Landscape dynamics, Rainfall and Stream Flow: Linkages

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Land use Land cover (LULC) and rainfall are critical for ecological stability of watersheds. The role of LULC on hydrological processes is crucial in many ways because they maintain catchment's water balance through interception and transpiration. Forests are important for hydrological systems as they aid in increasing rainfall and runoff, regulate water flow, reduce erosion and improve water quality. Soil with vegetation cover acts as a reservoir that store vast quantity of water used by plants and trees or released into streams and rivers. Increased reforestation on unstable land and around lakes, rivers and streams help to increase the water-retention capacity of land and improve water quality. However in recent times human activities have led to serious LULC changes, vegetation degradation, natural resource exploitation and wetland disappearance. To a large extent, afforestation and deforestation are major human activities responsible for these enormous environmental changes. Indiscriminate cutting of trees have decreased the storage of ground water sponge, leading to water shortages during dry seasons and, in wet seasons, to brief destructive floods, during which very little water is absorbed by the soil. Large productive land, where annual rainfall is relatively high, becomes desert when vegetation cover is removed. Therefore, there is a need to study the linkages between LULC, forest fragmentation, rainfall and stream flow (seasonal and perennial). In this context, remote sensing data coupled with other primary data such as rainfall, amount of green cover, type of forest, and other ground level information, etc. can be used to analyse this relationship in watersheds. In this study, we attempt to study the Kali river basin in Uttara Kannada district, Karnataka state, India. The river basin is divided into ten small subbasins to study dynamics of LULC change and establish a relationship between stream flow and other parameters. Land use analysis (agriculture, evergreen forest, plantation, built up, waste land and water bodies) is done basin wise and forest fragmentation is computed to assess the amount of patch, transitional, edge, perforated and interior forest. Finally a mathematical relationship is established between the number of streams as a function of LULC, rainfall and forest fragmentation to identify the important parameters that play a pivotal role in deciding the water retaining capacity of the streams (seasonal or perennial).

Keywords: Land use land Cover, forest fragmentation, Kali river basin, deforestation, stream flow

INTRODUCTION

Water supply demand is increasing rapidly with increasing human population with changes in land use land cover (LULC). In land use types such as forest, hydrology plays an important role in studying the link between water movements through the forest. The major challenge in the 21st century is the proper management of the forest and water supply. Land cover (LC) of the tropics is now becoming more fragmented and highly complex, and secondary forest is now emerging as the dominant forest type interspersed with remnants of old-growth forest and other intermediate LCs (Giambelluca, 2002; Drigo, 2004; Holscher et al., 2004; Cuo et al., 2008). The dynamics of changes in forest and its hydrological effect on the rivers is also determined by land use (LU), its extent and climate of the area. Rivers in south India receive runoff due to rainfall and have good flow only during monsoon unlike rivers in northern part of India which are perennial since they receive snow melt runoff in summer. The knowledge of soil formation, recharge of streams and lakes, rainfall pattern, cropping patterns, etc. are required in understanding the hydrogeology of an area. In other words, the hydrological study helps in the assessment, development, utilization and management of water resources. The storm runoff hydrology of the intermediate LCs from many decades of human occupancy, and 'forestation' (afforestation–reforestation, defined in Scott et al., 2004; Wiersum, 1984) of land in various states of degradation, have been much less studied across a range of soils and scales (Giambelluca, 2002; Bruijnzeel, 2004; Holscher et al., 2004; Scott et al., 2004).

In forests LU types, most water transactions in the atmosphere are mainly due to interception, evaporation, transpiration, and evapotranspiration from irrigated and cropped land. Transpiration is the process by which water vapour escapes from the living plant leaves and enters the atmosphere. Interception is due to the water held up by the surface of the leaves and buildings, which are in turn returned to the atmosphere by evaporation without reaching the ground surface. Evapotranspiration is the total water lost from the cropped land due to evaporation from the soil and transpiration by the plants or used by the plants in the formation of the plant tissue. Climatological factors like percentage sunshine hours, wind speed, mean monthly temperature and humidity, cropping factor and the moisture level of the soil affects evapotranspiration. How much these maninduced impacts have been influential on climate –water relations, as against the effects of inherent climatic variability and predicted climate change scenarios, still remains a major challenge to quantify. Thus embedded within the global warming issue are these additional LULC change that impacts climate-rainfall-storm runoff across scales which also require consideration under the broader mandate of 'global change' (Mike et. al., 2010). Water entering the soil at the ground surface is called infiltration, which replenishes the soil moisture deficiency and excess water seeps and build up the water table. The infiltration depends on the duration of rainfall, temperature, soil type, vegetation cover, LU, etc. Rainfall is one of the important climatic parameter influencing the cropping pattern, productivity, flooding and drought hazards, erosion and sedimentation (Kusre et. al.,2012). In case of perennial streams, ground water table never drops below the bed of the streams and therefore flows throughout the year. Ground water is widely distributed in the ground and is replenishable resource unlike other resources in the earth. During a storm, portion of rain water seeps into the soil and some may evaporate and the rest may flow over the land surface which is the overland flow. Run off is the balance of rain water, which flows or run over the natural ground surface after losses by evaporation, interception, and infiltration. Rain helps in the recharge of ground water as it seeps down through soil and rock layer of the ground from surface water sources. The entire area of the river basin whose surface runoff due to rain drains into the river in the basin is considered as a hydrological unit and is called drainage basin, watershed or catchment's area of the river flowing. When the storm water infiltrates in the ground then some portion of it evaporates and the rest flows as a thin sheet of water over land surface termed as overland flow.

Climatic and human activities can influence land cover status and eco-environment quality (Hao et.al., 2012). On the other hand, dramatic changes in the humid tropics of LC and LU have occurred (Drigo 2004) from the mid-20th century to the present that have resulted in rapid rates of forest conversion and an expansion of 'land and forest degradation' (Lal 1987; Scott et al. 2004; Safriel 2007). To a large extent, afforestation and deforestation are major human activities responsible for these enormous environmental changes. Indiscriminate cutting of trees have decreased the storage of ground water sponge, leading to water shortages during dry seasons and, in wet seasons, to brief destructive floods, during which very little water is absorbed by the soil. Large productive land becomes desert when vegetation cover is removed. Therefore, there is a need to study the linkages between LULC, forest fragmentation, rainfall and stream flow (seasonal and perennial). In this context, remote sensing data coupled with other primary data such as rainfall, amount of vegetation and forest, and other ground level information, etc. can be used to analyse this relationship in watersheds.

In this study, we attempt to study the Kali river basin in Uttara Kannada district, Karnataka state, India. The river basin has been divided into ten subbasins based on the tributaries (drainage network) to study dynamics of LULC change and establish a relationship between stream flow and other parameters. LU analysis (agriculture, evergreen forest, plantation, built up, waste land and water bodies) is carried out for each basin and forest fragmentation is computed to assess the amount of different types of patch, transitional, edge, perforated and interior forest. Finally a mathematical relationship is established between the number of streams as a function of LULC, rainfall and forest fragmentation to identify the important parameters that play a pivotal role in deciding the water retaining capacity of the streams which may be wither seasonal or perennial. The objectives of this study are:

(i) to delineate sub-basins based on drainage patterns in the main river basin.

(ii) to perform LU analysis of the river basin (subbasin wise).

(iii) to compute forest fragmentation in each subbasin.

(iv) to carry out multivariate statistical analysis and establish a regression model to find the linkages between the LU, forest fragmentation, order of streams, stream density, rainfall and infiltration of the river basin.

The analysis will reveal the role of LU, rainfall, number and types of streams and vegetation types in the catchments in deciding the seasonality and perenniality of the river.

2. STUDY REGION

Kali river basin situated in the northern part of Karnataka State, India (Figure 1) is chosen as the study area. This region has spatial extent of 440031 ha and is further divided into 10 sub-basins for a detailed analysis as shown in Figure 2.

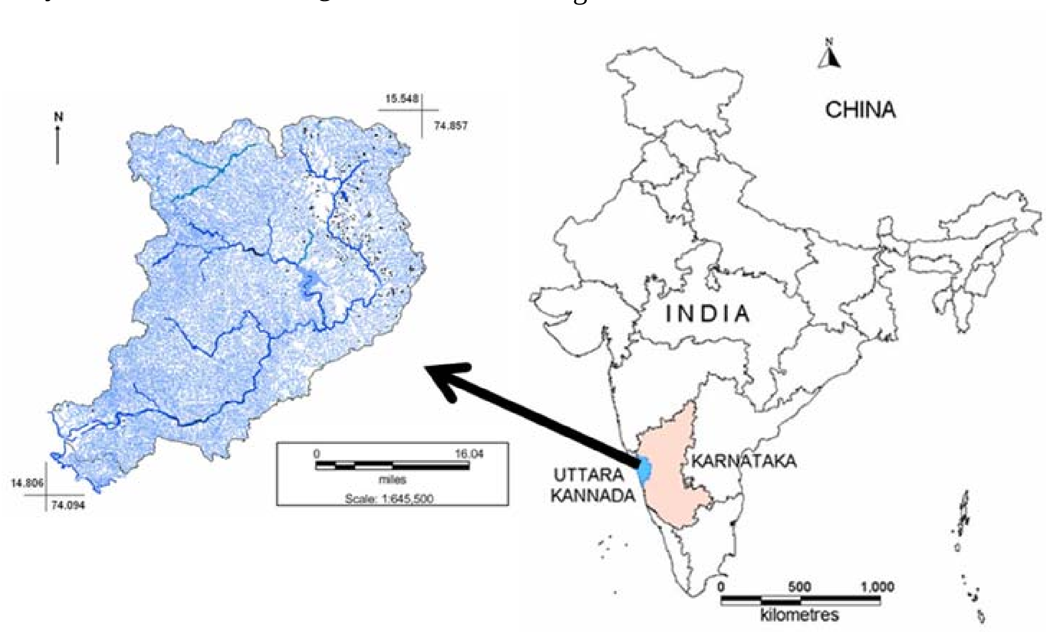


Figure 1: Study area (Kali river basin).

Methods

The overall method is depicted in Figure 3. IRS data of the year 2010 were used to classify the Kali river basin into eleven LU categories (builtup, water, agriculture, open land, semievergreeen, evergreen, scrubforest_grasslands, acacia plantation, teak plantation, coconut_and arecanut gardens, and dry deciduous forest). Subbasins were delineated from the digitized layer of Kali basin and numbers of streams were counted (first, second, third and fourth order) to find the total number of streams belonging to each order. Perennial streams were identified from Google Earth for the entire river basin.

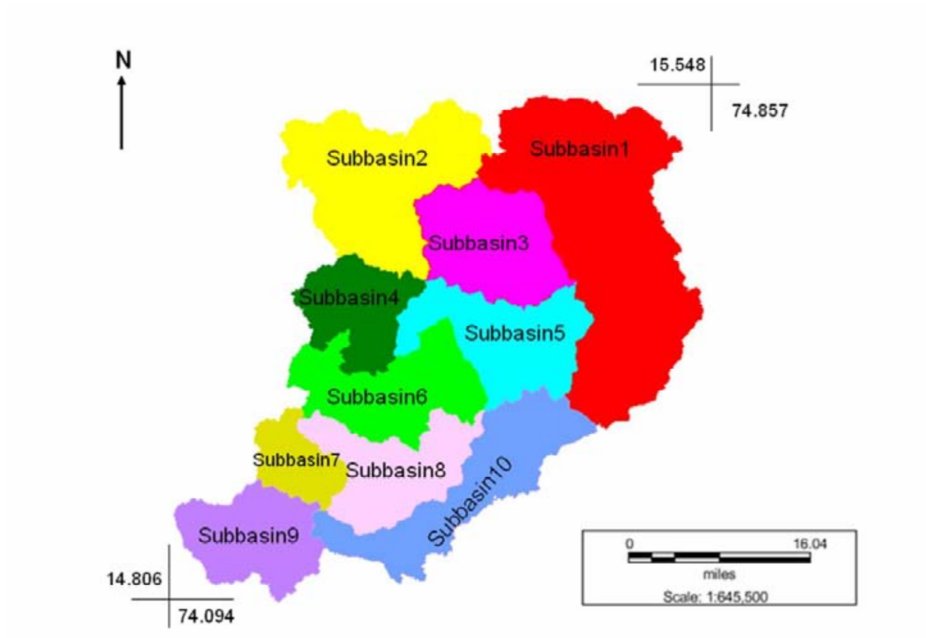


Figure 2: Kali River basin divided into 10 subbasins.

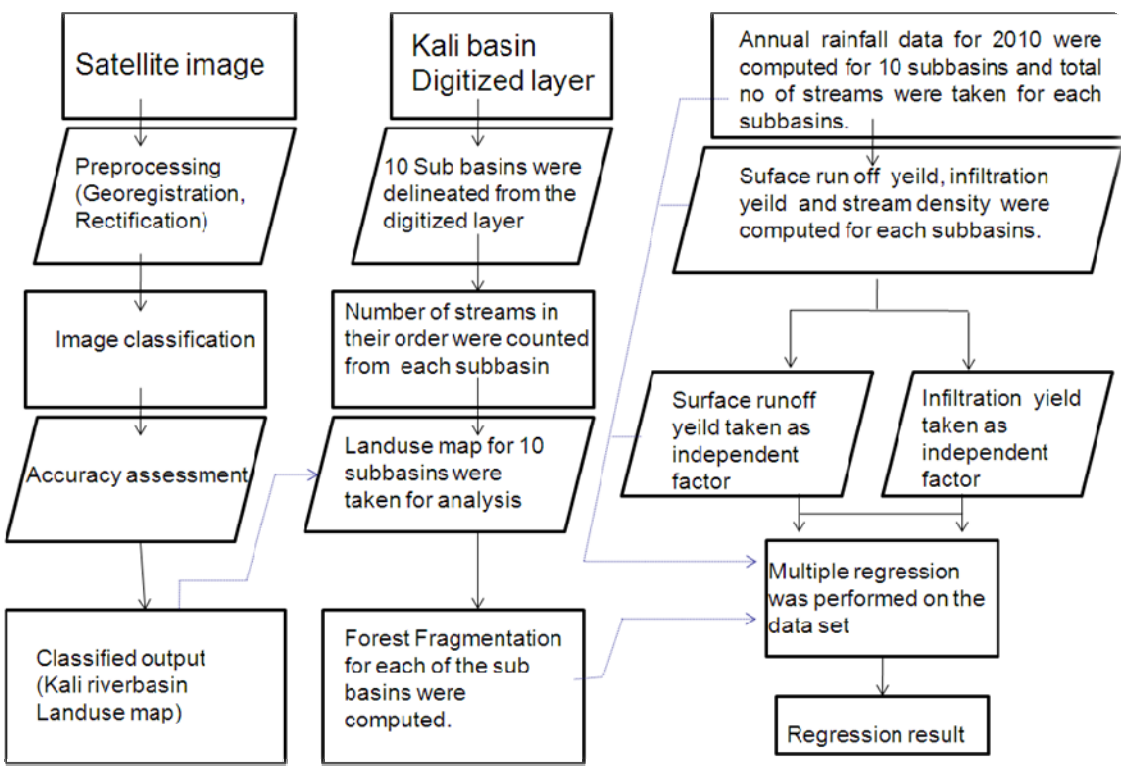


Figure 3: Method of the study shown in Flow chart.

Forest fragmentation model was used on the derived LU information to obtain fragmentation indices, which gives forest continuity values. These values are used in conjunction with the total proportion of forest for a given area (excluding water) to produce an index of forest fragmentation (Hurd et.al, 2002). This was done for each of the sub-basins in order to get the proportion of patch, transitional, edge, perforated and interior forest. Average rainfalls for the year 2010 were calculated taking rain gauge stations present in the villages of each sub-basin. The yield of the catchment is the net quantity of water available for storage, after taking in to account all losses for the purpose of water resources utilization and planning like irrigation, water supply etc. Surface runoff yield of the catchment assuming a suitable runoff coefficient is expressed as:

Surface runoff yield = C*A*P

- A= Area of the catchment
- P= Precipitation
- C=runoff coefficient

Here, the drainage area was divided into a number of subbasins, and the runoff contribution of each area is determined. Similarly, infiltration runoff yield is computed by taking runoff coefficient value as (1-C).

The stream density of the drainage basin is expressed as the number of streams per square kilometer. Stream density = number of streams / area of the basins. Table 1 shows the perennial and seasonal streams in the Kali river basin.

Table 1: Perennial and seasonal streams in the subbasins

Subbasin	Number of perennial streams	Number of seasonal Streams in Order					Total No. of Streams	Catchment area (m^2)	Stream Density (m^{-2})
		1	2	3	4	5			
Subbasin1	3	2520	435	119	37		3114	824892470	3.78E-06
Subbasin2	3	2155	482	109	18	2	2769	616985070	4.49E-06
Subbasin3	2	996	213	53	11		1275	435939850	2.92E-06
Subbasin4	1	1171	248	50	18	1	1489	293294700	5.08E-06
Subbasin5	2	932	189	48	10		1181	431371540	2.74E-06
Subbasin6	1	1258	256	62	11		1588	428604850	3.71E-06
Subbasin7	1	879	172	47	16	3	1118	173502600	6.44E-06
Subbasin8	1	1328	281	58	7		1675	370847390	4.52E-06
Subbasin9	1	1220	258	73	18		1570	346938410	4.53E-06
Subbasin10	1	1389	270	69	8	1	1738	477931910	3.64E-06

RESULTS

Figure 4 shows the LU maps derived from the classification of remote sensing data. Table 2 and 3 depicts the area of the various LU types in ha and percentages. The results reveal that evergreen forests are dominating in sub basin 2, 3, 4, 5, 9 and 10 while sub basin 6, 7 and 8 have more than 70% of the LC as evergreen forest. Water class is dominating in sub basin 4 and 8 with 14.62 and 7.25% respectively.

Semi-evergreen is majorly present in sub basin 2, 6, 7 and 10 while sub basin 3 has major semi-evergreen cover of 31.18%. Agriculture class is present in subbasin1 and subbasin9 as 47.54% and 13.93%.

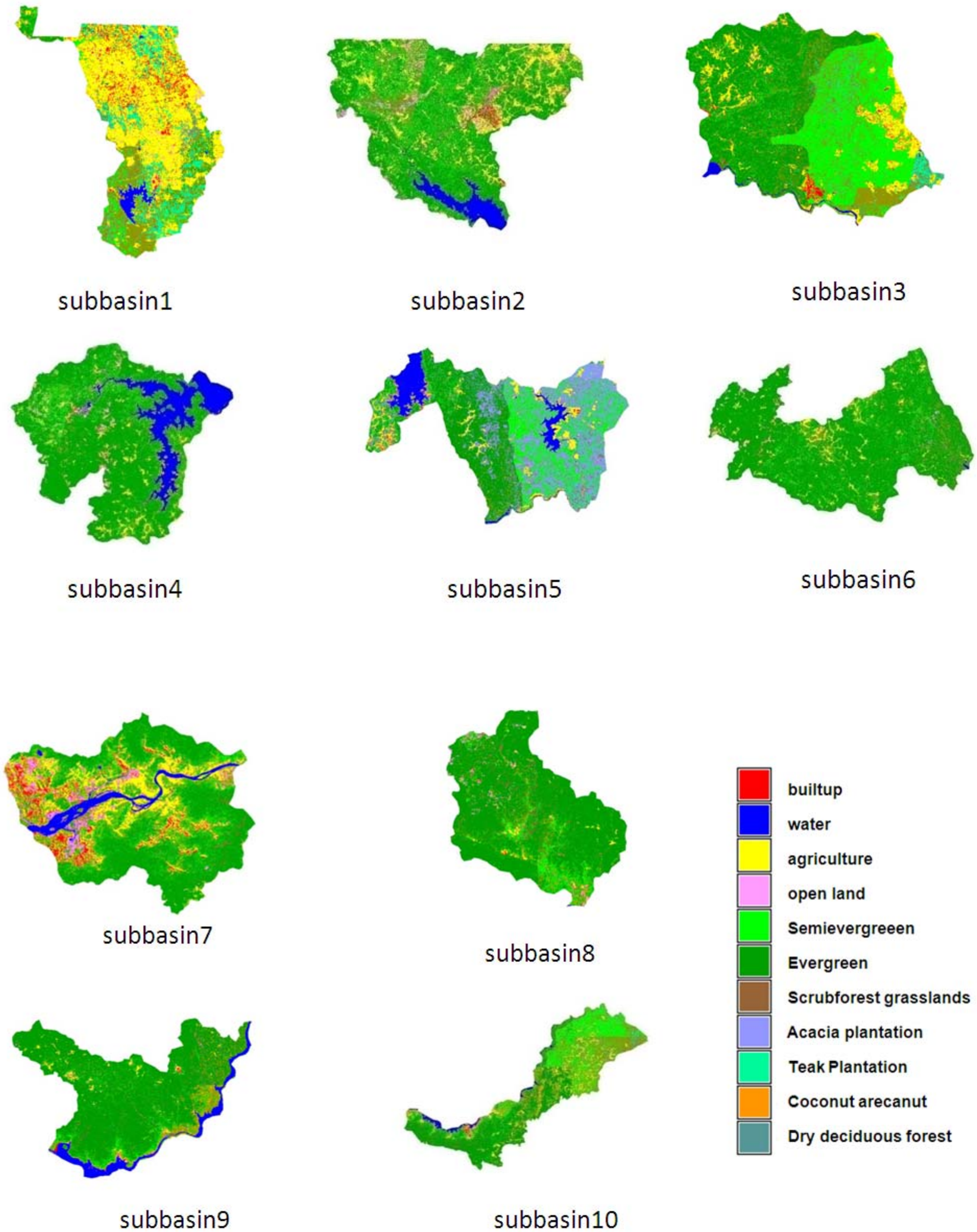


Figure 4: LULC of the 10 kali subbasins

Table 2: LULC in hectares (area) of the 10 subbasins

Class	Area in hectares									
	Sb1	**Sb2**	**Sb3**	**Sb4**	**Sb5**	**Sb6**	**Sb7**	**Sb8**	**Sb9**	**Sb10**
Builtup	4736.53	366.44	473.45	57.68	129.26	80.12	24.56	92.68	1589.61	226.54
Water	1943.27	3332.50	389.98	4288.84	3301.63	40.73	6.69	2687.41	1672.85	977.97
Agriculture	39216.35	6959.04	3235.04	939.15	2047.27	1375.29	187.11	692.01	4831.72	2525.10
Open land	1346.86	3397.94	249.81	974.01	350.85	483.29	295.00	379.54	2133.25	602.54
Semi evergreen	2795.36	10215.23	13591.5	2721.57	8143.19	2863.30	1648.00	2598.08	4296.36	10489.95
Evergreen	4109.08	28142.97	16154.24	17896.36	12039.49	34044.09	13539.09	27102.22	15476.34	17242.58
Scrubforest grasslands	2405.83	5318.92	1484.98	955.43	2502.32	1071.65	580.51	746.99	615.03	3225.89
Acacia plantation	12590.66	3573.13	5930.26	1156.64	11752.39	1953.88	903.51	1690.49	1758.70	9047.17
Teak Plantation	11039.54	-	1215.12	-	2278.18	134.41	-	94.02	-	1593.29
Coconut arecanut	836.00	392.35	740.61	339.78	586.63	813.70	165.77	1001.31	2319.98	1862.14
Dry deciduous forest	1469.78	-	129.02	-	5.94	-	-	-	-	-
Total	82489.25	61698.51	43593.99	29329.47	43137.15	42860.49	17350.26	37084.74	34693.84	47793.19

Table 3: Percentage cover of LULC of the 10 subbasins

Class	Percentage cover									
	Sb1	**Sb2**	**Sb3**	**Sb4**	**Sb5**	**Sb6**	**Sb7**	**Sb8**	**Sb9**	**Sb10**
Builtup	5.74	0.59	1.09	0.2	0.3	0.19	0.14	0.25	4.58	0.47
Water	2.36	5.4	0.89	**14.62**	7.65	0.1	0.04	**7.25**	4.82	2.05
Agriculture	**47.54**	11.28	7.42	3.2	4.75	3.21	1.08	1.87	**13.93**	5.28
Open land	1.63	5.51	0.57	3.32	0.81	1.13	1.7	1.02	6.15	1.26
Semievergreeen	3.39	**16.56**	**31.18**	9.28	18.88	**6.68**	**9.5**	7.01	12.38	**21.95**
Evergreen	4.98	**45.61**	**37.06**	**61.02**	**27.91**	**79.43**	**78.03**	**73.08**	**44.61**	**36.08**
Scrubforest_grasslands	2.92	8.62	3.41	3.26	5.8	2.5	3.35	2.01	1.77	6.75
Acacia plantation	**15.26**	5.79	13.6	3.94	**27.24**	4.56	5.21	4.56	5.07	18.93
Teak Plantation	13.38	-	2.79	1.16	5.28	0.31	-	0.25	-	3.33
Coconut_arecanut	1.01	0.64	1.7	-	1.36	1.9	0.96	2.7	6.69	3.9
Dry deciduous forest	1.78	-	0.3	-	0.01	-	-	-	-	-
Total	100	100	100	100	100	100	100	100	100	100

Figure 5 shows the forest fragmentation maps of the 10 sub basins in Kali river. The statistics are given in Table 3 and 4 (in ha and percentages). Subbasin1 has edge forest as the most dominating class (34.36%) while in all other sub basins the interior forest is the most dominating class. Sub basin 6, 7 and 8 consists of more than 80% of interior forest.

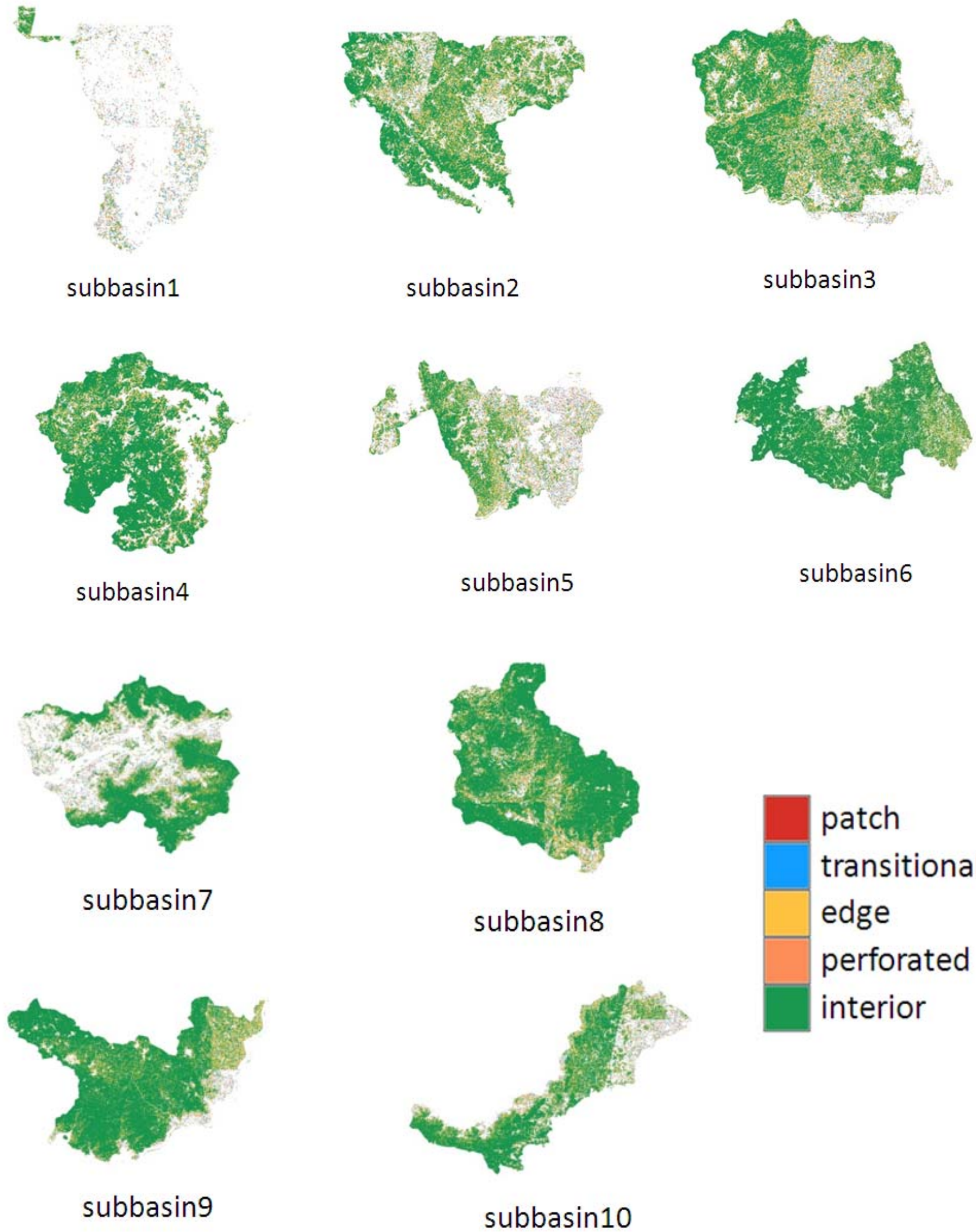


Figure 5: **Forest Fragmentation of the 10 kali subbasins.**

Table 3: Forest Fragmentation in hectares of the Kali subbasins

Class	Area in hectares									
	Sb1	**Sb2**	**Sb3**	**Sb4**	**Sb5**	**Sb6**	**Sb7**	**Sb8**	**Sb9**	**Sb10**
Patch	1810.8	456.43	570.3	140	1301.5	218.3	63.3	199.1	565.8	784.0
Transitional	2559.8	1983.6	1956.6	570.4	2556.8	817	313.5	617.1	1433.4	1723.8
Edge	3654.2	12672	9420.3	3784.3	8069.2	6244	2534.9	4990	4306.8	8550.6
Perforated	335.3	594.19	464	162.3	511.7	241	89.9	159	223.8	373.8
Interior	2275.4	27821	18844	16814.3	10374.3	30427	12726.5	24451.7	13937.4	23094.0
Total	10636	43528	31255	21471.4	22813.4	37946	15728.2	30416.4	20467.1	34526.2

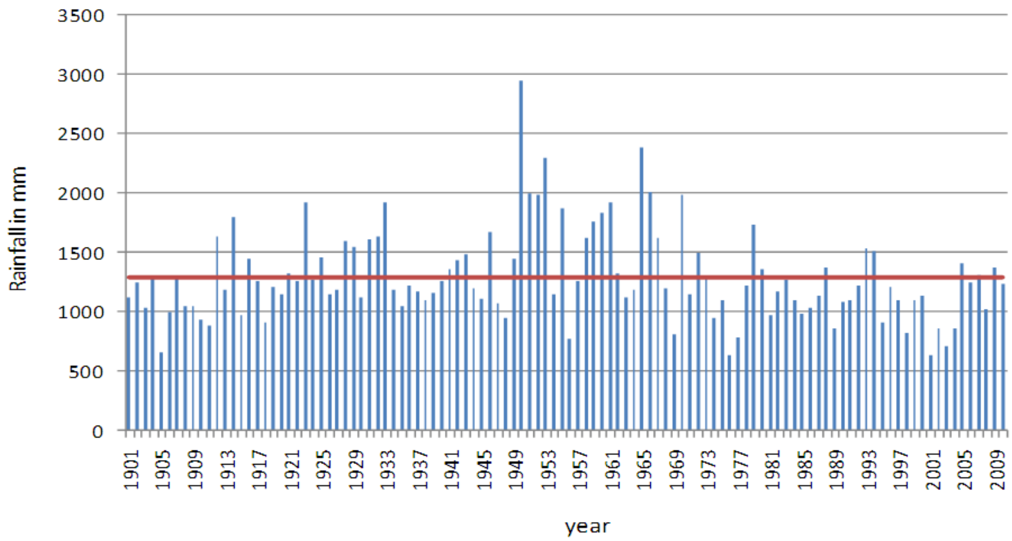
Table 4: Forest Fragmentation in percentage of Kali subbasins

Class	Percentage cover									
	Sb1	**Sb2**	**Sb3**	**Sb4**	**Sb5**	**Sb6**	**Sb7**	**Sb8**	**Sb9**	**Sb10**
Patch	17.03	1.05	1.82	0.65	5.7	0.58	0.4	0.65	2.76	2.27
Transitional	24.07	4.56	6.26	2.66	11.21	2.15	2.11	2.03	7	4.99
Edge	**34.36**	29.11	30.14	17.62	35.37	16.45	16.02	16.41	21.04	24.77
Perforated	3.15	1.37	1.48	0.76	2.24	0.63	0.57	0.52	1.09	1.08
Interior	21.39	**63.92**	**60.29**	**78.31**	**45.47**	**80.18**	**80.87**	**80.39**	**68.1**	**66.89**
Total	100	100	100	100	100	100	100	100	100	100

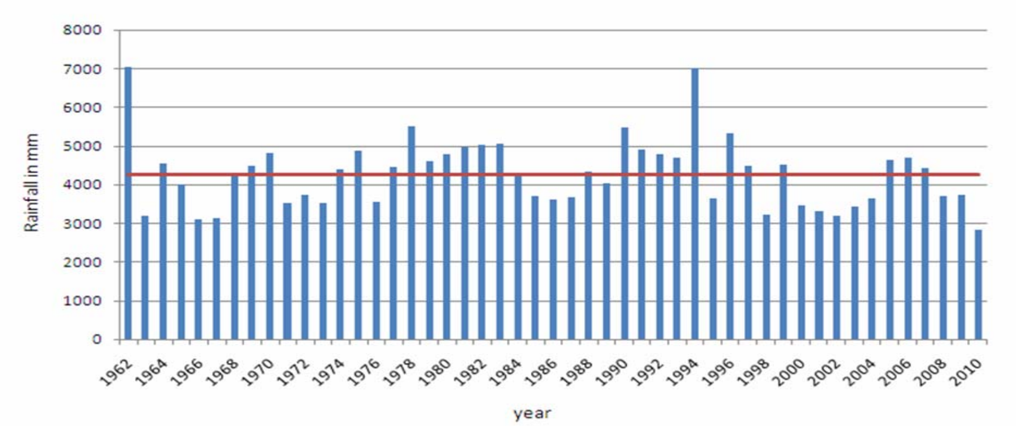
5. RAINFALL DATA ANALYSIS

Kali river basin is divided further into 9 sub basins and annual rainfall was analysed for each of them. Figure 6 shows 100 years rainfall pattern for the 9 sub basins and Figure 7 shows rainfall in Kali River basin for the year 2010.

Rainfall data of 1950 and 1953 showed maximum rainfall and the year 1965 and 1966 showed above average rainfall in subbasin1 (6a). In subbasin2, 1962 and 1994 received the highest rainfall and the rainfall was above the average rainfall in the year 1978, 1990, 1996 (6b). The years such as 1970, 1978, 1986, 1993, 1994, 2009, 2010 received more than average annual rainfall in subbasin3 (6c). In subbasin4, the rainfall in the year 1970, 1972, 1978, 1980, and 2009 etc were higher than the annual average rainfall (6d). More than average rainfall was experienced in the year 1970, 1981,1988, 1989, 1990, 1991, 1992, 1994 and 1999 etc. in subbasin5 (6e). In the year 1974, 1975, 1978, 1983, 1984, 1985, 1994, 2005, 2009 etc. there were more than average rainfall in the subbasin6 (6f).


3500
3000
2500
2000
1500
1000
500
0
Rainfall in mm
1901
1905
1909
1913
1917
1921
1925
1929
1933
1937
1941
1945
1949
1953
1957
1961
1965
1969
1973
1977
1981
1985
1989
1993
1997
2001
2005
2009
year

(a)


8000
7000
6000
5000
4000
3000
2000
1000
0
Rainfall in mm
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
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1988
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1998
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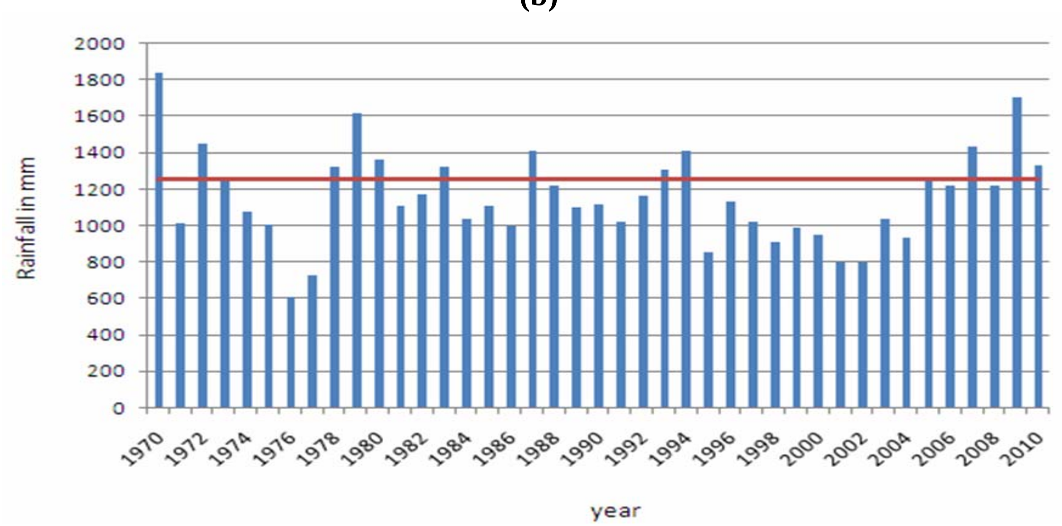
2002
2004
2006
2008
2010
year

(b)


2000
1800
1600
1400
1200
1000
800
600
400
200
0
Rainfall in mm
1970
1972
1974
1976
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1984
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1992
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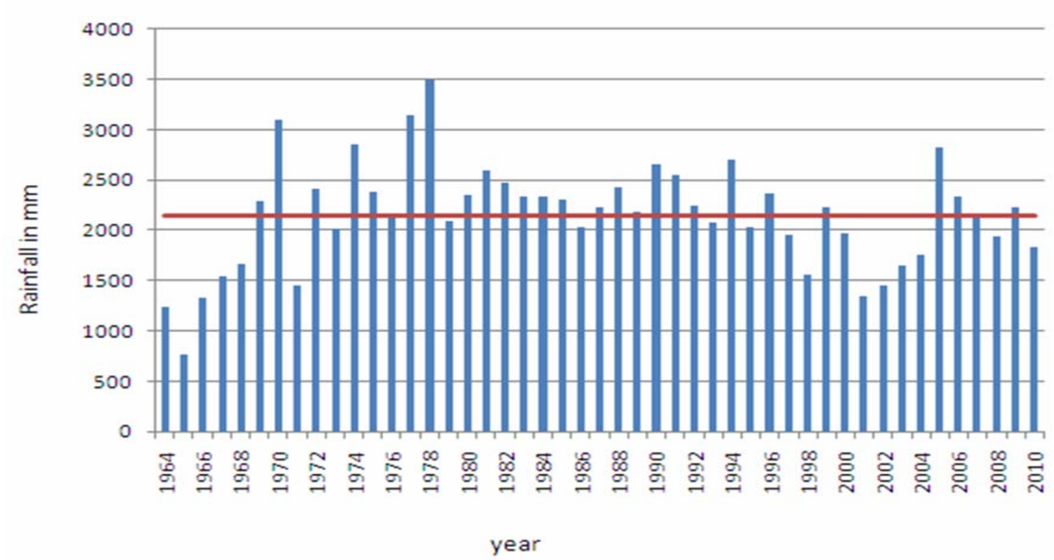
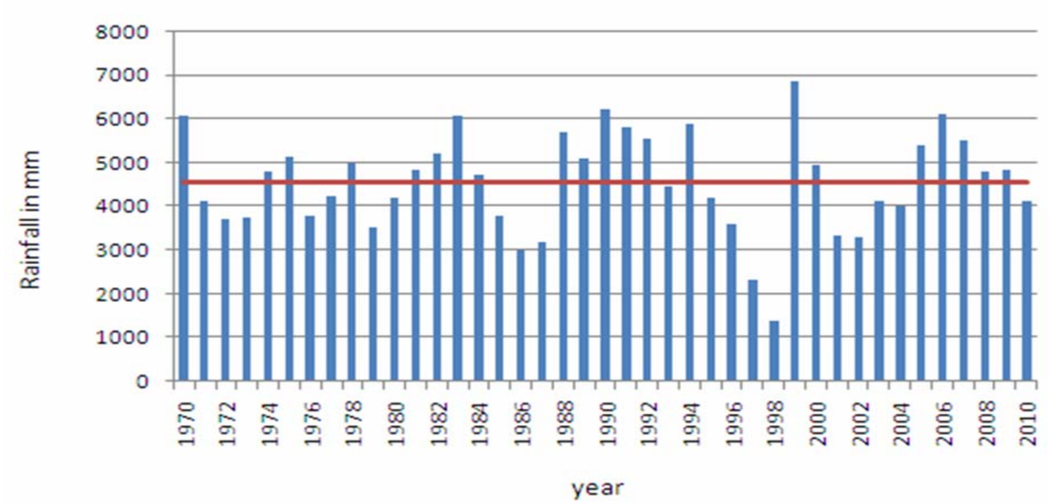
2010
year

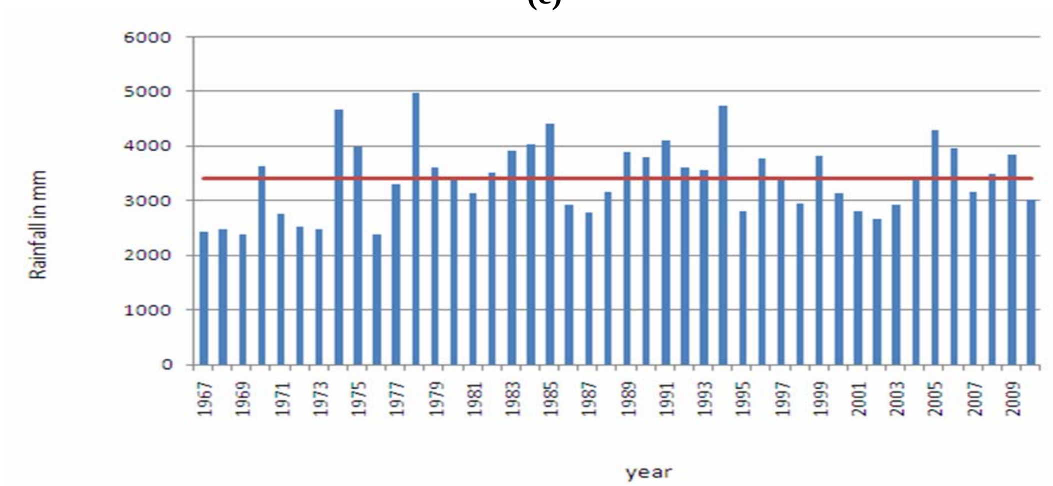
(c)



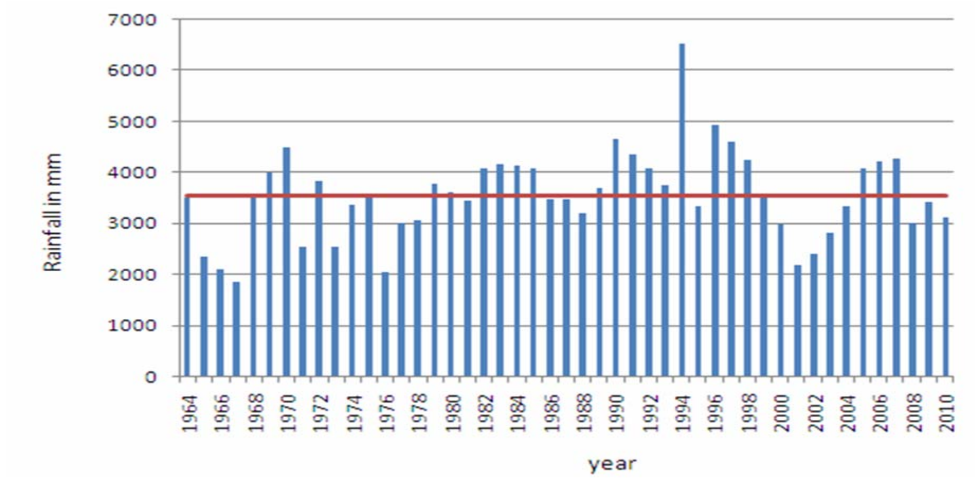
(d)



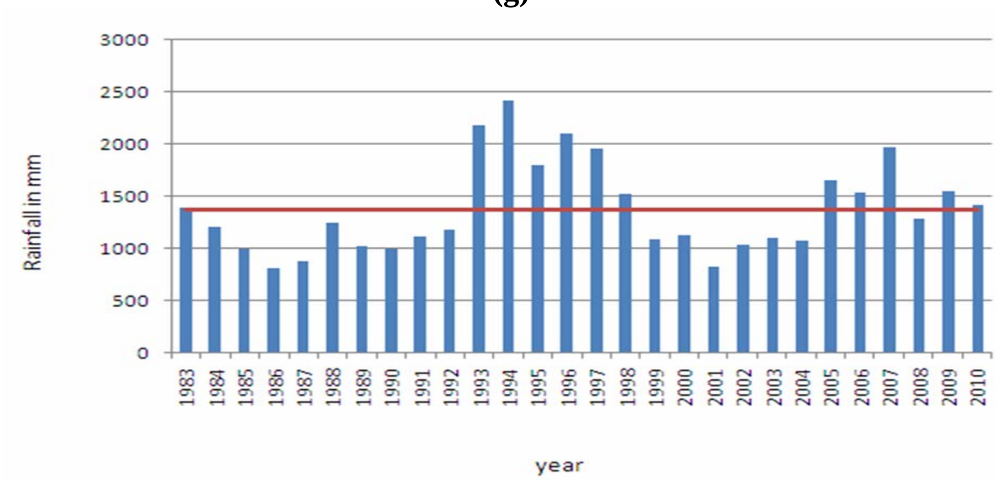
(e)



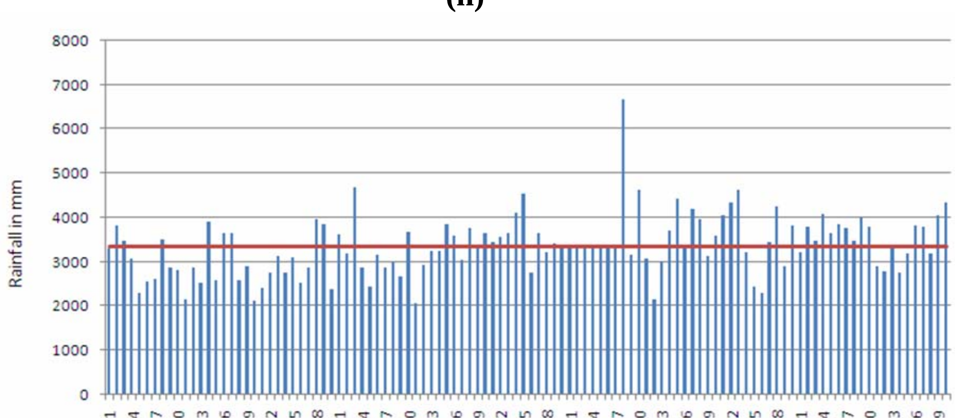
(f)



(g)



(h)



(i)

(a) subbasin1, (b) subbasin 2, (c) subbasin 3 ,(d) subbasin 4, (e) subbasin5,(f) subbasin6,(g) subbasin7, (h) subbasin8, (i) subbasin9

Figure 6: 100 year of rainfall in the Kali subbasins.

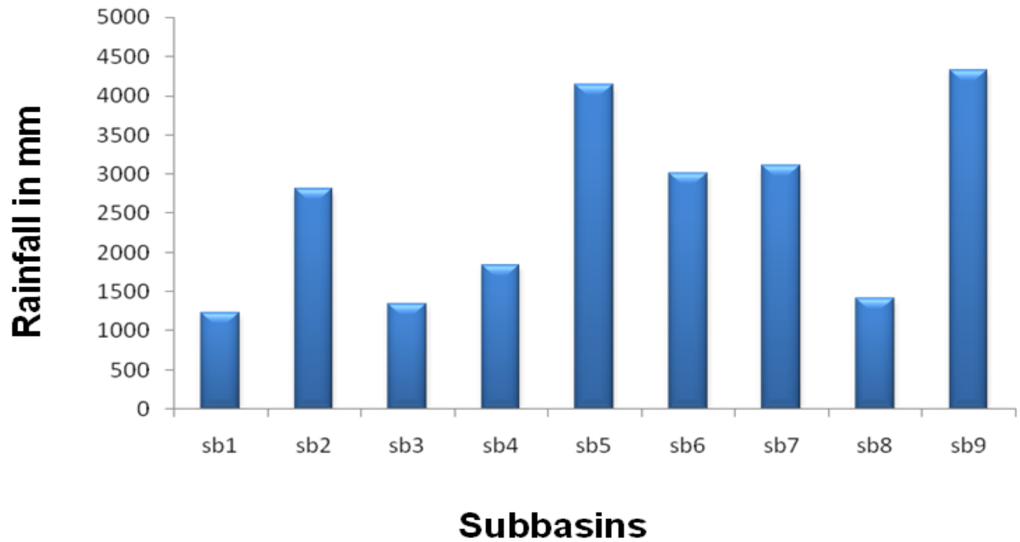


Figure 7: Rainfall in Kali River basin for the year 2010.

Year 1993 has the highest rainfall as the shown by the peak in the graph in subbasin7 (6g). 1971, 1972, 1981, 1982, 1983, 1984 and 1985 had above average rainfall in subbasin7 (6g). In subbasin8, the rainfall is above average in the year 1993, 1994, 1995, 1996, 1997, 2005, 2007 etc (6h). In the hundred year rainfall history of Kali sub basin 9, the year 1968 showed maximum rainfall and year 1933, 1940, 1954, 1955, 1970, 1973, 1974 etc. showed above average rainfall (7i). In the year 2010, sub basin 9 received the maximum rainfall while subbasin1 received minimum among the nine sub basins (Fig 7). Among all the Kali sub basins sb1, sb3, sb4, sb8 received minimum rainfall while sb2, sb5, sb6, sb7 and sb8 received maximum rainfall in the year 2010.

STATISTICAL ANALYSIS (MULTIPLE REGRESSION)

Multiple regression was carried out taking the surface runoff values as a function of classified LU categories, fragmentation results along with the annual rainfall for each subbasins. The regression (correlation) coefficient was (*r*) was 0.901325716 (p=0.05), showing a strong positive relationship between surface runoff and various factors like rainfall, built-up, perforated and interior forest.

CONCLUSION

The above study was carried out to understand the linkages between LULC, forest fragmentation, rainfall and stream flow (seasonal and perennial). LU analysis revealed major presence of evergreen forests in sub basins 2, 3, 4, 5, 9 and 10 while semi-evergreen is dominating in sub basin 2, 6, 7 and 10. Major agricultural land was found in subbasin1 and 2 (47.54% and 13.93%). Sub basin 4 and 8 had 14.62 and 7.25% of area under water, which is highest among all the sub basins. Subbasin1 had edge forest as the most dominating class (34.36%) while in all other sub basins the interior forest was the most dominating class. A positive relationship between surface runoff and various factors like rainfall, built-up, perforated forest was noticed. Also, infiltration and factors like rainfall, patch forest, perforated forest and the number of streams were positively correlated.

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