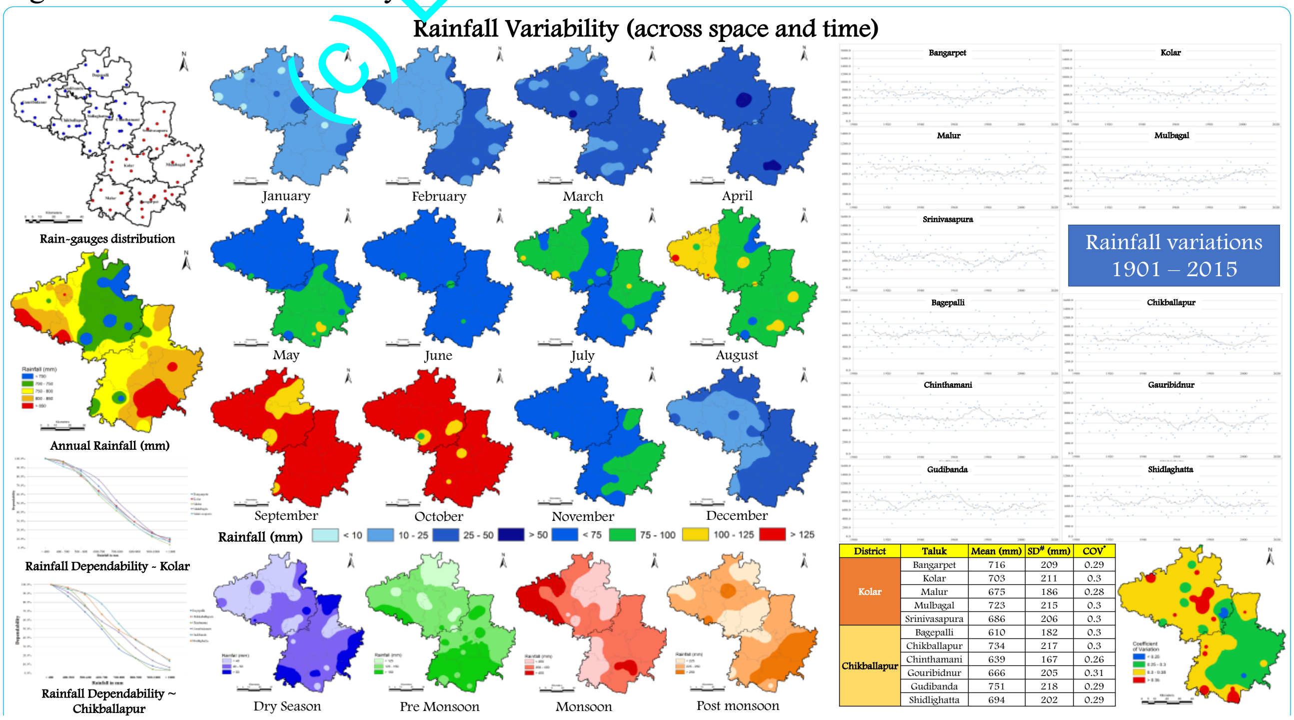
reveals that taluks in Kolar district (Bangarpete receives 716±209 mm annual rainfall (with COV 0.29), Kolar taluk receives 703±211 mm annual rainfall (with COV 0.30), Malur receives 675±186 mm (COV:0.28), Mulbaglu receives 723±215 mm (COV:0.30) and Srinvasapura 686±206 mm (COV: 0.30)) receives on an average rainfall of 400-500 mm. Similar is the case with Chikballapur district (Bagepalli 610±182 (COV:0.3), Chikballapur 734±217 (COV:0.30), Chintamani 639±167 (COV: 0.26), Gouribidanuru 666±205 (COV:0.30), Gudibande 751±218 (COV:0.29) and Shidlaghatta 694±202 (COV:0.29). The analyses highlights that there is no decline in rainfall and the variation follow the cycle of few years above normal rainfall and few years below normal rainfall. This trend is summarised in Figure 3.15. Water scarcity in the district is mainly due to mismanagement of water bodies – not removing silt regularly, deforestation (every catchment/watershed of a water body should have minimum of 33-45% green cover of native vegetation, which will help in retaining the water), over exploitation of ground water resources, monoculture plantations of exotic species such as Eucalyptus, etc. Karnataka administrators should learn from Rajasthan of ensuring water sustainability through indigenous techniques in the management of water bodies despite annual rainfall less than 400 mm. Water scarcity despite annual rainfall of 600±150 mm annual rainfall only reflects inefficient management of natural resources by incompetent and dishonest decision makers during the post-independence era. Figure 3.16 illustrates the path to be adopted to sustain water in the district and ensure food security.

4.0 Conclusion: Sufficient water is available in the region, provided the district administrators sensibly practice integrated watershed management. Suggestions in this regard are:

- Decentralized rain water harvesting through lakes;
- Constructed wetlands integration with lakes to prevent water contamination (with agriculture run off, sewage inflow, etc.);
- Catchment/watershed management for effective soil and water conservation;
- Rejuvenation of existing lakes
  - De-silting to enhance the storage capacity as well as groundwater recharge;
  - Reestablish inter-connectivity among lakes;
  - Removal of all encroachments (lake bed, natural drains);
  - Maintaining at least 33% green cover (of native species) in the catchment;
  - catchment treatment (through planting native saplings)

- Incentive to create farm ponds in all agricultural field (this helps in ground water recharge, and also helps in fish rearing and hence local livelihood)
- Phasing out monoculture plantations of exotic species (such as eucalyptus, etc. which sucks groundwater) with native species on priority.
- Appropriate cropping pattern and restriction on crops that are water intensive.
- Allowing only dry land crops;
- Incentives to farmers growing crops suitable for semi arid region;
- Greening/afforestation in the catchments of water bodies (lakes, rivers, etc.) with native species, ensure that at least 33% is maintained with native trees and grasses to enhance water retaining capacity of Catchment/watershed;
- Inclusions of concepts - watershed, environment, afforestation, reforestation in the education curriculum (Schools and Colleges);
- Management of water bodies involving all stakeholders, and constitution of joint environment management committee at each village level to address the issue of forest as well as water bodies;
- Restriction on sand mining beyond sustainable yield;
- Kolar has distinction of having highest barren area (un-productive land) and is heralding towards desertification (next to Rajasthan). This requires immediate afforestation in the catchment through CAMPA. Auditing of these activities through independent and unbiased academic institutions.

Figure 3.15: rainfall variability - space and time in Kolar district



District	Taluk	Mean (mm)	SD# (mm)	COV*
Kolar	Bangarpet	716	209	0.29
	Kolar	703	211	0.3
	Malur	675	186	0.28
	Mulbagal	723	215	0.3
	Srinivasapura	686	206	0.3
Chikballapur	Bagepalli	610	182	0.3
	Chikballapur	734	217	0.3
	Chinthamani	639	167	0.26
	Gouribidnur	666	205	0.31
	Gudibanda	751	218	0.29
	Shidlighatta	694	202	0.29

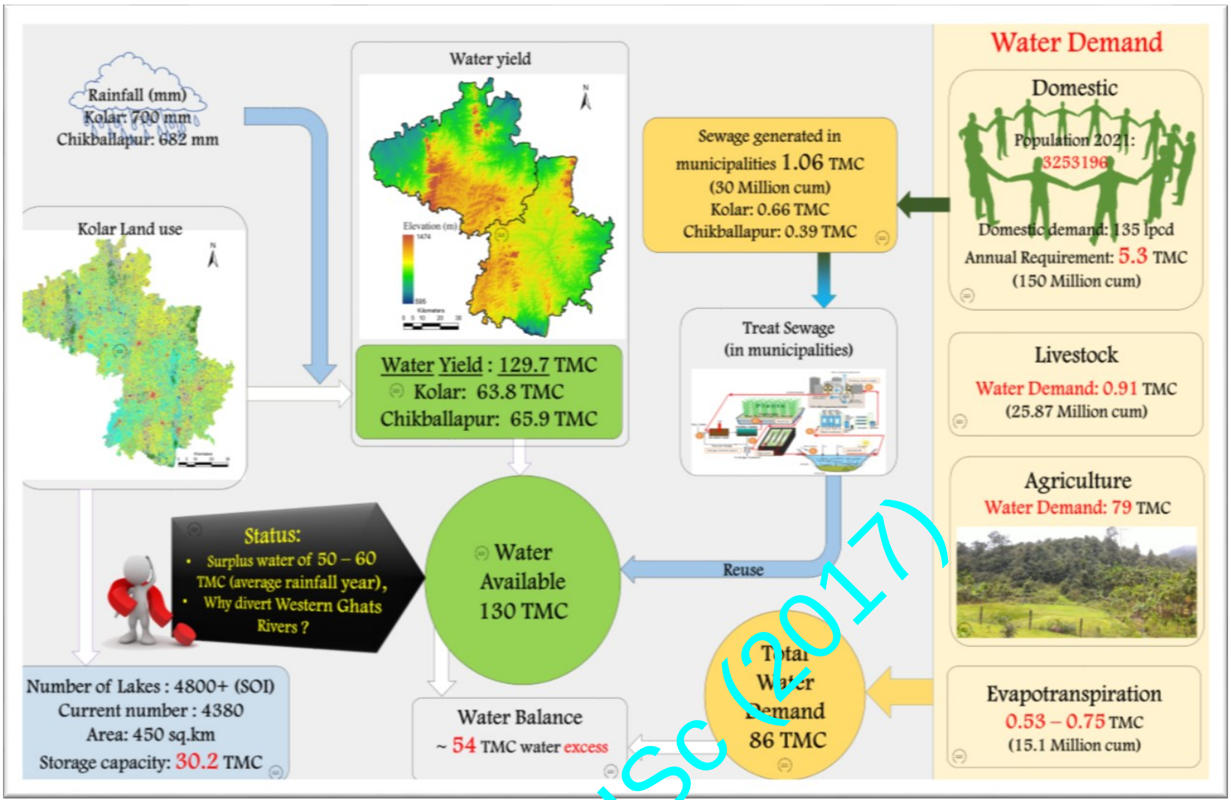
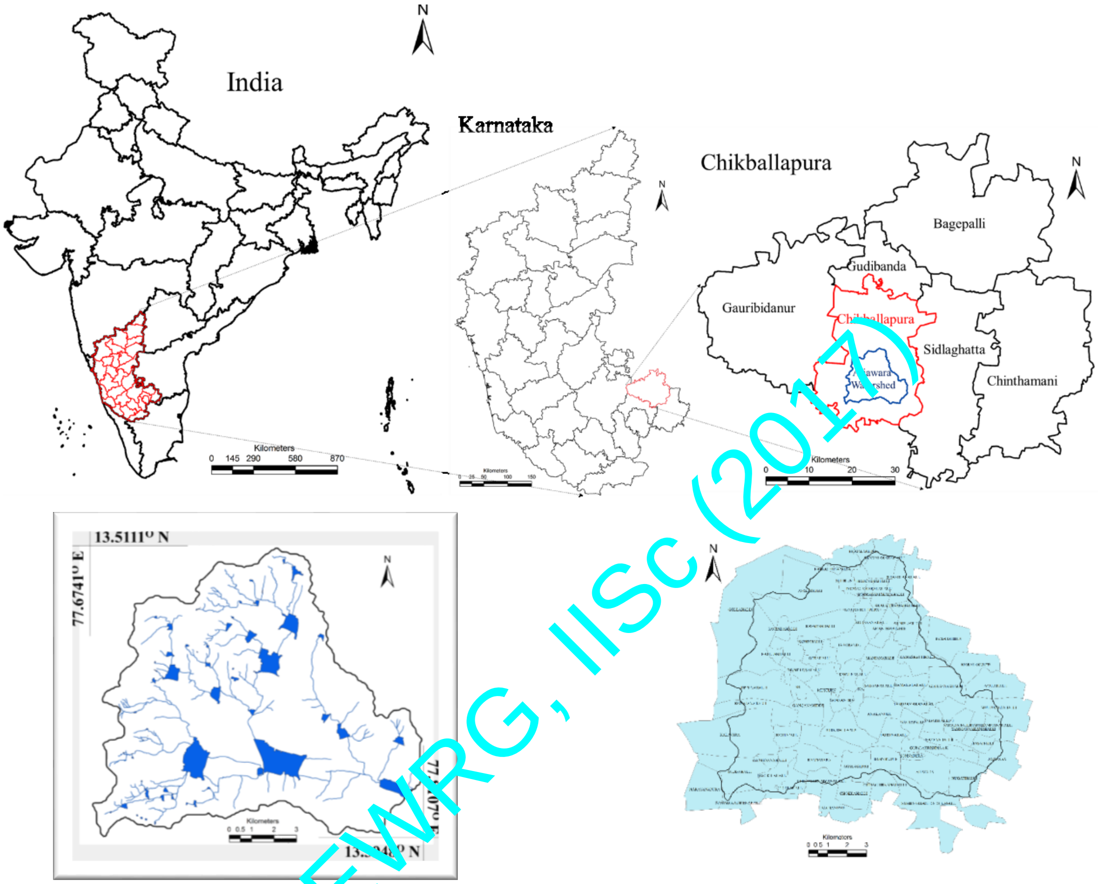


Figure 3.16: Solutions to water crisis: Harvest Rainwater, Rejuvenate lakes, Watershed management, plant native samplings in the catchment, de-siltation of water bodies, good governance involving all sensible stakeholders

5.0 AJJAWARA WATERSHED

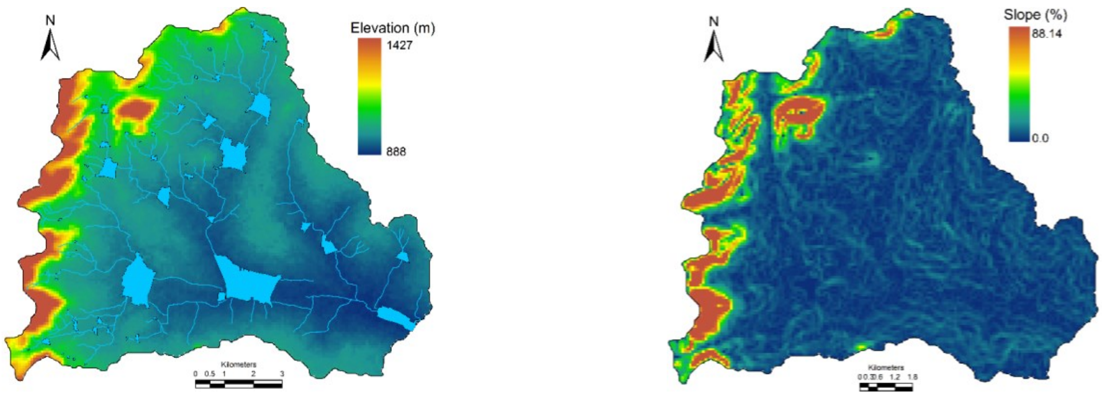
Ajjawara watershed is located in Chikballapur Taluk of Chikballapur District, Karnataka (Figure 5.1). Extending between 13.3948° to 13.5111°N and 77.6741 to 77.8107 °E, Ajjawara catchment has as area of 122.14 km^2, covering about 71 villages (Figure 5.1).



Watershed Villages

Figure 5.1: Ajjawara Watershed

Ajjawara watershed is bounded by Rocky hills in the west. Elevation in the watershed varies between 888m to 1427m AMSL (Figure 5.2). Slopes (Figure 5.2) are gentle across the catchment and steep at the hillocks. Slope ranges between 0% to 88.14%.



DEM – SRTM 90m Slope (%)

Figure 5.2: Topography

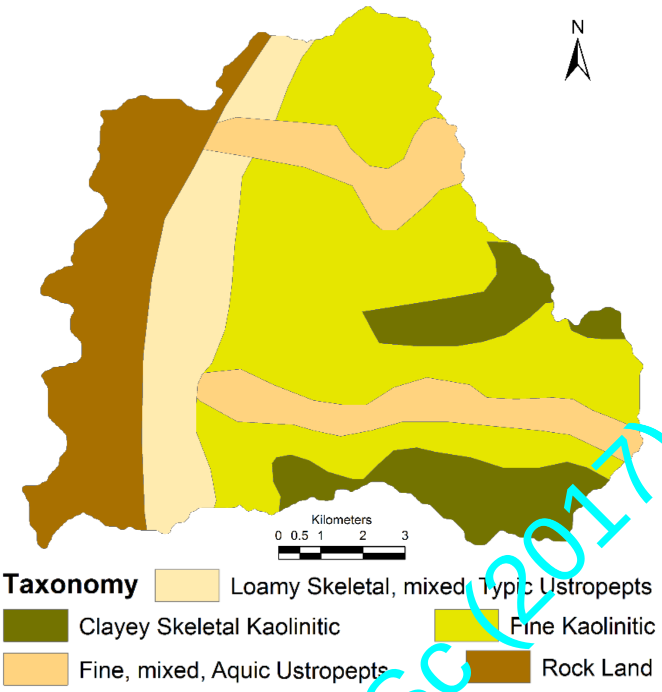


Figure 5.3: Soil

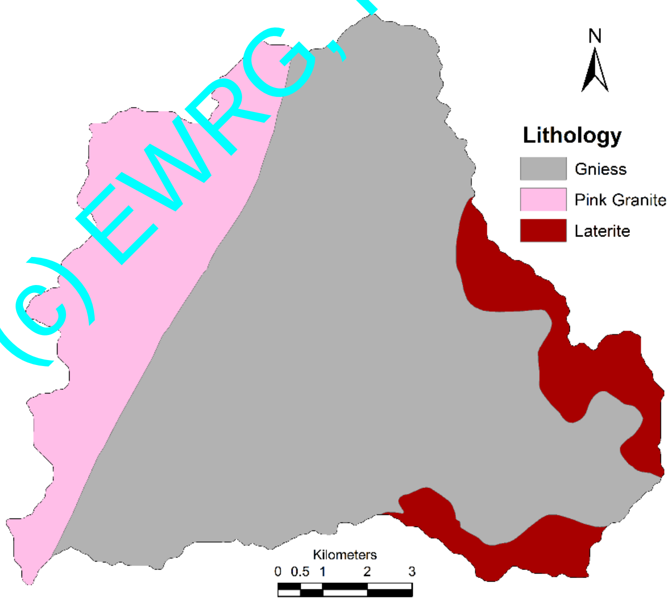


Figure 5.4: Geology

Soils vary between loamy to clayey (Figure 5.3) (http://eusoils.jrc.ec.europa.eu/, National Bureau of Soil Survey and Land Use Planning). Rock type includes Gneiss, Pink Granite and Laterite (Figure 5.4). Ground water status is as depicted in Figure 5.5 (Central Ground Water Board), on an average in the catchment, Ground water is under moderate condition.

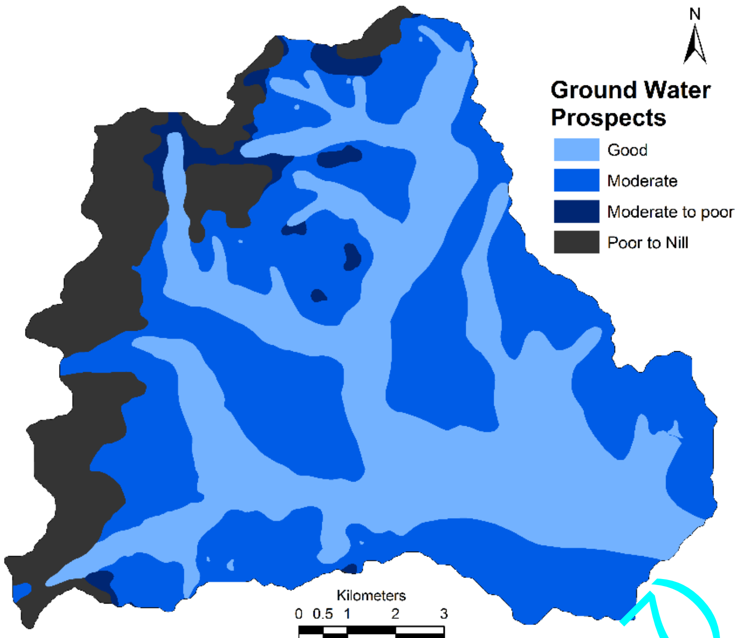


Figure 5.5: Ground Water Status

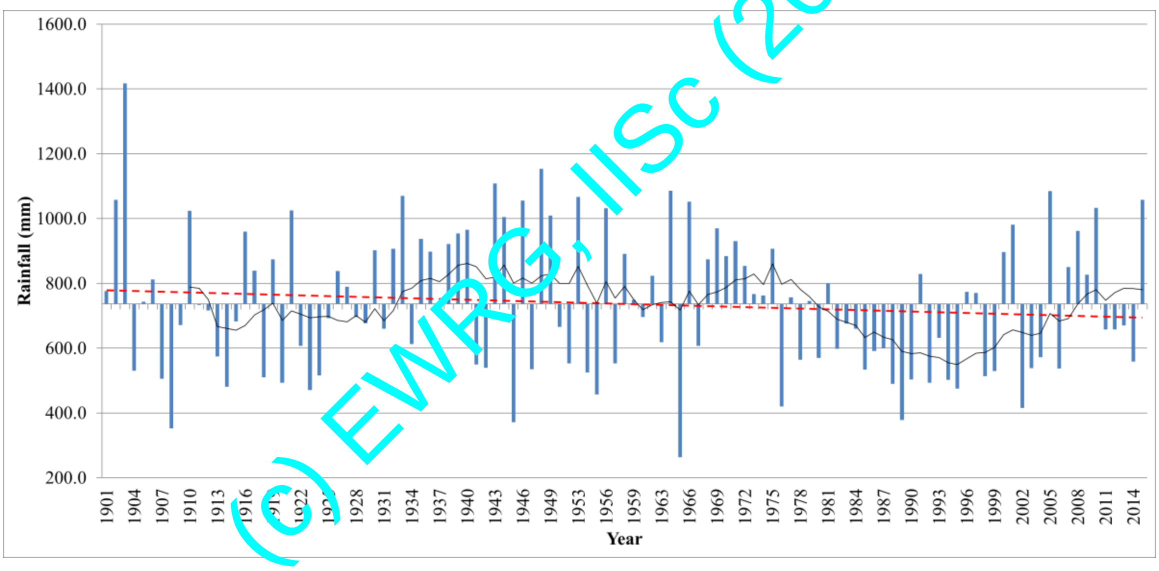


Figure 5.6: Rainfall regime (Annual Rainfall in Chikballapur)

Rainfall analysis was carried out in the catchment between 1901 to 2015. Rainfall variations across time and space is as depicted in Figure 5.6 to Figure 5.8 and Table 5.1. Average rainfall in the catchment is about 698 mm (Median). Analysis of annual rainfall in the catchment shows that rainfall is below average for long duration since 1980's. Rainfall in the catchment is highly variable across time, it can be observed that normal rainfall occurs with a return period of 2.5 years where as Drought or excess rainfalls occurs at a return period of 3.3 years. Spatial distribution of rainfall is as depicted in Figure 5.8, across space, rainfall varies between 750 mm to 900 mm.

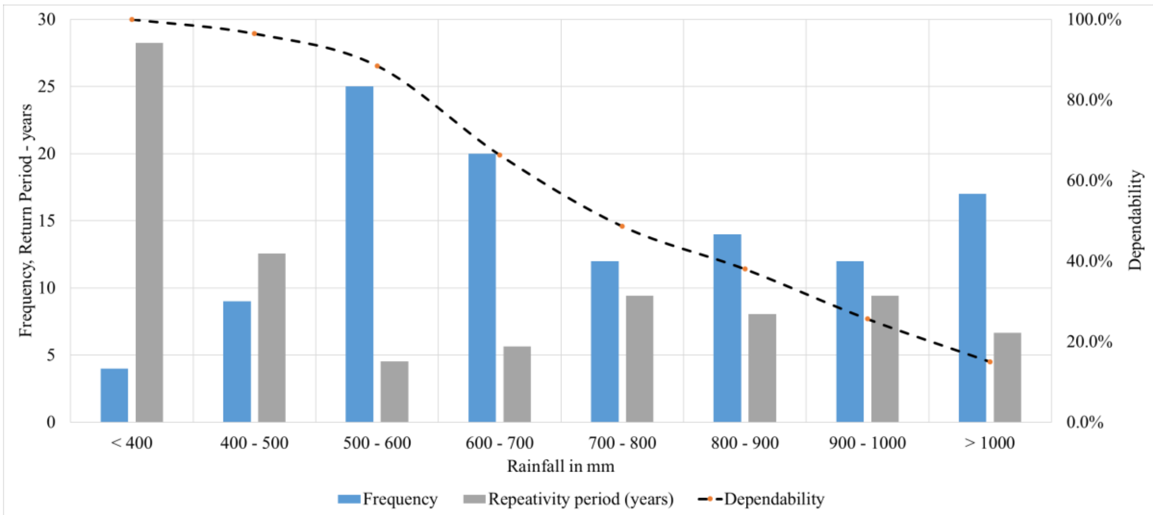


Figure 5.7: Rainfall Characteristics – Frequency, Dependability and Return Period

Table 5.1: Rainfall Characteristics

Rainfall (mm)	Frequency	Probability of Occurrence	Dependability	Return Period (years)
< 400	5	4	100.0%	28
400 - 500	15	9	96.5%	13
500 - 600	12	25	88.5%	5
600 - 700	19	20	66.4%	6
700 - 800	21	12	48.7%	9
800 - 900	15	14	38.1%	8
900 - 1000	4	12	25.7%	9
> 1000	2	17	15.0%	7

Minimum	263 mm	Maximum	1416 mm
Mean	736 mm	Median	698 mm
Standard Deviation	±216 mm	Coefficient of Variation	**0.29**

Indian Meteorological Department – Rainfall Distribution All India Scenario

Rainfall Distribution	*Condition*	*Rainfall*	*Probability of Occurrence*	*Return Period (Year)*
Excess	*> 20% Average*	*> 883 mm*	*0.29*	*3.4*
Normal	*± 20% Average*	*588 – 883 mm*	*0.40*	*2.5*
Drought	*-20% Average to -60% Average*	*294 – 588 mm*	*0.30*	*3.3*
Severe Drought	*> -60% Average*	*< 294 mm*	*0.01*	*113*

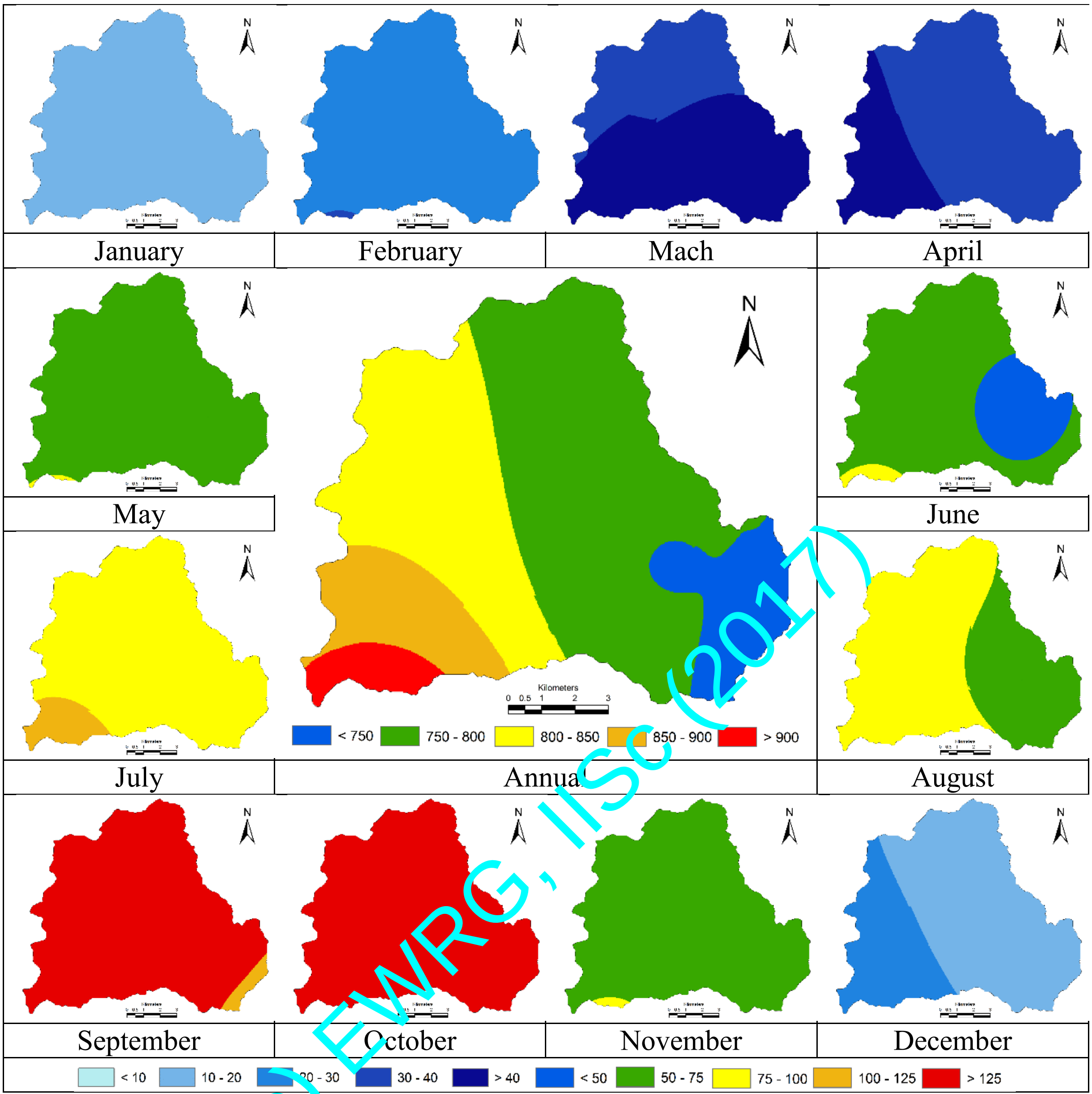


Figure 5.8: Spatial Distribution of Rainfall (All units in mm)

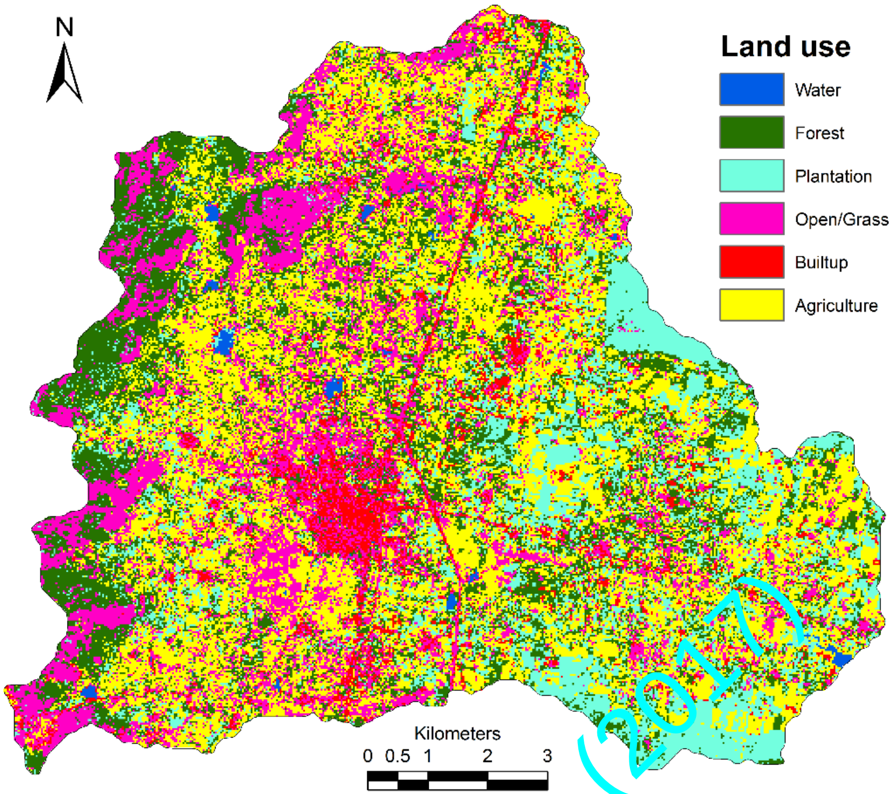


Figure 5.9: Land use

Land use of 2016 was assessed using Landsat 8 data (resolution 30 m). Signatures were collected from Google earth and field visit. Gaussian Maximum likelihood classifier was used to classify the satellite image to 6 categories namely Water, Forest, Plantation, Open lands, Built-up and Agriculture. The results of Land use is as presented in Figure 5.9 and Table 5.2. Ajjawara catchment is dominated with Agriculture lands (3.3%) followed by Forest patch in that occurs on Hill and surrounding the West. Major Cereals in the catchment are Ragi and Maize, Pulses include Avare, Horsegram, Tur, Fruits and Vegetables are also grown extensively. Figure 5.10 depicts Google earth image of the catchment.

Table 5.2: Land use

Land Use	Area	
	Hectare	%
Water	81.72	0.67
Forest	2764.08	22.63
Plantation	1889.46	15.47
Open	2355.84	19.29
Built up	687.06	5.62
Agriculture	4436.91	36.32

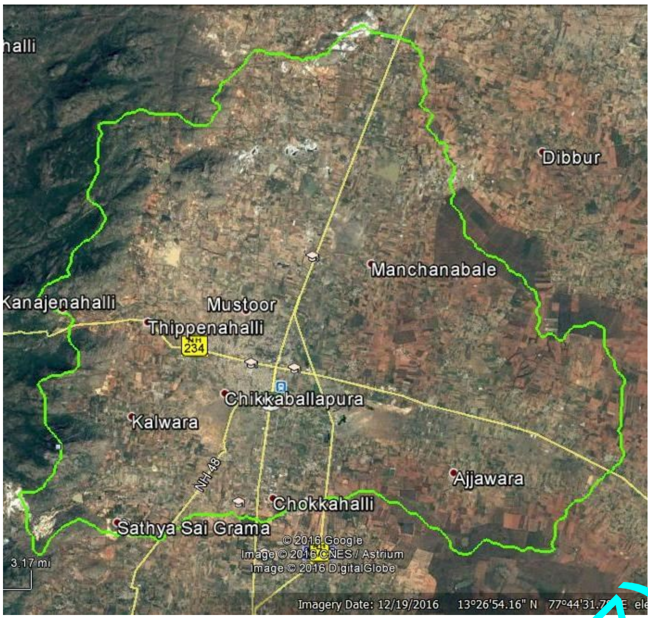


Figure 5.10: Google Earth

Kolar (Kolar +Chikballapur districts) Tree list

Dry Deciduous forests: Generally found in higher elevations like Antaragange range forests with good amount of rain fall. The important species are:	**AVENUE TREES:** These includes those trees planted along the roadsides and those growing in village limits. They include:
1. *Azadirachta indica*	1. *Acacia nilotica*
2. *Bauhinia racemosa*	2. *Aegle marmelos*
3. *Bombax cieba*	3. *Albizzia lebbeck*
4. *Bridelia crenulata*	4. *Arachis hypogea*
5. *Bridelia crenulata*	5. *Artocarpus integrifolia*
6. *Butea monosperma*	6. *Azadirachta indica*
7. *Cassia fistula*	7. *Butea monosperma*
8. *Cassina glauca*	8. *Dalbergia sissoo*
9. *Cochlospermum religiosum*	9. *Delonix regia*
10. *Dalbergia sympathetica*	10. *Ficus benghalensis*
11. *Diospyros chloroxylon*	11. *Ficus racemosa*
12. *Diospyros melanoxylon*	12. *Ficus religiosa*
13. *Ficus racemosa*	13. *Holoptelia integrifolia*
14. *Ficus tinctoria*	14. *Jacaranda acutifolia*
15. *Grewia laevigata*	15. *Madhuca indica*
16. *Holarrhena pubescens*	16. *Mangifera indica*
17. *Lagerstoemia parviflora*	17. *Melia dubia*
18. *Phyllanthus emblica*	18. *Michelia champaka*
19. *Pongamia pinnata*	19. *Millingtonia hortensis*
20. *Terminalia alata*	20. *Phyllanthus emblica*
21. *Terminalia bellarica*	21. *Pongamia pinnata*
22. *Wrightia tinctoria*	22. *Prosopis juliflora*
	23. *Samanea saman*
	24. *Spathodea companulata*
	25. *Syzygium cumini*
	26. *Tabuebia arjentia*
	27. *Tabuebia rosea*
	28. *Tamarindus indica*
	29. *Terminalia arjuna*
	30. *Thespesia populnea*
	31. *Vitex negundo*

THORN SCRUB FOREST: This spreads over places having a very dry climatic conditions like Muduvadi range forest, dry hills of Antaragange etc. They inhabit very small stunted trees like: 1. *Acacia leucophloea* 2. *Diospyros chloroxylon* 3. *Diospyros montana* 4. *Santalum album* 5. *Ziziphus jujuba*	**SECONDARY FORESTS:** Consists of forest tree plantations mostly for timber purposes. Common plantation species are: 1. *Albizzia amara* 2. *Albizzia lebbeck* 3. *Cassia siamea* 4. *Dalbergia sissoo* 5. *Gliricedia sepium* 6. *Tamarindus indica* 7. *Tectona grandis*
ORCHARDS Most of the villages have one or the other fruit orchards like in village Kondasandra most of the areas are mango cultivated, hence covering nearly half of the village. It may be intermixed with trees like *Anacardium occidentale*, Tamarind, etc. 1. *Anacardium occidentale* 2. *Mangifera indica* 3. *Manilkara zapota* 4. *Psidium guajava*	**GROOVES AND PLANTATIONS:** Kolar being a dry district, one hardly finds a continuous or large patch of forests. However, small grooves or clumps of trees like *Pongamia pinnata*, *Wrightia tinctoria*, *Azadirachta indica* are found along the edges and borders of fields and in waste lands. Large plantations of hardy fuel trees, which survive in Kolar's dry climate (depends on scanty rainfall) have been planted both by farmers and by the forest department under social forestry programme. 1. *Acacia nilotica* 2. *Azadirachta indica* 3. *Casuarina equisetifolia* 4. *Cocus nucifera* 5. *Pongamia pinnata* 6. *Tamarindus indica* **7.** *Tectona grandis*

COMMON FUEL AND TIMBER TREES: Household surveys conducted in selected households of Kolar, indicates high dependence on bio resources (such as fuel wood, agricultural residues etc.) for cooking, etc. Preferred tree species for fuel wood are Eucalyptus, Pongamia, etc. As more number of lakes are drying due to various reasons like siltaton, encroachment of those natural and manmade channels which bring them water, many of these wetlands like Holali tank of Huthur have been fully planted by timber and fuel trees like *Acacia nilotica*, *Prosopis juliflora* etc. More and more farmers have long back started planting Eucalyptus and other fuel trees discarding their traditional farming due to poor yeild, depletion of water table in wells and borewells and erratic electricity supply. Common fuel wood and timber species are: *Acacia auriculiformis*, *Acacia nilotica*, *Azadirachta indica*, *Cassia fistula*, *Cassia siamea*, *Casuarina equisetifolia*, *Eucalyptus sp.*, *Gliricidia sepium*, *Jatropha sp.*, *Pongamia pinnata, Prosopis juliflora, Tectona grandis, etc.*

6.0 KANDAVARA KERE

Threats	1. Encroachment of lake bed and buffer zone (75 m is buffer and is to be without any construction activities). 2. Loss of interconnectivity among drains – due to encroachments or dumping of soil, etc. 3. Silt accumulation in the water body – de-silting should have been done at least once in three years 4. Removal of macrophytes in the buffer zone (these macrophytes were helping in bioremediation) 5. Unplanned urbanisation in the catchment would be detrimental to the sustenance of water in the lake.
Solutions	1. Re-establish interconnectivity among lakes (Figure 6.6) by removal of all drain encroachments and blockages. 2. De-silting of lakes. 3. Maintaining green cover (grasses and trees – native species) at least 30-40% of the catchment area. 4. Encouraging farmers to adopt agro forestry of native species 5. Phasing out exotic water demanding species such as Eucalyptus, etc. 6. Aquatic emergent macrophytes in the buffer zone of the lake (Figure 6.7). 7. Appropriate soil and water conservation (drip or sprinklers to minimize water use) measures.

Kandavar Lake located in Chikkaballapur is one of the main water source for Chikkaballapur City. Lake (Figure 6.1) is spread across 4 villages (Figure 6.2 to Figure 6.5) of Chikkaballapur taluk namely Kandavara, Ammanikere-Kandavara, Mallappanahalli and Ganganamidde encompassing an area of ~ 1.68 sq.km. Majority of lake is covered in Kandavara Ammanikere Village. The lake has a catchment area of 35.25 sq.km.(Figure 6.6). Figure 6.7 depicts the Lake with buffer zone of 75 meters and Figure 6.8 depicts encroachment in the lake. Current encroachment of 7.89 hectares. Rainfall in the catchment is about 880 mm (Figure 6.9). Land use in the catchment is dominated by agriculture (Figure 6.6). With existing rainfall, annual yield of 13750 Million liters (0.48 TMC) can be expected in the catchment.

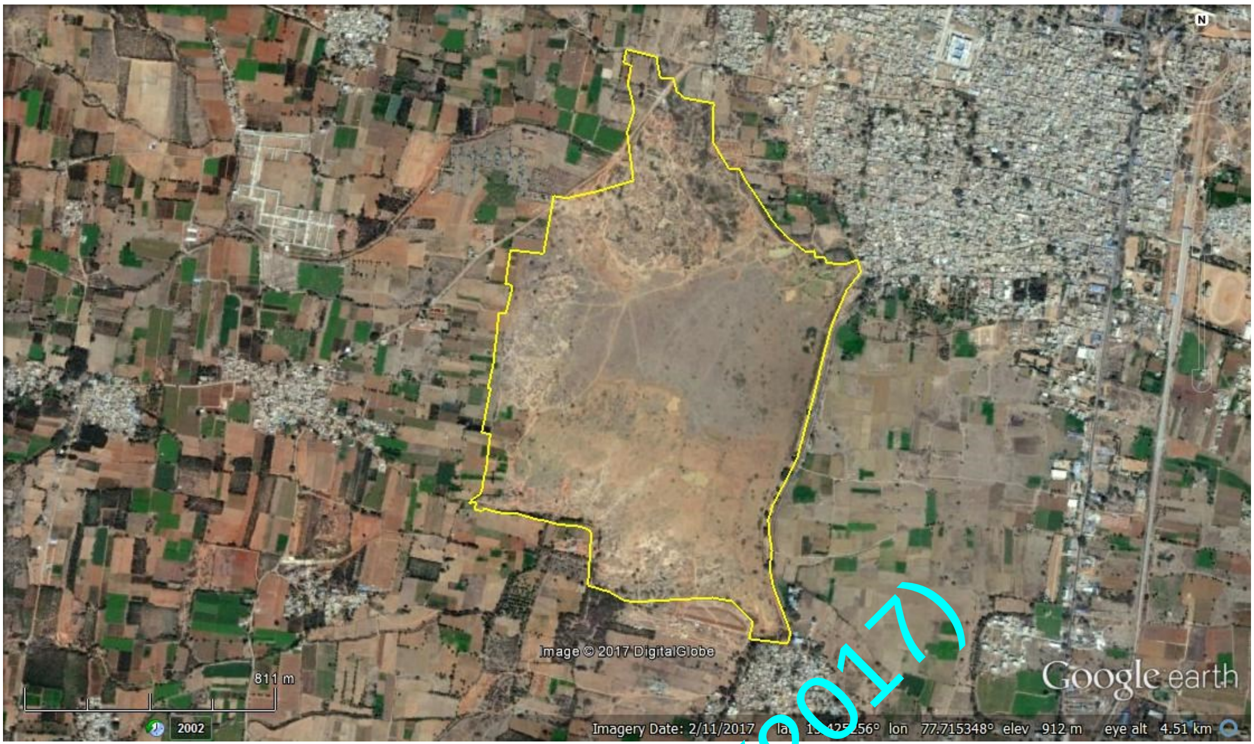


Figure 6.1: Kandavara Lake

Figure 6.2: Kandavara Ammanikere Village

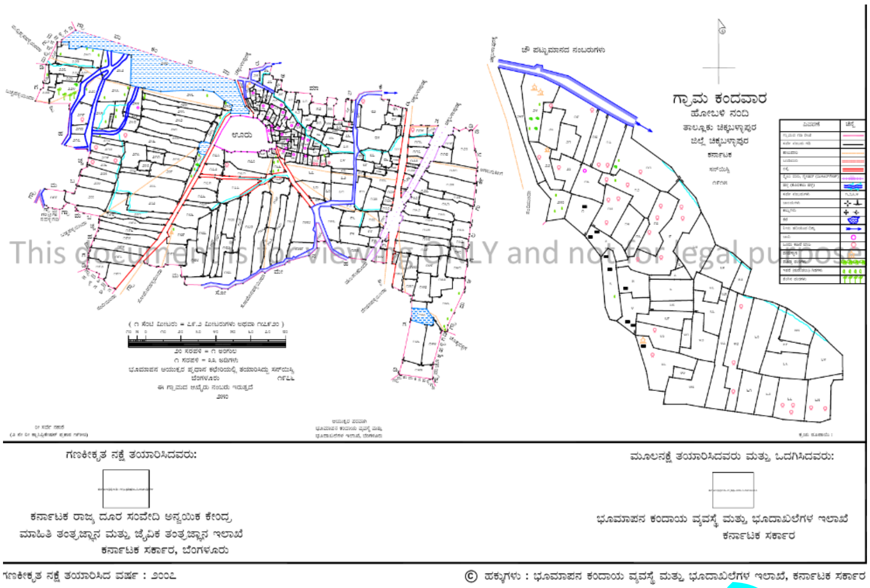


Figure 6.3: Kandavara Village

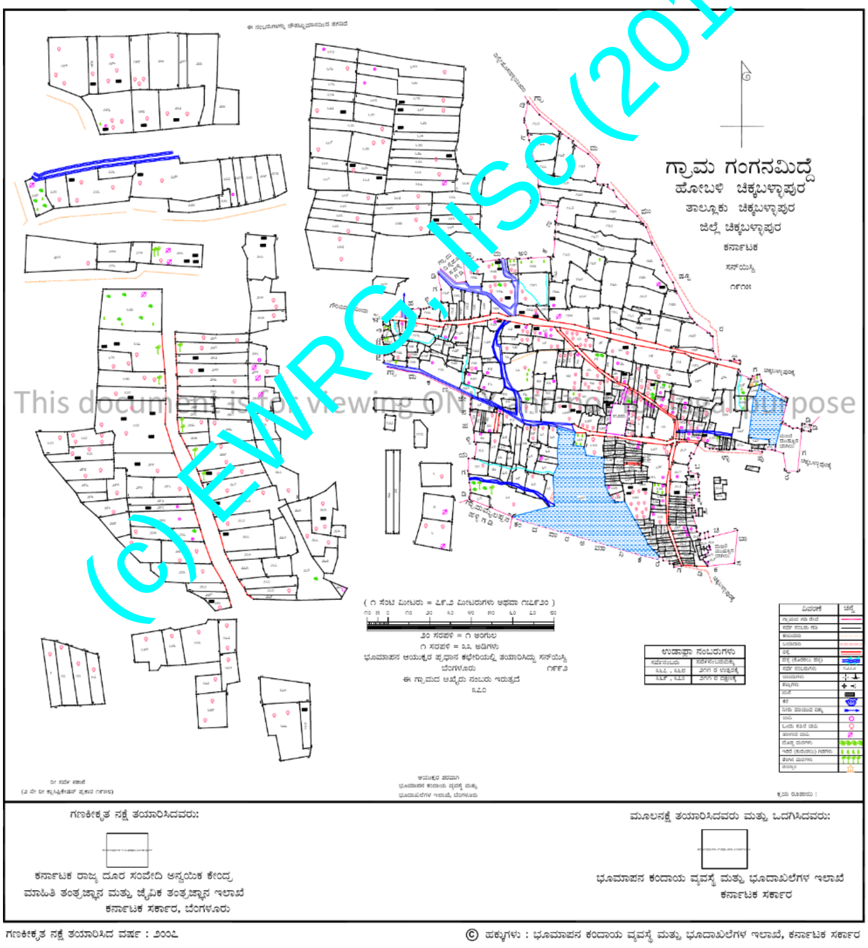


Figure 6.4: Ganganamidde Village

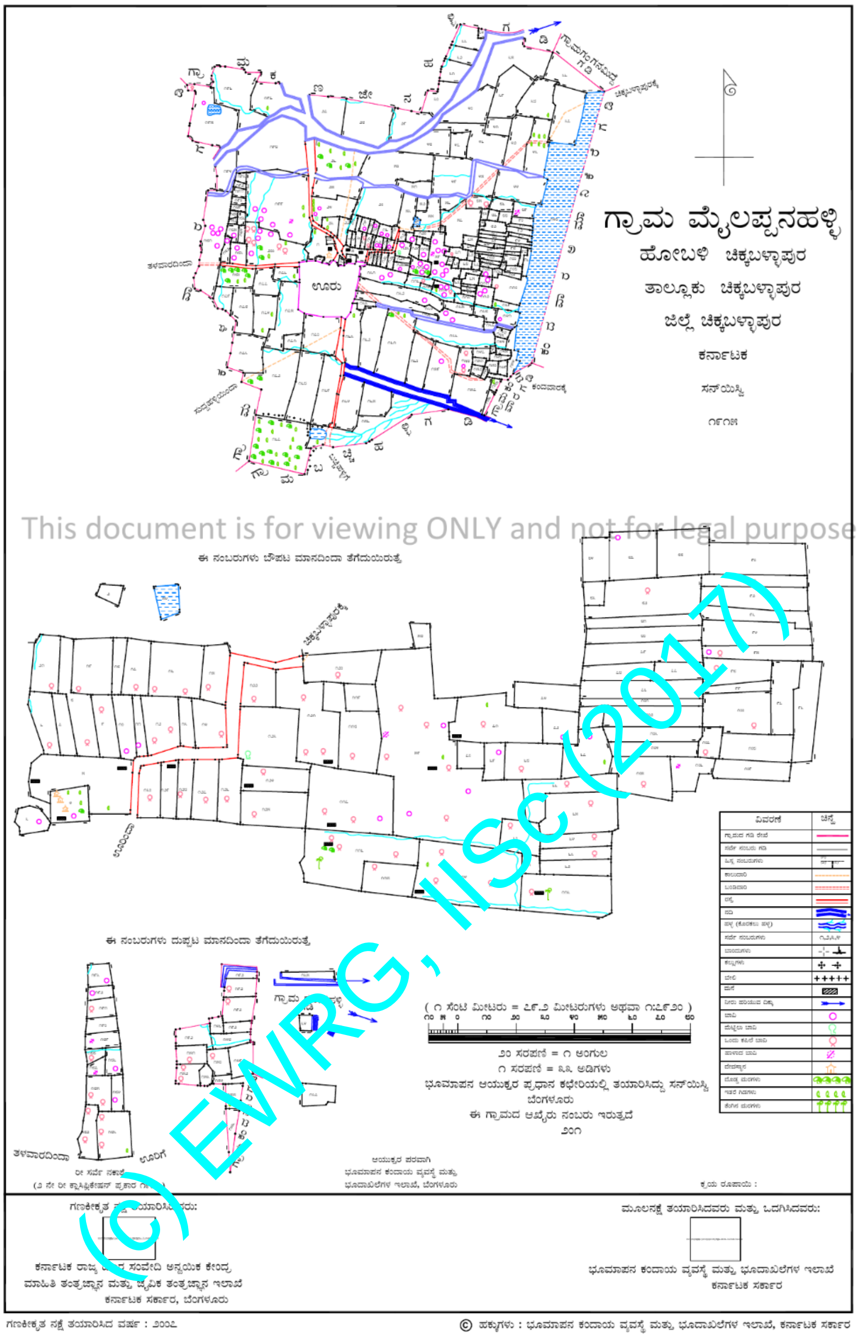


Figure 6.5: Mallappanahalli Village

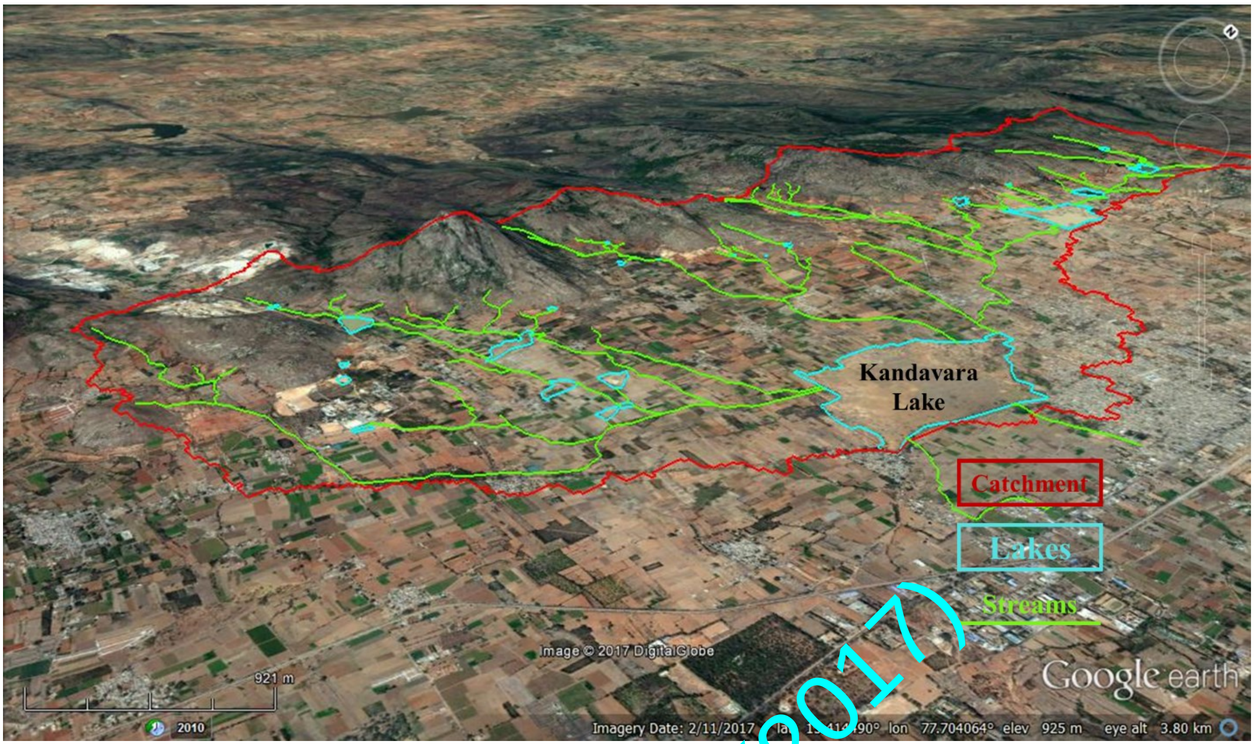


Figure 6.6: Kandavara lake, catchment and its drains as on Google Earth.

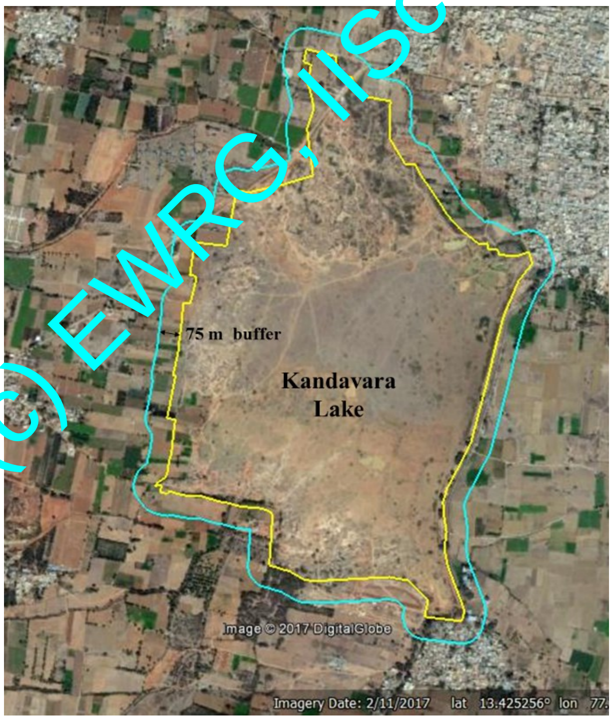


Figure 6.7: Kandavara Lake and Buffer distance of 75 meters

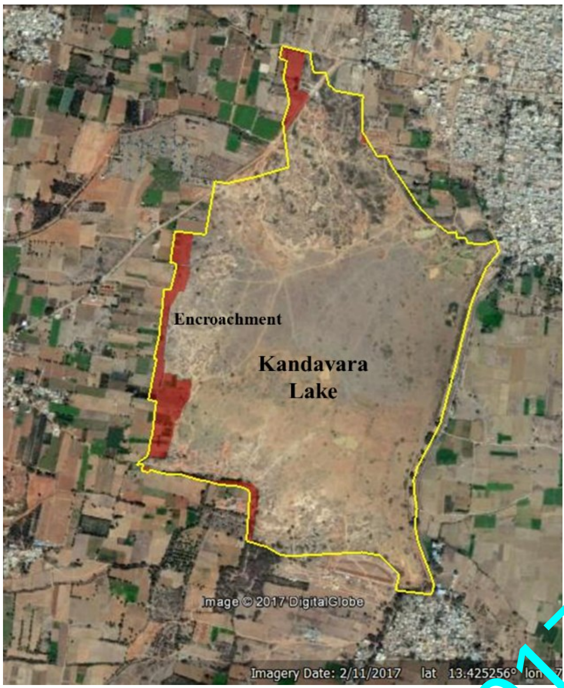


Figure 6.8: Lake Encroachment

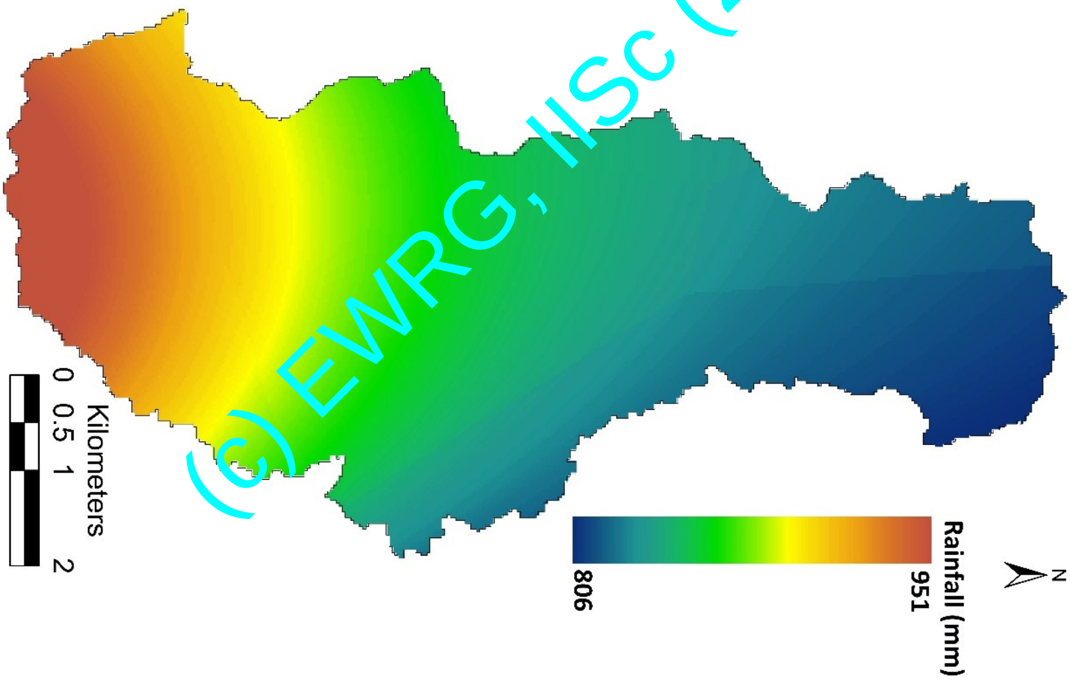


Figure 6.9: Rainfall distribution

Recommendations

- Decentralized rain water harvesting through lakes, recharge pits, etc.;
- Constructed wetlands integration with lakes to prevent water contamination (with agriculture run off, sewage inflow, etc.);
- Catchment/watershed management for effective soil and water conservation;
- Rejuvenation of existing lakes

- De-silting to enhance the storage capacity as well as groundwater recharge;
- Reestablish inter-connectivity among lakes;
- Removal of all encroachments (lake bed, natural drains);
- Maintaining at least 33% green cover (of native species) in the catchment;
- catchment treatment (through planting native saplings)

- Incentive to create farm ponds in all agricultural fields (this helps in ground water recharge, and also helps in fish rearing and hence local livelihood)
- Restrictions on any construction activity in the buffer zone of a lake (75 m).
- Maintaining aquatic macrophytes in the buffer zone of each lake, which helps in bioremediation.
- Phasing out monoculture plantations of exotic species (such as eucalyptus, etc. which sucks groundwater) with native species on priority.
- Appropriate cropping pattern and restriction on crops that are water intensive.
- Allowing only dry land crops;
- Incentives to farmers growing crops suitable for semi-arid region;
- Greening/afforestation in the catchments of water bodies (lakes, rivers, etc.) with native species, ensure that at least 33% is maintained with native trees and grasses to enhance water retaining capacity of Catchment/watershed;
- Inclusions of concepts - watershed, environment, afforestation, reforestation in the education curriculum (Schools and Colleges);
- Management of water bodies involving all stakeholders, and constitution of joint environment management committee at each village level to address the issue of forest as well as water bodies;
- Restriction on sand mining beyond sustainable yield;
- Restrictions on bore wells and regulation of number of wells in a region (to mitigate overexploitation)
- Kolar has distinction of having highest barren area (un-productive land) and is heralding towards desertification (next to Rajasthan). This requires immediate afforestation in the catchment through CAMPA. Auditing of these activities through independent and unbiased academic institutions.
- Environment education / awareness programmes to sensitize farmers, youth and school children.

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Geographic Resources Decision Support System for land use, land cover dynamics analysis

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Abstract

Change detection is the measure of the distinct data framework and thematic change information that can guide to more tangible insights into underlying process involving land cover and land use changes than the information obtained from continuous change. Digital change detection is the process that helps in determining the changes associated with landuse and land cover properties with reference to geo-registered multitemporal remote sensing data. It helps in identifying change between two (or more) dates that is uncharacterised of normal variation. Change detection is useful in many applications such as landuse changes, habitat fragmentation, rate of deforestation, coastal change, urban sprawl, and other cumulative changes through spatial and temporal analysis techniques such as GIS (Geographic Information System) and Remote Sensing along with digital image processing techniques.

GIS is the systematic introduction of numerous different disciplinary spatial and statistical data, that can be used in inventorying the environment, observation of change and constituent processes and prediction based on current practices and management plans. Remote Sensing helps in acquiring multi spectral spatial and temporal data through space borne remote sensors. Image processing technique helps in analyzing the dynamic changes associated with the earth resources such as land and water using remote sensing data. Thus, spatial and temporal analysis technologies are very useful in generating scientifically based statistical spatial data for understanding the land ecosystem dynamics. Successful utilization of remotely sensed data for land cover and landuse change detection requires careful selection of appropriate data set. This paper discusses the land use/land cover analysis and change detection techniques using GRDSS (Geographic Resources Decision Support System) for Kolar district considering temporal multispectral data (1998 and 2002) of the IRS 1C / 1D (Indian Remote Sensing Satellites).

GRDSS is a freeware GIS Graphic user interface (GUI) developed in Tcl/Tk is based on command line arguments of GRASS (Geographic Resources Analysis Support System). It has the capabilities to capture, store, process, display, organize, and prioritize spatial and temporal data. GRDSS serves as a decision support system for decision making and resource planning. It has functionality for raster analysis, vector analysis, site analysis, image

processing, modeling and graphics visualisation. This help in adopting holistic approaches to regional planning which ensures sustainable development of the region.

Keywords: Land use/Land cover Dynamics, Change detection, GIS, Remote Sensing, GRASS, GRDSS

1 Introduction

Land-cover refers to the physical characteristics of earth's surface, captured in the distribution of vegetation, water, soil and other physical features of the land, including those created solely by human activities e.g., settlements. Land-use refers to the way in which land has been used by humans and their habitat, usually with accent on the functional role of land for economic activities. It is the intended employment of management strategy placed on the land-cover type by human agents, and/or managers (LUCC Report series No. 3). Land-use/Land-cover change information has an important role to play at local and regional as well as at macro level planning. The planning and management task is hampered due to insufficient information on rates of land-cover/land-use change. The land-cover changes occur naturally in a progressive and gradual way, however sometimes it may be rapid and abrupt due to anthropogenic activities. Remote sensing data of better resolution at different time interval help in analysing the rate of changes as well as the causal factors or drivers of changes. Hence it has a significant role in regional planning at different spatial and temporal scales. This along with the spatial and temporal analysis technologies namely Geographic Information System (GIS) and Global Positioning System (GPS) help in maintaining up-to-date land-use dynamics information for a sound planning and a cost-effective decision.

Change detection in watersheds helped in enhancing the capacity of local governments to implement sound environmental management (Prenzel *et al.,* 2004). This involved development of spatial and temporal database and analysis techniques. Efficiency of the techniques depends on several factors such as classification schemes, spatial and spectral resolution of remote sensing data, ground reference data and also an effective implementation of the result.

Coastal environment changes were analysed through qualitative evaluation techniques (Debashis Mitra, 1999). The techniques included change map derived from vegetation index differencing, Image ratioing, image differencing and image regression. The basic principle of all change detection techniques was that the digital number of one date is different from the digital number of another date.

Remotely sensed change detection based on artificial neural networks (Dai *et al.*, 1999) presents a new technique for multispectral image classification using training algorithm. The trained neural network detected changes on a pixel-by-pixel basis in real time applications. The trained four-layered neural network provided complete categorical information about the nature of changes and detected complete land-cover change "from-to" information, which is desirable in most change detection applications.

Post classification change detection techniques with the comparison of land-cover classifications of different dates have limitations, as it does not allow the detection of subtle changes within land-cover categories (Macleod and Congalton, 1998).

In this regard Open Source GIS such as GRASS (Geographic Resources Analysis Support System) helps in land cover and land use analysis in a cost-effective way. Most of the commands in GRASS are command line arguments and requires a user friendly and cost-effective graphical user interface (GUI). GRDSS (Geographic Resources Decision Support System) has been developed in this regard to help the users. It has functionality such as raster, topological vector, image processing, graphics production, etc. Figure 1 depicts the Main menu of GRDSS. It operates through a GUI developed in Tcl/Tk under LINUX. GRDSS include options such as Import / Export (of different data formats), extraction of individual bands from the IRS (Indian Remote Sensing Satellites) data (in Band Interleaved by Lines format), display, digital image processing, map editing, raster analysis, vector analysis, point analysis, spatial query, etc. These are required for regional resource mapping, inventorying and analysis such as Watershed Analysis, Landscape Analysis, etc.

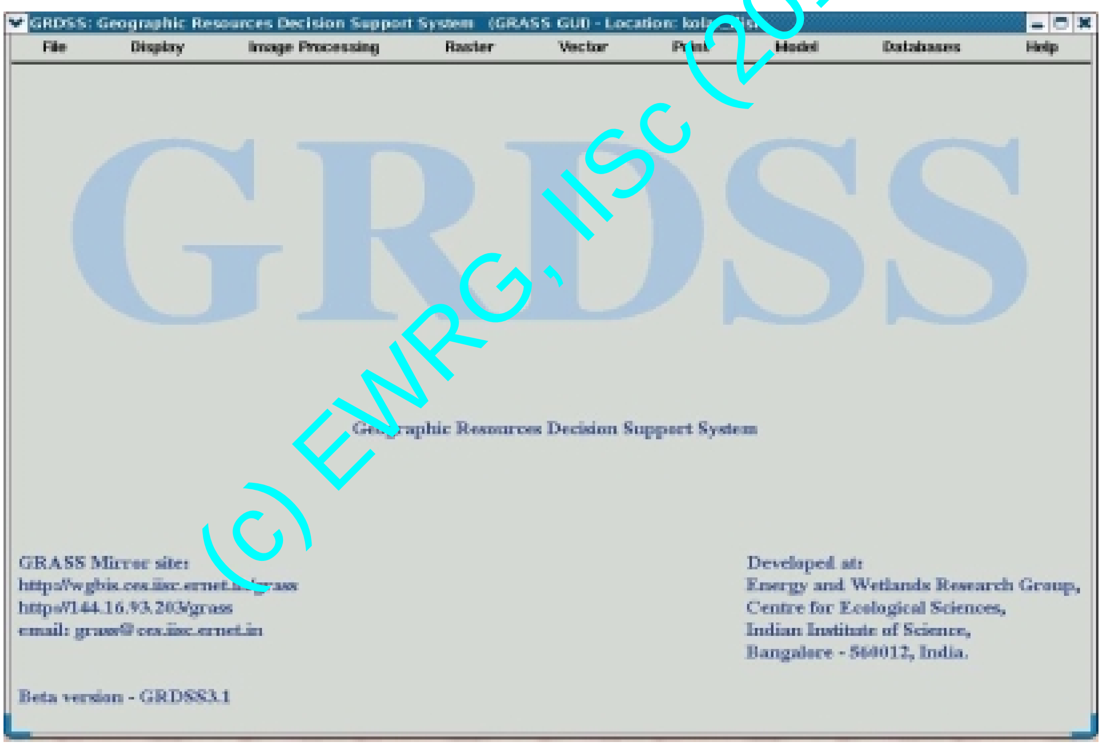

Figure 1: Geographic Resources Decision Support System – Main menu

Objective of this endeavor is to carry out the land use/land cover and temporal change analysis for Kolar district, Karnataka State, India using GRDSS (Geographic Resources Decision Support System).

2 Study area

Burgeoning population coupled with lack of holistic approaches in planning process has contributed to a major environmental impact in dry arid regions of Karnataka. The Kolar district in Karnataka State, India was chosen for this study is located in the southern plain regions (semi arid agro-climatic zone) extending over an area of 8238.47 sq. km. between 77°21’ to 78°35’ E and 12°46’ to 13°58’ N. (shown in Figure 2.)

Kolar is divided into 11 taluks for administrative purposes (Bagepalli, Bangarpet, Chikballapur, Chintamani, Gudibanda, Gauribidanur, Kolar, Malur, Mulbagal, Sidlaghatta, and Srinivaspur). The distribution of rainfall is during southwest and northeast monsoon seasons. The average population density of the district is about 2.09 persons/hectare.

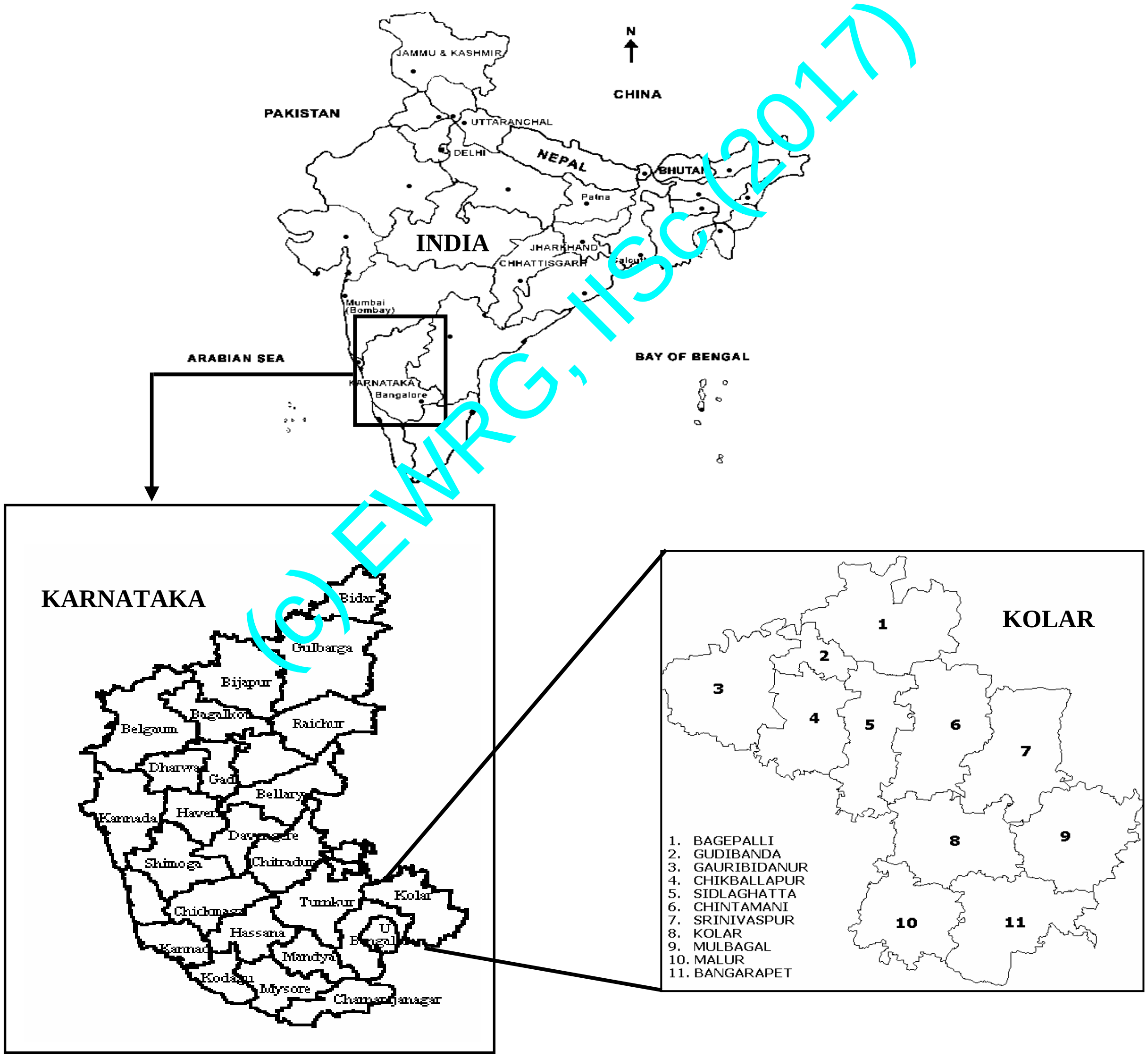

Figure 2: Study area – Kolar district, Karnataka State, India

The Kolar district forms part of northern extremity of the Bangalore plateau and since it lies off the coast, it does not enjoy the full benefit of northeast monsoon and being cut off by the high Western Ghats. The rainfall from the southwest monsoon is also prevented, depriving of both the monsoons and subjected to recurring drought. The rainfall is not only scanty but also erratic in nature. The district is devoid of significant perennial surface water resources. The ground water potential is also assessed to be limited. The terrain has a high runoff due to less vegetation cover contributing to erosion of top productive soil layer leading to poor crop yield. Out of about 280 thousand hectares of land under cultivation, 35% is under well and tank irrigation (http://wgbis.ces.iisc.ernet.in/energy/ paper/).

The main sources of primary data were from field (using GPS), the Survey of India (SOI) toposheets of 1:50,000, 1:250,000 scale and multispectral sensors (MSS) data of the IRS (Indian Remote Sensing satellites) -1C and IRS -1D (1998 and 2002). LISS-III MSS data scenes corresponding to the district for path-rows (100,63) (100,64) and (101, 64) was procured from the National Remote Sensing Agency, Hyderabad, India (http://www.nrsa.gov.in). The secondary data was collected from the government agencies (Directorate of census operations, Agriculture department, Forest department and Horticulture department).

3 Methodology

The methodology of the study involved -

1. Creation of base layers like district boundary, district with taluk and village boundaries, road network, drainage network, contours, mapping of waterbodies, etc. from the SOI toposheets of scale 1:250000 and 1:50000.
2. Extraction of bands (LISS3 with resolution 23.5 m and PAN with resolution 5.8 m of 1998 and 2002) from the data (in BIL and BSQ format) respectively procured from NRSA.
3. Identification of ground control points (GCP's) and geo-correction of bands through resampling.
4. Cropping and mosaicing of data corresponding to the study area.
5. Fusion of LISS3 and PAN data using RGB (Red, Green, Blue) to HIS (Hue, Intensity, Saturation) and HIS to RGB conversion technique.
6. Histogram generation, Bi-spectral plots, Regression analysis.
7. Computation and analysis of various vegetation indices.
8. Generation of FCC (False Colour Composite) and identification of training sites on FCC.
9. Collection of attribute information from field corresponding to the chosen training sites using GPS.
10. Classification of remote sensing data (1998 and 2002): Land cover and land use analyses (both district wise and taluk wise).
11. Change detection analysis using different techniques (Image differencing, Image ratioing, etc.).
12. Detection, visualisation and assessment of change analysis.
13. Statistical analysis and report generation.

4 Results and Discussion

Land cover analysis was done by computing Normalized Difference Vegetation Index (NDVI) which shows 46.03 % area under vegetation and 53.98 % area under non-vegetation. Vegetation index differencing technique was used to analyze the amount of change in vegetation (green) versus non-vegetation (non-green) with the two temporal data. NDVI is based on the principle of spectral difference based on strong vegetation absorbance in the red and strong reflectance in the near-infrared part of the spectrum.

$D_{NDVI} = (IR-R)/(IR+R)\ t_2 - (IR-R)/(IR+R)\ t_1$ ----------equation (1)

t_1 and t_2 in the equation denote the two different dates, where t_1 is for the year 1998 and t_2 for 2002.

The result shows a 16.46 % difference in the vegetation area between the two dates. Figure 3 depicts the image obtained from Vegetation Index Differencing between the two dates (1998 and 2002).

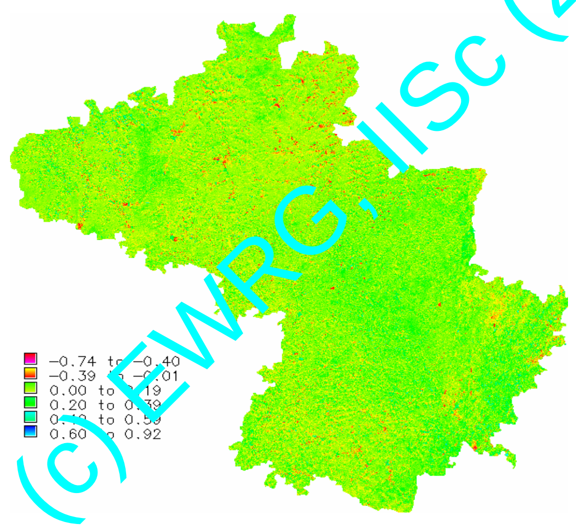

Figure 3: Vegetation Index Differencing

Land use analysis was done by both Supervised classification (accuracy 94.67 %) and unsupervised classification approach (accuracy 78.08 %) using Gaussian Maximum Likelihood Classifier (GMLC) to classify the data in to five categories (agriculture, built-up, forest, plantation and waste land) as depicted in Figure 4.

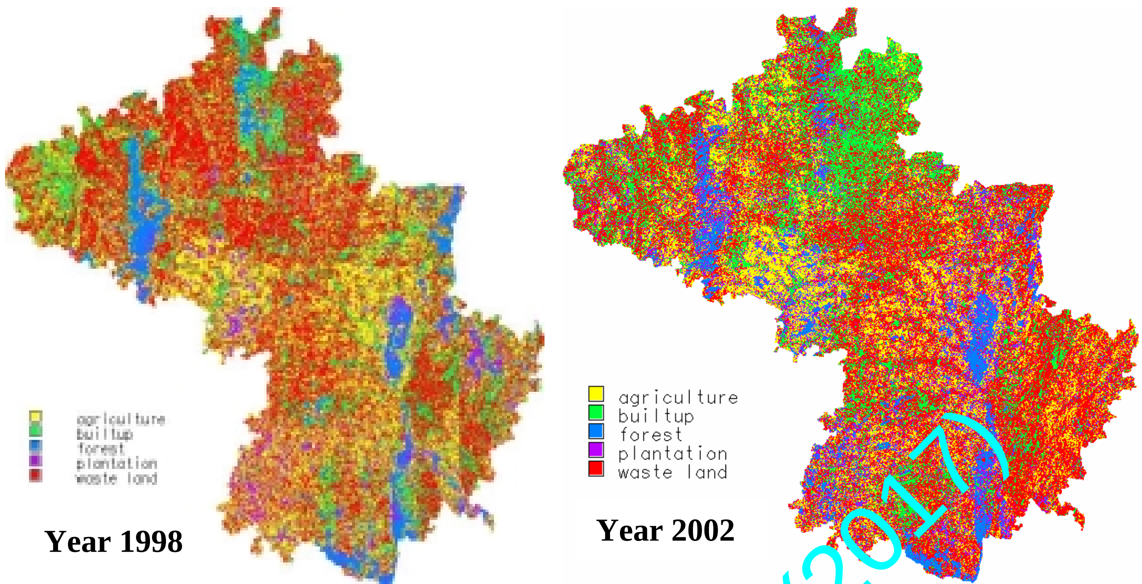

Figure4: Classified image

The Land use analyses as given in table 1, indicates increase of non-vegetation area from 451752 ha. (54.84% in 1998) to 495238 ha (60.17% in 2002). The results also show decrement in forest area and increment in builtup (18.79 %), plantation (12.53 %) and waste land (41.38 %) in 2002 against that in 1998 (builtup-15.96%, plantation-8.53% and waste land-38.88%). Further, taluk wise land use data was extracted by overlaying taluk boundaries and results are tabulated in Table 2.

	1998		2002	
Categories	**Area (in ha)**	**Area (%)**	**Area (in ha)**	**Area (%)**
Agriculture	233519	28.34	165711.42	20.13
Builtup	131468	15.96	154668.68	18.79
Forest	68300	8.29	58979.35	7.17
Plantation	70276	8.53	103110.13	12.53
Waste land	320284	38.88	340570.16	41.38

Table 1: Land use details of Kolar district

Taluk	Agriculture (%)		Built up (%)		Forest(%)		Plantation(%)		Waste land (%)	
	1998	2002	1998	2002	1998	2002	1998	2002	1998	2002
Bagepalli	15.75	12.69	22.46	44.65	09.26	03.28	03.65	07.51	48.88	31.86
Bangarpet	27.43	14.15	15.83	09.65	15.95	12.59	13.97	13.32	26.82	50.28
Chikballapur	30.61	30.28	10.56	13.59	18.30	13.35	08.16	15.18	32.37	27.60
Chintamani	29.94	20.07	13.59	20.11	01.95	01.61	05.52	08.52	49.00	49.69
Gauribidanur	22.75	17.24	22.11	23.97	06.50	04.12	02.61	11.57	46.03	43.10
Gudibanda	15.58	22.71	11.04	19.69	04.47	04.67	02.55	09.42	66.36	43.52
Kolar	33.47	21.81	13.09	12.93	05.70	08.62	07.67	14.25	40.07	42.40
Malur	40.95	22.56	08.52	12.84	03.03	09.05	19.62	17.12	27.88	38.42
Mulbagal	22.85	19.26	21.13	12.72	06.25	01.98	09.35	06.58	40.42	59.46
Sidlaghatta	32.47	24.72	13.95	24.76	03.27	07.61	10.75	15.92	39.56	26.98
Srinivaspur	36.52	22.93	15.34	08.04	13.65	12.67	09.34	19.10	25.15	37.25
District	**28.35**	**20.13**	**15.96**	**18.79**	**08.29**	**07.17**	**08.53**	**12.53**	**38.87**	**41.38**

Table 2: Taluk wise land use in percentage area (1998 and 2002)

LISS3 multispectral (MSS) data of the IRS 1C and 1D of resolution-23.5 meters (both 1998 and 2002) were merged with the PAN data of IRS 1C resolution-5.8 meters using the HIS fusion technique for better spatial and spectral resolutions. HIS fusion converts a color image from the RGB (Red, Green, Blue) space into HIS (Hue, Intensity, Saturation) colour space. The intensity (I) component resembles a panchromatic image, and hence is replaced by a panchromatic image of better spatial resolution. A reverse HIS transformation of the panchromatic together with the hue (H) and saturation (S) bands, result in the fused image. Supervised classifications were performed for selected taluks with ground truth data and figure 5 gives the classified image for Chikballapur taluk. The comparative results of the taluks where subtle change detection could be observed in 2002 are as listed in Table 3 and the corresponding taluk wise area in percentage are as listed in Table 4.

Taluk	Agriculture	Built up	Forest	Plantation	Waste land
Chikballapur	19220.54	9293.13	7143.66	9099.19	19064.50
Chintamani	19958.61	19957.48	1488.25	7358.55	40140.64
Gauribidanur	15612.86	19447.85	3310.56	10929.94	39557.35
Gudibanda	5080.74	4662.85	846.32	2738.80	9398.59
Mulbagal	13251.53	10034.88	2578.21	4940.57	51168.42
Sidlaghatta	15872.94	13614.46	5145.42	12425.18	19999.06
Srinivaspur	20189.23	7650.96	11006.07	15490.01	31942.53

Table 3: Talukwise land use area in hectares (ha) of the year 2002

Taluk	Agriculture (%)		Built up (%)		Forest(%)		Plantation(%)		Waste land (%)	
	1998	**2002**	**1998**	**2002**	**1998**	**2002**	**1998**	**2002**	**1998**	**2002**
Chikballapur	32.08	30.12	08.57	14.56	17.55	11.19	10.97	14.26	30.82	29.87
Chintamani	23.45	22.45	12.90	22.45	04.22	01.67	08.13	8.28	51.00	45.15
Gauribidanur	25.46	17.57	21.43	21.89	07.98	03.73	02.77	12.30	42.36	44.52
Gudibanda	16.71	22.36	12.63	20.52	05.25	03.72	03.29	12.05	62.12	41.35
Mulbagal	23.23	16.17	20.68	12.24	06.59	03.15	09.37	06.03	40.13	62.42
Sidlaghatta	30.94	23.67	15.18	20.30	03.12	07.67	09.94	18.53	40.83	29.82
Srinivaspur	33.39	23.40	17.97	08.87	10.29	12.76	09.70	17.95	28.64	37.02

Table 4: Taluk wise land use in percentage area (1998 and 2002)

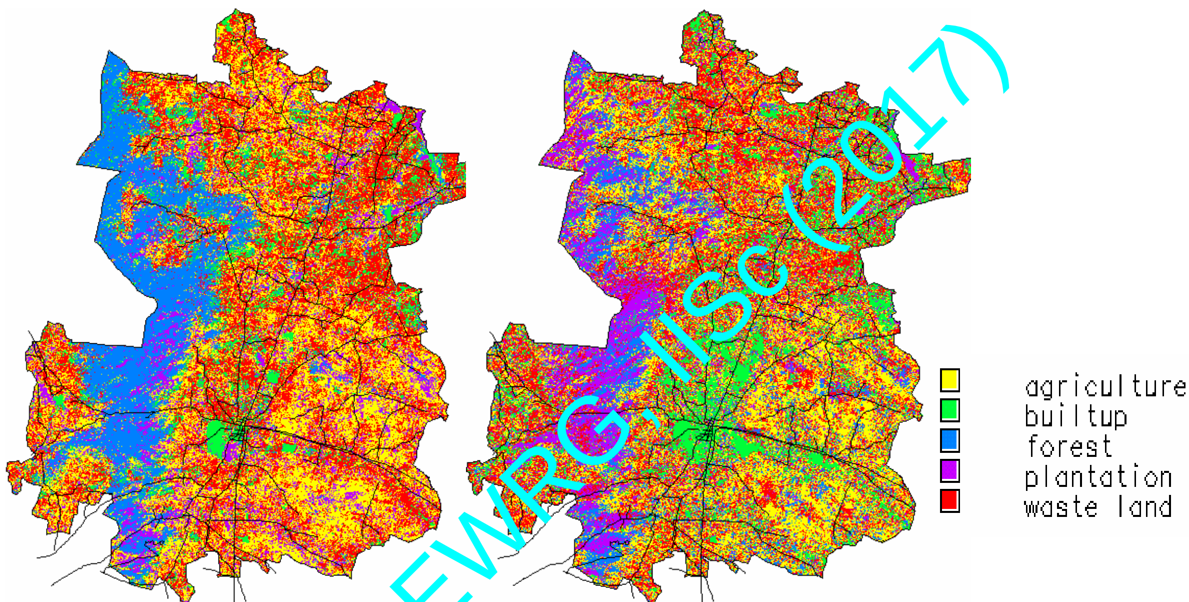

Figure 5: Classified MSS and PAN fused image of Chikballapur taluk (1998 and 2002)

Comparison of the temporal data shows that builtup has considerably increased in Chikballapur (14.56 %) showing urban sprawl in and around the center of the town at the road junction and the forest area has decreased by 6.36%.

5 Change detection techniques

Different change detection techniques such as image differencing, image ratioing, vegetation index differencing and Image regression were attempted to assess the amount of change in the study area.

5.1 Image differencing - Georeferenced images of two different time periods t1 and t2 were subtracted on a band by band and pixel by pixel basis to produce an image which represents the change between the two time periods.

$$D_x{}^k{}_{ij} = X^k{}_{ij}(t_2) - X^k{}_{ij}(t_1) + C \qquad \text{----------equation (2)}$$

where, $X^k{}_{ij}$ = pixel value for band k and i and j are line and pixel numbers in the image, t_1 = first date and t_2 = second date and C = a constant to produce positive digital numbers.

This technique takes into account the difference of radiance values of pixels between two different dates. Differences in atmospheric condition, differences in sensor calibration, moisture condition, illumination condition also affect the radiance of the pixels. Therefore this technique is better suited to cases as changes in radiance in the object scene is larger compared to changes due to other factors. Frequency analysis of the image show that the pixels with the radiance are found in the tails of the distribution while non-radiance change pixels tend to be grouped around the mean. Figure 6 shows the histogram obtained for the band 4 (near infrared) from image differencing.

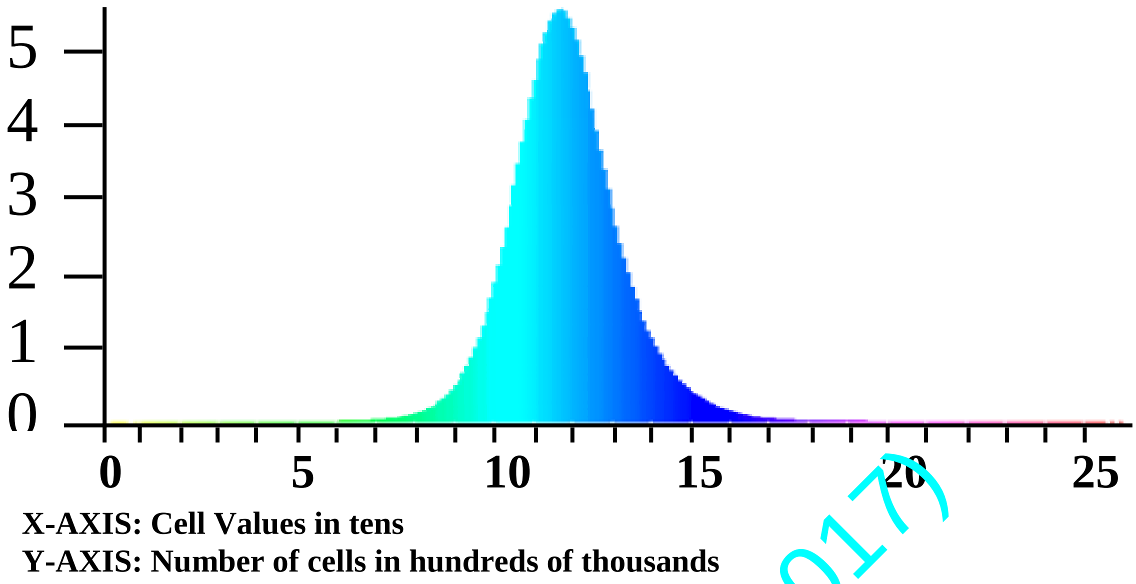

Figure 6: Histogram of the near-infrared band obtained from image differencing

The histogram of the difference image with an ample amount of pixels in the tails clearly indicates changes. However the actual change was unpredictable due to lack of detailed ground truth data pertaining to different categories. The false colour composite (FCC) of the bands obtained by image differencing is depicted in Figure 7, highlighting the changes between the two dates.

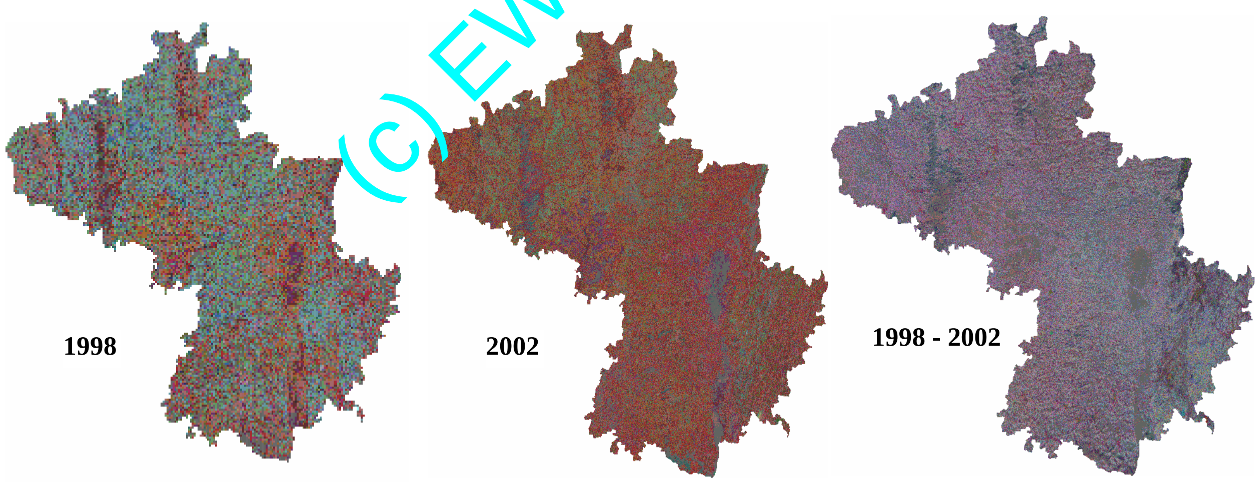

Figure 7: False Colour Composite images

The false colour composite of difference image shows the degradation in area under vegetation (forest, plantation or agriculture), while the unproductive land (barren land) has increased with respect to the time and space.

5.2 Image ratioing – Geocorrected images (G, R and NIR bands) of different dates were ratioed pixel by pixel (band by band) basis.

$$Rx^{k}_{ij} = X^{k}_{ij}(t_2) / X^{k}_{ij}(t_1) \qquad \text{----------equation (3)}$$

Where, $X^{k}_{ij}(t_2)$ is the pixel value of band k for pixel x at row i and column j at time t_2. If the intensity of reflected energy is nearly the same in each image then $Rx^{k}_{ij} = 1$ indicating no change.

The ratio value greater than 1 or less than 1 represents a change depending upon the nature of changes occurred between the two dates. Figure 8 shows the histogram obtained for the near infrared band after performing the image ratioing.

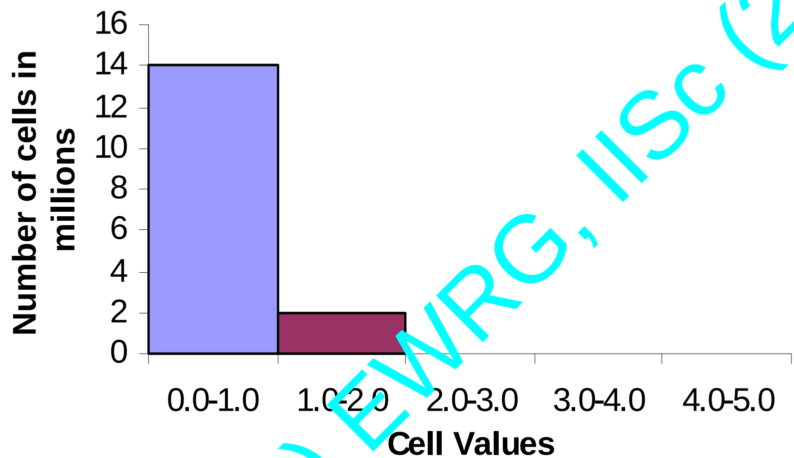

Figure 8: Histogram of the NIR band after temporal date images ratioing

The histogram generated for the different bands showed that a significant part of the image has no change as the number of pixels falling to the category ‘1’ was dominating (with a high peak in the histogram) compared to pixels that had values greater than or less than ‘1’.

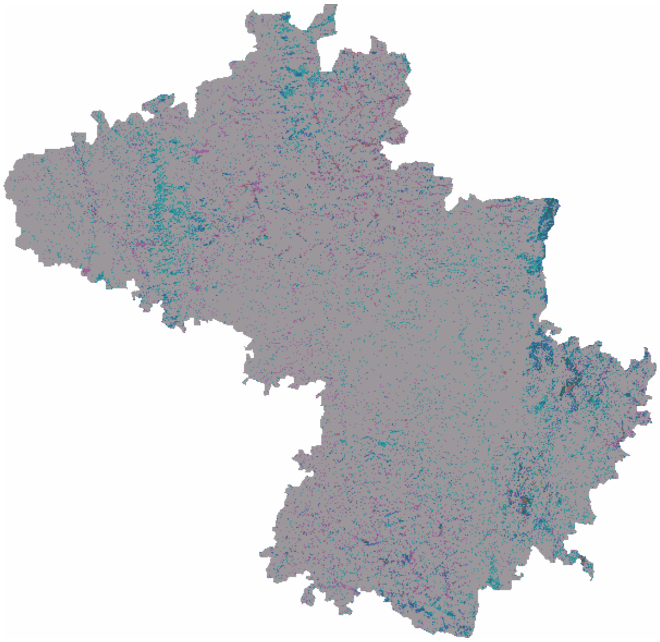

Figure7: False colour composite of the image ratio bands (G, R and NIR)

The false colour composite image obtained after performing the image ratio shows degradation in the forest patches of Chikballapur, Gauribidanur and Srinivaspur taluk, and increase in wasteland. These regions correspond to the values either greater than or less than ‘1’ in the histogram of the ratio image.

5.3 Image regression – It is assumed that pixels from time t_1 are in a linear function of the time t_2 pixels. Using linear regression $X^k_{ij}(t_1)$ was regressed against $X^k ij(t_2)$. It accounts for the differences in the mean and variance between digital number of pixels of different dates in order to reduce the differences in atmosphere condition or Sun angle. The difference image DX^k_{ij} is given with the predicted value $X^{\wedge k}_{ij}(t_2)$, is given by

$$DX^k_{ij} = X^{\wedge k}_{ij}(t_2) - X^k_{ij}(t_1) \qquad \text{----------equation (4)}$$

Regression analysis was performed for each band (Green, Red and Near-infrared of 1998 and 2002) and the results are listed in Table 5.

X (1998) (Independent variable)	Y (2002) (dependent variable)	S	I	r	R	P (Significant value)	DN (Digital number)	D (difference)
Band2	Band2	-0.43	149.62	-0.636	0.404	< 0.011	128	-33.42
Band3	Band3	-0.55	151.80	-0.694	0.482	< 0.004	117	-29.55
Band4	Band4	-0.67	172.17	-0.546	0.298	< 0.035	111	-13.20

Table 5: Image regression results

S = slope, I = intercept obtained from linear regression, r = the correlation coefficient, R = coefficient of determination, P = significant value or significance level, DN = digital number of the pixel that was chosen from the set of numbers in the bands and D = the predicted value that would be obtained from *equation 4*.

In this method the mean and variance of the pixels takes care of environmental interferences like adverse effects from atmospheric condition and sun angle by distributing these variations to all the pixels. Thus the differences obtained in this analysis is minimal when compared to other methods.

6 Conclusion

Holistic decisions and scientific approaches are required for sustainable development of the region. Change detection techniques using temporal remote sensing data provide detailed information for detecting and assessing land cover and land use dynamics. Different change detection techniques were applied to monitor the changes. The change analysis based on two dates, spanning over a period of four years using supervised classification, showed an increasing trend (2.5 %) in unproductive waste land and decline in spatial extent of vegetated areas (5.33 %). Depletion of water bodies and large extent of barren land in the district is mainly due to lack of integrated watershed approaches and mismanagement of natural resources.

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