Annexure C

Annexure C: HYDROLOGICAL ASSESMENT

Rainfall Dynamics: Rainfall data from 1901 to 2013 were collected from Directorate of Economics and Statistics, and District at a Glance. About 65 Rain Gauge stations from Mangalore, Udupi, Hassan, Kodagu and Chikmagaluru were analysed for understanding the spatial and Temporal variability of rainfall. Figure 1 depicts the method involved in understanding the temporal dynamics of precipitation. Distribution of Rain Gauge Stations and Spatial Rainfall variability across the catchments are as depicted in Figure 2.

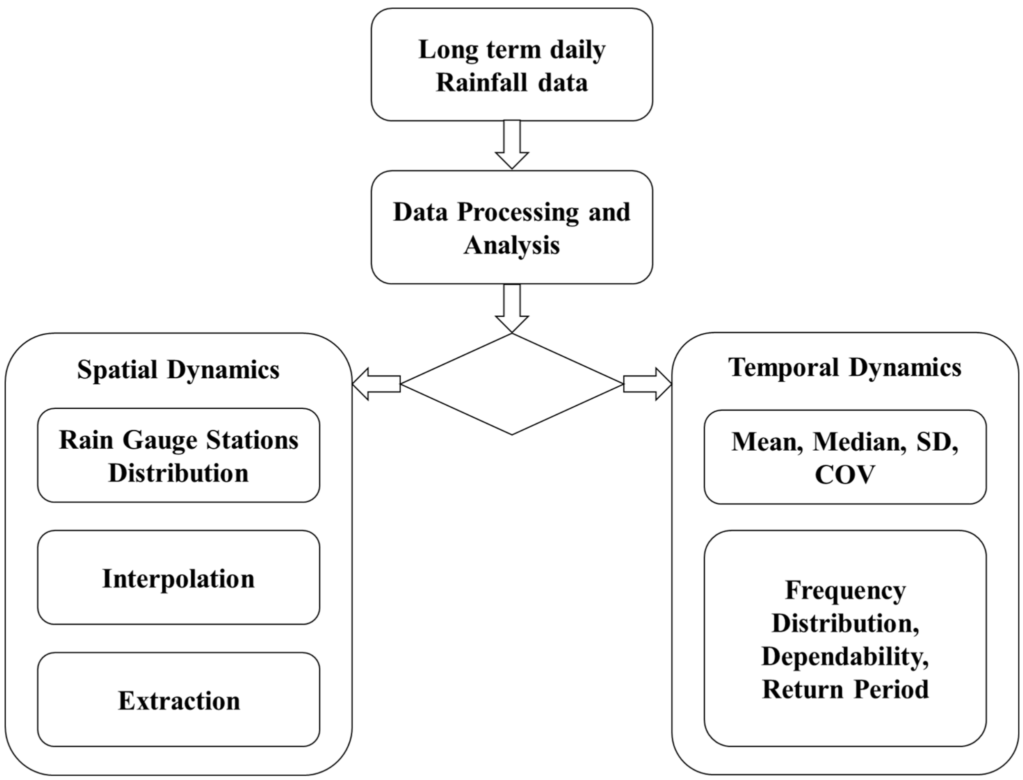

Figure 1: Method involved in understanding temporal dynamics of precipitation data.

Data Preprocessing and Analysis: Rainfall data collected from the Directorate of Economics and Statistics were preprocessed in order to rectify missing/erroneous rainfall records considering rainfall in neighboring rain gauge stations. Rectified data were further analysed for spatio-temporal variations.

***Spatial Analysis**:* Rain Gauge stations were identified and located using Google earth and Karnataka State Rain gauge station map. Interpolation was carried out understand the spatial dynamics of rainfall across the catchment. Post-processing (extraction) was carried out to quantify rainfall within the catchment.

Temporal Analysis: Temporal analysis was carried out to understand the variability, dependability, return period of rainfall at each taluk. India Meteorological Department classifies rainfall at regional scale as Excess, Normal, Deficient/Drought, Scanty/Severe Drought conditions as below.

i) Excess: Rainfall > + 20% average annual rainfall

ii) Normal: - 20% average annual rainfall < Rainfall < + 20% average annual rainfall

iii) Deficient: - 60% average annual rainfall < Rainfall < - 20% average annual rainfall

iv) Scanty: - 99% average annual rainfall < Rainfall < - 60% average annual rainfall

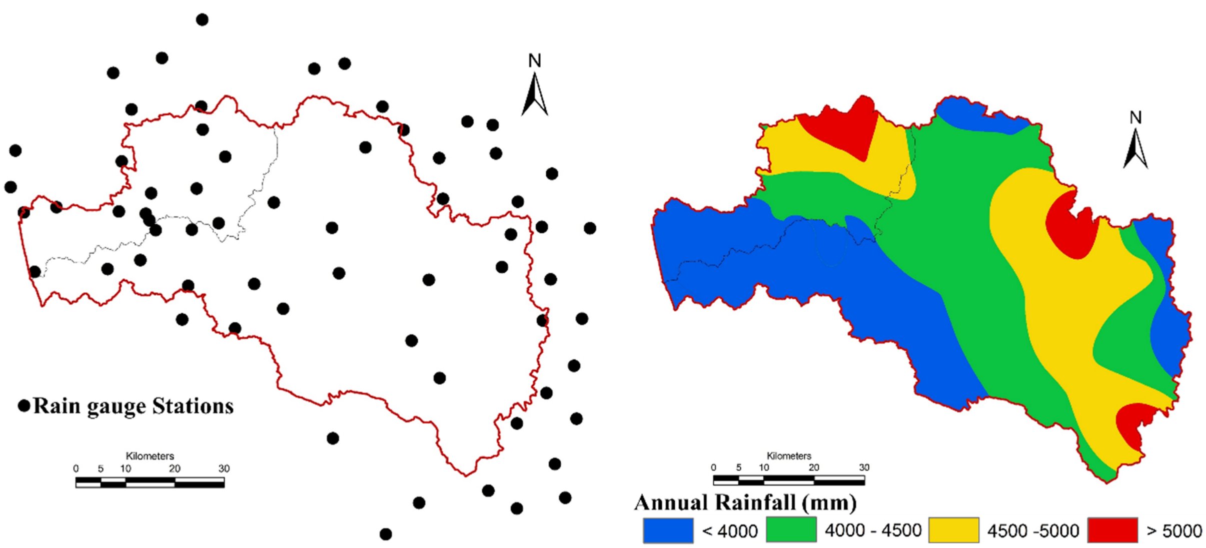

Figure 2: Rain Gauge Stations and Spatial Rainfall variability.

Annual Average Rainfall in the catchment is about 4047mm. Spatial variability analyses indicate that Ghats receive highest rainfall in the catchment of about Average Annual rainfall of 5200 mm, whereas the transition zones receive rainfall in the range of 4000 mm to 4500 mm, lowest rainfall is observed in the plains of Mudigere and Sakleshpura Taluks ranging between 2800 mm to 4000 mm. Temporal Variability across each taluk in the catchment is as explained below:

1) **Karkala**: Karkala taluk is a part of Udupi District. Average Annual rainfall measured between 1901-2013 in the taluk is about 4959 ± 836 mm (COV 0.17). Highest and

lowest rainfall recorded in the taluk were 6900 mm and 3242 mm respectively. Variability of rainfall across last 50 years is as depicted in Table 1 and Figure 3. Trend line shows increasing rainfall in the catchment. Normal rainfall has a dependability of 84% with return period of 1.3 years. No cases of severe Meteorological drought have been recorded in Karkala Taluk, whereas moderate droughts can be expected once in 6.4 years, and excess rain once in 10.2 years.

Table 1: Temporal Variations in Karkala

IMD Classification	Rainfall	Frequency	Probability	Dependability	Return Period (Years)
Severe Drought	< 2975	0	0		
Moderate Drought	2975 to 3967	8	0.157	100%	6.4
Normal Rainfall	3967 to 5950	38	0.745	84%	1.3
Excess Rainfall	> 5950	5	0.098	10%	10.2

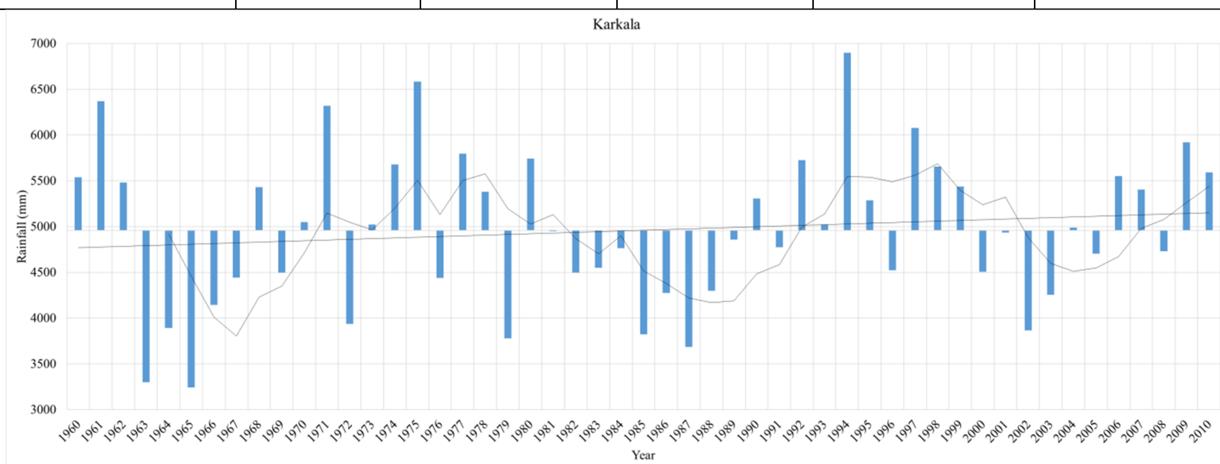

Figure 3: Rainfall Dynamics in Karkala.

2) **Mangalore**: Mangalore taluk is a part of Dakshina Kannada District. Average Annual rainfall measured between 1901 – 2013 in the taluk is about 3445 ± 781 mm (COV 0.23). Highest and lowest rainfall recorded in the taluk were 6791 mm and 1496 mm respectively. Variability of rainfall across last 50 years is as depicted in Table 2 and Figure 4. Trend line shows decreasing rainfall in the catchment. Normal rainfall has a dependability of 94% with return period of 1.3 years. No cases of severe Meteorological

drought have been recorded in Mangalore Taluk, whereas moderate droughts can be expected once in 25.5 years, and excess rain once in 5.1 years.

Table 2: Temporal Variations in Mangalore

IMD Classification	Rainfall	Frequency	Probability	Dependability	Return Period (Years)
Severe Drought	< 2067	0	0		
Moderate Drought	2067 to 2756	2	0.039	100%	25.5
Normal Rainfall	2756 to 4134	39	0.765	94%	1.3
Excess Rainfall	> 4134	10	0.196	20%	5.1

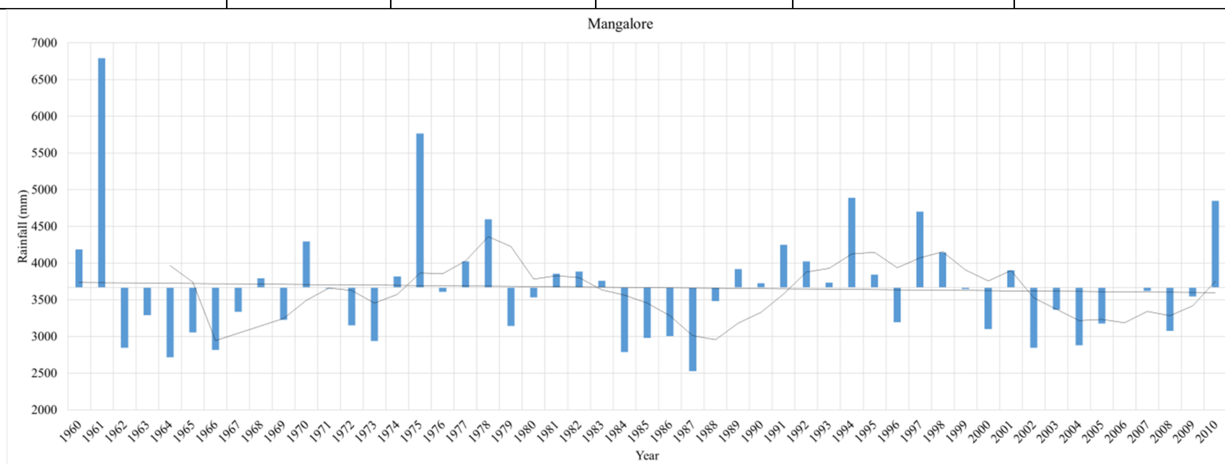

Figure 4: Rainfall Dynamics in Mangalore

3) **Bantwala**: Bantwala taluk is a part of Dakshina Kannada District. Average Annual rainfall measured between 1901 – 2013 in the taluk is about 3762 ± 747 mm (COV 0.20). Highest and lowest rainfall recorded in the taluk were 6057 mm and 1900 mm respectively. Variability of rainfall across last 50 years is as depicted in Table 3 and Figure 5. Trend line shows decreasing rainfall in the catchment. Normal rainfall has a dependability of 92% with return period of 1.3 years. No cases of severe Meteorological drought have been recorded in Bantwala Taluk, whereas moderate droughts can be expected once in 12.8 years, and excess rain once in 6.4 years.

Table 3: Temporal Variations in Bantwala

IMD Classification	Rainfall	Frequency	Probability	Dependability	Return Period (Years)
Severe Drought	< 2257	0	0		
Moderate Drought	2257 to 3009	4	0.078	100%	12.8
Normal Rainfall	3009 to 4514	39	0.765	92%	1.3
Excess Rainfall	> 4514	8	0.157	16%	6.4

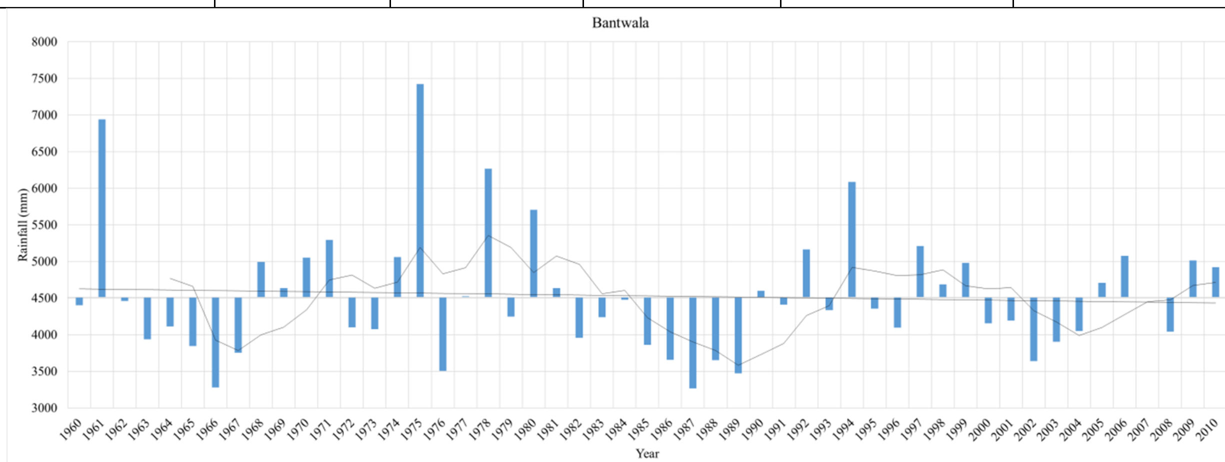

Figure 5: Rainfall Dynamics in Bantwala

4) **Beltangadi**: Beltangadi taluk is a part of Dakshina Kannada District. Average Annual rainfall measured between 1901 – 2013 in the taluk is about 4528 ± 850 mm (COV 0.19). Highest and lowest rainfall recorded in the taluk were 7424 mm and 2520 mm respectively. Variability of rainfall across last 50 years is as depicted in Table 4 and Figure 6. Trend line shows decreasing rainfall in the catchment. Normal rainfall has a dependability of 92% with return period of 1.2 years. No cases of severe Meteorological drought have been recorded in Beltangadi Taluk, whereas moderate droughts can be expected once in 12.8 years, and excess rain once in 10.2 years.

Table 4: Temporal Variations in Beltangadi

IMD Classification	Rainfall	Frequency	Probability	Dependability	Return Period (Years)
Severe Drought	< 2716	0	0		
Moderate Drought	2716 to 3622	4	0.078	100%	12.8
Normal Rainfall	3622 to 5433	42	0.824	92%	1.2
Excess Rainfall	> 5433	5	0.098	10%	10.2

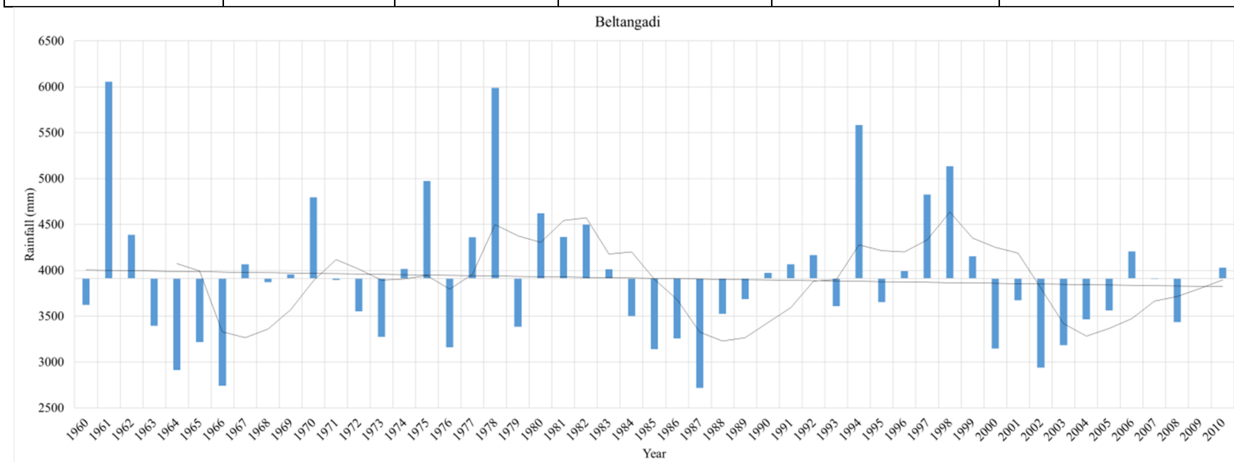

Figure 6: Rainfall Dynamics in Beltangadi

5) **Puttur**: Puttur taluk is a part of Dakshina Kannada District. Average Annual rainfall measured between 1901 – 2013 in the taluk is about 3995 ± 719 mm (COV 0.18). Highest and lowest rainfall recorded in the taluk were 7205 mm and 1734 mm respectively. Variability of rainfall across last 50 years is as depicted in Table 5 and Figure 7. Trend line shows decreasing rainfall in the catchment. Normal rainfall has a dependability of 98% with return period of 1.2 years. No cases of severe Meteorological drought have been recorded in Puttur Taluk, whereas moderate droughts can be expected once in 51 years, and excess rain once in 5.7 years.

Table 5: Temporal Variations in Puttur

IMD Classification	Rainfall	Frequency	Probability	Dependability	Return Period (Years)
Severe Drought	< 2716	0	0		
Moderate Drought	2716 to 3622	1	0.020	100%	51.0
Normal Rainfall	3622 to 5433	41	0.804	98%	1.2
Excess Rainfall	> 5433	9	0.196	18%	5.7

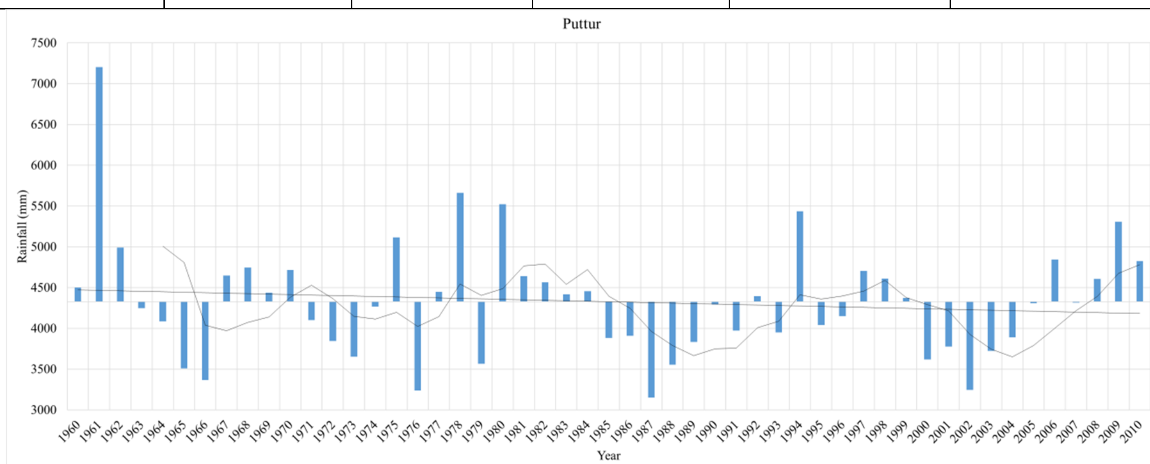

Figure 7: Rainfall Dynamics in Puttur

6) **Sulya**: Sulya taluk is a part of Dakshina Kannada District. Average Annual rainfall measured between 1901 – 2013 in the taluk is about 3947 ± 726 mm (COV 0.18). Highest and lowest rainfall recorded in the taluk were 5863 mm and 1733 mm respectively. Variability of rainfall across last 50 years is as depicted in Table 6 and Figure 8. Trend line shows increasing rainfall in the catchment. Normal rainfall has a dependability of 88% with return period of 1.2 years. Severe Meteorological drought were recorded in Sulya Taluk with return period of 51 years, whereas moderate droughts can be expected once in 10.2 years, and excess rain once in 10.2 years.

Table 6: Temporal Variations in Sulya

IMD Classification	Rainfall	Frequency	Probability	Dependability	Return Period (Years)
Severe Drought	< 2367	1	0.020	100%	51.0
Moderate Drought	2367 to 3157	5	0.098	98%	10.2
Normal Rainfall	3157 to 4736	40	0.784	88%	1.2
Excess Rainfall	> 4739	5	0.098	10%	10.2

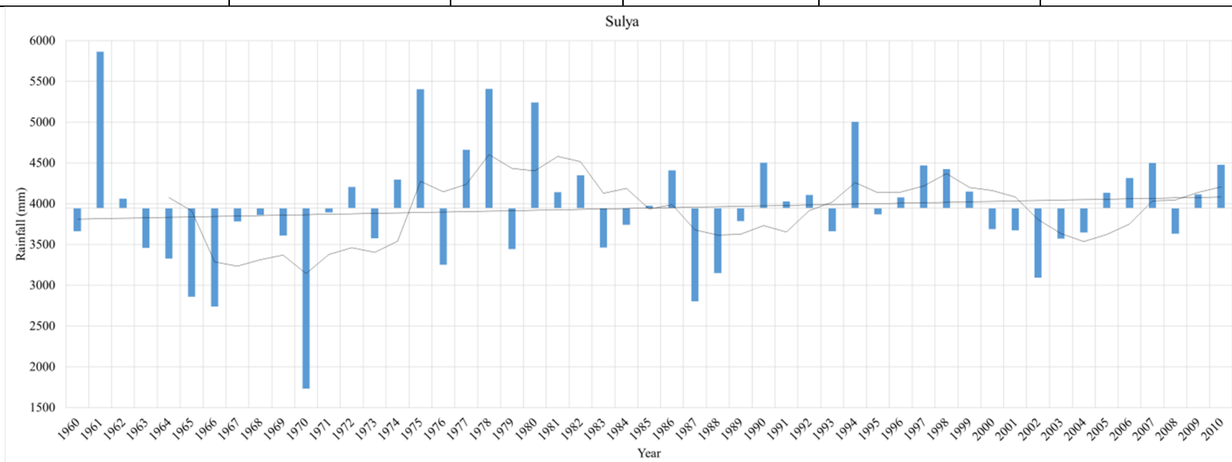

Figure 8: Rainfall Dynamics in Sulya

7) **Mudigere**: Mudigere taluk is a part of Chikmagalur District. Average Annual rainfall measured between 1901 – 2013 in the taluk is about 3123 ± 847 mm (COV 0.27). Highest and lowest rainfall recorded in the taluk were 5869 mm and 1606 mm respectively. Variability of rainfall across last 50 years is as depicted in Table 7 and Figure 9. Trend line shows decreasing rainfall in the catchment. Normal rainfall has a dependability of 82% with return period of 1.7 years. Severe Meteorological drought were recorded in Mudigere Taluk with return period of 51 years, whereas moderate droughts can be expected once in 6.4 years, and excess rain once in 4.3 years.

Table 7: Temporal Variations in Mudigere

IMD Classification	Rainfall	Frequency	Probability	Dependability	Return Period (Years)
Severe Drought	< 1873	1	0.020	100%	51.0
Moderate Drought	1873 to 2498	8	0.157	98%	6.4
Normal Rainfall	2498 to 3747	30	0.588	82%	1.7
Excess Rainfall	> 3747	12	0.235	24%	4.3

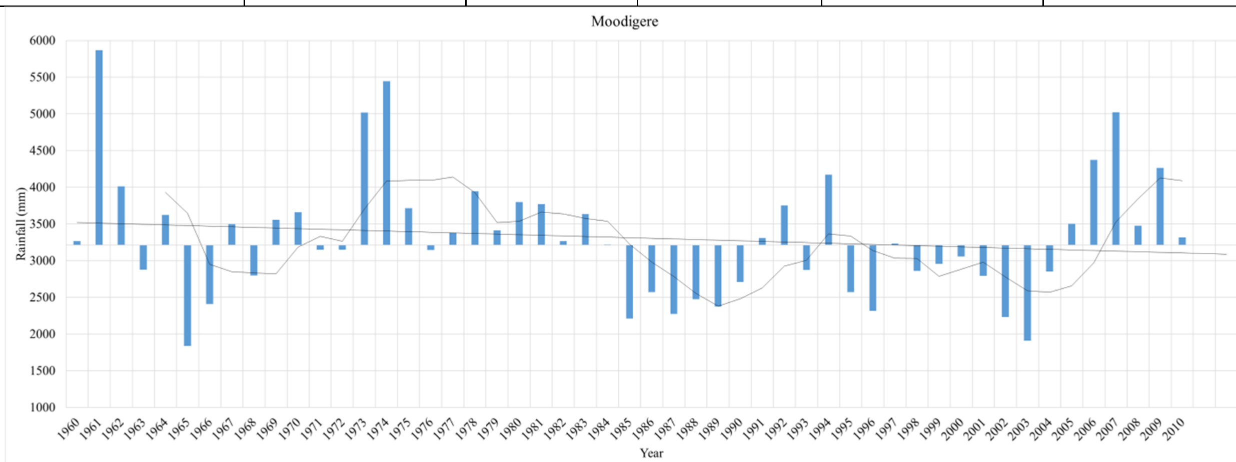

Figure 9: Rainfall Dynamics in Mudigere

8) **Sakleshpura**: Sakaleshpura taluk is a part of Hassan District. Average Annual rainfall measured between 1901 – 2013 in the taluk is about 3909 ± 757 mm (COV 0.26). Highest and lowest rainfall recorded in the taluk were 5059 mm and 1585 mm respectively. Variability of rainfall across last 50 years is as depicted in Table 8 and Figure 10. Trend line shows decreasing rainfall in the catchment. Normal rainfall has a dependability of 71% with return period of 1.7 years. Severe Meteorological drought were recorded in Sakaleshpura Taluk with return period of 51 years, whereas moderate droughts can be expected once in 3.6 years, and excess rain once in 6.4 years.

Table 8: Temporal Variations in Sakaleshpura

IMD Classification	Rainfall	Frequency	Probability	Dependability	Return Period (Years)
Severe Drought	< 1745	1	0.020	100%	51.0
Moderate Drought	1745 to 2327	14	0.275	98%	3.6
Normal Rainfall	2327 to 3491	28	0.549	71%	1.7
Excess Rainfall	> 3491	8	0.157	16%	6.4

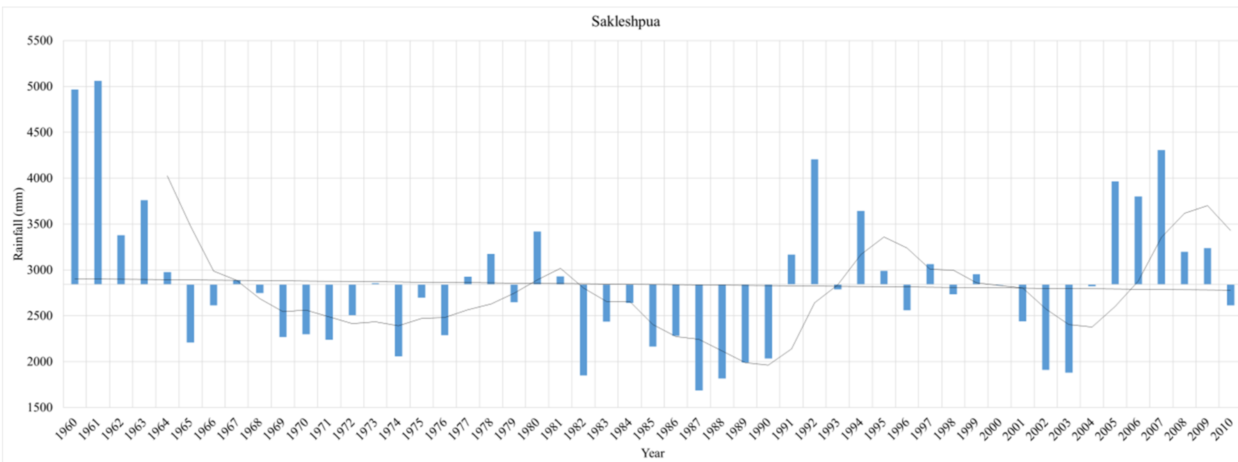

Figure 10: Rainfall Dynamics in Sakaleshpura

9) **Somvarpet**: Somvarpet taluk is a part of Kodagu District. Average Annual rainfall measured between 1901 – 2013 in the taluk is about 2537 ± 696 mm (COV 0.27). Highest and lowest rainfall recorded in the taluk were 4246 mm and 1522 mm respectively. Variability of rainfall across last 50 years is as depicted in Table 9 and Figure 11. Trend line shows increasing rainfall in the catchment. Normal rainfall has a dependability of 73% with return period of 2.2 years. Severe Meteorological drought were recorded in Somvarpet Taluk with return period of 12.8 years, whereas moderate droughts can be expected once in 5.1 years, and excess rain once in 3.6 years.

Table 9: Temporal Variations in Somvarpet

IMD Classification	Rainfall	Frequency	Probability	Dependability	Return Period (Years)
Severe Drought	< 1522	4	0.078	100%	12.8
Moderate Drought	1522 to 2029	10	0.196	92%	5.1
Normal Rainfall	2029 to 3044	23	0.451	73%	2.2
Excess Rainfall	> 3044	14	0.275	27%	3.6

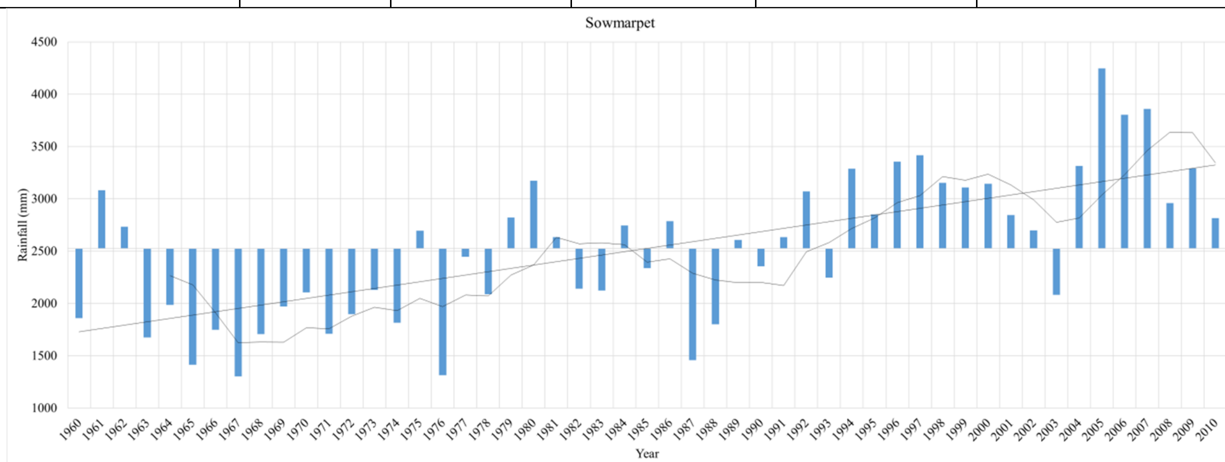

Figure 11: Rainfall Dynamics in Somvarpet

10) **Marcera/Madikeri**: Marcera/taluk is a part of Kodagu District. Average Annual rainfall measured between 1901 – 2013 in the taluk is about 3966 ± 932 mm (COV 0.24). Highest and lowest rainfall recorded in the taluk were 6213 mm and 2089 mm respectively. Variability of rainfall across last 50 years is as depicted in Table 10 and Figure 12. Trend line shows decreasing rainfall in the catchment. Normal rainfall has a dependability of 73% with return period of 1.7 years. Severe Meteorological drought were recorded in Marcera Taluk with return period of 51 years, whereas moderate droughts can be expected once in 5.7 years, and excess rain once in 4.6 years.

Table 10: Temporal Variations in Madikeri

IMD Classification	Rainfall	Frequency	Probability	Dependability	Return Period (Years)
Severe Drought	< 2379	1	0.020	100%	12.8
Moderate Drought	2379 to 3172	9	0.176	92%	5.1
Normal Rainfall	3172 to 4758	30	0.588	73%	2.2
Excess Rainfall	> 4758	11	0.216	27%	3.6

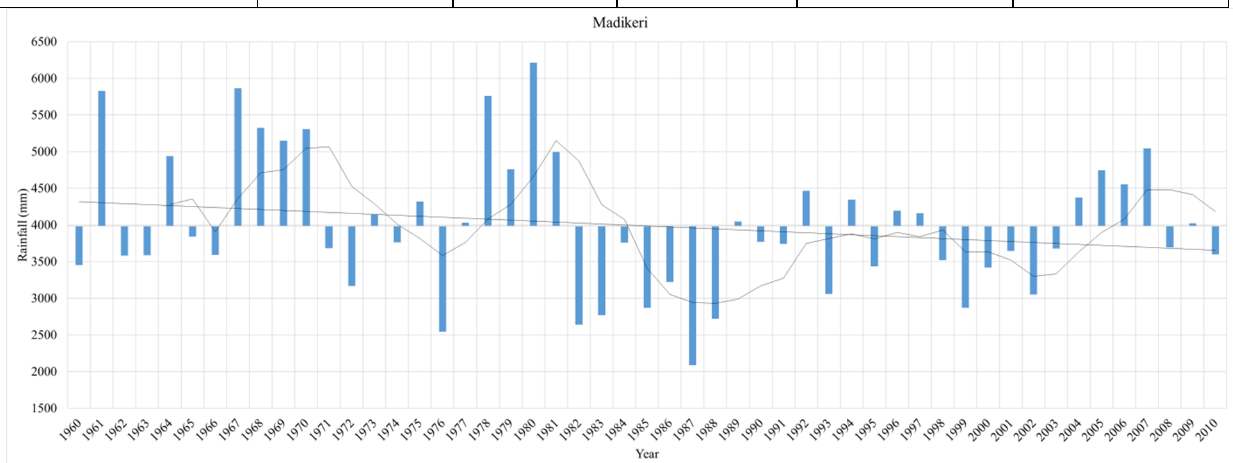

Figure 12: Rainfall Dynamics in Madikeri

Stream Density: Stream density is defined as the ratio of stream length the catchment area. Higher the stream density. Stream density has a direct impact on lag time and hydrograph peak. For a rainfall event, basins with high drainage densities will have relatively rapid response time (shorter lag time) and steeper limbs as against low density drainages, i.e., precipitation gets into streams quicker in high dense drainages, in contrary for catchments with low dense drainages, precipitation has to travel as surface runoff, base flow, pipe flow (sub surface flow), through fall enhancing lag time. Figure 13 depicts that Ghats have higher drainage density as against the coast and plains. Netravathi and Gurupura catchment together have Stream density of 2.5km per sq.km. Figure 14 depicts stream density of each sub catchment. Ghats indicates higher stream density as against the coastal plains.

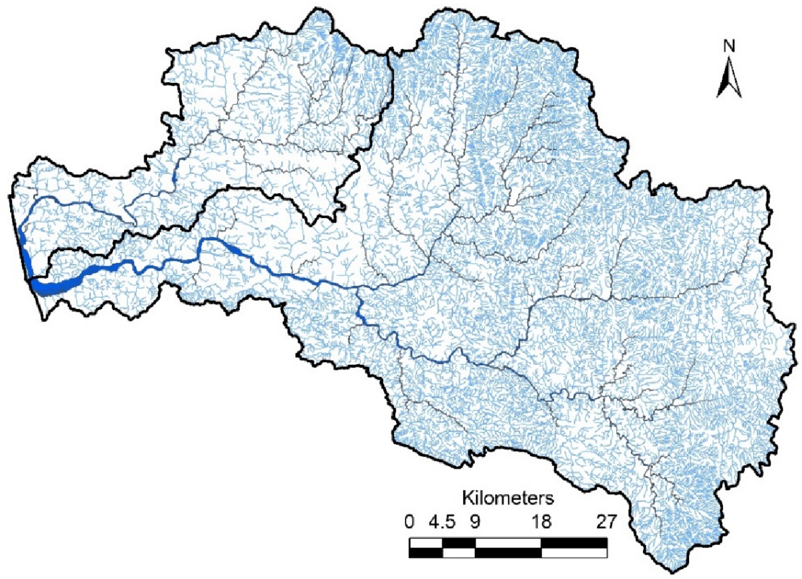

Figure 13: Stream Network

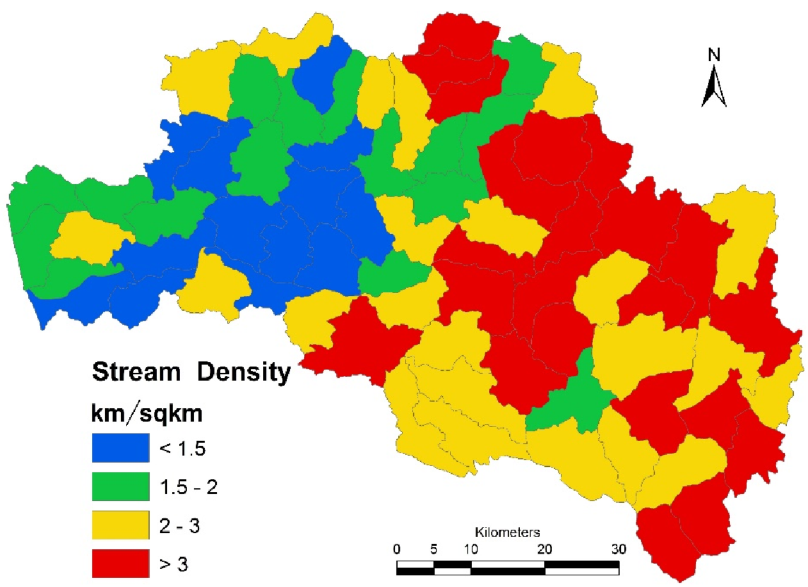

Figure 14: Stream Density – Sub catchment wise

Runoff: Estimate runoff was based on the Natural Resource Conservation Series (NRCS) (*United States Department of Agriculture*; NRCS, 1986; Walker, Prestwich and Spofford, 2006; Williams *et al.*, 2012) earlier known as Soil Conservation Series (SCS) (USDA - Soil Conservation Service, 1972; Mishra *et al.*, 2006) runoff curve number method. NRCS method

(Figure 15) involves quantification of runoff considering precipitation data, land use, soil characteristics.

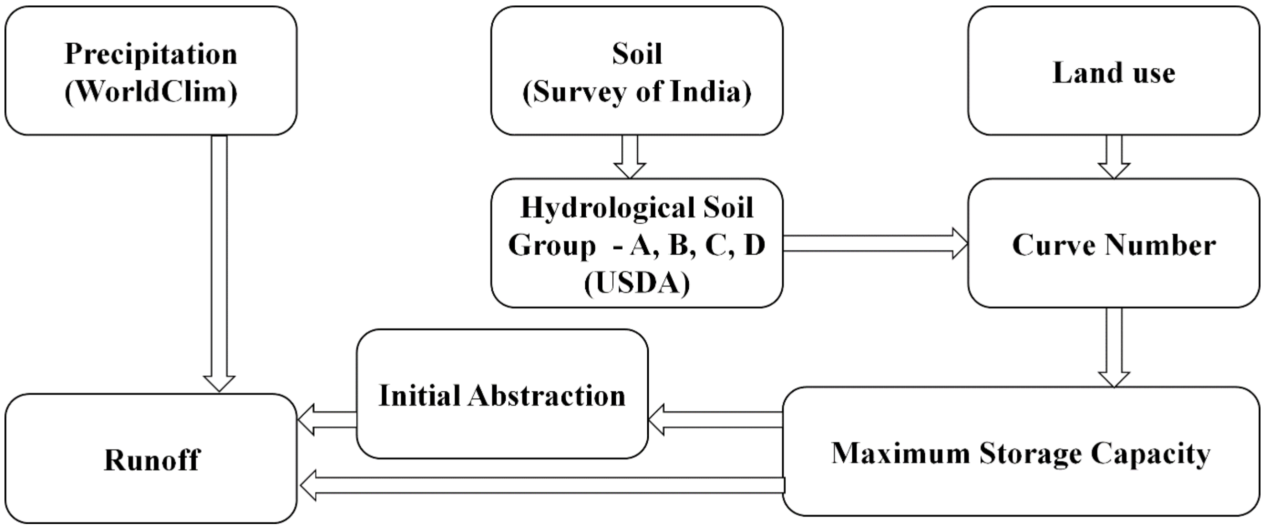

Figure 15: Steps involved in NRCS method of Runoff quantification

Mathematically Yield using NRCS is given as

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S}$$

Where

Q - Discharge/Yield as mm,

P - Precipitation in mm,

I_a - Initial Abstraction in mm,

S – Maximum Storage/Retention Potential in mm

Initial Abstraction (I_a) consists mainly interception, portion of infiltration and surface depression storage. In general, I_a is estimated based on landscape and surface conditions. I_a is estimated as function of maximum potential retentions (S). I_a is generalized as 20% of maximum storage capacity (NRCS, 1986), whereas for Indian conditions, I_a can be taken as 30% of maximum potential storage (Gupta and Panigrahy, 2008). Maximum retention potential is estimated as a function of curve number (USDA-NRCS, 2004a)and is given by

$$S = 25.4 * (\left(\frac{1000}{CN}\right) - 10)$$

CN represents curve number and is dependent on Soil Hydrological characteristics (Hydrological Soil Group) and Land use characteristics.

Hydrologic Soil group is defined by various soil properties such as density, texture, particle size, *etc.* which defines infiltration rates, storage capabilities of soil. Table 11 provides the details of HSG according national and international definitions and Table 12 provides the details of curve numbers associated with land use and soil group. The estimated runoff was validated with the field data.

Table 11: Hydrologic Soil Groups and their characteristics.

HSG	National (Dhruvananarayan, 1993; Gupta and Panigrahy, 2008)	International (USDA-NRCS, 2009)
A	Sandy and Loamy Soils	• Low runoff potential when thoroughly wet • Less than 10 % clay and more than 90 % sand or gravel and have gravel or sand textures
B	Sandy Loamy and Loam	• Moderately low runoff potential when thoroughly wet • Water transmission through the soil is unimpeded • 10 % and 20 % clay and 50 % to 90 % sand and have loamy sand or sandy loam textures
C	Clay loam	• Moderately high runoff potential when thoroughly wet • Water transmission through the soil is somewhat restricted. • 20 % and 40 % clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures
D	Clay	• High runoff potential when thoroughly wet • Water movement through the soil is restricted or very restricted • Greater than 40 percent clay, less than 50 percent sand, and have clayey textures. • High shrink-swell potential

Table 12: Curve numbers based on Land use and Hydrological Soil Group(Mutreja, 1995; USDA-NRCS, 2004b)

Sl.no.	Land use	Hydrological condition	A	B	C	D
1	**Pasture, Grassland or range-continuous forage for grazing**	Poor	68	79	86	89
		Fair	49	69	79	84
		Good	36	61	74	80
2	**Meadow - continuous grass, protected from grazing and generally moved for hay**	Good	30	58	74	78
3	**Brush-weed -grass mixture with Brush as major element**	Poor	48	67	77	83
		Fair	35	56	70	77
		Good	30	48	65	73
4	**Woods- Grass combination (orchard or tree farm)**	Poor	57	73	82	86
		Fair	43	65	76	82
		Good	32	58	72	79
5	**Woods**	Poor	45	66	77	83
		Fair	36	60	73	79
		Good	30	55	70	77
6	**Farmstead - Buildings, lanes, drive ways and surrounds**	-	59	74	82	86
7	**Open space**	Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
8	**Impervious areas**					
	Paved parking lots, roofs and drive ways, etc.		98	98	98	98
	Streets and Roads					
	Paved; curbs and storm sewers		83	89	92	93
	Paved; open ditches		76	85	89	91
	Gravel		76	85	89	91
	Dirt		72	82	87	89
9	**Urban Area**					
	Commercial	85 % impervious	89	92	94	95
	Industrial	72% impervious	81	88	91	93

	Residential	65% impervious	77	85	92	92
		38% impervious	61	75	83	87
		30% impervious	57	72	81	86
		25% impervious	54	70	81	85
		20% impervious	51	68	79	84
		12% impervious	46	65	77	82
10	**Herbaceous : mixture of grass weed an low growing brush**	Poor		80	87	93
		Fair		71	81	89
		Good		62	84	85
11	**Oak-aspen : Mountain bush mixture of oak brush, aspen, mahogany, maple and other**	Poor		66	74	79
		Fair		48	57	63
		Good		30	41	48
12	**Pinyon-juniper: Pinyon, Juniper or both; grass understory**	Poor		75	85	89
		Fair		58	73	80
		Good		41	61	71
13	**Sage with grass understory**	Poor		67	80	85
		Fair		51	63	70
		Good		35	47	55
14	**Desert Shrub: saltbush, greasewood, cactus, mesquite, etc.**	Poor	63	77	85	88
		Fair	55	72	81	86
		Good	49	68	79	84
Agriculture						
15	**Fallow Land**					
	Bare Soil		77	86	91	94
	Crop Residue	Poor	76	85	90	93
		Good	74	83	88	90
16	**Row Crops**					
	Straight Row	Poor	72	81	88	91
		Good	67	78	85	89
	Crop Residue + Straight Row	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured	Poor	70	79	84	88

		Good	65	75	82	86
	Contoured + Crop Residue	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured + Terraced	Poor	66	74	80	82
		Good	62	71	78	81
	Contoured + Terraced + Crop residue	Poor	65	73	79	81
		Good	61	70	77	80
17	**Small Grains**					
	Straight Row	Poor	65	76	84	88
		Good	63	75	83	87
	Crop Residue + Straight Row	Poor	64	75	83	86
		Good	60	72	80	84
	Contoured	Poor	63	74	82	85
		Good	61	73	81	84
	Contoured + Crop Residue	Poor	62	73	81	84
		Good	60	72	80	83
	Contoured + Terraced	Poor	61	72	79	82
		Good	59	70	78	81
	Contoured + Terraced + Crop residue	Poor	60	71	78	81
		Good	58	69	77	80
18	**Close Seeded or Broadcast Legumes or Rotation Meadows**					
	Straight Row	Poor	66	77	85	89
		Good	58	72	81	85
	Contoured	Poor	64	75	83	85
		Good	55	69	78	83
	Contoured + Terraced	Poor	63	73	80	83
		Good	51	67	76	80

Natural Resource Conservation method was used to quantify the Runoff at Sub basin level in the catchment. Gauging station at Bantwala (Yettinaholé DPR) indicates average of 395 TMC yield between 1971 to 2012. In the last decade, yield in the catchment is about 350 TMC, maximum yield was observed in the year 1980- 81 with yield of 576 TMC and minimum in 226 TMC in 1987-88. Annual water yield is represented in Figure 16. The catchment has an annual average yield about 400 TMC (2603 mm). Runoff Rainfall ratio across sub catchments area as depicted in Figure 18, indicating that the Ghats with good forest cover have lower runoff capabilities i.e., high retention capacities, compared to the coastal and plain lands.

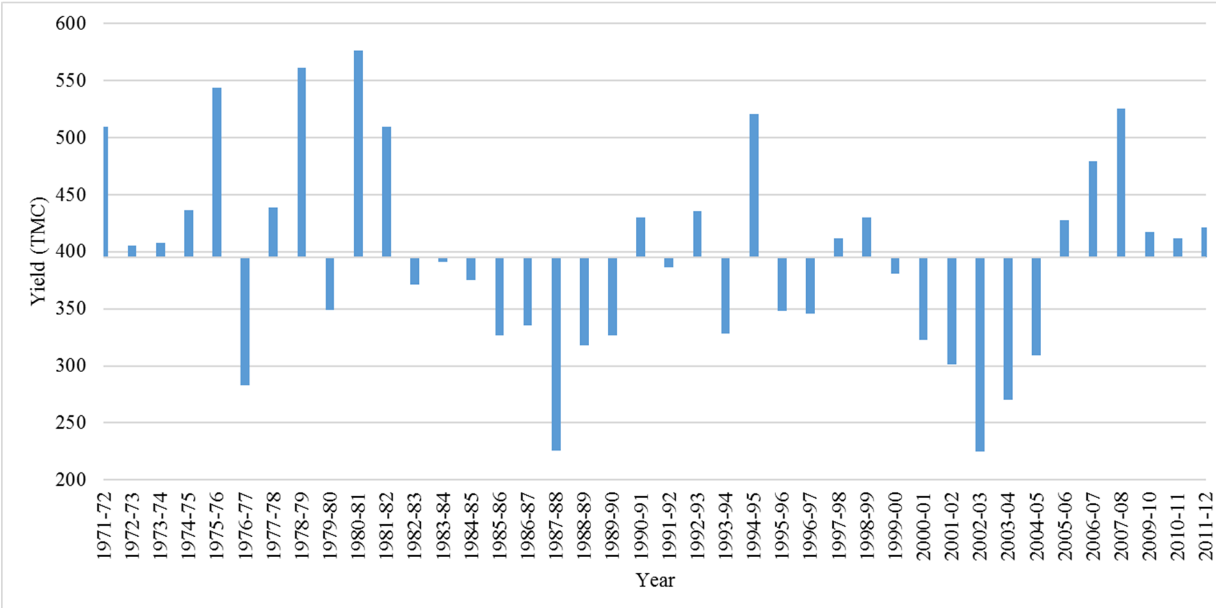

Figure 16: Yield at Bantwala between 1971 – 2012 (June to November Month)

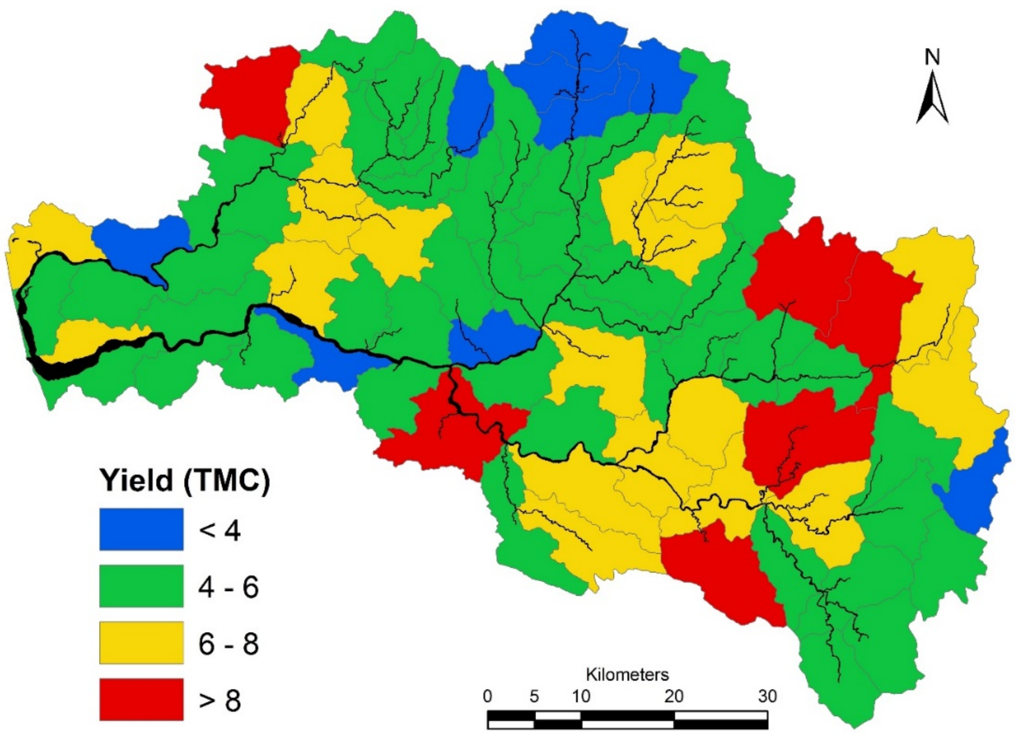

Figure 17: Yield in the catchment

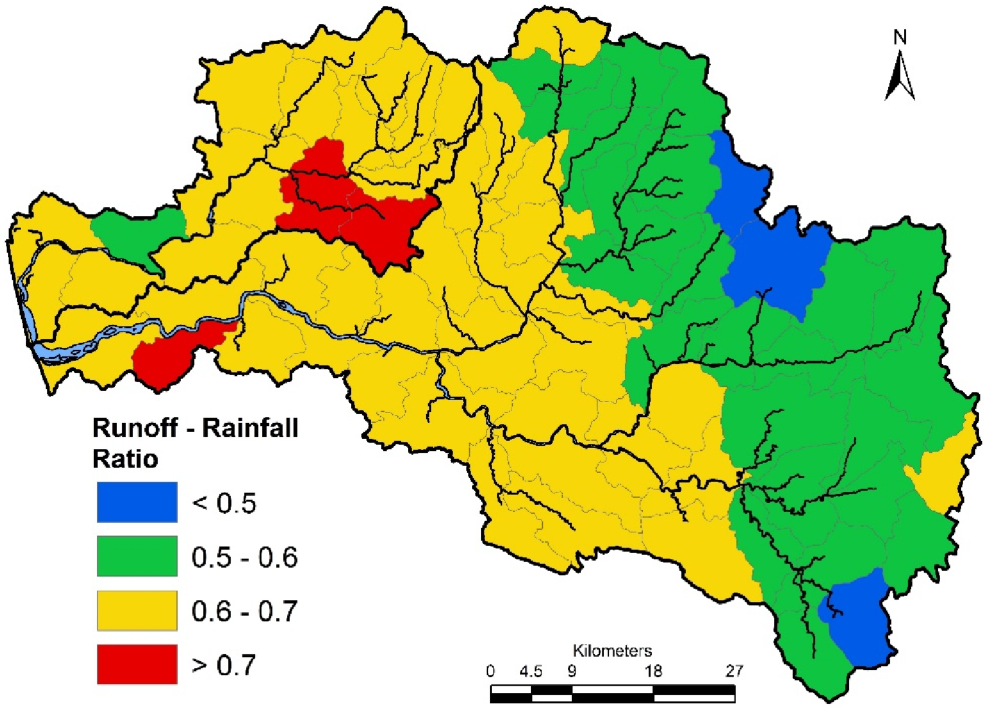

Figure 18: Runoff Rainfall ratio in Netravathi catchment.

Infiltration: Infiltration is amount of water that enters soil surface replenishing soil moisture and building up ground water table (Mutreja, 1995). Infiltration is estimated as function of Rainfall, Runoff, Interception and Evapotranspiration (Figure 19). Interception is quantified across different vegetative landscape based on interception equations as shown in Table 13.

Infiltration = Precipitation – (Runoff + Interception + Evapotranspiration)

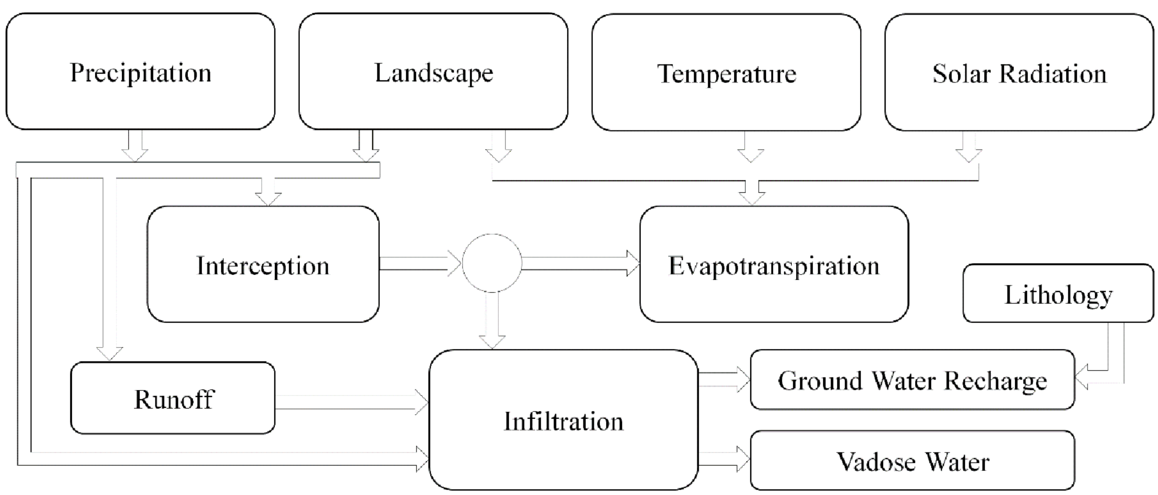

Figure 19. Method involve in estimating Infiltration

Table 13: Interception equations (Ramachandra *et al.*, 2014)

Vegetation types	Interception
Evergreen/semi-evergreen forests	I = 5.5 + 0.3 (P)
Moist deciduous forests	I = 5 + 0.3 (P)
Plantations	I = 5 + 0.2 (P)
Grasslands and scrubs	I = 3.5 +0.18 (P)

Interception during monsoon in the catchment is about 465 mm (86 TMC) and is as depicted in Figure 20, Infiltration about 137 TMC and is as depicted in Figure 21. The Ghats and transitions zones of Netravathi indicates higher interception and infiltration capabilities, whereas the coastal and uplands plains had lower interception and infiltration. Presence of forest across the Ghats play a prominent role in both Intercepting and Infiltrating large quantity of rain water. Larger infiltration capabilities in the catchment upstream are the ones which keep the river perennial.

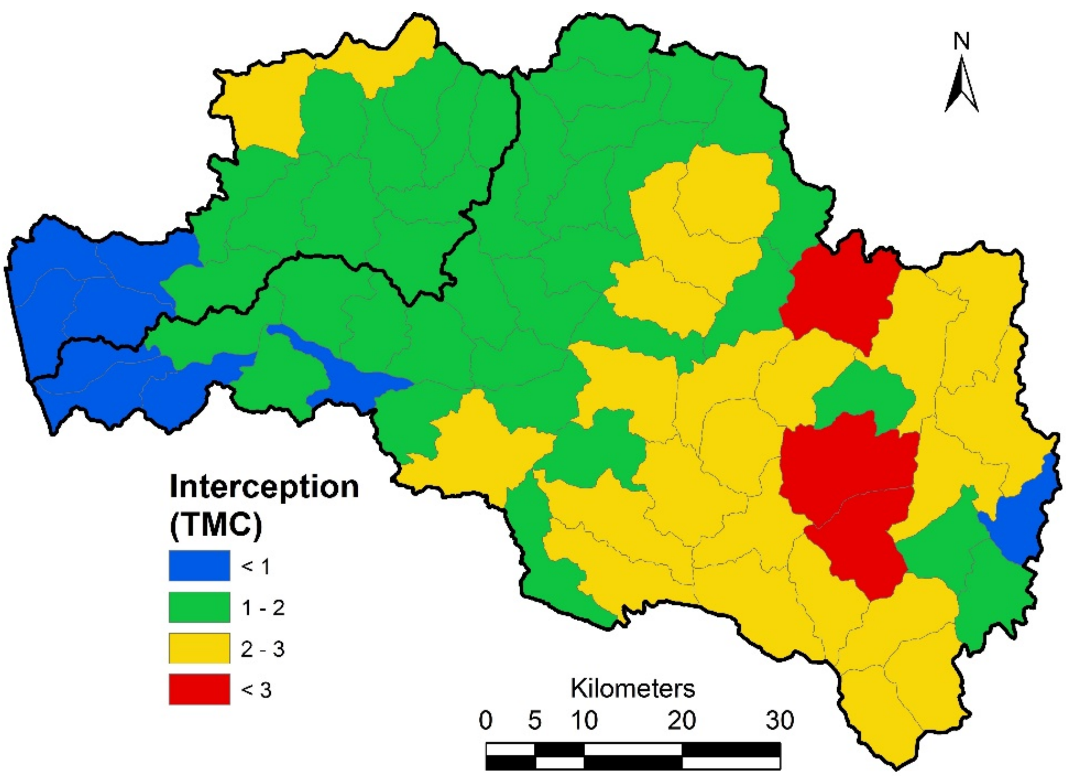

Figure 20: Interception in Netravathi

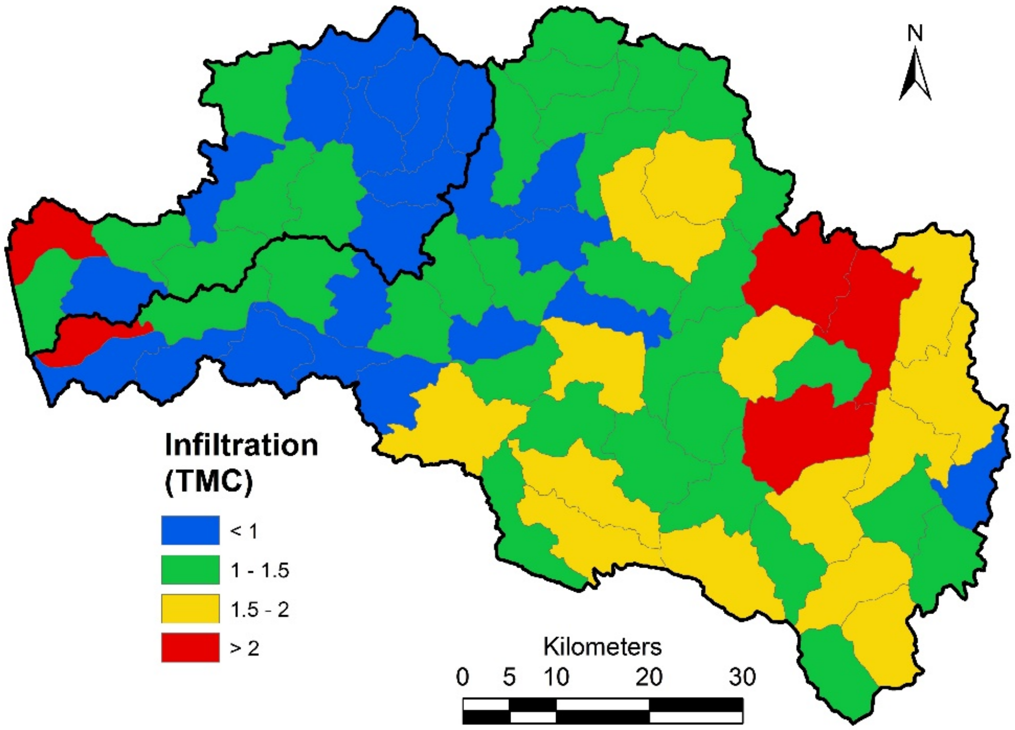

Figure 21: Infiltration in Netravathi

Ground Water Recharge: Ground Water recharge was estimated as function of Porosity of sub strata and Annual Average Rainfall. Porosity of various rock types (Manger, 1963; Morris and Johnson, 1967; Mutreja, 1995; Ramachandra et al., 2013) are as presented in Table 14.

Table 14 Porosity of Rocks

Rock Type	Porosity
Alluvial area Sandy	20 - 25%
Alluvial area Clayey	10 - 20%
Limestone Sandstone, Phyllite, Shale	10 - 20%
Conglomarate	8-12%
Charnokites	8 - 12%
Schist	15-20%
Basaltic - Vesicular	10 - 15%
Basaltic- Weathered	4 - 10%
Granite Weathered	10 -15%
Granite Unweather	5 - 10%

Ground water recharge was estimated as function of porosity of Bed rocks and Rainfall. Ground water recharge in the entire catchment is 62 TMC (405 mm). Figure 22 depicts sub basin wise

Ground water recharge in the catchment. Ghats towards Kumara parvatha have higher volume of Ground water recharge potential in the catchment.

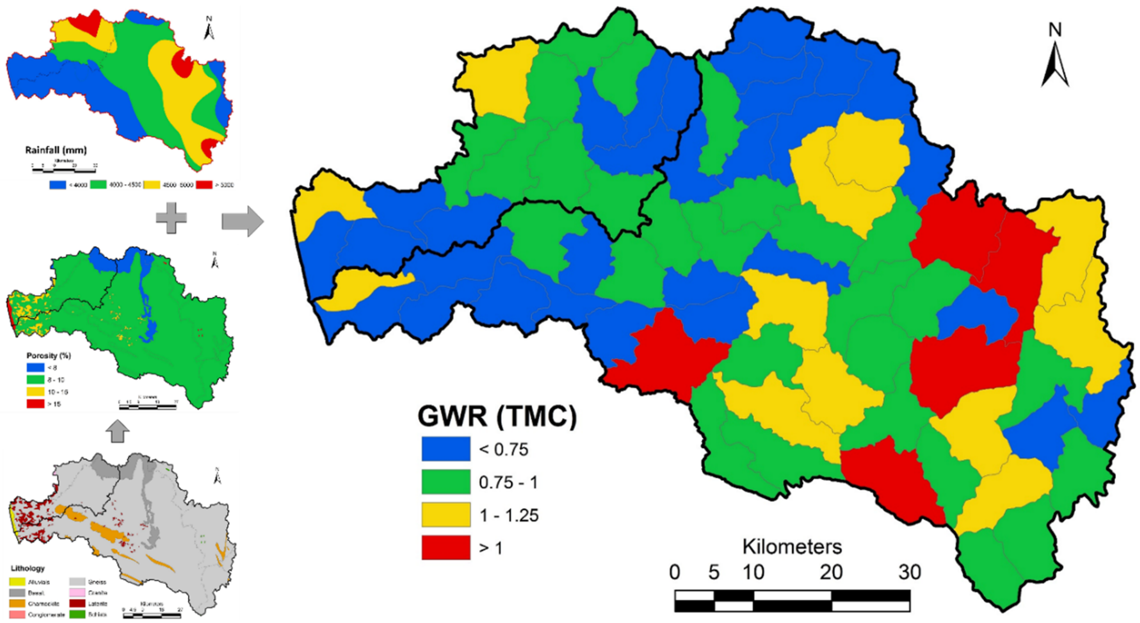

Figure 22: Ground Water Recharge

Evapotranspiration: Potential evapotranspiration (PET) is determined using Hargreaves method (Xu and Singh, 2000, 2001; Alexandris et al., 2008; Rao et al., 2012) which is a radiation based equation (Figure 17). PET is estimated as mm using the Hargreaves equation is given as

$$PET = 0.0023 * \left(\frac{R_A}{\lambda}\right) * \sqrt{T_{max} - T_{min}} * \left(\frac{T_{max} + T_{min}}{2} + 17.8\right)$$

Where R_A is Extra-terrestrial radiation (MJ/m2/day) which depends on the latitudinal gradients(*Food and Agriculture Organisation*), T_{max} is Maximum temperature in degree Celsius (Hijmans et al., 2007), T_{min} Minimum Temperature in degree Celsius (Hijmans et al., 2007) and λ is latent heat of vaporization of water (2.501 MJ/kg) (*Food and Agriculture Organisation*). Actual evapotranspiration is estimated as a product of Potential evapotranspiration (PET) and Evapotranspiration coefficient (K_C) (*Food and Agriculture Organisation*).

Evapotranspiration using Modified Hargreaves method was estimated for non-agriculture/horticulture landscapes only since the crop water demand takes care of the Evaporative fraction in the same. Net Evapotranspiration was quantified as the difference between Gross Evapotranspiration in each sub catchment and Interception, since, during Monsoons, Evaporation water was a part of Intercepted quantity of water. Figure 23 depicts Net

Annual Evapotranspiration in the catchment. Annually about 97.8 TMC of water is transferred from surface to atmosphere as Evapotranspiration from Netravathi Basin. Since the Ghats are dominated by forests, Net Evapotranspiration is higher in those regions.

Table 15: Evapotranspiration coefficients

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

Note: Evapotranspiration was quantified only for nonagricultural landscape only. transpiration from agriculture and horticulture were quantified as a part of crop water demand

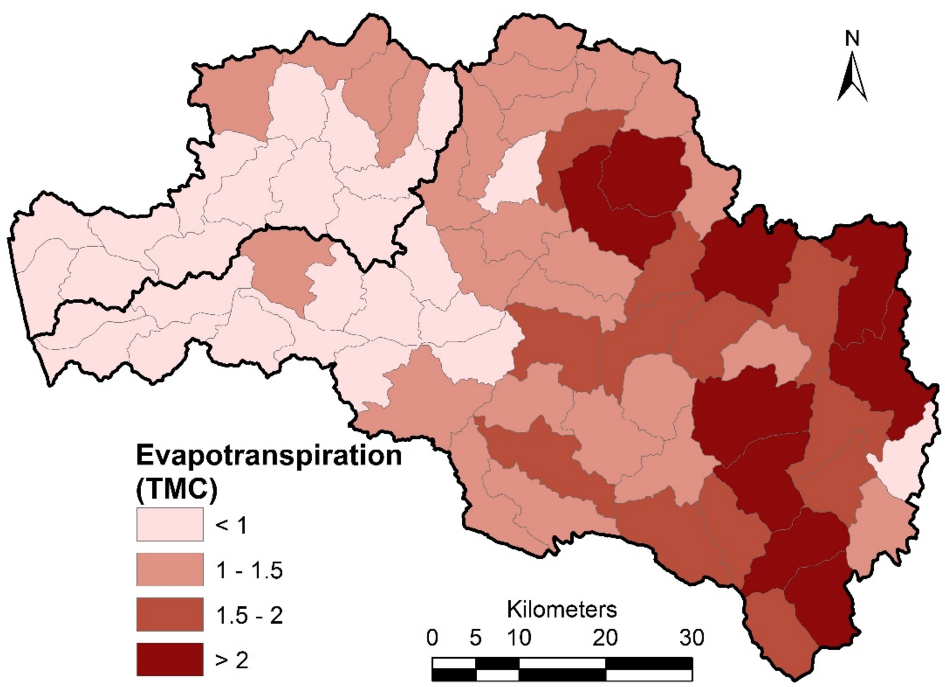

Figure 23: Evapotranspiration

Domestic, Livestock and Irrigation Water Requirements

Domestic Water Demand: Domestic water demand is the amount of water required for the population in the catchment. Figure 24 depict the method involved in estimating domestic water requirement across sub basin level in the catchment.

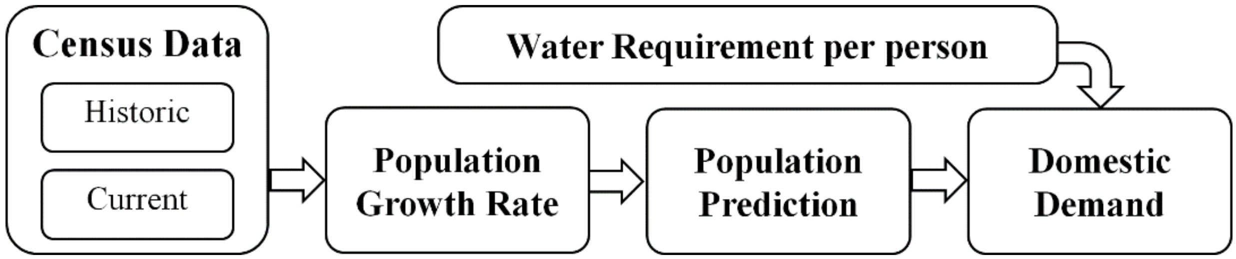

Figure 24: Method involved in estimating Domestic Demand.

Population data for each district in the basin was collected from census of India (Office of the Registrar General & Census Commissioner, 2011), based on the growth rate between 2001 and 2011, population for the year 2021 was predicted across the basin using simple interest method. Demand of 150 lpcd was considered to estimate domestic water demand in the basin. Proportional population was considered for districts which extends beyond the basin boundary.

$$\text{Population 2021} = \text{Population 2011 } (1 + n.r)$$

Where r is the growth rate between 2011 and 2001, n is number of decades (= 1).

$$r = \frac{Population\ 2011}{Population\ 2001} - 1$$

Domestic Demand was estimated considering population dynamics across the catchment. 135 litres per capita per day was assumed to quantify the water demand. Population for the year 2018 and 2021 was estimated based on the growth rate in each village between 2001 and 2011. Figure 25 depicts the Population dynamics and Figure 26 depicts Annual Domestic water demand in the catchment. Annually 3.71 TMC of water is required to cater the domestic water demand in the catchment. Major cities and towns such as Mangalore, Bantwala, Puttur, Dharmastala, Bajpe, Beltangadi, Padu, Konje have population over 10000 people indicating higher water demand. The coastal catchments have higher water demand compare to the sub catchments in the Ghats.

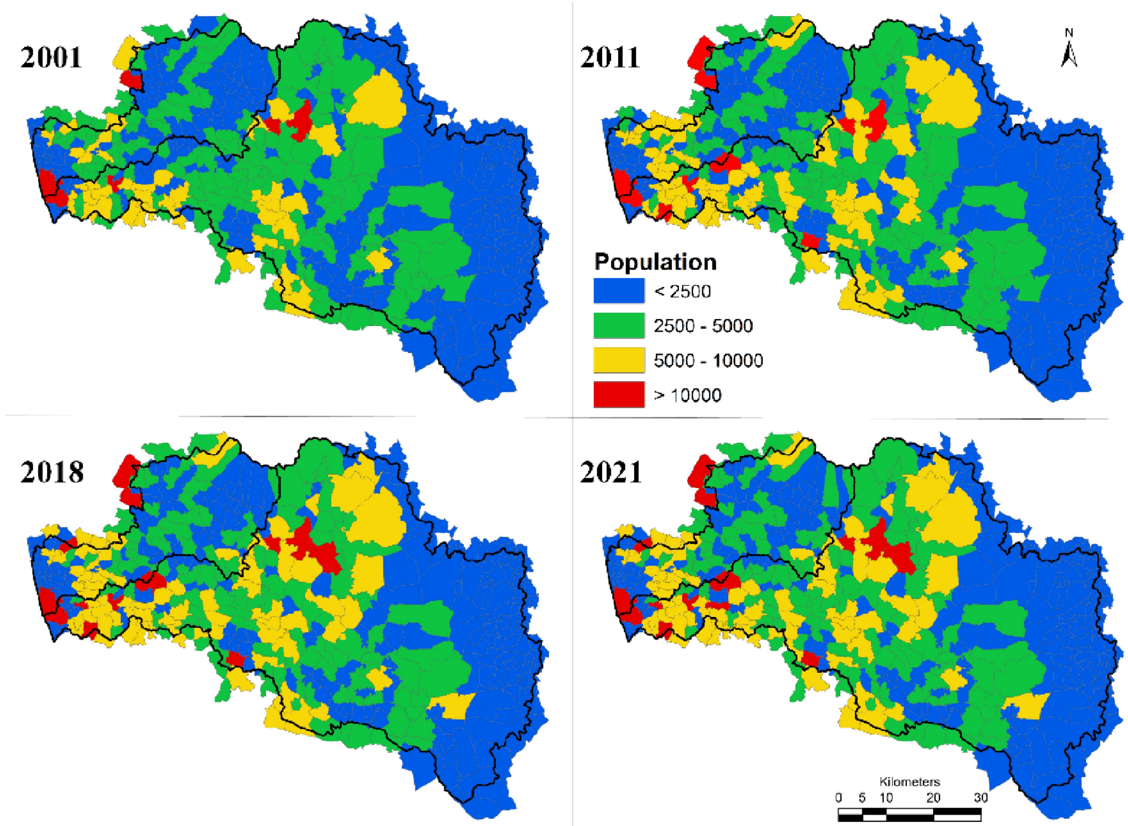

Figure 25: Population Dynamics in the Basin.

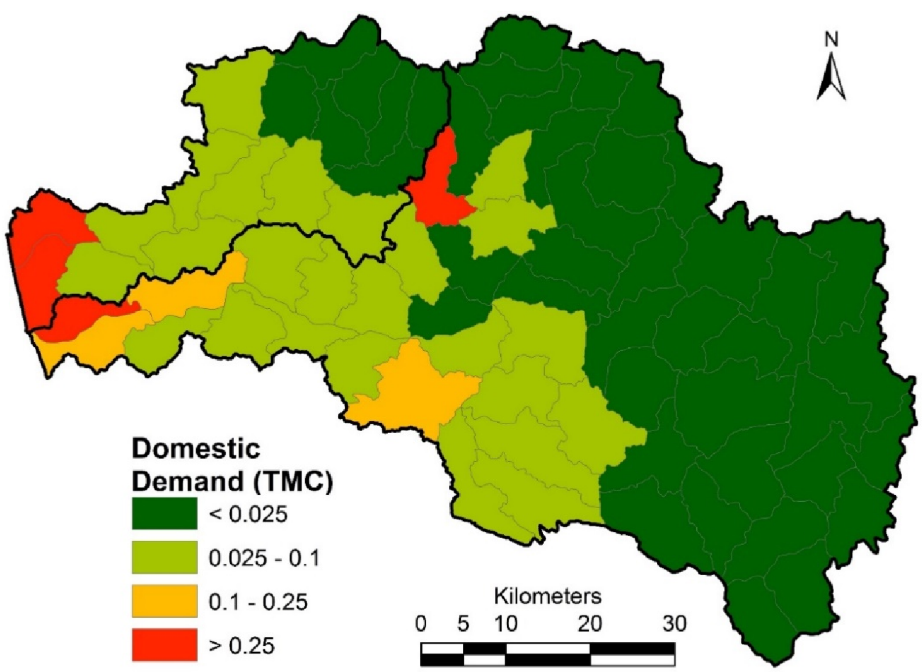

Figure 26: Domestic Water requirement.

Livestock Demand: Similar to domestic demand, livestock demand was estimated considering livestock census across each districts (Department of Animal Husbandry and Veterinary Services, 2012; Department of Statistics, 2012; Department of Animal Hubandry Dairy and Fisheries, 2015). Water demand for livestock was established through telephonic interviews and through literature(Markwick, 2007; Ramachandra *et al.*, 2014; Meehan A, Stokka and Mostrom, 2015). Table 16 provides insights to water demand for various livestock.

Table 16: Livestock Water demand

Livestock	Cattle	Buffalo	Sheep	Goat	Pig	Rabbit	Dog	Poultry
Water ltr/animal	70 - 120	75 - 130	15 - 20	15 - 22	20 - 30	1 - 2	6 – 10	0.25 – 0.35

Livestock Demand in the catchment is about 0.37 TMC in the catchment. Figure 25 depicts the livestock water demand in each sub catchment. The plane lands show higher water demand for livestock compared to the Ghats and the transition zones.

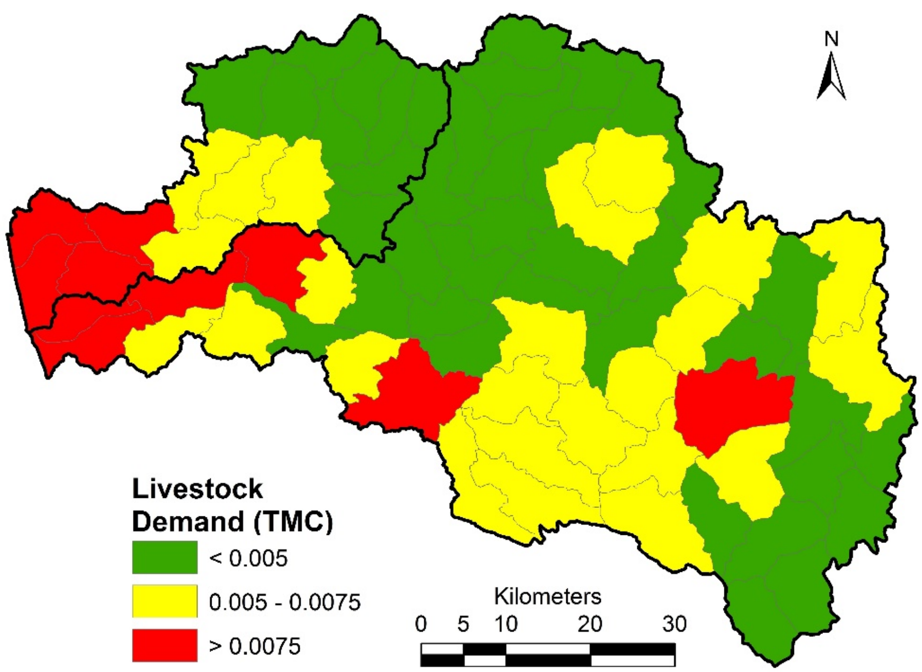

Figure 27: Livestock demand.

Agricultural Demand: Agriculture demands depends on such as type of plant, growth phase of plant. In order to estimate crop water requirements, area under different at district level was established based on the statistical data published by the Government agencies and NGO's (Karnataka State Department of Agriculture, no date; Department of Economics and Statistics, 2011, 2016; Department of Economics & Statistics, 2015). Water requirement for each crop based on their growth phases (*Food and Agriculture Organisation*; *ICAR-Indian Agricutlre Research Institute*; *Karnataka State Department of Agriculture; National Food Security Mission*) were accounted to quantify agriculture demand. Agriculture Demand is the major component in the catchment. The catchment is dominated by Paddy (mono crop and double crop), Horticulture (Rubber, Arecanut, Banana, Coconut) followed Fruits and Vegetable. Across time Large scale landscape changes have occurred in the region converting forest into monoculture(horticulture). Based on the data available at district at a glance, cropping area under each crop for sub catchments were quantified. Based on the crop water requirement for each crop according to the growing season, Crop water demand was estimated. The Basin has crop water demand of 120 TMC. Figure 28 Depicts the crop water requirement for each sub basin. Horticulture dominated Transition zones, Paddy dominated plane lands shows higher water demand as against the Ghats or the Coasts.

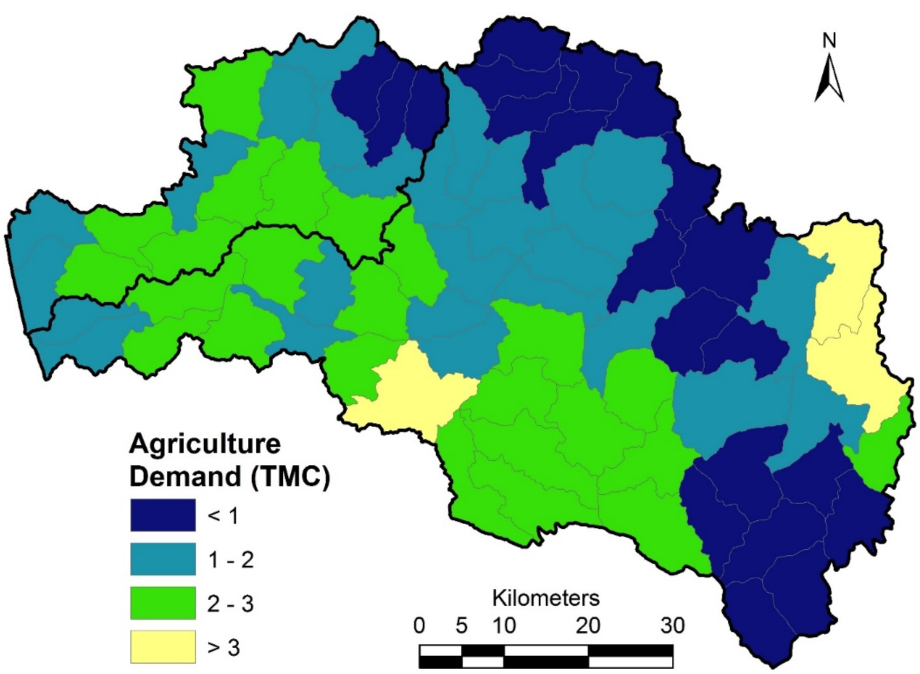

Figure 28: Agriculture Water Demand

Hydrological Status: Hydrological status is estimated as a function of Demand and Available functions. It is a non-dimensional value indicating deficit or excess water availability in the region. Values greater than 1 indicate excess water, values equal to 1 indicate water availability and demands are equal, values less than 1 indicate deficiency.

$$Hydrological\ Status = \frac{f(Water\ Supply)}{f(Water\ Demand)} = \frac{f(Rainfall, Runoff, Infiltration)}{f(Agriculture\ , Domestic\ and\ Livestock\ Demand)}$$

Total Water demand was quantified as function of Agriculture Demand, Domestic and Livestock water demands. Figure 4.23 depicts the total water demand in the catchment. Total water demand other than Terrestrial Environmental demand (Evapotranspiration from forest) and Aquatic Environmental Demand (Stream flow maintenance), is about 124 TMC. Adding Evaporation about 98 TMC, Total water demand would increase to 222 TMC, considering Environmental flow as 30% Mean Annual Runoff, about 128 TMC, Total water Demand would increase to 350 TMC

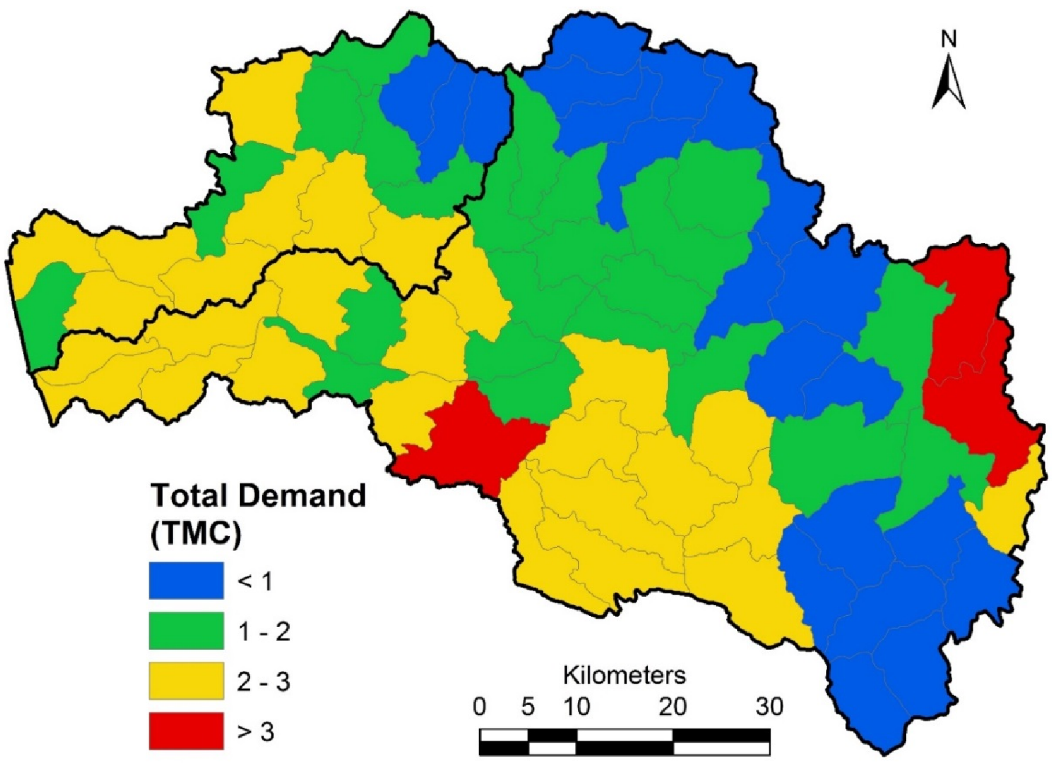

Figure 29: Total Water Demand

Hydrological status, i.e., ratio of Supply to Demand (ratio of 1.14) indicates that the water available in the catchment is just over the demand.

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