RUNOFF ESTIMATION OF KCAET CAMPUS BY CURVE NUMBER METHOD ADOPTING REMOTE SENSING AND GIS TECHNIQUES

By

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ABSTRACT OF THESIS

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ABSTRACT

This study mainly focused to estimate the runoff of KCAET Campus using the curve number method. The study was carried out in GIS environment using remote sensing data. Also the curve number method was validated for selected storm events in the study area. The analysis was done for the year 2004 to 2007, 2018 and 2019 upto June. The land use map was digitized from Google earth of year 2006 and 2018. ArcGIS 10.2 was used for the analysis. About 28.5% of the total area belongs to high runoff potential class, 33.7% have medium runoff potential and 37.7% of the area has low runoff potential.

The runoff percentage from the annual rainfall varied from 16% to 23% for the study period. The runoff percentage in 2007 and 2018 were almost similar but the rainfall depths of both years were 3971.8 mm and 2919.8 mm respectively. The rainfall amount in the study area is showing a decreasing trend and runoff is showing increasing trend. Seasonal analysis showed that maximum rainfall depth was observed in south west monsoon and thereby runoff yield. The runoff percentage was lower in the pre monsoon season as the major part of the rainfall will infiltrates into the soil. Also the runoff depth was highly influenced by antecedent moisture condition and potential maximum retention capacity. The curve number values for normal conditions were 57.77 and 58.95 for the year 2006 and 2018 respectively. The curve number value tends to increase as antecedent moisture condition increases. The simulated runoff was compared with observed runoff for selected storm events in the study area. The correlation coefficient was found to be 0.928. The integration of remote sensing and GIS along with NRCS curve number method was found to be a powerful tool in estimating runoff.

APPENDIX I

Comparison of Observed and Simulated runoff from the study area

Event Date	Rainfall (mm)	Head (mm)	Duration (s)	Observed runoff (mm)	Simulated runoff (mm)
25-10-18	14	15	2000	0.8331	0.7783
05-06-19	10.2	12	900	0.2623	0.1140
05-06-19	12.3	20	1500	0.4589	0.4150
09-06-19	4.2	7	270	0.0532	0.0000
09-06-19	12	15	1080	0.5653	0.3615
10-06-19	12.8	14	1200	0.7741	0.5113
11-06-19	5.6	9	630	0.1638	0.1521
11-06-19	10	10	870	0.2536	0.0947
11-06-19	12.6	20	1660	0.5079	0.4717
12-06-19	4.8	8	300	0.0683	0.0000
12-06-19	13.8	16	1500	1.0616	0.7304
13-06-19	4.2	8	275	0.0802	0.0000
14-06-19	3.2	5	240	0.0325	0.0000
15-06-19	4.4	7	280	0.0551	0.0000
18-06-19	12.4	13	1020	0.7219	0.4335
19-06-19	12.6	15	1080	0.5653	0.4717
03-07-19	13	16	1230	0.7164	0.5524

APPENDIX II

Weight retained in each seive

Point	Latitude	Longitude	Weight retained (g)			Soil texture
			2mm	0.02mm	0.002mm	
P1	N 10°51′17″	E 75°59′10″	79.2	378.8	42	Silt loam
P2	N 10°51′17″	E 75°59′14″	104.6	389.8	5.6	Silt loam
P3	N 10°51′18″	E 75°59′13″	266.6	221.4	12	Sandy loam
P4	N 10°51′19″	E 75°59′17″	33.4	419.4	47.2	Silt
P5	N 10°51′23″	E 75°59′19″	314.2	166	19.8	Sandy loam
P6	N 10°51′08″	E 75°59′12″	171.6	317.2	11.2	Silt loam
P7	N 10°51′07″	E 75°59′11″	158.8	325.6	15.6	Silt loam
P8	N 10°51′07″	E 75°59′09″	108.8	356.2	35	Silt loam
P9	N 10°51′07″	E 75°59′08″	315.8	173.6	10.6	Sandy loam
P10	N 10°51′08″	E 75°59′05″	292.6	194.4	13	Sandy loam
P11	N 10°51′12″	E 75°59′05″	232	258.6	9.4	Silt loam
P12	N 10°51′08″	E 75°59′16″	242.6	233.4	24	Sandy loam
P13	N 10°51′09″	E 75°59′18″	210.2	275.6	14.2	Silt loam
P14	N 10°51′12″	E 75°59′21″	78	395	27	Silt loam
P15	N 10°51′17″	E 75°59′22″	40.4	420	39.6	Silt
P16	N 10°51′14″	E 75°59′16″	35.2	452.6	12.2	Silt
P17	N 10°51′22″	E 75°59′14″	18.8	431.8	49.4	Silt
P18	N 10°51′26″	E 75°59′17″	46.6	395	58.4	Silt loam
P19	N 10°51′22″	E 75°59′07″	74.4	409.2	16.4	Slit
P20	N 10°51′18″	E 75°59′08″	155.2	287.4	57.4	Silt loam

APPENDIX III

CN Values for different AMC conditions

CN I	CN II	CN III
0	0	0
15.81	30	50.09
17.76	33	53.56
19.09	35	55.77
21.89	39	59.96
23.35	41	61.94
27.99	47	67.50
35.80	56	74.88
44.86	65	81.31
47.07	67	82.62
52.96	72	85.76
54.21	73	86.36
59.44	77	88.69
62.21	79	89.81
66.59	82	91.43
71.25	85	92.99

Sample Calculation:

To calculate CN_I value, consider CN_{II} =30

According to the equation,

$$CN_I = \frac{CN_{II}}{(2.281-0.01281\ CN_{II})}$$

$$= \frac{30}{(2.281- \ .01281*30)}$$

$$=15.81$$

To calculate CN_{III} value, Consider CN_{II} =30

According to the equation,

$$CN_{III} = \frac{23\ CN_{II}}{(10+0.13\ CN_{II})}$$

$$= \frac{30}{(10+0.13*30)}$$

$$=50.09$$

APPENDIX IV

Direct runoff of the year 2004

Date	Rainfall	5 day cumulative rainfall	AMC Condition	CN	S	Q (mm)
28-03-04	2	2.9	I	37.47	423.87	0
24-03-04	0.9	0.9	I	37.47	423.87	0
01-04-04	7	9	I	37.47	423.87	0
04-04-04	10.8	17.8	II	57.77	185.67	0
06-04-04	34	44.8	III	75.92	80.56	0
10-04-04	0.6	34.6	III	75.92	80.56	0
15-04-04	0.8	0.8	I	37.47	423.87	0
19-04-04	8.5	9.3	I	37.47	423.87	0
21-04-04	4.5	13	II	57.77	185.67	0
23-04-04	14.2	18.7	II	57.77	185.67	0
26-04-04	24	38.2	III	75.92	80.56	0.703356944
27-04-04	18.2	56.4	III	75.92	80.56	0.052722117
29-04-04	26	68.2	III	75.92	80.56	1.080836971
30-04-04	1.5	69.7	III	75.92	80.56	0
01-05-04	0.65	46.35	III	75.92	80.56	0
03-05-04	54	82.15	III	75.92	80.56	12.11868085
04-05-04	46.6	102.75	III	75.92	80.56	8.369958792
05-05-04	50.5	151.75	III	75.92	80.56	10.28704491
06-05-04	170	321.1	III	75.92	80.56	101.0080381
07-05-04	80.5	401.6	III	75.92	80.56	28.60117659
08-05-04	16.9	364.5	III	75.92	80.56	0.00762253
10-05-04	6.5	273.9	III	75.92	80.56	0
15-05-04	10.6	10.6	II	57.77	185.67	0
16-05-04	18.18	28.78	III	75.92	80.56	0.051729211
17-05-04	42.6	71.38	III	75.92	80.56	6.553802214
18-05-04	64	135.38	III	75.92	80.56	17.85290813
19-05-04	19.3	154.68	III	75.92	80.56	0.121312062
20-05-04	21	165.08	III	75.92	80.56	0.279546235
21-05-04	24.5	171.4	III	75.92	80.56	0.79088666
22-05-04	29.6	158.4	III	75.92	80.56	1.934197603
23-05-04	54.8	149.2	III	75.92	80.56	12.55109111
24-05-04	34	163.9	III	75.92	80.56	3.24998201
25-05-04	8.2	151.1	III	75.92	80.56	0
28-05-04	3.2	45.4	III	75.92	80.56	0
29-05-04	6.6	18	II	57.77	185.67	0
30-05-04	0.45	10.25	I	37.47	423.87	0
31-05-04	4.6	14.85	II	57.77	185.67	0
6-2-04	4.6	16.25	I	37.47	423.87	0

6-3-04	17.8	27.45	I	37.47	423.87	0
6-4-04	115.8	142.8	III	75.92	80.56	55.13221117
6-5-04	61.4	199.6	III	75.92	80.56	16.29679381
6-6-04	21	220.6	III	75.92	80.56	0.279546235
6-7-04	66.5	282.5	III	75.92	80.56	19.38826353
6-8-04	19.2	283.9	III	75.92	80.56	0.113955699
6-9-04	35	203.1	III	75.92	80.56	3.587084933
6-10-04	36	177.7	III	75.92	80.56	3.937386383
6-11-04	31	187.7	III	75.92	80.56	2.322012705
6-12-04	21	142.2	III	75.92	80.56	0.279546235
6-13-04	1.2	124.2	III	75.92	80.56	0
6-14-04	9.4	98.6	III	75.92	80.56	0
6-15-04	43.5	106.1	III	75.92	80.56	6.948326943
6-16-04	22.4	97.5	III	75.92	80.56	0.455176596
6-17-04	16.7	93.2	III	75.92	80.56	0.004252731
6-18-04	1	93	III	75.92	80.56	0
6-19-04	1.2	84.8	III	75.92	80.56	0
6-23-04	7	8.2	I	37.47	423.87	0
6-24-04	5.2	12.2	I	37.47	423.87	0
6-25-04	1.4	13.6	I	37.47	423.87	0
6-26-04	1.6	15.2	I	37.47	423.87	0
6-27-04	115.6	130.8	III	75.92	80.56	54.9722083
6-28-04	12.5	136.3	III	75.92	80.56	0
6-29-04	57.6	188.7	III	75.92	80.56	14.10247561
6-30-04	3.8	191.1	III	75.92	80.56	0
7-1-04	13	202.5	III	75.92	80.56	0
7-2-04	11.5	98.4	III	75.92	80.56	0
7-3-04	11.5	97.4	III	75.92	80.56	0
7-4-04	5.6	45.4	II	57.77	185.67	0
7-7-04	5.8	22.9	I	37.47	423.87	0
7-8-04	3.6	15	I	37.47	423.87	0
7-9-04	0.6	10	I	37.47	423.87	0
7-12-04	7.2	11.4	I	37.47	423.87	0
7-13-04	2.8	10.6	I	37.47	423.87	0
7-14-04	17.1	27.1	I	37.47	423.87	0
7-15-04	57	84.1	III	75.92	80.56	13.76518937
7-16-04	4.8	88.9	III	75.92	80.56	0
7-17-04	4.3	86	III	75.92	80.56	0
7-18-04	2	85.2	III	75.92	80.56	0
7-19-04	7.4	75.5	III	75.92	80.56	0
7-20-04	4.8	23.3	I	37.47	423.87	0
7-22-04	23.1	37.3	II	57.77	185.67	0

7-23-04	9.6	44.9	II	57.77	185.67	0
7-24-04	5	42.5	II	57.77	185.67	0
7-25-04	13.6	51.3	II	57.77	185.67	0
7-26-04	6.2	57.5	III	75.92	80.56	0
7-27-04	5.2	39.6	II	57.77	185.67	0
7-28-04	11.4	41.4	II	57.77	185.67	0
7-29-04	34.8	71.2	III	75.92	80.56	3.5185957
7-30-04	1	58.6	III	75.92	80.56	0
8-1-04	6.4	53.6	III	75.92	80.56	0
8-2-04	13.4	55.6	III	75.92	80.56	0
8-3-04	13.2	34	I	37.47	423.87	0
8-4-04	60.4	93.4	III	75.92	80.56	15.70986522
8-5-04	43.2	136.6	III	75.92	80.56	6.815879593
8-6-04	45	175.2	III	75.92	80.56	7.624341417
8-7-04	11.2	173	III	75.92	80.56	0
8-8-04	4.4	164.2	III	75.92	80.56	0
8-9-04	1.6	105.4	III	75.92	80.56	0
8-11-04	18.3	35.5	I	37.47	423.87	0
8-12-04	3.9	28.2	I	37.47	423.87	0
8-13-04	26.4	50.2	II	57.77	185.67	0
8-14-04	30.5	79.1	III	75.92	80.56	0
8-15-04	14.1	93.2	III	75.92	80.56	0
8-16-04	2.7	77.6	III	75.92	80.56	0
8-17-04	6.9	80.6	III	75.92	80.56	0
8-18-04	2	56.2	III	75.92	80.56	0
8-19-04	4.6	30.3	I	37.47	423.87	0
8-20-04	0.4	16.6	I	37.47	423.87	0
8-21-04	0.4	14.3	I	37.47	423.87	0
8-22-04	3.6	11	I	37.47	423.87	0
8-23-04	2.5	11.5	I	37.47	423.87	0
8-26-04	0.2	6.3	I	37.47	423.87	0
9-5-04	1.3	1.3	I	37.47	423.87	0
9-6-04	0.8	2.1	I	37.47	423.87	0
9-7-04	1.8	3.9	I	37.47	423.87	0
9-8-04	2.3	6.2	I	37.47	423.87	0
9-10-04	19	23.9	I	37.47	423.87	0
9-14-04	5.2	24.2	I	37.47	423.87	0
9-16-04	0.8	6	I	37.47	423.87	0
9-17-04	29.2	35.2	I	37.47	423.87	0
9-18-04	39.2	74.4	III	75.92	80.56	5.142595454
9-19-04	0.3	69.5	III	75.92	80.56	0
9-24-04	4	4	I	37.47	423.87	0

9-25-04	15	19	I	37.47	423.87	0
9-27-04	33.1	52.1	II	57.77	185.67	0
9-28-04	3	55.1	III	75.92	80.56	0
10-1-04	1	37.1	II	57.77	185.67	0
10-2-04	104	108	III	75.92	80.56	45.85454712
10-3-04	110	215	III	75.92	80.56	50.52936228
10-4-04	23.5	238.5	III	75.92	80.56	0.620517048
10-5-04	0.2	238.7	III	75.92	80.56	0
11-1-04	3.6	241.3	III	75.92	80.56	0
11-9-04	3.3	3.3	I	37.47	423.87	0
11-10-04	38.2	41.5	II	57.77	185.67	0.006074808
11-12-04	4.2	45.7	II	57.77	185.67	0
11-15-04	1.2	5.4	I	37.47	423.87	0

Direct runoff of the year 2005

Date	Rainfall	5 day cumulative rainfall	AMC Condition	CN	S	Q (mm)
03-04-05	32	32	III	75.92	80.56	2.617013862
04-04-05	1	33	I	37.47	423.87	0
06-04-05	37.6	70.6	III	75.92	80.56	4.524353189
07-04-05	1	71.6	III	75.92	80.56	0
08-04-05	1	40.6	III	75.92	80.56	0
12-04-05	0.4	1.4	I	37.47	423.87	0
15-04-05	32	32.4	III	75.92	80.56	2.617013862
20-04-05	7.3	7.3	I	37.47	423.87	0
21-04-05	3.4	10.7	I	37.47	423.87	0
23-04-05	4.1	14.8	II	57.77	185.67	0
26-04-05	1.3	5.4	I	37.47	423.87	0
10-05-05	3.1	3.1	I	37.47	423.87	0
11-05-05	0.3	3.4	I	37.47	423.87	0
12-05-05	0.3	3.7	I	37.47	423.87	0
13-05-05	0.2	3.9	I	37.47	423.87	0
22-05-05	0.3	0.3	I	37.47	423.87	0
23-05-05	3.2	3.5	I	37.47	423.87	0
26-05-05	54.3	57.8	III	75.92	80.56	12.28025429
27-05-05	3.1	60.6	III	75.92	80.56	0
28-05-05	0.2	57.6	III	75.92	80.56	0
29-05-05	51	108.6	III	75.92	80.56	10.54251393
30-05-05	2.9	111.5	III	75.92	80.56	0
31-05-05	32	89.2	III	75.92	80.56	2.617013862
01-06-05	4.5	90.6	III	75.92	80.56	0
04-06-05	2	38.5	II	57.77	185.67	0
05-06-05	38.8	45.3	II	57.77	185.67	0.014799378
07-06-05	5.3	46.1	II	57.77	185.67	0

08-06-05	10.2	56.3	III	75.92	80.56	0
09-06-05	28.3	82.6	III	75.92	80.56	1.601444096
10-06-05	8.2	52	II	57.77	185.67	0
11-06-05	0.3	52.3	II	57.77	185.67	0
12-06-05	29	76	III	75.92	80.56	1.777275086
13-06-05	4	69.8	III	75.92	80.56	0
15-06-05	31	64.3	III	75.92	80.56	2.322012705
16-06-05	107.1	171.1	III	75.92	80.56	48.25829401
17-06-05	45	187.1	III	75.92	80.56	7.624341417
18-06-05	44.8	227.9	III	75.92	80.56	7.532898841
19-06-05	56	283.9	III	75.92	80.56	13.2088619
20-06-05	50.8	303.7	III	75.92	80.56	10.44007171
21-06-05	29	225.6	III	75.92	80.56	1.777275086
22-06-05	17	197.6	III	75.92	80.56	0.009669547
23-06-05	0.2	153	III	75.92	80.56	0
24-06-05	8	105	III	75.92	80.56	0
25-06-05	29	83.2	III	75.92	80.56	1.777275086
26-06-05	2.9	57.1	III	75.92	80.56	0
27-06-05	6.8	46.9	II	57.77	185.67	0
28-06-05	22	68.7	III	75.92	80.56	0.400950001
29-06-05	7.2	67.9	III	75.92	80.56	0
30-06-05	61.1	100	III	75.92	80.56	16.12002432
01-07-05	42.8	139.9	III	75.92	80.56	6.640741235
02-07-05	46.2	179.3	III	75.92	80.56	8.181238005
03-07-05	23	180.3	III	75.92	80.56	0.542447412
04-07-05	64.1	237.2	III	75.92	80.56	17.91360196
05-07-05	33.3	209.4	III	75.92	80.56	3.022080002
06-07-05	5	171.6	III	75.92	80.56	0
07-07-05	1	126.4	III	75.92	80.56	0
08-07-05	107	210.4	III	75.92	80.56	48.18036079
09-07-05	66	212.3	III	75.92	80.56	19.07823456
10-07-05	16.1	195.1	III	75.92	80.56	0
11-07-05	5.8	195.9	III	75.92	80.56	0
12-07-05	3	197.9	III	75.92	80.56	0
13-07-05	2.8	93.7	III	75.92	80.56	0
14-07-05	3	30.7	I	37.47	423.87	0
16-07-05	13.1	21.9	I	37.47	423.87	0
17-07-05	28.8	47.7	II	57.77	185.67	0
18-07-05	10.5	55.4	III	75.92	80.56	0
19-07-05	9.2	61.6	III	75.92	80.56	0
20-07-05	9.8	71.4	III	75.92	80.56	0
21-07-05	1.6	59.9	III	75.92	80.56	0

22-07-05	10	41.1	II	57.77	185.67	0
23-07-05	6.7	37.3	II	57.77	185.67	0
24-07-05	22.8	50.9	II	57.77	185.67	0
25-07-05	3.6	44.7	II	57.77	185.67	0
26-07-05	10.8	53.9	III	75.92	80.56	0
27-07-05	17.8	61.7	III	75.92	80.56	0.034620273
28-07-05	41	96	III	75.92	80.56	5.87372936
29-07-05	27	100.2	III	75.92	80.56	1.296190169
30-07-05	70	166.6	III	75.92	80.56	21.59802889
31-07-05	24.1	179.9	III	75.92	80.56	0.720490244
01-08-05	47	209.1	III	75.92	80.56	8.560196161
02-08-05	36.4	204.5	III	75.92	80.56	4.081114604
03-08-05	9	186.5	III	75.92	80.56	0
04-08-05	5	121.5	III	75.92	80.56	0
05-08-05	6.2	103.6	III	75.92	80.56	0
08-08-05	10.2	21.4	I	37.47	423.87	0
09-08-05	5.2	21.6	I	37.47	423.87	0
10-08-05	7	22.4	I	37.47	423.87	0
11-08-05	2	24.4	I	37.47	423.87	0
13-08-05	32	46.2	II	57.77	185.67	0
14-08-05	19.8	60.8	III	75.92	80.56	0.161392752
15-08-05	55	108.8	III	75.92	80.56	12.65996301
16-08-05	22.8	129.6	III	75.92	80.56	0.512573601
17-08-05	0.8	130.4	III	75.92	80.56	0
18-08-05	11.8	110.2	III	75.92	80.56	0
24-08-05	2.4	2.4	I	37.47	423.87	0
31-08-05	13.8	13.8	I	37.47	423.87	0
03-09-05	23.2	37	II	57.77	185.67	0
04-09-05	42.1	79.1	III	75.92	80.56	6.338311596
05-09-05	7.2	72.5	III	75.92	80.56	0
06-09-05	45.6	118.1	III	75.92	80.56	7.901036592
07-09-05	87.6	205.7	III	75.92	80.56	33.61033669
08-09-05	26.4	208.9	III	75.92	80.56	1.164905439
09-09-05	16.2	183	III	75.92	80.56	0
10-09-05	138.2	314	III	75.92	80.56	73.55211637
11-09-05	40	308.4	III	75.92	80.56	5.462995739
12-09-05	6	226.8	III	75.92	80.56	0
13-09-05	7.4	207.8	III	75.92	80.56	0
14-09-05	12	203.6	III	75.92	80.56	0
18-09-05	25.4	37.4	II	57.77	185.67	0
19-09-05	9.4	34.8	II	57.77	185.67	0
20-09-05	33.9	68.7	III	75.92	80.56	3.217013137

21-09-05	0.8	69.5	III	75.92	80.56	0
05-10-05	13	13	I	37.47	423.87	0
06-10-05	0.6	13.6	I	37.47	423.87	0
07-10-05	0	13.6	I	37.47	423.87	0
08-10-05	0	13.6	I	37.47	423.87	0
09-10-05	22	35.6	I	37.47	423.87	0
10-10-05	49.2	71.8	III	75.92	80.56	9.632895018
11-10-05	2.9	74.1	III	75.92	80.56	0
12-10-05	50.25	124.35	III	75.92	80.56	10.16010987
13-10-05	3.75	128.1	III	75.92	80.56	0
14-10-05	8.1	114.2	III	75.92	80.56	0
15-10-05	1.2	66.2	III	75.92	80.56	0
19-10-05	1.7	2.9	I	37.47	423.87	0
20-10-05	4.4	6.1	I	37.47	423.87	0
22-10-05	18.9	25	I	37.47	423.87	0
23-10-05	9	34	I	37.47	423.87	0
24-10-05	1.4	33.7	I	37.47	423.87	0
25-10-05	3.1	32.4	I	37.47	423.87	0
26-10-05	0.6	33	I	37.47	423.87	0
28-10-05	10.2	15.3	I	37.47	423.87	0
29-10-05	5.6	19.5	I	37.47	423.87	0
31-10-05	4	19.8	I	37.47	423.87	0
01-11-05	31.0	50.8	II	57.77	185.67	0
02-11-05	0.5	41.1	II	57.77	185.67	0
03-11-05	18.2	53.7	III	75.92	80.56	0
05-11-05	2.6	52.3	II	57.77	185.67	0
06-11-05	17.2	38.5	II	57.77	185.67	0
07-11-05	58.0	96	III	75.92	80.56	14.32876342
10-11-05	1.0	76.2	III	75.92	80.56	0
13-11-05	9.5	10.5	I	37.47	423.87	0
04-12-05	17	26.5	I	37.47	423.87	0

Direct runoff of the year 2006

Date	Rainfall (mm)	5 day cumulative rainfall	AMC Condition	CN	S	Q (mm)
17-04-06	20	20	II	57.77	185.67	0
05-05-06	15.4	15.4	II	57.77	185.67	0
08-05-06	14.6	30	III	75.92	80.56	0
17-05-06	22.2	22.2	II	57.77	185.67	1.30638464
18-05-06	0.4	22.6	II	57.77	185.67	0
19-05-06	16.8	39.4	III	75.92	80.56	0.005816628
22-05-06	2.9	20.1	III	75.92	80.56	0
24-05-06	60	62.9	III	75.92	80.56	15.47695252
25-05-06	20	82.9	III	75.92	80.56	0.17894992

26-05-06	28	110.9	III	75.92	80.56	1.528517849
27-05-06	53.8	161.8	III	75.92	80.56	12.01135543
28-05-06	122.8	284.6	III	75.92	80.56	60.78613948
29-05-06	94.2	318.8	III	75.92	80.56	38.43457554
30-05-06	81	379.8	III	75.92	80.56	28.94725303
31-05-06	47	398.8	III	75.92	80.56	8.560196161
01-06-06	118.2	463.2	III	75.92	80.56	57.05907785
02-06-06	10.2	350.6	III	75.92	80.56	0
03-06-06	1.2	257.6	III	75.92	80.56	0
04-06-06	9.6	186.2	III	75.92	80.56	0
05-06-06	33	172.2	III	75.92	80.56	2.926483931
06-06-06	16	70	III	75.92	80.56	0
07-06-06	4.4	64.2	III	75.92	80.56	0
08-06-06	2.1	65.1	III	75.92	80.56	0
09-06-06	1.3	56.8	III	75.92	80.56	0
14-06-06	2.6	2.6	I	37.47	423.87	0
15-06-06	1.6	4.2	I	37.47	423.87	0
16-06-06	3.6	7.8	I	37.47	423.87	0
21-06-06	115.8	115.8	III	75.92	80.56	55.13221117
22-06-06	5.4	121.2	III	75.92	80.56	0
23-06-06	96.4	217.6	III	75.92	80.56	40.07503871
24-06-06	139.6	357.2	III	75.92	80.56	74.73237483
25-06-06	106.6	463.8	III	75.92	80.56	47.86888593
26-06-06	22	370	III	75.92	80.56	0.400950001
27-06-06	11.8	376.4	III	75.92	80.56	0
28-06-06	10.6	290.6	III	75.92	80.56	0
29-06-06	30	181	III	75.92	80.56	2.041940031
30-06-06	58.2	132.6	III	75.92	80.56	14.44233222
01-07-06	17.6	128.2	III	75.92	80.56	0.026965685
02-07-06	12	128.4	III	75.92	80.56	0
03-07-06	26.8	144.6	III	75.92	80.56	1.251743712
04-07-06	6.8	121.4	III	75.92	80.56	0
05-07-06	9.4	72.6	III	75.92	80.56	0
06-07-06	9.8	64.8	III	75.92	80.56	0
07-07-06	13.2	66	III	75.92	80.56	0
08-07-06	46.2	85.4	III	75.92	80.56	8.181238005
09-07-06	6.2	84.8	III	75.92	80.56	0
10-07-06	8.2	83.6	III	75.92	80.56	0
11-07-06	67	140.8	III	75.92	80.56	19.6997377
12-07-06	32.2	159.8	III	75.92	80.56	2.677764735
13-07-06	26.8	140.4	III	75.92	80.56	1.251743712
14-07-06	34.8	169	III	75.92	80.56	3.5185957

15-07-06	6	166.8	III	75.92	80.56	0
16-07-06	5	104.8	III	75.92	80.56	0
17-07-06	7.8	80.4	III	75.92	80.56	0
18-07-06	16	69.6	III	75.92	80.56	0
19-07-06	16.2	51	II	57.77	185.67	2.660383327
20-07-06	2.8	47.8	II	57.77	185.67	0
21-07-06	13.2	56	III	75.92	80.56	0
22-07-06	10	58.2	III	75.92	80.56	0
23-07-06	6.8	49	II	57.77	185.67	0
24-07-06	1.6	34.4	II	57.77	185.67	0
25-07-06	22	53.6	III	75.92	80.56	0.400950001
26-07-06	43.8	74.2	III	75.92	80.56	7.081702991
27-07-06	0.4	67.8	III	75.92	80.56	0
28-07-06	13	79.2	III	75.92	80.56	0
01-08-06	14	71.2	III	75.92	80.56	0
02-08-06	4.8	76	III	75.92	80.56	0
03-08-06	32	64.2	III	75.92	80.56	2.617013862
04-08-06	15	78.8	III	75.92	80.56	0
05-08-06	19.2	85	III	75.92	80.56	0.113955699
06-08-06	0.4	71.4	III	75.92	80.56	0
08-08-06	11.6	46.2	II	57.77	185.67	0
09-08-06	11	42.2	II	57.77	185.67	0
10-08-06	29.6	52.6	II	57.77	185.67	0.318710245
11-08-06	55.4	107.6	III	75.92	80.56	12.87861924
12-08-06	54.2	161.8	III	75.92	80.56	12.2263187
13-08-06	40.2	190.4	III	75.92	80.56	5.544241532
14-08-06	52.2	231.6	III	75.92	80.56	11.16419237
15-08-06	20	222	III	75.92	80.56	0.17894992
16-08-06	34	200.6	III	75.92	80.56	3.24998201
17-08-06	33.4	179.8	III	75.92	80.56	3.054223886
18-08-06	14.4	154	III	75.92	80.56	0
19-08-06	50.8	152.6	III	75.92	80.56	10.44007171
29-08-06	8.2	8.2	I	37.47	423.87	0
30-08-06	10.4	18.6	I	37.47	423.87	0
09-09-06	3.2	3.2	I	37.47	423.87	0
10-09-06	6.4	9.6	I	37.47	423.87	0
11-09-06	25	34.6	I	37.47	423.87	9.81340512
12-09-06	6	40.6	II	57.77	185.67	0
13-09-06	79	119.6	III	75.92	80.56	27.56938535
14-09-06	52.4	168.8	III	75.92	80.56	11.26896027
15-09-06	18.2	180.6	III	75.92	80.56	0.052722117
16-09-06	32	187.6	III	75.92	80.56	2.617013862

17-09-06	30	211.6	III	75.92	80.56	2.041940031
18-09-06	50	182.6	III	75.92	80.56	10.03371247
19-09-06	33	163.2	III	75.92	80.56	2.926483931
20-09-06	10.6	155.6	III	75.92	80.56	0
21-09-06	8.6	132.2	III	75.92	80.56	0
23-09-06	28.6	80.8	III	75.92	80.56	1.675834546
24-09-06	3.6	51.4	II	57.77	185.67	0
26-09-06	92	124.2	III	75.92	80.56	36.80984877
27-09-06	43	167.2	III	75.92	80.56	6.728101143
30-09-06	2	137	III	75.92	80.56	0
01-10-06	8.8	53.8	III	75.92	80.56	0
02-10-06	8.4	19.2	I	37.47	423.87	0
03-10-06	2.25	21.45	I	37.47	423.87	0
05-10-06	5	24.45	I	37.47	423.87	0
06-10-06	1.6	17.25	I	37.47	423.87	0
07-10-06	10	18.85	I	37.47	423.87	0
08-10-06	35	51.6	II	57.77	185.67	0
09-10-06	1.2	52.8	II	57.77	185.67	0
10-10-06	2.9	50.7	II	57.77	185.67	0
14-10-06	2	4.9	I	37.47	423.87	0
15-10-06	28.2	30.2	I	37.47	423.87	0
16-10-06	6	36.2	II	57.77	185.67	0
17-10-06	5	41.2	II	57.77	185.67	0
18-10-06	12.6	53.8	III	75.92	80.56	0
19-10-06	2	53.8	III	75.92	80.56	0
20-10-06	1	26.6	I	37.47	423.87	0
21-10-06	20	40.6	II	57.77	185.67	0
22-10-06	16.6	52.2	II	57.77	185.67	0
29-10-06	74	74	III	75.92	80.56	24.20335324
30-10-06	0.4	74.4	III	75.92	80.56	0
01-11-06	1.6	76	III	75.92	80.56	0
02-11-06	7	83	III	75.92	80.56	0
03-11-06	6.4	15.4	I	37.47	423.87	0
04-11-06	8	23	I	37.47	423.87	0
05-11-06	55.2	78.2	III	75.92	80.56	12.76913956
07-11-06	27.2	96.8	III	75.92	80.56	1.341315526
08-11-06	1.8	92.2	III	75.92	80.56	0
19-11-06	43	43	II	57.77	185.67	0.179593253
22-11-06	11.6	54.6	III	75.92	80.56	0

Direct runoff of the year 2007

Date	R.F(mm)	5 day cumulative rainfall	AMC Condition	CN	S	Q (mm)
11.04.07	30	30	III	75.92	80.56	2.041940031
14.04.07	2.4	32.4	III	75.92	80.56	0
15.04.07	15.2	47.6	III	75.92	80.56	0
16.04.07	2.4	20	II	57.77	185.67	0
17.04.07	9	29	III	57.77	185.67	0
22.04.07	45	45	III	75.92	80.56	7.624341417
30.04.07	104	104	III	75.92	80.56	45.85454712
02.05.07	43	147	III	75.92	80.56	6.728101143
03.05.07	10	157	III	75.92	80.56	0
04.05.07	14.8	171.8	III	75.92	80.56	0
10.05.07	32	32	III	75.92	80.56	2.617013862
25.05.07	3	3	I	37.47	423.87	0
28.05.07	127.6	130.6	III	75.92	80.56	64.71983138
29.05.07	4.8	135.4	III	75.92	80.56	0
30.05.07	20	152.4	III	75.92	80.56	0.17894992
31.05.07	25	177.4	III	75.92	80.56	0.883027549
01.06.07	3	180.4	III	75.92	80.56	0
03.06.07	4	52	II	57.77	185.67	0
06.06.07	28	32	I	37.47	423.87	0
08.06.07	30.8	58.8	III	75.92	80.56	2.264788845
10.06.07	9.6	68.4	III	75.92	80.56	0
11.06.07	41	81.4	III	75.92	80.56	5.87372936
12.06.07	16	97.4	III	75.92	80.56	0
13.06.07	72.2	138.8	III	75.92	80.56	23.02085316
14.06.07	25.2	164	III	75.92	80.56	0.921157752
15.06.07	24.2	178.6	III	75.92	80.56	0.737810496
16.06.07	14	151.6	III	75.92	80.56	0
17.06.07	24.2	159.8	III	75.92	80.56	0.737810496
18.06.07	51	138.6	III	75.92	80.56	10.54251393
19.06.07	82	195.4	III	75.92	80.56	29.64255899
20.06.07	44	215.2	III	75.92	80.56	7.171132492
21.06.07	42	243.2	III	75.92	80.56	6.295534197
22.06.07	94	313	III	75.92	80.56	38.286213
23.06.07	88	350	III	75.92	80.56	33.89833793
24.06.07	72.8	340.8	III	75.92	80.56	23.41322022
25.06.07	7	303.8	III	75.92	80.56	0
26.06.07	6	267.8	III	75.92	80.56	0
27.06.07	20	193.8	III	75.92	80.56	0.17894992
28.06.07	2.4	108.2	III	75.92	80.56	0

29.06.07	2	37.4	I	37.47	423.87	0
30.06.07	19	49.4	I	37.47	423.87	0
01.07.07	31	74.4	III	75.92	80.56	2.322012705
02.07.07	58	112.4	III	75.92	80.56	14.32876342
03.07.07	98	208	III	75.92	80.56	41.27762179
04.07.07	65.5	271.5	III	75.92	80.56	18.76966746
05.07.07	20	272.5	III	75.92	80.56	0.17894992
06.07.07	30.4	271.9	III	75.92	80.56	2.152147464
07.07.07	8	221.9	III	75.92	80.56	0
08.07.07	31	154.9	III	75.92	80.56	2.322012705
09.07.07	39	128.4	III	75.92	80.56	5.063654394
10.07.07	53	161.4	III	75.92	80.56	11.58520996
11.07.07	35	166	III	75.92	80.56	3.587084933
12.07.07	32.2	190.2	III	75.92	80.56	2.677764735
13.07.07	29.2	188.4	III	75.92	80.56	1.828951766
14.07.07	39.8	189.2	III	75.92	80.56	5.382205597
15.07.07	23.8	160	III	75.92	80.56	0.669653743
16.07.07	4.8	129.8	III	75.92	80.56	0
17.07.07	116	213.6	III	75.92	80.56	55.2923027
18.07.07	76	260.4	III	75.92	80.56	25.53580553
19.07.07	2	222.6	III	75.92	80.56	0
20.07.07	26.2	225	III	75.92	80.56	1.122522687
21.07.07	40.2	260.4	III	75.92	80.56	5.544241532
22.07.07	12	156.4	III	75.92	80.56	0
23.07.07	0.2	80.6	III	75.92	80.56	0
24.07.07	2	80.6	III	75.92	80.56	0
25.07.07	107	161.4	III	75.92	80.56	48.18036079
26.07.07	7.2	128.4	III	75.92	80.56	0
27.07.07	4	120.4	III	75.92	80.56	0
28.07.07	8	128.2	III	75.92	80.56	0
29.07.07	14	140.2	III	75.92	80.56	0
30.07.07	2.4	35.6	I	37.47	423.87	0
31.07.07	6	34.4	I	37.47	423.87	0
01.08.07	2	32.4	I	37.47	423.87	0
02.08.07	10.2	34.6	I	37.47	423.87	0
03.08.07	12.4	33	I	37.47	423.87	0
04.08.07	22.2	52.8	III	75.92	80.56	0.427664253
05.08.07	18.2	65	III	75.92	80.56	0.052722117
06.08.07	42.7	105.7	III	75.92	80.56	6.597218967
07.08.07	22	117.5	III	75.92	80.56	0.400950001
08.08.07	45.2	150.3	III	75.92	80.56	7.716180007
09.08.07	22	150.1	III	75.92	80.56	0.400950001

10.08.07	96	227.9	III	75.92	80.56	39.77563138
11.08.07	31	216.2	III	75.92	80.56	2.322012705
12.08.07	5	199.2	III	75.92	80.56	0
20.08.07	3	3	I	37.47	423.87	0
21.08.07	8	11	I	37.47	423.87	0
22.08.07	13.2	24.2	I	37.47	423.87	0
23.08.07	4	28.2	I	37.47	423.87	0
25.08.07	4.8	30	I	37.47	423.87	0
29.08.07	49	53.8	III	75.92	80.56	9.533570297
30.08.07	53	102	III	75.92	80.56	11.58520996
31.08.07	27.2	129.2	III	75.92	80.56	1.341315526
01.09.07	14.2	143.4	III	75.92	80.56	0
02.09.07	3	146.4	III	75.92	80.56	0
03.09.07	17	114.4	III	75.92	80.56	0.009669547
05.09.07	34	68.2	III	75.92	80.56	3.24998201
06.09.07	43	97	III	75.92	80.56	6.728101143
08.09.07	2	79	III	75.92	80.56	0
10.09.07	14	59	III	75.92	80.56	0
12.09.07	7	23	I	37.47	423.87	0
14.09.07	20	41	II	57.77	185.67	0
15.09.07	22	49	II	57.77	185.67	0
16.09.07	102	151	III	75.92	80.56	44.31750594
17.09.07	18	162	III	75.92	80.56	0.043208008
18.09.07	98	260	III	75.92	80.56	41.27762179
19.09.07	60	300	III	75.92	80.56	15.47695252
20.09.07	6	284	III	75.92	80.56	0
23.09.07	5.6	71.6	III	75.92	80.56	0
24.09.07	43	54.6	III	75.92	80.56	6.728101143
25.09.07	89	137.6	III	75.92	80.56	34.62089556
26.09.07	22	159.6	III	75.92	80.56	0.400950001
28.09.07	8	162	III	75.92	80.56	0
30.09.07	12	42	II	57.77	185.67	0
02.10.07	2	22	I	37.47	423.87	0
04.10.07	7.2	21.2	I	37.47	423.87	0
05.10.07	13	22.2	I	37.47	423.87	0
07.10.07	5	25.2	I	37.47	423.87	0
17.10.07	5.2	5.2	I	37.47	423.87	0
19.10.07	49.6	54.8	III	75.92	80.56	9.832603731
20.10.07	159	213.8	III	75.92	80.56	91.37082981
21.10.07	58.8	272.6	III	75.92	80.56	14.78472167
22.10.07	6	273.4	III	75.92	80.56	0
23.10.07	3.6	277	III	75.92	80.56	0

27.10.07	5	8.6	I	37.47	423.87	0
28.10.07	32	37	I	37.47	423.87	0
29.10.07	50	87	III	75.92	80.56	10.03371247
30.10.07	17	104	III	75.92	80.56	0.009669547
03.11.07	6	23	I	37.47	423.87	0
04.11.07	7	13	I	37.47	423.87	0
07.11.07	82	95	III	75.92	80.56	29.64255899

Direct runoff of the year 2018

Date	Rainfall	5 day cumulative rainfall	AMC Condition	CN	S	Q (mm)
12-04-18	15.6	15.6	II	58.95	176.87	0
13-04-18	30.2	45.8	III	77.08	75.52	2.514199757
17-04-18	13.1	43.3	III	77.08	75.52	0
18-04-18	12.6	55.9	III	77.08	75.52	0
21-04-18	3.6	29.3	III	77.08	75.52	0
23-04-18	9	12.6	I	38.61	403.86	0
26-04-18	5	14	II	58.95	176.87	0
28-04-18	0.4	5.4	I	38.61	403.86	0
01-05-18	6.2	6.6	I	38.61	403.86	0
03-05-18	2.8	9	I	38.61	403.86	0
04-05-18	21	30	III	77.08	75.52	0.426720289
05-05-18	18.1	48.1	III	77.08	75.52	0.114193356
08-05-18	10.5	49.6	III	77.08	75.52	0
11-05-18	29.4	39.9	III	77.08	75.52	2.274840742
12-05-18	28.2	68.1	III	77.08	75.52	1.93478079
14-05-18	14.2	71.8	III	77.08	75.52	0
16-05-18	36	78.4	III	77.08	75.52	4.527773487
20-05-18	9.6	45.6	III	77.08	75.52	0
24-05-18	3.8	13.4	II	58.95	176.87	0
25-05-18	97.2	101	III	77.08	75.52	42.75728815
26-05-18	4.2	105.2	III	77.08	75.52	0
27-05-18	4.6	109.8	III	77.08	75.52	0
28-05-18	2.2	112	III	77.08	75.52	0
29-05-18	108.6	216.8	III	77.08	75.52	51.71634926
30-05-18	25.2	144.8	III	77.08	75.52	1.190086848
31-05-18	1.8	142.4	III	77.08	75.52	0
03-06-18	0.6	27.6	I	38.61	403.86	0
04-06-18	36.5	38.9	II	58.95	176.87	0.007113782
05-06-18	24.6	61.7	III	77.08	75.52	1.060246838
06-06-18	28.2	89.9	III	77.08	75.52	1.93478079
07-06-18	7.1	97	III	77.08	75.52	0
09-06-18	36.8	96.7	III	77.08	75.52	4.840962178

10-06-18	55	127.1	III	77.08	75.52	13.7890872
11-06-18	58	156.9	III	77.08	75.52	15.53706522
12-06-18	17.2	167	III	77.08	75.52	0.056513588
13-06-18	3.6	170.6	III	77.08	75.52	0
14-06-18	69.4	203.2	III	77.08	75.52	22.7071084
15-06-18	11.4	159.6	III	77.08	75.52	0
16-06-18	0.6	102.2	III	77.08	75.52	0
17-06-18	44.6	129.6	III	77.08	75.52	8.283223305
18-06-18	0.6	126.6	III	77.08	75.52	0
19-06-18	29.3	86.5	III	77.08	75.52	2.245623836
20-06-18	58.6	133.7	III	77.08	75.52	15.89423468
21-06-18	74.2	207.3	III	77.08	75.52	25.94039785
22-06-18	18.3	181	III	77.08	75.52	0.129626615
23-06-18	5.2	185.6	III	77.08	75.52	0
24-06-18	1.8	158.1	III	77.08	75.52	0
25-06-18	0.2	99.7	III	77.08	75.52	0
26-06-18	26.8	52.3	II	58.95	176.87	0
27-06-18	8.8	42.8	II	58.95	176.87	0
28-06-18	15	52.6	II	58.95	176.87	0
29-06-18	22.8	73.6	III	77.08	75.52	0.711402872
30-06-18	1.2	74.6	III	77.08	75.52	0
06-07-18	11.8	11.8	I	38.61	403.86	0
08-07-18	51.4	63.2	III	77.08	75.52	11.78019017
09-07-18	11.6	74.8	III	77.08	75.52	0
10-07-18	22.4	97.2	III	77.08	75.52	0.642447978
11-07-18	97.2	182.6	III	77.08	75.52	42.75728815
12-07-18	31.8	214.4	III	77.08	75.52	3.022098142
13-07-18	23	186	III	77.08	75.52	0.747070811
14-07-18	26.7	201.1	III	77.08	75.52	1.543018798
15-07-18	26.4	205.1	III	77.08	75.52	1.469261603
16-07-18	42.8	150.7	III	77.08	75.52	7.430400954
17-07-18	28.2	147.1	III	77.08	75.52	1.93478079
18-07-18	77	201.1	III	77.08	75.52	27.87702651
19-07-18	27.6	202	III	77.08	75.52	1.773543436
20-07-18	47.8	223.4	III	77.08	75.52	9.87714887
21-07-18	16.6	197.2	III	77.08	75.52	0.028996478
22-07-18	5	174	III	77.08	75.52	0
23-07-18	15.8	112.8	III	77.08	75.52	0.006326989
24-07-18	12.8	98	III	77.08	75.52	0
25-07-18	7	57.2	III	77.08	75.52	0
26-07-18	13	53.6	III	77.08	75.52	0
27-07-18	4.8	53.4	III	77.08	75.52	0

29-07-18	14.2	39	II	58.95	176.87	0
30-07-18	3.7	35.7	II	58.95	176.87	0
31-07-18	14.8	37.5	II	58.95	176.87	0
01-08-18	16.6	49.3	II	58.95	176.87	0
02-08-18	2	51.3	II	58.95	176.87	0
03-08-18	11.2	48.3	II	58.95	176.87	0
04-08-18	2	46.6	II	58.95	176.87	0
05-08-18	12	43.8	II	58.95	176.87	0
06-08-18	11.2	38.4	II	58.95	176.87	0
07-08-18	17.1	53.5	III	77.08	75.52	0.051312006
08-08-18	65.4	107.7	III	77.08	75.52	20.10401358
09-08-18	2.4	108.1	III	77.08	75.52	0
10-08-18	2	98.1	III	77.08	75.52	0
11-08-18	5.1	92	III	77.08	75.52	0
12-08-18	22.6	97.5	III	77.08	75.52	0.676526682
13-08-18	23.6	55.7	III	77.08	75.52	0.85876859
14-08-18	20	73.3	III	77.08	75.52	0.297873118
15-08-18	131	202.3	III	77.08	75.52	70.16700347
16-08-18	213.2	410.4	III	77.08	75.52	143.4145641
17-08-18	98.8	486.6	III	77.08	75.52	43.99361423
18-08-18	18.4	481.4	III	77.08	75.52	0.137694478
19-08-18	21.4	482.8	III	77.08	75.52	0.484221421
20-08-18	2	353.8	III	77.08	75.52	0
02-09-18	3.2	3.2	I	38.61	403.86	0
06-09-18	15.4	18.6	I	38.61	403.86	0
07-09-18	9.6	25	I	38.61	403.86	0
12-09-18	4.2	4.2	I	38.61	403.86	0
15-09-18	18.1	22.3	I	38.61	403.86	0
16-09-18	24	46.3	II	58.95	176.87	0
22-09-18	36	36	II	58.95	176.87	0.00220266
23-09-18	6.2	42.2	II	58.95	176.87	0
24-09-18	7.4	49.6	II	58.95	176.87	0
25-09-18	6.1	55.7	III	77.08	75.52	0
27-09-18	2.4	22.1	I	38.61	403.86	0
29-09-18	14.7	23.2	I	38.61	403.86	0
04-10-18	14	14	I	38.61	403.86	0
06-10-18	3.7	17.7	I	38.61	403.86	0
07-10-18	17.6	35.3	I	38.61	403.86	0
08-10-18	10	45.3	II	58.95	176.87	0
09-10-18	7	38.3	II	58.95	176.87	0
10-10-18	4.6	42.9	II	58.95	176.87	0
15-10-18	4.2	4.2	I	38.61	403.86	1

16-10-18	50.4	54.6	III	77.08	75.52	11.2405086
19-10-18	18.3	72.9	III	77.08	75.52	0.129626615
23-10-18	104.6	122.9	III	77.08	75.52	48.53441285
24-10-18	5.2	109.8	III	77.08	75.52	0
26-10-18	18	127.8	III	77.08	75.52	0.106829752
06-11-18	14	14	I	38.61	403.86	0

RUNOFF ESTIMATION OF KCAET CAMPUS BY CURVE NUMBER METHOD ADOPTING REMOTE SENSING AND GIS TECHNIQUES

By

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THESIS

Submitted in partial fulfillment of the requirement for the degree of

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(Soil and Water Engineering)

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DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY, TAVANUR - 679 573

KERALA, INDIA

2019

DECLARATION

I, hereby declare that this thesis entitled "**RUNOFF ESTIMATION OF KCAET CAMPUS BY CURVE NUMBER METHOD ADOPTING REMOTE SENSING AND GIS TECHNIQUES**" is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Tavanur **ANJANA S.R.**

Date: (2017-18-010)

<u>CERTIFICATE</u>

Certified that this thesis entitled "**RUNOFF ESTIMATION OF KCAET CAMPUS BY CURVE NUMBER METHOD ADOPTING REMOTE SENSING AND GIS TECHNIQUES**" is a record of research work done independently by Er. Anjana, S.R. under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

Tavanur

Date:

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ANJANA S.R.

Dedication

This thesis is dedicated to my Father, Mother and lovely sister who sacrificed much to bring me up to this level and for the devotion they made to make my life successful

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SYMBOLS AND ABBREVIATIONS

<	:	Less than
>	:	Greater than
%	:	Percent
≤	:	Less than or equal to
≥	:	Greater than or equal to
×	:	Multiplication
°	:	Degree
°C	:	Degree Celsius
1D	:	One Dimensional
3D	:	Three Dimensional
AGNPS	:	Agricultural-Non-Point-Source Pollution
AMC	:	Antecedent Moisture Condition
ANN	:	Artificial Neural Network
ANSWERS	:	Areal Nonpoint Source Watershed Environment Simulation model
cm	:	Centimeter
CN	:	Curve Number
CREAMS	:	Chemicals, Runoff and Erosion from Agricultural Management Systems
DBW	:	Drop Box Weir
DEM	:	Digital Elevation Model
DLCMCU	:	Data Logger cum Microprocessor Control Unit
E	:	East
EPIC	:	Environmental Policy Impact Climate
ERDAS	:	Earth Resources Data Analysis System
ESRI	:	Environmental Systems Research Institute
et al.,	:	and others
etc	:	et cetera
FAO	:	Food and Agriculture Organization

FCC	:	False Color Composite
Fig.	:	Figure
GIS	:	Geographic Information System
GPS	:	Global Positioning System
h	:	Hour
ha	:	Hectare
HRU	:	Hydrologic Response Unit
HSG	:	Hydrologic Soil Group
ICAR	:	Indian Council of Agricultural Research
ICRISAT	:	International Crop Research Institute for the Semi-Arid Tropics
IDRSMU	:	Integrated Digital Runoff and Soil Loss Monitoring Unit
i.e.,	:	Which is to say, in other words
IMD	:	Indian Meteorological Department
IRS	:	Indian Remote Sensing
ISRO	:	Indian Space Research Organization
IWM	:	Integrated Watershed Management
KAU	:	Kerala Agricultural University
KCAET	:	Kelappaji College of Agricultural Engineering and Technology
kg/ha/h	:	kilogram per hectare per hour
LISS	:	Linear Imaging and Self Scanning
LULC	:	Land use Land Cover
m	:	meter
m^3/s	:	meter cube per second
m^2	:	meter square
MLP	:	Multi Layer Perceptron
mm	:	millimeter
mm/h	:	millimeter per hour
Mm^3	:	Million meter cube
MODIS	:	Moderate Resolution Imaging Spectroradiometer
N	:	North

NBSS & LUP	:	National Bureau of Soil Survey and Land Use Planning
NEH	:	National Engineering Handbook
NIT	:	National Institute of Technology
NRCS	:	Natural Resource Conservation Service
NRSA	:	National Remote Sensing Agency
PWD	:	Public Work Department
R^2	:	Coefficient of Determination
RS	:	Remote Sensing
s	:	second
SOI	:	Survey of India
SRTM	:	Shuttle Radar Topography Mission
SWAT	:	Soil and Water Assessment Tool
TM	:	Thematic Mapper
USDA	:	United States Department of Agriculture
USGS	:	United States Geological Survey
UTM	:	Universal Transverse Mercator Co-ordinate System
viz.,	:	Namely
WEPP	:	Water Erosion Prediction Project
WGS	:	World Geodetic System
y	:	year

CHAPTER VI

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CHAPTER I

INTRODUCTION

Water is the principal constituent of all living things, which is essential for the survival and also the most abundant resource on earth. It is a vital factor for augmenting the growth of agriculture, industry and economic development, especially in the perspective of rapidly increasing population and urbanization. Hydrology is the branch of science which deals with occurrence, circulation and distribution of water on the earth and it's atmosphere (Chow *et al.,* 2002). Also it is a subject of great importance to the people and their environment. Various aspects of water which related to earth were represented in terms of hydrologic cycle. Precipitation and runoff are the two important hydrologic variables and the main transportation components of the hydrologic cycle. The runoff events are generated by rain storms and its quantity and occurrence are dependent upon the rainfall characteristics such as intensity, distribution and duration (Pradhan *et al.,* 2010). Runoff from a watershed is affected by several geo-morphological parameters (Chavda *et al.,* 2016).

In the coming decades, climate change, surface water pollution and population growth together may produce a severe decline in fresh water supply. With an approximate annual population growth of 1.8% and per capita water availability the most of the parts of India facing the water stress level (<1700 m^3 per person per year). Considering the above factors, the quantification and conservation of available water resources is essential to ensure sustainability. Estimation of surface runoff is essential to assess the potential water yield of a watershed, to plan water conservation measures including recharging of the ground water zones and reduction of the sedimentation. This also helps in reducing the flood hazards at the downstream and it is an essential prerequisite of integrated watershed management (IWM) (Patil *et al*., 2008). Watershed management implies the proper usage of land, water and other natural resources in a watershed and for which the estimation of runoff is essential for planning, developing and managing the water resources (Amutha *et al*., 2009). The prediction and evaluation of the quantitative amount of runoff generated and transported to the outlet point of the watershed has much importance (Khosravi *et al.,* 2013; Gopal *et al.,* 2015).

Runoff plots are the widely used conventional method for the runoff quantification, but its usage is limited to small plots. However, the conventional methods for the reliable prediction and quantification of runoff from land surfaces is time consuming, expensive and difficult process (Kumar *et al.,* 2010) due to the requirement of hydrological and meteorological data especially in ungauged watersheds (Ponce and Hawkins, 1996). The hydrologic studies often encounter the problem of lacking the records of precipitation and observed runoff. By comparing the runoff characteristics with watershed features, the problem can be solved to some extent (Singh, 2014).

Various parametric models such as empirical, semi-emperical (conceptual) and deterministic (physical process based) have been developed and used by a number of researchers. Empirical models are the simplest among them which is primarily based on the observations and characteristic responses. They are statistical in nature and data requirement are less compared to conceptual and physically based models. The conceptual models play an intermediate role in between physical and empirical models. The physically based models will rely on the combination of components that affect the runoff and it considers the spatial and temporal variations. The Sacramento model, Tank model, HBV model, MIKE 11/NAM model, NRCS-CN model (NEH, 1954) etc, are some of the runoff estimation models (Gopal *et al.,* 2015).

Natural Resources Conservation Services Curve Number (NRCS-CN) method is widely used, simple empirical model with few data requirements and clearly stated assumptions. The method was originally developed by Soil Conservation Service, United States Department of Agriculture (USDA). The NRCS-CN method has been widely used for storm water modeling, water resource management and runoff estimation from rainfall events in urban or agricultural watersheds (Greene and Cruise, 1995; Tsihrintzis and Humid, 1997; Lewis *et al.*, 2000). The method had also been adopted by some ecological and hydrological models for runoff estimation including ANSWERS, CREAMS (Knisel, 1980), EPIC, AGNPS (Najim *et al.,* 2006) and SWAT (Smic *et al.,* 2009). The model was recently extended to model soil moisture and sediment yield (Reshmidevi *et al.,* 2008; Xiao *et al.,* 2011). The NRCS CN method accounts many factors which influence the runoff generation including land use, surface condition, soil type and antecedent moisture condition incorporated into a single parameter called curve number. Furthermore, it is the only methodology with reasonably well stated environmental inputs and widely accepted in United States and other countries (Kumar *et al.,* 2010).

Generation of too many spatial input data is one of the major problems in the runoff estimation models. Conventional methods are too costly and tedious for the generation of input data. With the advent of Remote Sensing and Geographic Information System (GIS) technology, the derivation of such spatial information has become cost effective and easier. Remote sensing technology can enhance the conventional methods to a great extent in rainfall-runoff studies. Many researchers have been using the Geographic Information System along with remote sensing data to estimate runoff curve number value all over the world. Singh (2014) reported that there exists a good correlation between the estimated runoff depth and measured runoff depth using NRCS CN method along with GIS. The incorporation of remote sensing data and application of the NRCS CN model in a GIS platform provides a powerful tool in the assessment of runoff (Bhuktar and Regulwar, 2015). The catchment management, including the land use, plays an important role in the rainfall-runoff relationships (Jabari *et al.,* 2009). The remote sensing data will provide multi-resolution, multi-spectral and multi-temporal data which can be applied extensively in land use mapping (Nayak *et al.,* 2012). The thematic information on soil, land use, vegetation etc which is necessary inputs for rainfall- runoff models can be derived and analyzed in remote sensing and GIS environment.

In the present study, NRCS CN method is employed along with the Geographic Information System (GIS) platform to estimate the runoff yield of KCAET Campus and also the method was validated using field runoff measurements from selected storm events.

The specific objectives of the study are:

1. To estimate the runoff using curve number method in GIS environment using RS data at different temporal scale.
2. To validate the curve number method for estimation of runoff in the study area.

CHAPTER II

REVIEW OF LITERATURE

A review of the important studies conducted in the past related to runoff, various factors affecting the runoff and runoff estimation by adopting different methodologies are described in this chapter.

2.1 RUNOFF

Runoff is the flow of water due to the excess storm water, melt water or from other sources through the earth surface. In other words, runoff is the part of the water cycle in which the water flows over the land as surface water rather than absorbed into groundwater or evaporated. Runoff occurs only when the rate of precipitation exceeds the rate at which water may infiltrate into the soil. When rainfall occurs, a part of precipitation/rainfall is intercepted by vegetation. Some part is stored in the ground surface depressions is known as depression storage, which later evaporates or infiltrates. Depending on the soil moisture condition at the time of precipitation, some part of rainfall is absorbed by the soil. If the rain continues further, the excess water will flow overland and joins the lakes, streams, rivers etc, is known as surface runoff. It is that part of water which can be used for engineering purposes and hence known as yield of catchment. It is generally expressed in volume, in a season or a year.

The main components or types of runoff from a catchment area are distinguished as channel runoff, surface runoff, subsurface flow and base flow (USDA[b], 2004). The channel runoff occurs when rain falls on a water surface or flowing stream which contributes to runoff without any abstractions are there from. However, this quantity is very small and generally ignored except in special studies. When the rainfall rate is greater than infiltration rate, surface runoff occurs. Subsurface flow usually referred as interflow infiltrates into the ground and moves laterally as per the slope above the water table without coming to contact with it. This component will find an outlet into the stream and it moves slowly as compared to the overland flow. The interflow is also known as storm seepage or quick return flow. If not obstructed by any impervious layer in between, part of infiltrated water may reach the groundwater storage through percolation. This is called base flow and is a long term component of the total runoff.

2.2 FACTORS AFFECTING RUNOFF

The rainfall quantity or snow melt, its distribution with time and the associated edaphic, vegetal and climatic conditions will influence the runoff supply to a greater extend. The separate phases of rainfall runoff relation are climatic and physiographic factors. This section deals with the effect of these factors in producing the runoff.

2.2.1 Climatic Factors

The climatic factors that affect runoff are precipitation, temperature, wind direction and relative humidity.

2.2.1.1 *Rainfall*

The precipitation type has a greater effect on runoff. Precipitation in the form of rainfall will starts immediately as compared to snowfall. Also the runoff rate varies with intensity of rainfall, duration of rainfall and size of rain droplets. Surface runoff rate is directly proportional to rainfall intensity and duration and runoff rate will increase with intensity of rainfall (Kleinman *et al.,*2006; Assouline, 2009; Zhao and Hou, 2018). The rain drops can affect the sealing of soil surface by detaching and dispersing the soil particles which will be washed away later.

Faures *et al.,* (1995) studied the impact of spatial rainfall variability in a small scale semi arid catchment area on runoff modeling. It showed that the wind velocity and direction have less impact on peak runoff and runoff volume as compared to rainfall intensity variations. Five recording rain gauges were used and five model runs were conducted with input from one of the recording rain gauges. The coefficient of variation for runoff volume and peak runoff rate ranged from 2 to 65% and 9 to 76% respectively for eight observed storm events. The study showed that the rainfall with spatial variations yield more runoff and uniform rainfall assumption using a single rain gauge will lead to uncertainties in runoff estimation.

Fraster *et al.,* (1999) studied the effect of rainfall intensity, runoff and thereby erosion in twenty two sites which has conventionally managed arable land on slopes ranging from 1° to 11°. The sites were monitored for a number of rainfall events. Overland flow started when the rainfall intensity exceeded 0.8 mm/hr. The low intensity rainfall (<2 mm/hr) produced an average suspended losses of 14 kg/ha/hr and high intensity rainfall (>9 mm/hr) produced considerable loss of sediments. The study showed that there is a strong relationship between rainfall intensity, overland flow and sediment transfer.

The amount of surface runoff is mainly a function of rainfall duration. The transportation capacity of surface runoff was limited in the early stage of runoff and it will increase with duration. Rainfall frequency and distribution also have greater effect on runoff. Storm patterns based on the spatial and temporal variability of precipitation affect not only peak flow but also flood volume and duration for the various catchment sizes and are important in the design of hydraulic structures or in mapping flood plains (Javelle *et al*., 2002)

Mansoor (2013) studied the relationship between runoff, precipitation and basin flow index of Marg river basin in Mahidasht. The correlation and Debi with precipitation equations of Marg basin was gained as (p=17.2) Q=9.86. The results of the study showed that if annual precipitation quantity is equal or less than 17.2, surface flow will be 0 for the Marg river basin and the peak quantity for probable maximum precipitation of 24 h is 2528.8 m^3/s.

Emmanuel *et al.,* (2015) analyzed the influence of spatial variability of rainfall runoff modeling. The study was conducted using a simulation chain which has a stream network model, a distributed hydrological model and a rainfall simulator. The study concluded that there exist significant dispersions between various simulations and within each simulation scenario.

To evaluate the relationship between rainfall intensities and runoff, Szabo *et al.* (2017) measured runoff and infiltration on arable land with three rainfall intensities (30, 60 and 90 mm/h). Different rainfall intensities were applied on fenced ground with 6 m^2 plot size (3x2 m) and the rainfall intensity is adjusted with the number of nozzle-swing during a given time. The study revealed that under 20 mm/h rainfall intensity runoff doesn't occur, while at about 50 mmh^{-1}, the rate of infiltration and runoff is almost equal and above 50 mmh^{-1} the runoff rate exceeded the infiltration rate.

2.2.2 Physiographic Factors

The physiographic factors include both channel and watershed characteristics.

2.2.2.1 *Watershed Characteristics*

The overland flow plane characteristics or watershed characteristics such as shape and size of watershed, orientation of watershed or landscape position, drainage characteristics such as drainage density will have greater influence on watershed response (Woolhiser and Goodrich, 1988). With the entrance of additional water the channel size and runoff quantity will increase progressively. The near stream areas have saturation excess runoff due to proximity to water table (Kleinman *et al.,* 2006) and for large catchment area the runoff process will be more intensive (Wood *et al.,* 1988). The shape of watershed is generally expressed by the term "form factor" and "compactness coefficient". Form factor is the ratio of average width to axial length of watershed. The compactness coefficient is the ratio off perimeter of watershed to circumference of circle whose area is equal to area of watershed. Mainly two types of shapes are there; Fan shape and Fern shape. The fan shaped watershed tends to produce higher runoff very early and the fern shaped watershed tends to produce less runoff. The orientation of the watershed affects the evaporation and transpiration losses from an area. The drainage density is defined as the ratio of the total channel length (L) in the watershed to total watershed area (A). Greater drainage density gives more runoff.

2.2.2.2 *Vegetation*

Dunne *et al,* (1991) studied the effect of vegetation on infiltration and runoff. The vegetative cover may prevent surface scaling by intercepting the raindrop energy. The experiment was conducted in field plots having woody stems of bushes and grasslands. The infiltration rates are calculated by deducting runoff rates from rainfall intensities. The cover density affected the average conductivity and flow depth.

The vegetation or land use and land management practices have great effect in reducing the average velocity of flow, allowing the infiltration significantly and increasing the residence time to decrease the runoff yield. The land use is watershed cover which includes all agricultural and non-agricultural lands. Also the land use change can alter the runoff response of the watershed by increasing runoff volume, reducing time to peak and increasing peak runoff (Zuazo and Pleguezuelo, 2008). The poor water management practices and deforestation will increase runoff from an area (Defersha and Melesse, 2011).

Defersha and Melesse (2011) investigated the field scale effects of land use on runoff using data collected from runoff plots in the Mara river basin, Kenya. The evaluation was done by using two models: Water Erosion Prediction Project (WEPP) and Erosion 3D. The runoff plots were established in the three sites of the basin and three land use (bare land, crop land and grass land) with similar soil types and slope steepness were considered. The results from the plot scale research indicated that runoff and soil loss was higher in the cultivated land than in the grass lands. Both the models performed well in the evaluation done with observed runoff data.

2.2.2.3 ***Soil Properties***

Role of soil particle size distribution in runoff and soil erosion was studied by Figueiredo and Poesen (1998) by simulating the plots. The experimental setup consists of 48 metal boxes (612 m^2) with perforations at bottom. The boxes are placed at 10% slope and filled with silty loam soil, sand and rock fragment at different proportions. Twelve treatments with four replications with an exposure of 240 mm natural rainfall were carried out. The study revealed that the particle size has greater influence on runoff depth.

The soil properties such as soil crusting, hydraulic conductivity and surface roughness will vary spatially and temporally during the early stages of runoff. This will lead to the high rate of surface runoff and soil loss which occurs non uniformly across the soil surface (Zhao and Hou, 2018). The soil moisture is a key variable of the hydrologic cycle, playing an important role in hydrologic processes such as infiltration and runoff generation (Naz *et al.* 2019) and it was also potentially affected by particle size distribution (Kleinman *et al*., 2006).

2.2.2.4 ***Topographic Characteristics***

The runoff from the catchment area concentrates in erodible channels and it depends on the topography of the area (Watson and Laflen, 1985). Steep channel slopes associated with steep land slopes increase the severity of runoff. Stream density also tends to vary with slope. Fujimoto *et al,* (2011) investigated the role of different hillslope topographic characteristics on runoff response. Field observations were carried out at two types of hill slopes: a convergent hillslope (a valley-head) and a planar hill slope (a side slope). With the magnitude of rainfall, the runoff contributions varied. The runoff responses was negligible in the valley head for rainfall of >35 mm but the side slope showed quick responses for the same rainfall amount. The study revealed that both type of hillslope affected the runoff behavior.

Wakolbinger *et al,* (2016) revealed that stone bunds can reduce runoff from field plots in the study on impacts of stone bunds on runoff and soil loss. Field studies were carried out in runoff plots with average slope of 8%. Field plot observations conducted in Southwest China resulted in obtaining the non linear relationship between runoff and slope gradient. To analyze the effects of slope length and slope gradient, two sets of plots was constructed. Five slope gradient classes (5°, 10°, 15°, 20° and 25°) and five slope length classes (5m, 10m, 15m, 20m and 25m) was used. There was an increasing trend of runoff upto 15° slope gradient and later got reduced. Reduction in the runoff was due to the outcrops in the area. With the increase in slope length the runoff showed a decrease-increase-decrease trend. Hence it is proved that there exists a positive linear relationship between slope length and runoff (Zhang *et al.,* 2018).

2.3 RUNOFF COMPUTATION METHODS

This section includes critical reviews of various runoff computation methods, their advantages and disadvantages.

2.3.1 Rational Method

Nyarko (2002) used modified rational method with a storage coefficient factor (C_S) to calculate runoff rate and to assess the flood risk in the catchment. The results showed that the flood intensities differed for the areas which have same rainfall intensities. Modified rational method was integrated with GIS and by overlay analysis flood potential areas are identified and mapped. Akan (2002) used modified rational method for sizing infiltration structures to capture storm water runoff.

Young *et al.,* (2009) determined runoff coefficients (C) of rational method for 72 gauged rural watersheds having size ranging from 0.45 km^2 to 76.6 km^2. The study investigated the spatial variation of runoff coefficient and documented the dependence of it on recurrence interval. The C values for the area ranged from 0.17 to 0.97 for the 2 year recurrence interval and 100 year recurrence interval respectively. The study indicated that the runoff coefficient (C) values are not dependent on drainage area and the method is acceptable for use on larger basins.

The peak surface runoff is the maximum runoff which is used in design of structures that has to carry the runoff and for small watersheds it can be estimated by rational method (Rahman *et al.,* 2015). It is a simple technique used for drainage basin size is limited to less than 800 ha. According to this method,

$$Q_{peak} = \frac{CIA}{360} \qquad (2.1)$$

Where, Q_{peak} is the peak runoff rate, m^3/s, C is the runoff coefficient, A is the area of watershed, ha and for the duration equal to the time of concentration, I is the rainfall intensity in mm/hr (Bhagat and Patil, 2015).

The ratio of peak runoff rate to the rainfall intensity is the runoff coefficient. It is a dimensionless term and varies from 0 to 1. The runoff coefficient depends on soil type and land use. The high value of C indicates high risk of runoff and vice versa. The time required to reach the overland flow from the extreme point of the watershed to the outlet is called time of concentration and it is given by,

$$T_c = 0.0195 L^{0.77} S^{-0.385} \qquad (2.2)$$

Where, T_c is the time of concentration in minutes, L is the length of channel reach in m and S is the average channel slope in m/m. The condition to use rational method is that the rainfall throughout the watershed is uniform, but it will never get satisfied. Also the initial losses such as interception and depression storage are not considered in this model.

2.3.2 Cook's Method

The runoff characteristics of a watershed are evaluated by soil infiltration, relief, surface storage and vegetation cover in this method. Based on the observations and comparisons of these features, numerical values are assigned for the model. According to this method,

$$Q_{peak} = p \times f \times r \times s \qquad (2.3)$$

Where, Q_{peak} is the peak runoff for the recurrence interval and specified geographical location of watershed, ‘p’ is the uncorrelated runoff, ‘f’ is the recurrence interval factor, ‘r’ is the geographic rainfall factor and ‘s’ is the shape factor (Bhagat and Patil, 2015).

2.3.3 Curve Number Method

The CN is an empirical, event based method, developed by United States Department of Agriculture Soil Conservation Service (USDA-SCS), now United States Department of Agriculture Natural Resource Conservation Service (USDA-NRCS) which estimates runoff depth under varying soil type and land use using total volume of rainfall has been widely used (Chow *et al.,* 2002; Tasdighi *et al.,* 2018). Several studies have used the CN method to quantify runoff in agricultural, forested or mixed land use watershed and to predict changes in stream flow or runoff under projections of urban growth.

The runoff of Chaka block in Allahabad district of Uttar Pradesh was estimated by Yaligar *et al.* (2015) using SCS-CN method. The daily and monthly rainfall was collected from the weather station in Allahabad Agricultural Institute. AMC has been calculated by taking 5 days preceding rainfall data for each storm event. HSG of the block was considered as C. The weighted CN for the entire block was found to be 78. The maximum rainfall observed was 203 mm for which 2609.33 ha.m runoff volume was produced.

2.3.4 Infiltration Indices Method

The parameters for Greem ampt method is infiltration and other soil inbuilt properties. Viji *et al.* (2015) used Green-ampt method for surface runoff wodelling for the Kundahpallam watershed in western ghats. Sixteen soil samples were collected from different localities for the determination of hydraulic conductivity, moisture content, wetting front capillary pressure, bulk density, porosity etc. The infiltration rate of sample locations is determined by using double ring infiltrometer. All the parameters are assigned to the model to determine runoff characteristics of the study area. The accuracy and goodness of fit of the model are tested by determining the correlation coefficient (0.985) and coefficient determination (0.97) and it indicates statically positive correlations and perfect fit between the results of the study.

Tasdighi *et al.* (2018) assessed the performance of the physically based Green and Ampt (G&A) method in the SWAT model. The study area was Haw watershed in North Carolina which has mixed land use. The surface runoff from each HRU's within sub watershed is routed to the stream network and simulated using modified G&A method with sub daily rainfall. The G&A method along with SWAT model could potentially perform well in areas inside the watershed which has more developed land area and can simulate the stream flow and peak flows in well developed watersheds.

2.3.5 Artificial Neural Network (ANN)

Bhola and Singh (2010) calculated the runoff of Kosi river basin using ANN and NRCS CN method. The NRCS CN method requires the rainfall, soil information and vegetative cover properties while the ANN technique has the ability to learn from examples. Normalization of data was done to limit the range in between 0 and 1 before introducing the ANN model for training. The sigmoid function is selected as activation function. The coefficient of determination (R^2) was found to be 0.82 and 0.89 for NRCS CN method and ANN respectively.

Meher (2013) used ANN based Multilayer Perceptron (ANN-MLP) architecture with feed forward network for rainfall and runoff estimation in Mahanadi river basin, Odisha. The training process to adjust weights and biases was done using historical daily and monthly rainfall-runoff data. Training of the network can reduce the error to a greater extend. The study showed that the network has remarkable generalization ability.

The Artificial Neural Network (ANN) which is a black box model can be used for rainfall runoff modeling without considering the basin characteristics. It requires the historical data of rainfall and discharge for forecasting. The ANN models are powerful methods for predicting rainfall runoff relationship since it has the ability to model both non-linear and linear systems (Kumar and Tiwari, 2015).

2.4 RUNOFF PLOTS

Leonard *et al.* (2005) analyzed dynamics of infiltration and its relation to soil surface properties using 2 m^2 runoff plots. The continuous rainfall runoff measurements from nine plots for seasonal rainfall were considered. The data collected from runoff plots provided better results.

Runoff plots are the structures used to measure overland flow under controlled condition. The plot design, instrumentation and data collection procedures vary from place to place. The runoff plots are constructed to work with natural or simulated rainfall. The plots with natural rainfall are simple in construction and data collection will depends on the occurrence of rainfall. The soil and other parameters such as slope vegetations etc, can be changed or conserved as per the requirement. The runoff plots with artificial rainfall facility are equipped with rainfall simulators. The bounded type plots are use for the measurement of runoff and the plot size varies from 1 m^2 to 1 ha. The sheet flow will be encouraged to occur in planar surfaces. The plots are designed in such a way that it should ensure free flow of water over the surface without any interference from lateral sides of the plot. The rectangular plots will produce more runoff in comparison with round plots. Vertical drop at the bottom end of the plot surface is recommended. Also the storage system must have sufficient capacity to hold the runoff water without overflow (Kinnel, 2016).

Li *et al.* (2016) used runoff plots of 3.34 m^2 area for the determination of runoff coefficient characteristics and factors influencing it. Using the volume of runoff collected and the area, runoff depths were calculated. The results showed that the runoff data collected from the plots was consistent in estimating runoff characteristics.

Anache *et al.* (2017) analyzed the number of plot scale studies under natural rainfall in Brazil. The study reported the importance of field observations in the analysis of rainfall runoff behavior. Zhang *et al.* (2018) used field runoff plots to analyze the effect of topographic factors such as slope gradient and length on runoff in Southwest China and Defersha and Melesse, (2011) used runoff plots for analyzing the effects of land use on runoff and sediment yield.

2.5 FLOW MEASUREMENT

The measurement of water available from a particular source can be done with different flow measuring devices. The weirs and flumes are most commonly used structures because the measurements can be taken more precisely when installed properly (FAO, n.d). Inorder to obtain stage discharge relationship, pre calibrated structures such as weirs and flumes can be used. The area velocity method requires measurement of flow velocity, stage and cross sectional area. Portable devices such as current meters with revolving cups or Doppler, radars or electromagnetic technology can be used for the flow measurements. Mean flow velocity in the desired section is determined. Continuous measurement of stage can also be recorded and converted to discharge. Sensor types commonly used for this purpose are non contact sensors and floats. The installation of staff gauge is also recommended for the head measurements (Suresh, 1993; Harmel *et al.,* 2006).

The conventional flow measuring devices can easily become clogged with debris and sediments, especially for major runoff events. The loss of extreme event records will affect the analysis (Edwards and Owens, 1991). The drop box weirs (DBW) are designed in such a way that to overcome such problems of sediment entrainment and clogging. It keeps the V section of the weir clear without the sediments by creating turbulence in a box at the entrance of the water flow (Bonta and Pierson, 2003). Bonta (2002) analyzed the performance of modified drop box weir along with Coshocton wheel sampler. The sampling slot of Coshocton wheel was investigated to duplicate water sampling and control splashing of water. It was found that the Coshocton wheel worked well with drop box weir for steady and unsteady flow conditions.

Sun *et al,* (2014) designed and evaluated a portable insitu runoff monitoring device for plots ranging from 0.005 to 0.1 ha. The device has a runoff gauge which is capable of measure flow rates upto 82 mm h^{-1}. Calibration results showed that there is a maximum error of 2.1% for the device. Patak *et al*. (2016) measured surface runoff from two small agricultural watersheds in ICRISAT center at Patancheru using water-stage-level recorders and hydraulic structures. The Integrated Digital Runoff and Soil Loss Monitoring Unit (IDRSMU) which has Data Logger Cum Microprocessor Control Unit (DLCMCU) continuously measured the runoff in the drain by a float operated shaft encoder. This measured the surface runoff water level with least count of 1 mm.

2.6 CURVE NUMBER METHOD

The surface runoff of upper Bhopal Lake was calculated by Dwivedi *et al.* (2017) using curve number method. Around 80% of the catchment area was agricultural land, whereas 5% was forest area and rest was urban area. Right from the starting of the monsoon season itself it was found that the lake was receiving runoff. The water scarcity problem of the basin can be reduced since the region has good surface hydrologic environment. The study helped in proper planning and implementing runoff control measures.

Viji *et al.* (2015) used modified NRCS CN method to estimate runoff from a watershed in Nilgiri. By this method runoff at a point in the watershed is calculated using the equation 2.4 and 2.5.

$$q = P_e - \sigma \qquad \text{for } P_e > \sigma_e \qquad (2.4)$$

$$q = 0 \qquad \text{for } P_e \leq \sigma_e \qquad (2.5)$$

where, q is the runoff at a point location in mm, P_e is the depth of effective rainfall after runoff begins in mm and σ_e is the depth of local effective available storage after runoff begins in mm.

The depth of effective rainfall and local effective available storage after commencement of runoff were calculated by the equation (2.6).

$$P_e = P - I_a \qquad (2.6)$$

The depth of local effective available storage after runoff begins with each area was determined by equation (2.7)

$$\sigma_e = \frac{2S_e\left(\sqrt{1-A_{s,i}} - \sqrt{1-A_{s,i+1}}\right)}{A_{s,i+1} - A_{s,i}} - S_e \qquad (2.7)$$

where, S_e is the depth of effective available storage in mm and it is calculated by the equation (2.8)

$$S_e = 254\left(\frac{100}{CN_{II}-1}\right) \qquad (2.8)$$

Where, $A_{s,i}$ is the area of the watershed that has lower local moisture storage in m^2 $A_{s,i+1}$ is the area of the watershed that has higher local moisture storage in m^2 and CN_{II} is the curve number for average watershed moisture content. The curve number was chosen on the basis of soil type and land use characteristics.

Vithlani *et al.* (2016) estimated runoff for a semi arid region using SWAT model based on NRCS CN method. The best fit rainfall runoff relationship from the area for the NRCS method was given in equation 2.9.

$$R = 0.302\,P - 32.05 \quad (R^2 = 0.85) \qquad (2.9)$$

Where, R is the seasonal runoff (mm) and P is the seasonal rainfall (mm).

The weighted curve number for the Aji basin was 72.00. The coefficient of determination (R^2) for the daily and monthly runoff was obtained according to the SCS-CN and SWAT model are 0.852 and 0.947 respectively.

2.6.1 Parameters

The curve number method is most commonly used for ungauged watersheds because of its easily attainable watershed parameters and rainfall data (Singh, 2014). Land use and soil types are the main parameters required by the model. Based on the soil texture Hydrologic Soil Group (HSG) can be determined. The curve numbers are selected according to the land use and soil groups from standard tables.

2.6.1.1 *Land use*

Sound knowledge on land use/land cover distribution in a particular area is more important for reliable and accurate hydrological modeling. Many researchers have shown that the land use/land cover type is a functional character of an area which indicates occupation and culture (Kamaruzaman, 2009). The land use changes can be effectively detected using Remote Sensing (RS) techniques (Prakasam, 2010). The multi spectral, multi temporal, multi resolution Remote Sensing data can be turned to useful information (Nayak *et al.,* 2012).

Land use map for Jojri basin was prepared by Sharma and Singh (1992) using satellite data. False color composite (FCC) from Landsat TM generated by combination of bands 2, 3 and 4 on a scale of 1:50.000 was used. The FCC corresponding to the post-monsoon season with less cloud cover was selected. Based on the tonal variations and morphological features, the land use/land cover features were interpreted and demarcated.

Nayak *et al.* (2012) assessed the impact of land use change on the direct runoff volume for same rainfall depths in the Uri watershed of Narmada basin. The land use changes are evaluated in terms of curve number for the year 2001 and 2007 and interpreted in ILWIS GIS platform. A decrease in the forest area by 35% was observed and the average curve number value of AMC II was increased from 80.24 to 82.26. There was also a 20% to 40% increase in the runoff in the year 2007 than in year 2001 for the same rainfall events. Thus the study showed that the variation is due to the reduction in forest cover.

Malarvizhi *et al.* (2015) prepared land use map for an urban area, Vellore, Tamil Nadu. High resolution Google Earth images covering the study area were extracted and onscreen digitizing was done using GIS software. The land use map was prepared and zone wise analysis was done for various land use classes. Using Google Earth imagery urban change was analyzed. Google Earth is an excellent source of information which can be used in land use preparation.

2.6.1.2 *Hydrologic Soil Group (HSG)*

Bansal and Suman (2013) estimated runoff and soil erosion using GIS in NIT Hamirpur campus. The measurement of direct runoff was carried out using NRCS CN method. Field experiment for classifying the soil across NIT campus showed that it has soil of type A. Further according to land cover data lumped CN for AMC-II condition was calculated to be 36.7.

2.6.1.3 *Curve Number*

The curve number is a dimensionless parameter which indicates runoff responses of a drainage basin. It is mainly influenced by land use and soil type of the area. The curve number indicates the runoff potential of a complex storm during the particular period.

Hong and Alder (2008) attempted to derive a global curve number map for NRCS CN method. The HSG was categorized from digital soil map and land use map from Moderate Resolution Imaging Spectroradiometer (MODIS) of USGS. The curve numbers was estimated according to USDA and NEH-4 (1954) standard lookup tables. Jadhao *et al.* (2010) calculated the average weighted curve number for an agricultural watershed referring standard curve number tables for Indian conditions. Based on the hydrological conditions, soil properties and antecedent moisture condition (AMC II), the weighted average value of curve number for the Arang watershed was found to be 89 for the year 2002.

For Kardeh watershed, the HSG A and B lead to low CN value whereas the HSG D had higher CN value. The highest curve number value was found to be 93 in settlement areas and for forest and range lands the curve number value was found to be 35 and 36 which is in good condition (Ebrahimian, 2012). Chavda *et al*. (2016) estimated surface runoff in a catchment using curve number method and the weighted curve number was found to be 73. The parameters such as land use, soil cover and antecedent moisture condition were used.

2.6.1.4 ***Initial Abstraction Ratio (I_a)***

Baltas *et al*. (2007) determined and analyzed the initial abstraction ratio for an experimental watershed in Greece. The study was done by analyzing the 18 storm runoff events. The determined values of initial abstraction ratio were found to be closer to the suggested ratio of 0.05 by many researchers. The average ratio for northern sub watershed was 0.037 and for entire watershed it was found to be equal to 0.014. The urban development and human interventions along with impervious geological formation in the southern part led to the decrease in the initial abstraction ratio of the watershed. Therefore the runoff yield from these regions was higher.

Shi *et al.* (2008) determined the initial abstraction ratio for an experimental watershed in the Three Gorges of China and compared the results with the value suggested in the original development of SCS-CN method. The analysis was done using 6 years of rainfall runoff data sets measured from the experimental watershed. Using event rainfall-runoff data, the results varied with a median of 0.048 from 0.010 to 0.154. The average initial abstraction ratio for the watershed was found to be 0.053. The new value predicted runoff with an R^2 of 0.804.

2.6.1.5 ***Potential Maximum Retention (S)***

Chen *et al.* (2002) spatially modeled potential soil water retention which is driven by NRCS CN method using remote sensing and GIS. The spatial distribution of curve number was determined by intersecting soil and land cover data in ArcGIS which resulted the retention capacity map. The study showed that the essential information can be provided to environmental models by using remote sensing and GIS along with spatial hydrologic models.

Abu-Hashim *et al.* (2015) assessed potential soil water retention for an arid region using NRCS CN method by collecting soil samples with different hydrologic groups and land use. The potential soil water retention was reduced by 118.1 m^3 per ha from 1990 to 2015 due to decrease in cropland area. During this time frame of study, the urban lands were increased by 2.13% and croplands were decreased by 15.3%. The GIS technique provided better results of S value of the NRCS CN method.

2.7 STUDIES USING CN METHOD IN GIS ENVIRONMENT

Ebrahimian *et al.* (2009) estimated runoff using Natural resource curve number with GIS in Kardeh Watershed, Iran. Hydrologic soil group, land use and slope maps were generated in GIS environment. The curve number values from NRCS standard tables were assigned to the intersected hydrologic soil groups and land use maps to generate CN values map. The results indicated that the combined GIS and CN method can be used in ungauged watershed successfully.

Jadhao *et al.* (2010) estimated surface runoff from an agricultural watershed in eastern plateau of Mahanadi basin. The hydrologic soil group was determined on the basis of soil texture map generated using soil resource data collected by field visits in the watershed. The land use/cover map was prepared from IRS 1D (LISS III) image collected from National Remote Sensing Agency (NRSA). Supervised classification method in Maximum Likelihood Classifier (MLC) module of ERDAS IMAGINE image processing software was used to classify the land use. The weighted CN for the watershed was found to be 89. The coefficient of determination (R^2) of 0.73 indicated the close relationship between simulated and observed runoff.

Kumar *et al*. (2010) estimated runoff from a watershed in Hyderabad and Mahabubnagar district in Andhra Pradesh using SCS-CN method and Geographic Information Systems. The analysis indicated that there is a strong correlation between the obtained curve number values from the measured runoff and depth of rainfall. The hypothesis revealed the existence of an impermeable part in the permeable watershed at certain depth. It was found by simulation of the water flow model for the surface runoff prediction in different soil types of the watershed. The results support the linear runoff formula for better results.

Shadeed and Almasri (2010) studied about the application of GIS based SCS-CN method in West Bank catchments, Palestine. The approach was developed in this study to calculate the composite curve number of West Bank catchments. The soil texture of the region was defined on the basis of data published by the Ministry of Planning and International Cooperation (MPIC). The related attribute table data of HSG and land use were used to determine CN_{II} value for each catchment. Selected storm events in a sub catchment were chosen to access the applicability of the SCS-CN method in producing runoff amounts. The model output was compared with observed data for a given rainfall event. The simulated runoff values of the selected events were found slightly greater than observed ones. The runoff depth variation (D_v) values range between 7% and 20%. The applicability of the GIS based SCS-CN approach for the region in estimation of runoff was found to be 85%.

Bansode and Patil (2014) determined the runoff by using SCS Curve Number method and Arc GIS. The study area was delineated from the toposheet obtained from soil and survey department in Pune, Maharashtra. The land use/land cover map of the basin was prepared by using visual interpretation technique from IRS LISS-III data with a scale of 1:50,000 obtained from IRS Hyderabad. The Hydrologic Soil Group of the area was assigned according to the soil map obtained from National Bureau of Soil Survey and Land Use Planning (NBSS & LUP). Three HSG was found in the area: Group B, Group C and Group D. Among them majority of the area have Group C (>55% of total area). The curve number values were identified on the basis of land use type and HSG according to the HSG table by the National Bureau of Soil and Land use planning (NBSS & LUP). Based on the observations the average curve number and specific retention 'S' was calculated as 74.75 and 85.79 respectively. The calculated yearly runoff of the study area in mm for the years from 2003 to 2012 is 430, 401, 214, 582, 279, 499, 341, 707, 271 and 135 mm respectively. Minimum runoff was observed in the year 2012 and maximum runoff was observed in the year 2010 by using SCS-CN method.

Gitika and Ranjan (2014) estimated the surface runoff using NRCS curve number procedure in Buriganga watershed, Assam. Runoff varied spatially due to changes in soils, land use, slope and temporarily due to changes in soil water content etc. The mean annual surface runoff of the study area is varied from 572.40 mm to 1605.19 mm.

Zende *et al.* (2014) analyzed the rainfall – runoff from Yerala river basin, using NRCS CN method and GIS. The daily rainfall measurements of 10 rain gauge stations (1998 – 2011) was collected and used to predict the daily runoff from the watershed. For the study period 1998-2011, minimum and maximum of yearly average rainfall were 232.55 mm and 759.87 mm respectively and the yearly average runoff were 39.40 mm^3 and 153.63 mm^3 respectively. The weighted curve number for the area was found to be 87.49. The developed rainfall–runoff model has been used to understand the characteristics of the watershed and its runoff.

Ahmad *et al.* (2015) applied NRCS curve number method along with gis to estimate potential runoff. The IRS-LISS III satellite data of scale 1:50,000 was collected from Bhuvan portal of ISRO and soil data from National Bureau of Soil Survey & Land Use Planning (NBSS & LUP). The daily rainfall data from 1993 to 2005 was used. For each identified rain gauge stations, Theissen polygons were established. For each Theissen cell, weighted CN was determined. For those rainfall events which has intensity less than 0.3S, the runoff depth was taken as zero. The study stated that, land use planning and watershed management can be done effectively and efficiently using SCS-CN number method with GIS.

Buktar and Regulwar (2015) computed runoff using NRCS CN method and GIS with spatial and nonspatial data collected from various departments. The land use/land cover map was prepared from IRS LISS III satellite image and toposheet from Survey of India (SOI). The soil data was collected from NBSS, Nagpur, Digital Elevation Model (DEM) was derived from SRTM and IMD Pune provided rainfall data. The software used for the computation is Quantum GIS 2.2 and ERDAS Image 9. It was found that predominant land use was more than 60% of agricultural fields and predominant soil group was B. The calculated curve numbers for normal, wet and dry conditions were 85.92, 72.8 and 93.46 respectively. The calculated average annual runoff came to be 488.7mm and runoff volume for 26 yr is 4828.58Mm^3. The study revealed that the integration of remote sensing data along with curve number method in GIS platform is a powerful tool for the assessment of runoff. The study also suggested that there should be proper planning and management for controlling the runoff and thereby soil loss.

Inorder to estimate the water availability and surface runoff for two sites in Ozat catchment, Gujarat GIS based curve number method was used. It was found that calculated and observed runoff were good for both catchments. The NRCS-curve number method along with RS and GIS can be used successfully in semi-arid region to estimate runoff and to estimate total surface water (Chavda *et al.,* 2016).

Satheshkumar et al. (2017) estimated the rainfall-runoff using SCS-CN approach in the Pappiredipatti watershed of the Vaniyar sub basin, South India. The land use and land cover map are generated from Satellite image LISS III, toposheet were collected from Survey of India. The soil types (black soil, red soil and clay), texture and structure details were collected from Survey of india, Digital Elevation model (DEM) derived from USGS Website and rainfall data collected 2000–2014 from PWD Dharmapuri. For a given study area that is pappiredipatti watershed CN number calculated was 75.4 for AMC -I, 28.4 – AMC-II and 87.5 for AMC-III. The average annual runoff calculated come to be 181.7 mm and average runoff volume for fifteen years was 32,682,501 mm^2. The rainfall- runoff of the watershed are vigorously correlated with a correlation coefficient (R^2) value being 0.84.

2.8 VALIDATION OF MODEL

Patil *et al.* (2008) compared the calculated runoff depths using NRCS CN method with the runoff depth observed at the watershed outlet for selected rainfall events. The model was validated with 52 rainfall-runoff events for its AMC conditions and rainfall depths. The data was equipped with a rain gauge and stage level recorder in the gauging station located at outlet of the watershed. The R^2 values ranged from 0.42 to 0.92 and E ranged from 0.36 to 0.89. Ranzi *et al.* (2003) validated the NRCS CN method for Alpine basin. On the basis of storage changes and runoff measurements at stream gauges the runoff volumes were computed at 12 reservoirs in the basin.

Shadeed and Almasri (2010) evaluated the performance of NRCS CN method in West bank catchments of Palestine. Four rainfall events were chosen and discharge is measured in the outlet using flume. The runoff depth deviation (D_v) varied from 7 % to 19 % for the events. The results showed that the estimated and observed runoff depths of the four events were close enough to assume the applicability of the GIS-based SCS-CN approach for the region.

Yu *et al*. (2012) validated the NRCS CN method for runoff estimation in 7 sites of Australia and South East Asia. The study focused on the accuracy of the parameter values (ie, curve numbers) and it supported the assumption of proportionality given by NRCS between runoff and retention. The study showed that that the ratio between actual retention to maximum retention is directly proportional to the ratio of actual runoff to potential runoff.

CHAPTER III

MATERIALS AND METHODS

This chapter covers the description of the study area and methodology adopted for the study. The degree of accuracy of any prediction tool depends upon the correctness of the data sets along with relevant information and methodology adopted. Based on the reviews conducted, the NRCS curve number method along with GIS was used for the study. Different parameters for the runoff estimation are detailed in this chapter. The validation of the curve number method was also done using the field measurements.

3.1 DESCRIPTION OF THE STUDY AREA

The study was conducted in the KCAET Campus which is located in Tavanur village of Malappuram district. Area lies between 10° 51′ 6.51″ to 10° 51′ 31.417″ N latitude and 75° 59′ 2.37″ to 75° 59′ 25″ E longitude with elevation of about 13 m above MSL. The study area covers about 40 ha nourished by the river Bharathapuzha in the Northern side. The climate of the area falls under humid tropic and generally dry except during south west monsoon season. Average rainfall of the region is 2952 mm, in which south west monsoon contributes more. The average annual temperature of the study area is 30 °C and during summer it goes upto 33 °C to 37 °C (Deepak *et al.,* 2007). The soil is mainly loamy in texture and the soil temperature regime is isohyperthermic. The study area has undulating topography and varying land use patterns. Coconut, mango, paddy etc. are extensively cultivated in the area. The location map of the study area is given in Fig 3.1.

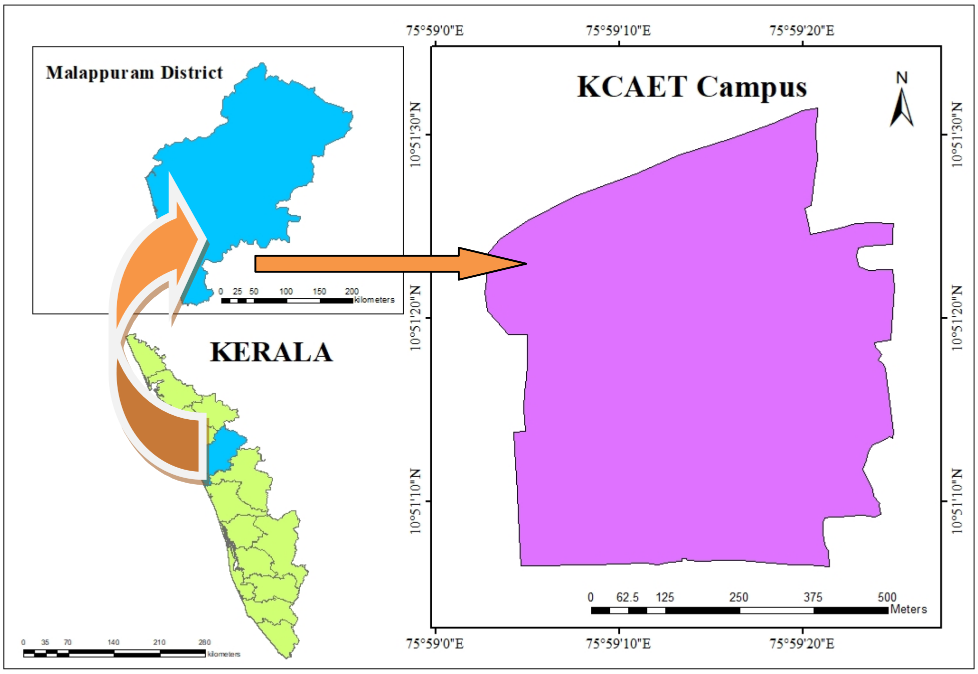

Fig. 3.1 Location map of the study area

3.2 SOFTWARE AND TOOLS USED

Software and tools used for the analysis are briefly described below.

3.2.1 Geographic Information System (GIS)

GIS can be summarized as a computer based software technology for capturing, storing, checking, integrating, manipulating, analyzing and displaying spatially referenced data. Thus the backbone of GIS is assembly hardware, software programs and databases. GIS uses any data that includes location or geospatial tag such as geographic co-ordinates. The basic functionality of GIS software is to process and display the data which have a spatial component. The location of the data model can be determined from the spatial information. The attributes or specific characteristics of the objects are also included within the data model. The attributes such as area, length and count are essential to differentiate between the data models (Singh, 2014; Unwin, 1996).

Mainly two spatial data types are used, raster and vector files. The point, line and polygon features are defined as vector data. The vector data models are used for storing and representing the discrete features such as buildings and ponds, as shape files. The rectangular matrix of cells are composed to form raster data model. Each cell has a cell value which represents the magnitude or spectral value. The reference system or projection defines the location of each cell. The complex spatial information is stored by GIS software in separate thematic layers (Singh, 2014; Unwin, 1996). This research work carried out using the Datum WGS_1984_UTM_Zone _43N for all data types.

3.2.2 ArcGIS 10.2

ArcGIS is a proprietary software developed by Environmental System Research Institute (ESRI) and was initially released in 1999 in NewYork. The particular version which was released in 2013 was used for the study. ArcGIS provides vector data as shape files and raster data as rectangular matrix of cells. The GIS stores each category of data as separate layer for ease of maintenance, analysis and visualization. It can store attribute data which is descriptive information of map features. ArcGIS for Desktop is licensed under three functionality levels and they are ArcGIS for Desktop Basic (ArcView), ArcGIS for Desktop Standard (ArcEditor) and ArcGIS for Desktop Advanced (ArcInfo). Among them, ArcGIS for Desktop Advanced which have more advanced tools for data manipulation, editing and analysis were used in this study.

ArcGIS for Desktop version consists of several integrated applications such as ArcCatalog, Arctoolbox, ArcMap etc. The user interface of ArcGIS 10.2 with Arc toolbox if given in Fig 3.2.

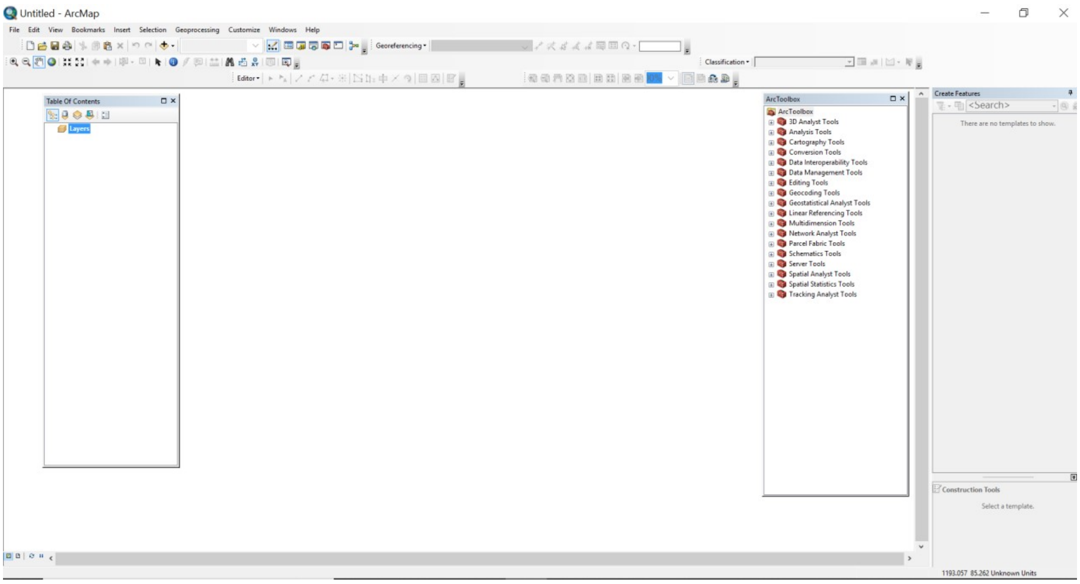

Fig. 3.2 User interface of ArcGIS 10.2

3.2.3 Google Earth Scenes

The land use map of the study area was prepared by digitizing from Google Earth imagery of 2018. Google Earth is a software that renders 2D and 3D representation of earth based on satellite imagery. It is formed by superimposing aerial photography, GIS data and satellite imageries onto a 3D globe with addresses and coordinates. It features realistic imagery of places (Sheppard and Cizek, 2008).

The core technology behind the Google Earth was originally developed at Intrinsic Graphics in 1990s. The spinning globe which was developed as a demo was later converted to Google Earth. The Google Earth supports the learning process by allowing the users to engage in the lesson, explore the earth, explain the identified area of interest and evaluate the implications (Patterson, 2007). The users can digitize and save the area of interest as *.kml* files. The user interface of Google Earth is shown in Fig. 3.3 and the view of KCAET Campus in Google Earth is shown in Fig. 3.4.

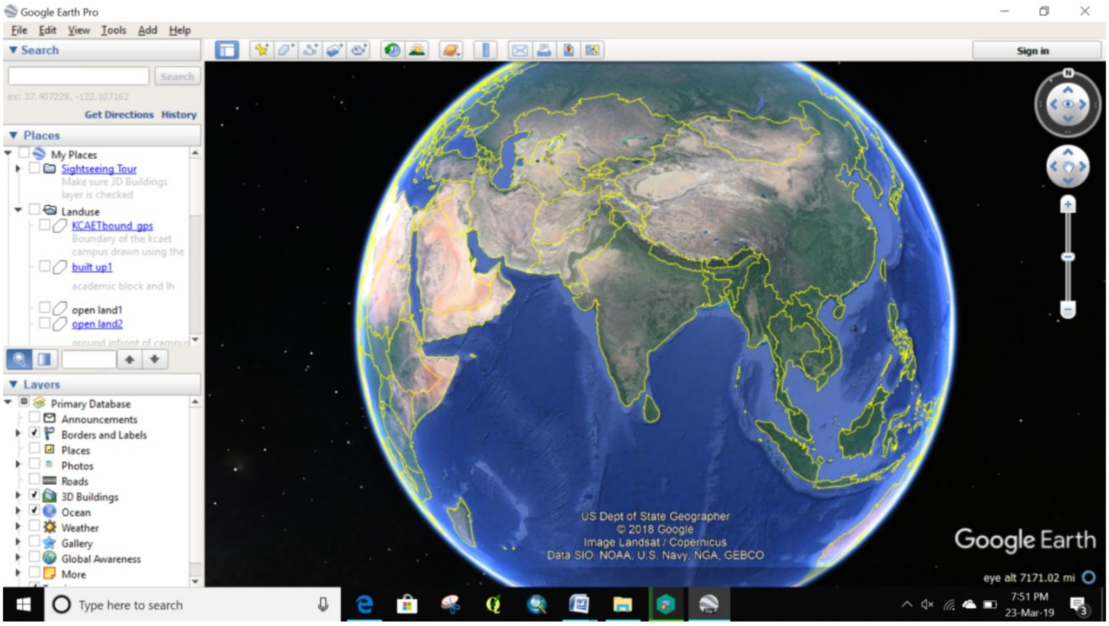

Fig. 3.3 User interface of Google Earth

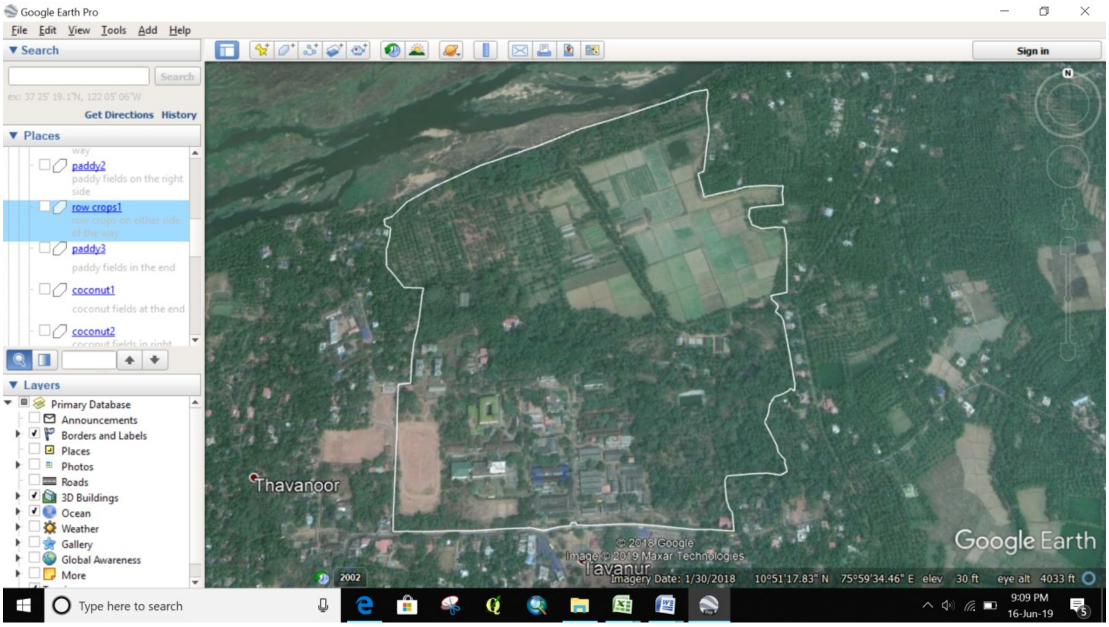

Fig. 3.4: Google earth view of KCAET Campus

3.3 METHODOLOGY ADOPTED

Runoff is the surface flow of precipitated water through a channel in the catchment area after satisfying all the subsurface and surface losses. One of the dynamic features of runoff is that it will affect the nature of flora and fauna and rate of weathering and erosion (Gitika and Ranjan, 2014). Also it is the most important hydrologic variable used in most of the water resource applications. Direct measurements of runoff provide excellent and timely data, but it is limited in use to exact location from where it was collected (Raj, 2017).

The NRCS CN method developed by Soil Conservation Service (SCS) now NRCS (Natural Resource Conservation Service) of United States Department of Agriculture (USDA) is a stable and well established conceptual method for the estimation of runoff (Amutha *et al.* 2009;Ebrahimian *et al.* 2012;Jabari *et al,* 2009;Singh, 2014) was used in the study. Based on the rainfall events of 2005, 2006, 2018 and 2019, runoff was estimated using the NRCS CN method for the years 2004 to 2007, 2018 and 2019.

3.3.1 NRCS CN Method

The curve number method of estimating direct runoff from storm rainfall is the result of field investigations and research of a number of early investigators (USDA[a], 2004). The runoff curve number equation is:

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \qquad P > I_a \qquad (3.1)$$

$$Q = 0 \qquad P \leq I_a \qquad (3.2)$$

Where, Q is the depth of runoff, in mm; P is the depth of rainfall, in mm; I_a is the initial abstraction, in mm; S is the maximum potential retention, in mm. The NRCS CN method based on water balance equation has two primary assumptions. First, the ratio of the actual amount of runoff (Q) to maximum potential runoff is equal to the ratio of the actual infiltration (F) to the potential maximum retention or infiltration (S). For initial abstraction loss, I_a=0:

$$\frac{F}{S} = \frac{Q}{P} \qquad (3.3)$$

Where, F is the actual retention after runoff begins, in mm

To satisfy the conservation of mass, F=P-Q

$$\frac{P-Q}{S} = \frac{Q}{P} \qquad (3.4)$$

And solving for Q gives,

$$Q = \frac{P^2}{P+S} \qquad (3.5)$$

This is the rainfall-runoff relationship in which the initial abstraction Ia is zero.

When the initial abstraction is not zero, the amount of rainfall available for runoff is (P – Ia) instead of P. Substituting (P – Ia) for P in equation gives

$$\frac{F}{S} = \frac{Q}{P-I_a} \qquad (3.6)$$

And F=(P-Ia) – Q (3.7)

Solving for the total storm runoff, Q, results in the runoff equation

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \qquad (3.8)$$

The initial abstraction consists mainly of interception, infiltration during early parts of the storm and surface depression storage. Interception and surface depression storage may be estimated from cover and surface conditions, but infiltration during the early part of the storm is highly variable and dependent on such factors as rainfall intensity, soil crusting and soil moisture. Second assumption is the amount of initial abstraction (I_a) is considered as some fraction of potential maximum retention (S).

$$Ia = \lambda S \qquad (3.9)$$

Where λ is the fraction of potential maximum retention and it was taken as 0.2 in this study.

3.4 BOUNDARY OF THE STUDY AREA

The boundary of the KCAET Campus was demarcated using GPS survey. The Global Positioning System (GPS) is a promising technology which provides flexibility and accuracy of surveying, positioning for navigation and GIS data capture. The location of the boundary points were identified using handheld GPS available at geo-spatial division of KCAET, Tavanur. These have receivers characterized by portable and small, battery powered and an inbuilt display. The principle behind GPS is the range between the receiver and satellites. The operation is based on a simple mathematical principle called trilateration. Land surveying using GPS technique is more appropriate than GIS for delineation of boundary for small areas (Jabari, 2007). The surveyed points are shown in Fig. 3.6. The points were transferred into ArcGIS. It is then converted from layer to kml file using conversion tool in arc toolbox (Fig. 3.5). The *.kml* file is opened in Google Earth and polygon boundary was created using the surveyed points. The polygon feature created was saved as shape file for further operations. The obtained boundary of the study area is shown in Fig. 3.7.

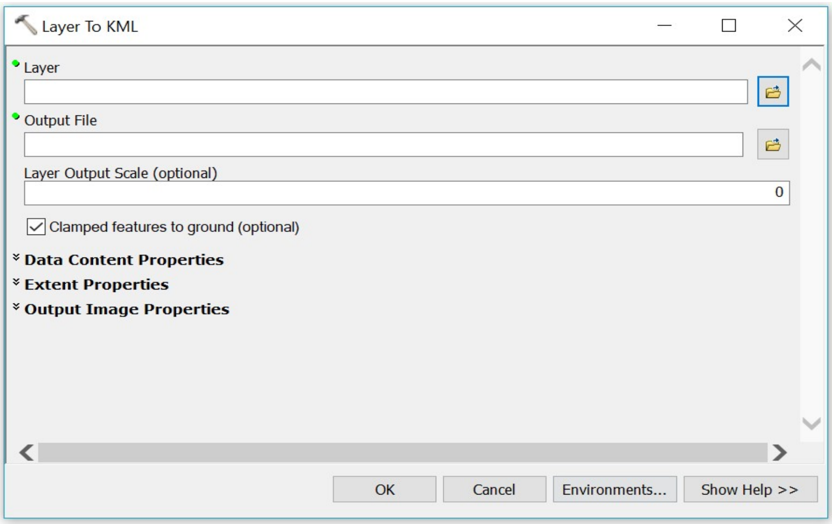

Fig. 3.5: Layer to kml conversion tool

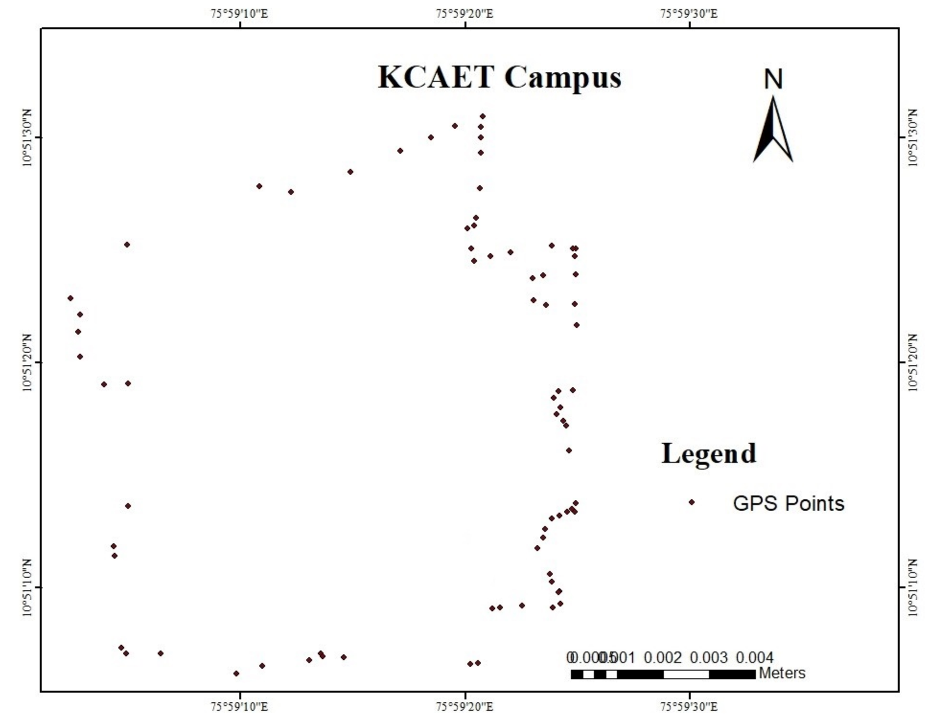

Fig. 3.6: GPS Points of Boundary

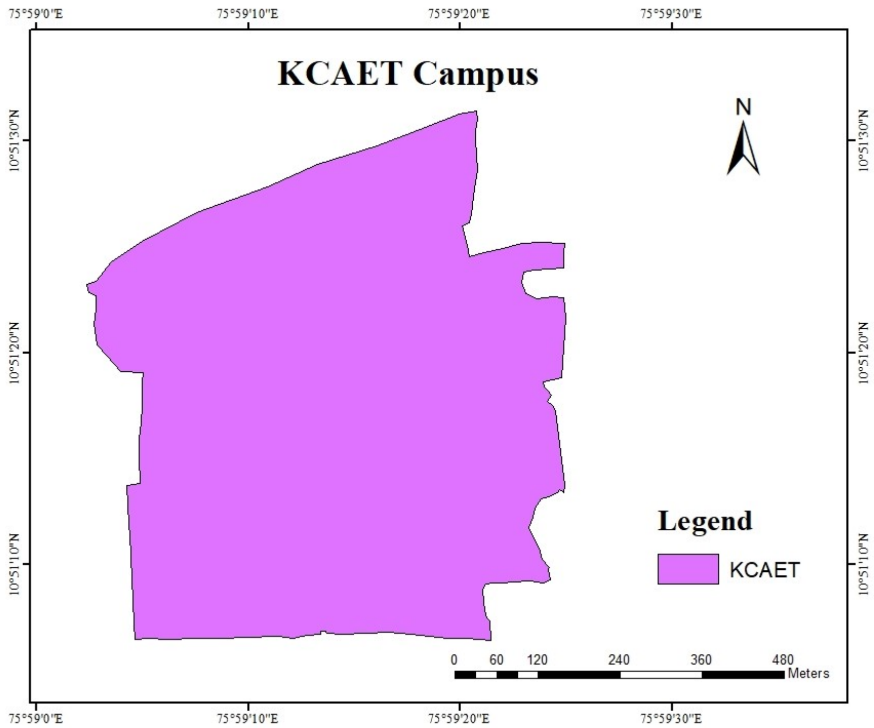

Fig. 3.7: Boundary of the study area

3.5 DEVELOPMENT OF MODEL DATABASE FOR NRCS CN METHOD

The NRCS CN method relies on only one parameter, the curve number. Curve number is a function of land use and HSG (Hydrologic Soil Group) (Muthu and Santhi, 2015). The preparation of thematic maps for these parameters is detailed below.

3.5.1 Rainfall Parameter

Rainfall is an important hydrologic phenomenon which cause runoff usually expressed in millimeters or inches. A rainfall map shows the amount of rainfall received in an area in a given period of time. In general not all the rainfall events are responsible for runoff. According to NRCS CN method, the runoff will occur for the events with $P > I_a$, where I_a is equal to 0.2 times potential maximum retention (Chow *et al.,* 2002; Srivalli and Singh, 2017). The daily rainfall data of the year 2004, 2005, 2006 and 2018 were collected from the non recording (Simons) type rain gauge in the meteorological observatory of the KCAET campus. The rain gauge is located in 10° 51′ 7.14″ N latitude and 75° 59′ 8.22″ E longitude. The tipping bucket (recording type) rain gauge is used to measure storm rainfall depths and it is located in 10° 51′ 7.02″ N latitude and 75° 59′ 8.46″ E longitude.

3.5.2 Preparation of Soil Map

The amount and rate of runoff from an area is affected by the infiltration rate, soil type and the surface roughness. The degree of percolation of water into the soil is influenced by the soil texture. The soils which have more pore space will allow water to infiltrate but the runoff risk is higher for the soils which does not have much pore space.

The Natural Resource Conservation Service (NRCS) classified the soils into four classes A, B, C and D based on the soil characteristics. Sieve analysis was done to find the soil texture of the study area. The soil samples collected from 20 different locations in the study area was analyzed in the soil laboratory of

KCAET, Tavanur. The GPS points from where soil samples are taken is shown in Fig. 3.8. 500g of oven dried sample was taken from each specimen and hand sieving was done for 10 minutes for all samples. Soil with small particle should be sieved for at least 10 minutes (Punmia *et al.,* 2005; Jabari, 2007). 2 mm, 0.02 mm and 0.002 mm sieves were used for the analysis. The amount of soil retained on each sieve was weighed and percentage retained was calculated. Soil texture of each sample was determined out using USDA soil texture calculator. The output obtained from the online USDA texture calculator (Fig. 3.9) was validated with graph obtained from soil textural triangle (Fig. 3.10).

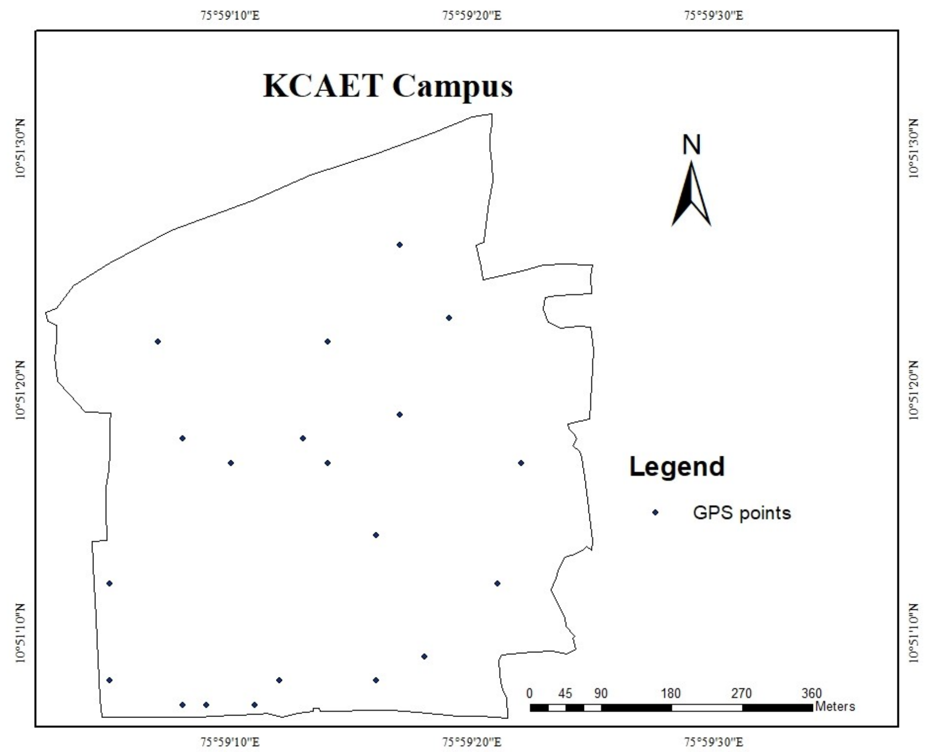

Fig. 3.8: Soil- GPS Points

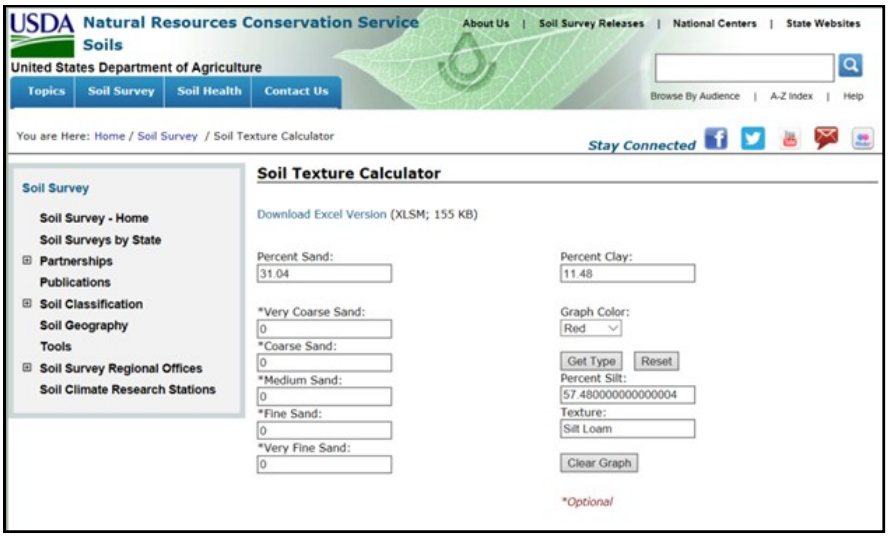

Fig. 3.9: USDA Soil Texture Calculator

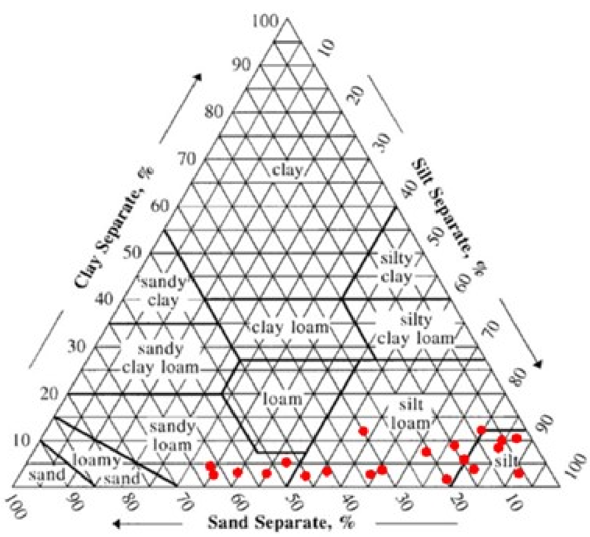

Fig. 3.10: Textural triangle

The soil types in the region were identified as sandy loam, silt loam and silt. Hydrologic Soil Groups (HSG) of the study area was found out on the basis of soil texture (Bhola and Singh, 2007; Jabari, 2007; Satheeshkumar *et al.,* 2017; Shadeed and Almasri, 2010; USDA, 1972). The HSG for different soil textures given by USDA is given in table 3.1.

Table 3.1. HSG for USDA soil texture classes

HSG	Soil Texture
A	Sand, loamy sand or sandy loam
B	Silt or loam
C	Sandy clay loam
D	Clay loam, silt clay loam, sandy clay, silt clay or clay

Different hydrologic soil groups and their characteristics given by USDA[a] (2004) were described below.

- Group A- These soils have low runoff potential. Water transmission capacity is high. The percentage of clay is less than 10% and sand or gravel is greater than 90%.
- Group B- These soils have moderately low runoff potential. Water transmission capacity is unimpeded. The percentage of clay is around 10% to 20% and sand is 50% to 90%.
- Group C- These soils have moderately high runoff potential and water transmission is somewhat restricted through the soil. Percentage of clay vary from 20% to 40% and sand less than 50%.
- Group D- These soils have high runoff potential and water transmission is restricted or very restricted through the soil. The clay content is greater than 40% and sand is less than 50%.

The inverse distance weighting method (IDW) in ArcGIS is used to interpolate the soil types identified from the 20 points in the study area. The IDW interpolation tool in ArcGIS is shown in Fig. 3.11.

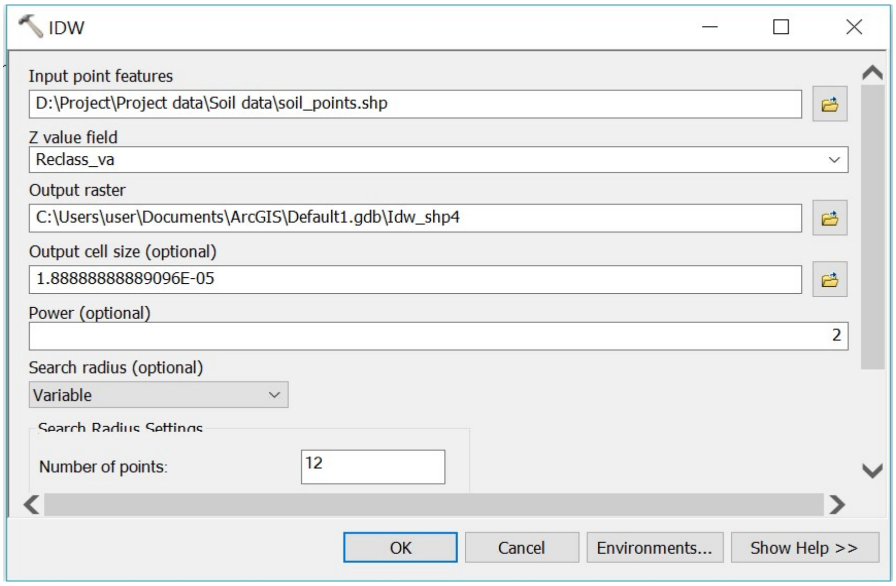

Fig. 3.11: IDW interpolation tool

3.5.3 Preparation of Land use Map

The land use/land cover shows present or past status of earth surface. The land cover refers to the biophysical state of the surface of earth which includes soil material, vegetation, water etc. The land use is the utilization of land resources by human being. The land cover change reflects in the impact on environment which is due to excessive human interventions (Singh, 2014). The Google Earth tool was developed recently and is widely used in many sectors. The Google Earth which releases high spatial resolution images is a free and open data source. The Google Earth images will provide detailed land use/land cover mapping facilities with relatively satisfactory results (Hu *et al.,* 2013).

Land use map of the study area was prepared by digitizing from Google Earth imagery 2006 and 2018. Land use features like vegetation (mango orchard, scattered coconut patches, agricultural fields), agricultural structures and built up area have been digitized. The land use classes were identified on the basis of ground truthing. The digitized files in Google Earth are transferred to ArcGIS for the map preparation. The procedure of land use mapping is shown in Fig. 3.12.

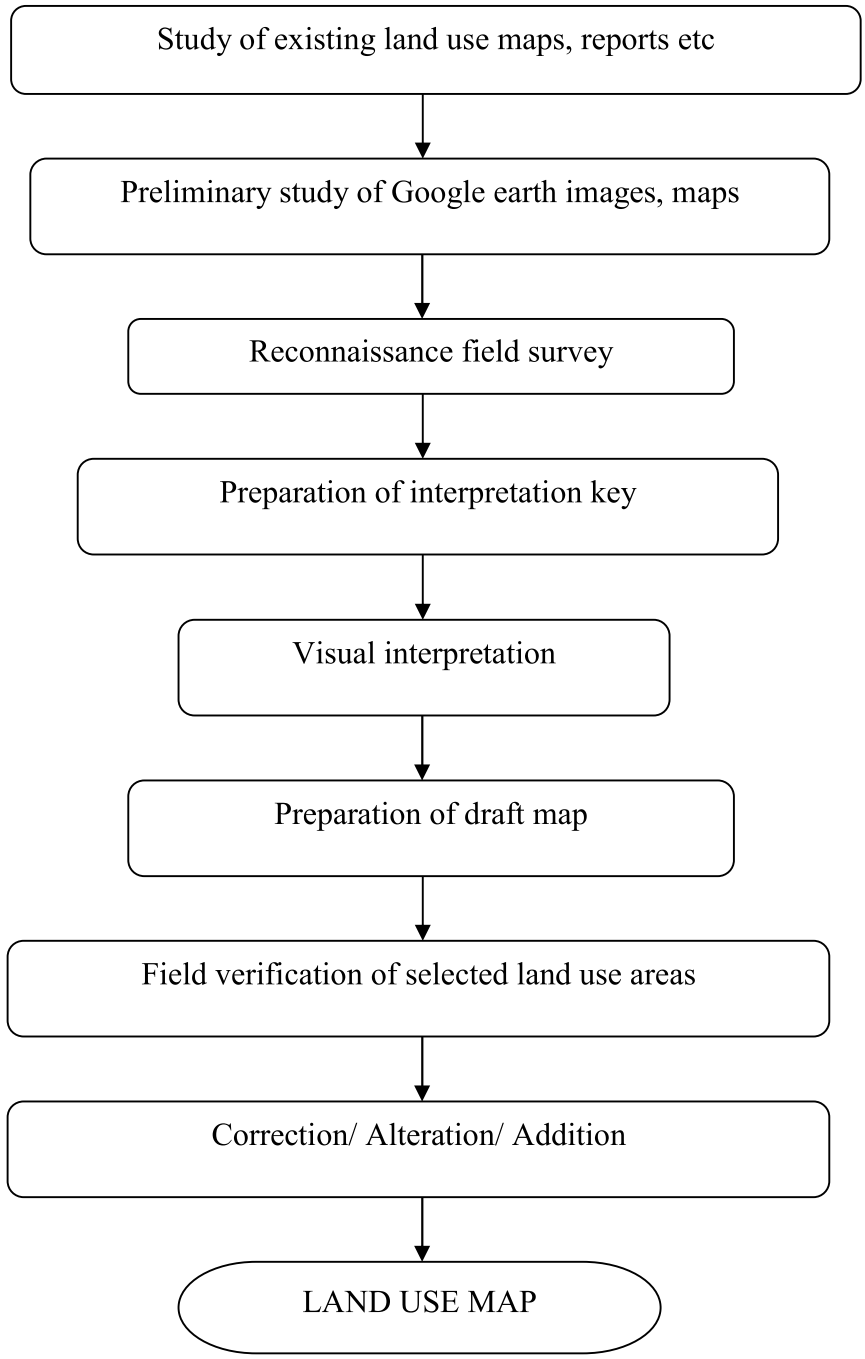

Fig. 3.12: Procedure of land use mapping

The land use map and hydrologic soil group map prepared were intersected in arc GIS platform using intersect tool in the arc toolbox (Fig. 3.13). The land use – soil intersected map is shown in Fig. 3.14.

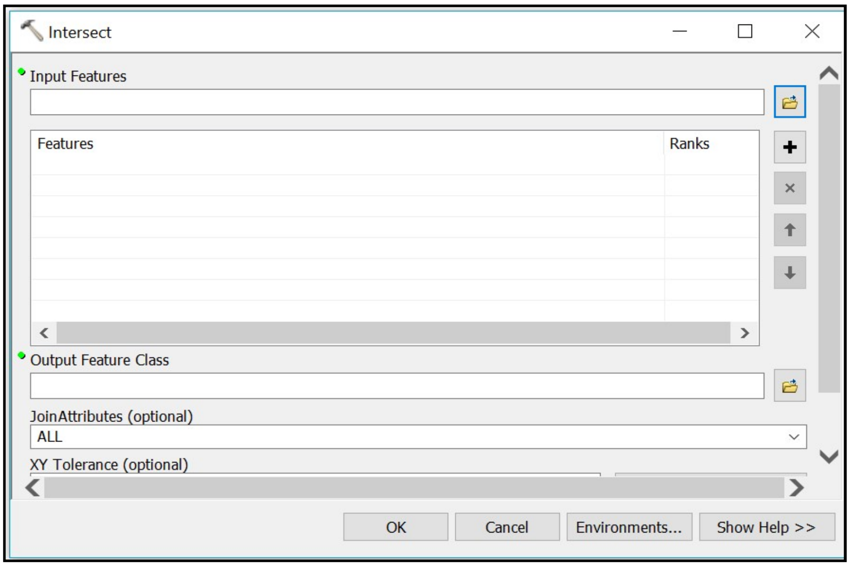

Fig. 3.13: Intersect tool in ArcGIS

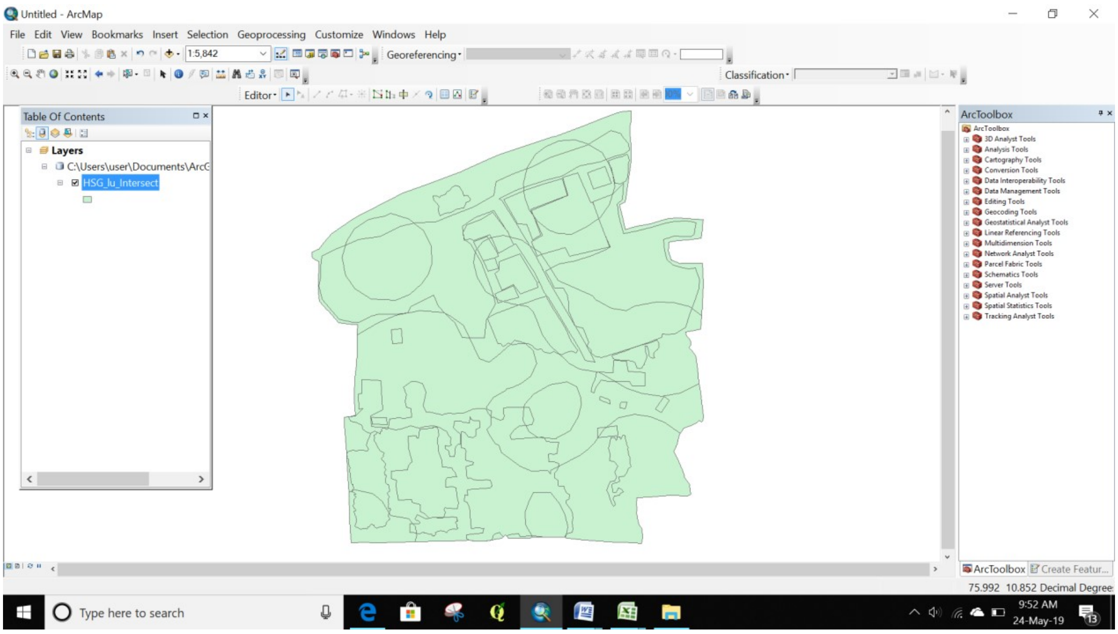

Fig. 3.14: Land use - Soil Intersect map

3.5.4 Curve Number

The runoff curve number is an empirical parameter which is used to predict the direct runoff which ranges from 0 to 100. A Lower value indicates the low runoff potential while the higher value indicates the high runoff potential. A CN of 100 represents a limiting condition of a perfectly impermeable catchment with zero retention, in which all rainfall becomes runoff. A CN of zero conceptually represents the other extreme, with the catchment abstracting all rainfall and with no runoff regardless of the rainfall amount (Im *et al.,* 2007). The curve numbers are assigned for different polygons in the intersected map on the basis of hydrologic soil group and land use type. Most of the previous studies assigned the curve number values for different land use classes according to Chow *et al,* (2002). The curve numbers for the land use classes and HSG is given in table 3.2. (Chen, 2012; Ebrahimian *et al.,* 2012; Jabari, 2007; USDA[a], 2004; Subrahmanya, 2008). The attribute data management for curve numbers in ArcGIS interface is shown in Fig. 3.15.

Table

HSG_lu_Intersect

OBJECTID *	Shape *	Landuse_type	HSG	Curve_Number
1	Polygon Z	Coconut	B	55
2	Polygon Z	Banana	B	47
3	Polygon Z	Paddy	B	95
4	Polygon Z	Paddy	B	95
5	Polygon Z	Row crops	B	75
6	Polygon Z	Pond	B	100
7	Polygon Z	Vegetation	B	55
8	Polygon Z	Coconut	B	55
9	Polygon Z	Vegetation	B	55
10	Polygon Z	Polyhouse	B	74
11	Polygon Z	Polyhouse	B	74
12	Polygon Z	Built up	B	68
13	Polygon Z	Coconut	B	55
14	Polygon Z	Banana	B	47
15	Polygon Z	Paddy	B	95
16	Polygon Z	Paddy	B	95

Fig. 3.15: Attribute data management for curve numbers

Table 3.2: Curve numbers for different land use classes

Land use	Cover description	Curve number for HSG	
		A	B
Row crops	Continuous bush grass combination	65	67
Built up	Residential area by average lot size	77	85
Woods	Woods with grass-Good condition. Litter and shrubs covered the soil	30	73
Polyhouse	Farmsteads-buildings	72	82
Open land	Open space- Ground	79	72
Mango	Orchard with understorey cover	39	53
Coconut	Orchard without understorey cover	41	65
Banana	Scrub	33	47
Agriculture	With bush weed grass	35	56
Pond	Water body	0	0
Pasture	Good grass cover	39	61

(Source: TR-55, USDA NRCS)

The farming practices in straight rows in slopes of < 2% is considered as contouring (USDA, 2002). The woods grown isolated can be evaluated on the basis of cover effectiveness and the hydrologic condition is visually interpreted. The pond is considered as tank with water and the curve number for it is 0 (Ningaraju *et al.,* 2016). The cover types, hydrologic conditions and treatments will also influence the curve number. The major cover types are impervious surfaces, vegetation and bare soil. The most common methods for determining cover types are field reconnaissance, aerial photographs and land use maps. Treatments are the modifications of cover type used to describe the management of agricultural lands. It includes mechanical practices, such as contouring and terracing and management practices, such as crop rotations and reduced or no tillage.

The hydrologic condition indicates the effects of cover type and treatment on infiltration and runoff and is generally estimated from density of plant and residue cover on sample areas. Good hydrologic condition indicates that the soil usually has a low runoff potential for that specific hydrologic soil group, cover type and treatment. Some factors to consider in estimating the effect of cover on infiltration and runoff are canopy or density of lawns, crops or other vegetative areas, amount of grass or close-seeded legumes, percent of residue cover and degree of surface roughness.

3.5.5 Antecedent Moisture Condition (AMC)

The index of runoff potential before a storm event is the antecedent moisture condition (AMC). The AMC condition has significant effect on the runoff volume. It is an indicator of availability of soil moisture before a storm and watershed wetness. The NRCS recommends to assign curve number values on the basis of AMC on the rainfall in 5 day period preceding a storm. AMC I is the optimum condition of soils in the watershed. In this condition the soils are not to the wilting point, but it will be dry. AMC II is the average moisture condition (Satheeshkumar *et al.,* 2017) and AMC III is the condition which occurred heavy rainfall or light rainfall at low temperatures in the preceding five days of the storm.

Table 3.3: Classification of AMC (Subrahmanya, 2008)

AMC	Total 5 days antecedent rainfall (mm)	
	Dormant Season	Growing Season
I	< 13	< 36
II	13-28	36-53
III	> 28	> 53

The curve number values are always meant for the condition of AMC II (USDA, 1972). For the conditions of AMC I and AMC III following equations are used (Chow *et al.,* 2002; Bhola and Singh, 2010; Singh, 2014; Satheeshkumar *et al.,* 2017).

For AMC I, $$CN_I = \frac{CN_{II}}{(2.281 - 0.01281\ CN_{II})} \qquad (3.10)$$

For AMC III, $$CN_{III} = \frac{23\ CN_{II}}{(10 + 0.13\ CN_{II})} \qquad (3.11)$$

The runoff curve numbers are adjusted for different AMC conditions based on the equations 3.10 and 3.11. January 1 to May 31 is considered as dormant season and June 1 to December 31 is considered as growing season (Jose and Thomas, 2007).

3.5.6 Potential Maximum Retention (S)

The potential maximum retention (S) is the recharge capacity of the watershed. The initial abstraction (I_a) is the fraction of potential soil water retention. The potential soil water retention map was generated using raster calculator tool in arc gis based on the equation 3.12.

$$S = \frac{25400}{CN} - 254 \qquad (3.12\ )$$

Where, S is the potential maximum retention in mm and CN is the curve number. For the curve number value the generated CN map was given as input in ArcGIS platform. The ArcGIS interface for raster calculator is shown in Fig. 3.16.

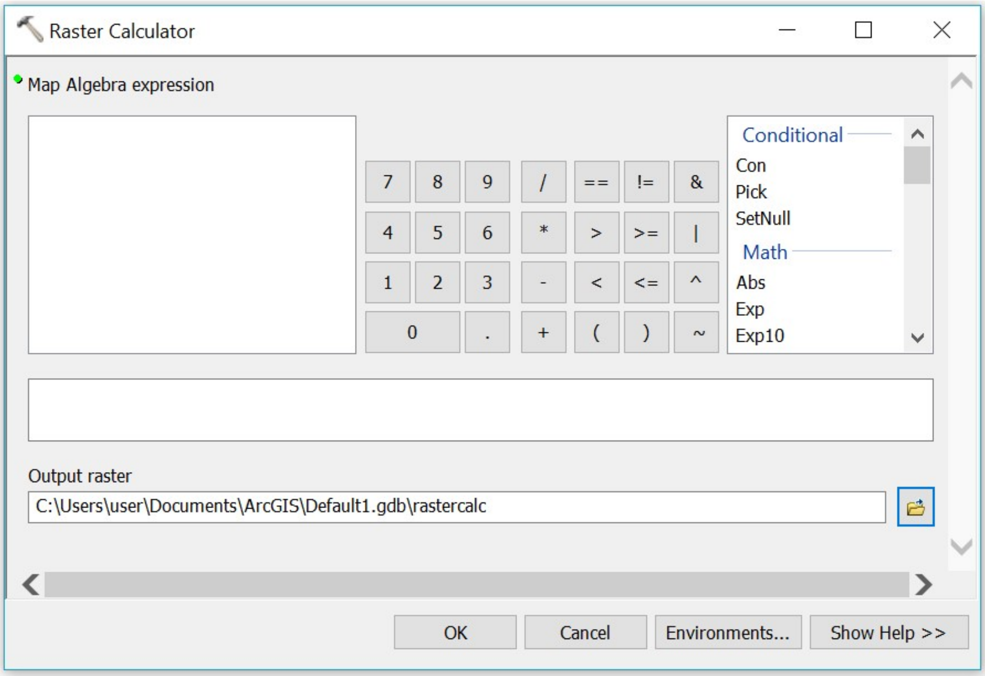

Fig. 3.16:ArcGIS Interface for Raster Calculator

3.6 ESTIMATION OF DIRECT RUNOFF

The NRCS CN method was combined with ArcGIS 10.2 to calculate the direct runoff occurring in the study area. The raster layer corresponding to hydrologic soil group is converted to polygon and is intersected with digitized land use map generated for the year 2006 and 2018. The curve number value corresponding to the particular land use and soil type is incorporated in the attribute table by attribute handling. The NRCS CN computations were done by using above mentioned ArcGIS tools and NRCS CN parameters. This combination computed the simulated runoff potential for the entire area. The season wise (Pre monsoon, SW monsoon, NE monsoon and post monsoon) analysis was done using daily rainfall observations of the year 2004, 2005, 2006, 2007 and 2018.

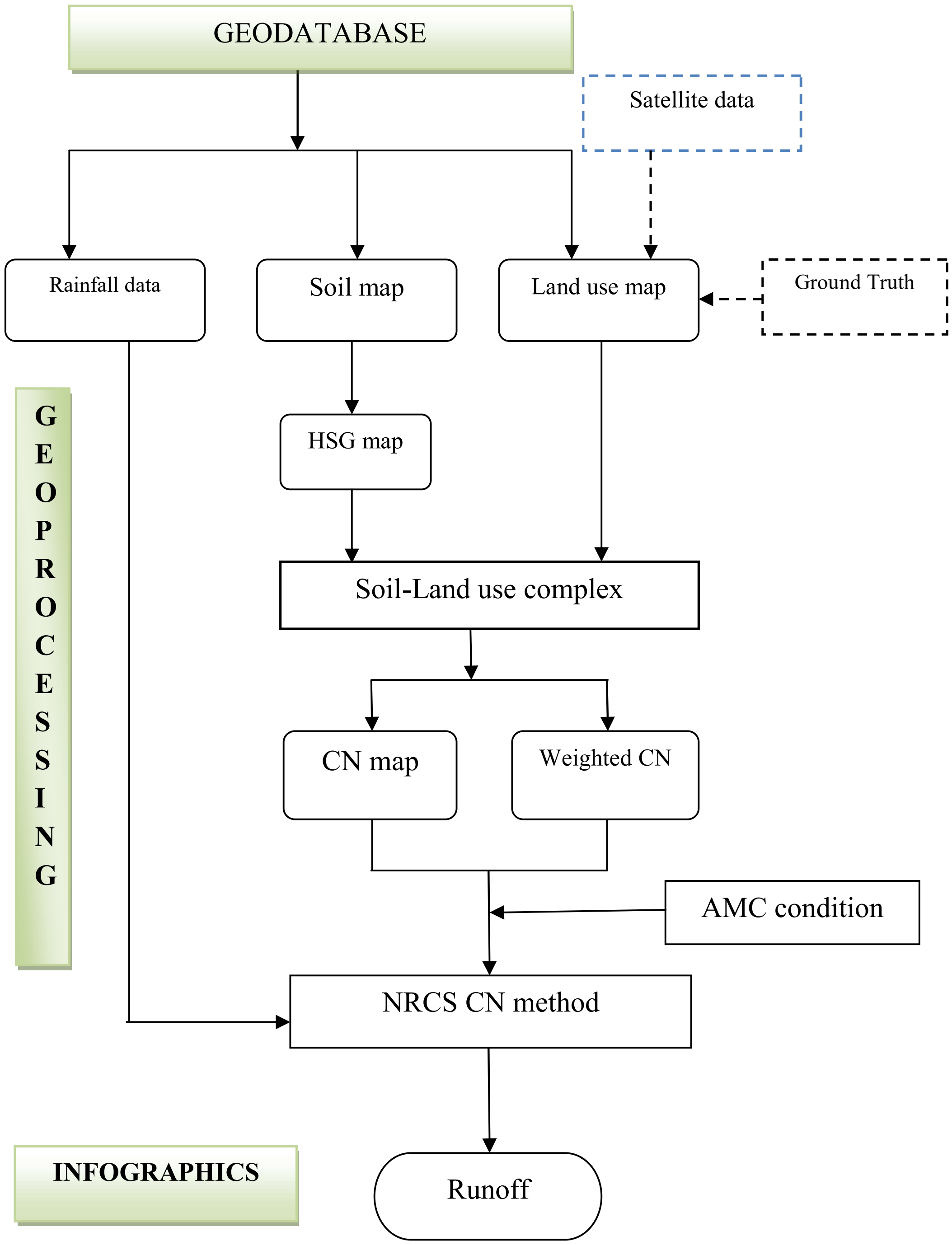

Fig. 3.17: Methodological framework adopted in NRCS CN method

The flow chart for the estimation of runoff using NRCS CN method with remote sensing and GIS is given in fig 3.17. The results obtained by the adaptation of the methodology are discussed in detail in the chapter IV.

3.7 RUNOFF MEASUREMENT

The NRCS CN method was validated for selected storm events by measuring the runoff depth. For this purpose, a runoff plot was constructed in the region having natural outlet of water flow. The surface water is diverted to the outlet by some earthwork around the plot. Weirs and flumes are highly recommended for the flow measurement in small catchment areas (Harmel *et al,* 2006). Drop box weir which was developed to overcome the sediment entraining problem and trash blockage was used for the flow measurement. Utility of the drop-box weir was extended to use it for small plot studies and smaller watersheds. The weir was calibrated using a measuring tank in the outlet.

During the study year 2018, the South West monsoon was started by early June. Runoff from isolated storms was measured. But the rainfalls of low intensity and short duration did not contribute to runoff yield (Raji and Uma, 2006). Time at which runoff just touch the crest of weir and the flow ending time was noted to measure the surface flow time. Average depth of flow for each selected isolated events was measured with staff gauge since water stage level recorders were not available. The flow rates were converted to depth of water.

Plate 3.1:Earthwork in Boundary

Plate 3.2:Flow to the outlet

The boundary of the catchment area was delineated using handheld GPS survey and the plot has an area of 5960 m^2. Land use of the area was found to be natural vegetation with good hydrologic cover. The soil type of the area is silt loam and the region belongs to HSG B. Curve number of the area is identified as 73 and runoff of the area was estimated for the selected storm events. The simulated runoff was compared with observed runoff from the study area.

3.7.1 Drop Box Weir

Drop box weirs are mainly of three configurations; Original Drop Box Weir (DBW-O), Modified Weirs for erosion plots (MDBW-e) and Weir for small watersheds (MDBW-sw). Original drop box weir (DBW-O) which can be used for small and high mode flows are used for the measurement of runoff in this study. Water flows through the rectangular holes in the chute walls at low flows and it will flow over upper side of the weir at large flows. At extreme high flows, the flow will overtops the back wall. The stage or head is measured in the V section of the weir at all flow types (Bonta and Pierson, 2003). Dimensions and rating curve of the original DBW are functions of V section and depth (D) of the weir. Turbulence created in the box will keeps sediments entrained in the box, providing a nappe to flow over the V section. Thus V section of the weir will be clear of sediments. It is useful for flows with large particles and flows in skewed and steep channels.

The dimensionless rating curve in terms of H is,

$$\frac{Q}{D^{2.5}\sqrt{g}} = M_i\left(\frac{H}{D}\right)^{N_i} \qquad (3.12)$$

Where, Q is the flow rate (L^3/T), D is the depth of V section of DBW, g is the gravitational acceleration (L/T^2), H is the depth of flow through the V section (L), M_i is the coefficient for rating-curve region i, and N_i is the exponent for region i. The parameters M_i and N_i are obtained from the table 3.3 on the basis of R value. For R values < 0.7, the flow is independent of upstream channel slope and water did not overtop. Chute walls and openings require frequent cleaning to avoid the accumulation of trash in the flow path.

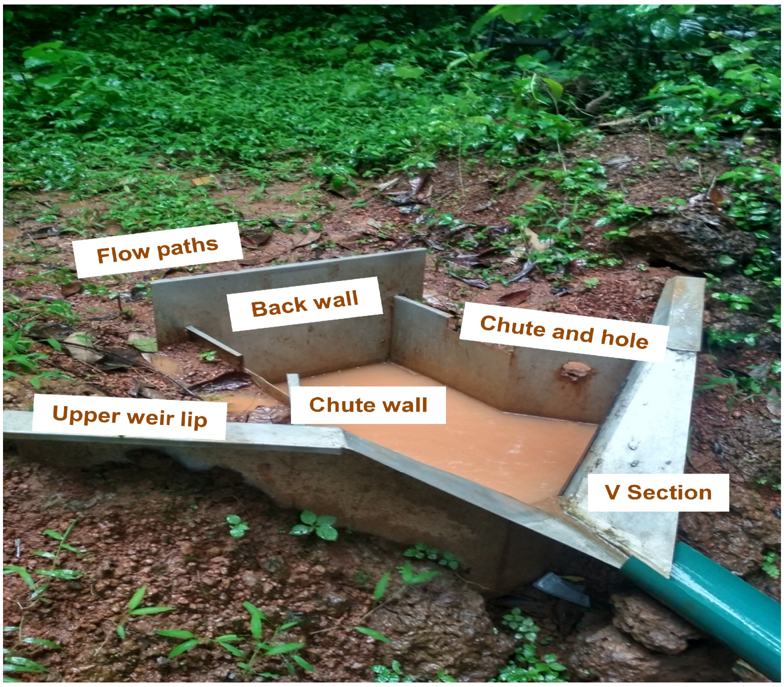

Plate 3.3: Drop Box Weir

Table 3.4: Values of parameters M_i and N_i (Bonta and Pierson,2003)

R	**M_i**	**N_i**
Upto 0.058	0.0265	1.10
0.058-0.11	0.124	1.64
0.11-0.27	0.874	2.52
0.27-0.49	1.67	3.01
0.49-0.70	1.67	3.01
>0.70	1.73	3.1

The flow rate is given by,

$$Q = D^{2.5}\sqrt{g}M_iR^{N_i} \qquad (3.13)$$

Where R=H/D, H is the stage height and D is the depth of V section. Stage and elevation data are used primarily for computing discharge. Effective stage is defined as the height of water surface over the measuring slot. Water line against the inclined staff gauge is recorded and converted to depth. The angle of the V section is 90°. The slant height is measured to reduce the error in measurement and it is converted to head using the equation 3.14.

Head above the section = Measured value * Cos 45° (3.14)

The difficulties in measurement caused due the water surge is eliminated by averaging the observations. The flow through V section of the DBW is similar to that of 90° V notch weir which has a triangular opening and this type is well suited for measuring small flows with high accuracy (Harmel *et al.,* 2006). The R values obtained were less than 0.7. Hence the weir can be best used for the study area.

CHAPTER IV

RESULTS AND DISCUSSION

This particular study was aimed at estimation of runoff using remote sensing and GIS techniques. The NRCS curve number method was used for the estimation of runoff. Results obtained from the study are discussed in this chapter. Input map layers required for the estimation of runoff from the NRCS curve number method are soil map and land use map of the study area and curve number map can be prepared on the basis of these input maps. Simulated runoff was validated with observed runoff at the outlet of the catchment area.

4.1 VALIDATION OF MODEL

4.1.1 Comparison of Simulated and Observed Runoff

The rainfall measurements are taken using tipping bucket rain gauge and drop box weir was used for the runoff measurement. Flow rates for the events were converted to depth of water for estimating the surface runoff that could be generated over the catchment area uniformly (Dile *et al.,* 2015). Measured runoff for the selected events was compared with calculated runoff from the runoff plot for the storm events for the validation of the model. The simulated and observed runoff is presented in table 4.1. The relative error between observed and simulated values varied from 7% to 160%. Also for some rainfall events, the runoff depth was observed in the range of 0.03 mm to 0.06 mm. But theoretically no runoff was observed due the rainfall amount less than 0.2 times of potential maximum retention values. The observed runoff values, which are higher than that of simulated values. It may be due to the slope effect in the study area since the NRCS CN method does not consider slope as its parameter for estimation of runoff.

Table 4.1: Observed and Simulated runoff of the study area

Rainfall (mm)	Observed runoff (mm)	Simulated runoff (mm)	Relative Error
14	0.8331	0.7783	7.04
10.2	0.2623	0.1140	130.12
12.3	0.4589	0.4150	10.59
4.2	0.0532	0.0000	-
12	0.5653	0.3615	56.37
12.8	0.7741	0.5113	51.38
5.6	0.1638	0.1521	7.64
10	0.2536	0.0947	167.90
12.6	0.5079	0.4717	7.66
4.8	0.0683	0.0000	-
13.8	1.0616	0.7304	45.35
4.2	0.0802	0.0000	-
3.2	0.0325	0.0000	-
4.4	0.0551	0.0000	-
12.4	0.7219	0.4335	66.52
12.6	0.5653	0.4717	19.84
13	0.7164	0.5524	29.68

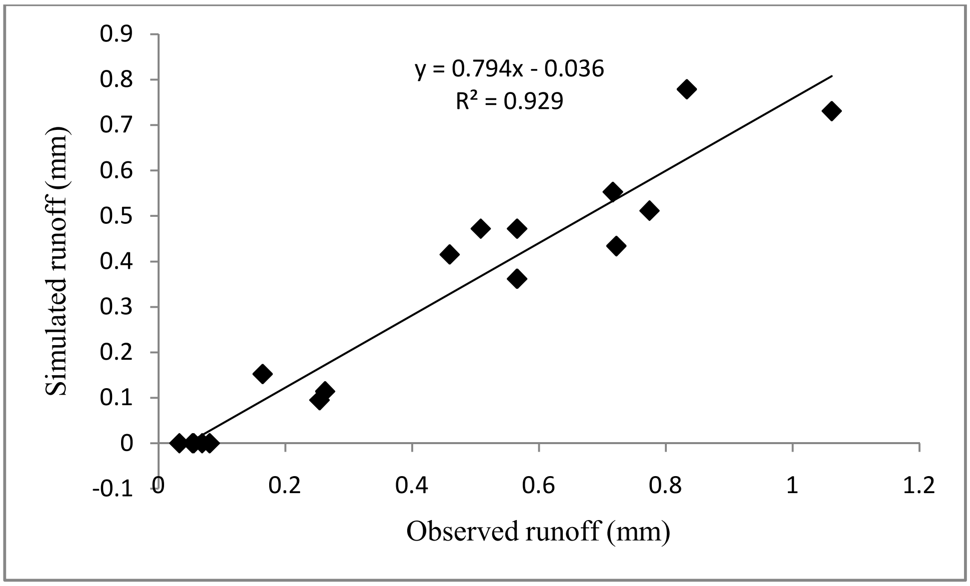

Fig. 4.1: Comparison between observed and simulated runoff

The trend line obtained by comparing the observed and simulated values is shown in Fig 4.1. Correlation coefficient, R^2 between the observed and simulated values is 0.929. This shows the NRCS curve number method can be best used in the study area for estimation of runoff.

4.2 RAINFALL

The assessment of rainfall can be done by dividing the annual rainfall into South – West monsoon (June – September), North – East monsoon (October – December), Pre monsoon (April – May) and Post monsoon (January – March) (Thomas and Prasannakumar, 2016; Varughese, A. 2016). Rainfall is the important climatic factor which affects the runoff (Mohamadi and Kavian, 2015). There was no runoff for rainfall depths less than or equal to initial abstractions, provided initial abstraction is 0.2 times of potential maximum retention for Indian conditions. The daily rainfall measurements from the non-recording rain gauge of the study area is given in Appendix IV. The average monthly rainfall depth of the study area was shown in Fig 4.2 and about 60% of the rainfall was received from South-West monsoon. Maximum average rainfall was observed in the month of June (731.38 mm) and minimum in the pre-monsoon months. There was a decreasing trend observed in the north east monsoon and pre-monsoon in the study area.

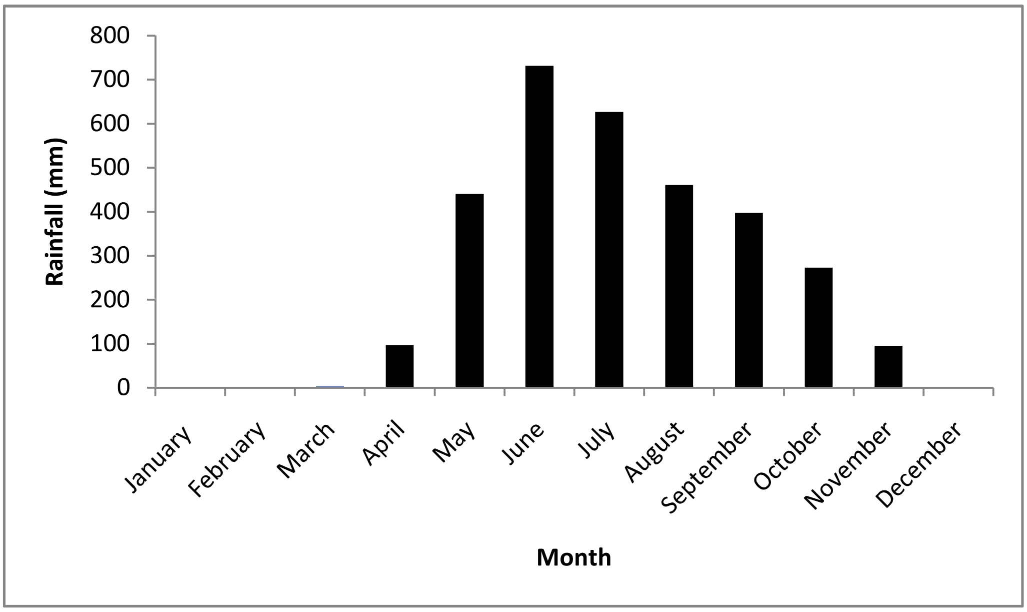

Fig. 4.2: Monthly average rainfall

4.3 PREPARATION OF INPUT MAP LAYERS

The thematic map layers required for the NRCS CN model are mainly soil map and land use map of the study area.

4.3.1 Soil Map

The soil type influences runoff rate from an area. Soil texture map of the study area was generated on the basis of sieve analysis data. Three textural groups like sandy loam, silt and silt loam were identified in the study area using texture calculator and USDA nomograph. The identified soil types are interpolated using Inverse Distance Weighting method in ArcGIS. Inverse Distance Weighted (IDW) estimates grid cell values by averaging of sample data points near the cell. The closer point to the center of the cell being estimated, the more influence or weight it has in the averaging process. Soil in the study area is loose, unconsolidated, usually fertile deposition in the river banks formed by the action of river. A considerable of the area (around 44.4%) have sandy loam soil, whereas silt and silt loam soil together constitutes 55.6% of the study area. The area covered by each soil type is given in Table 4.2 and the distribution is given in Fig. 4.3. Weight of soil retained in each sieve is shown in Appendix II. Sandy loam soil which have high infiltration rate as compared to silt and silt loam dominated in the study area.

Table 4.2: Classification of soil in the study area

Soil texture	**Area (m^2)**
Sandy loam	173538.327
Silt	58780.843
Silt loam	158273.33

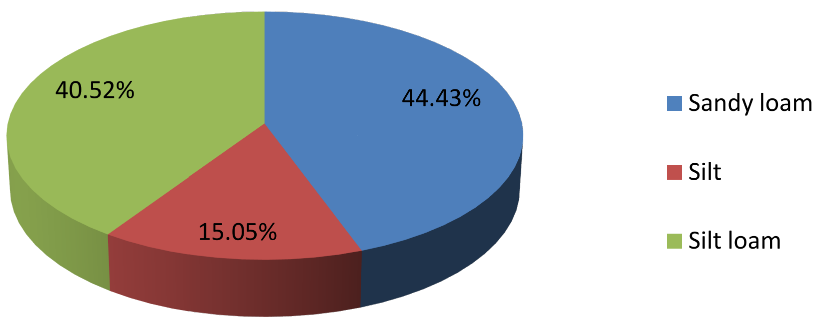

Fig 4.3: Distribution of soil type

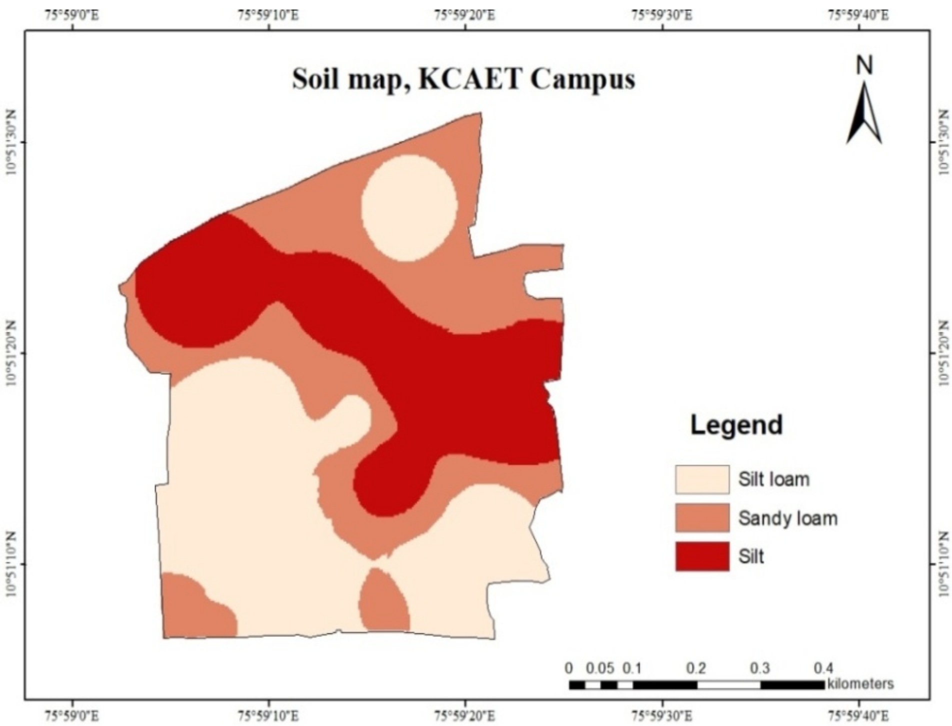

Fig. 4.4: Soil map of the study area

4.3.1.1 *HSG Map*

Soil properties are extremely important in determination of runoff curve number and these values can vary widely. Soils are divided into four hydrologic soil groups namely, A, B, C and D and they are classified on the basis of its water absorption or runoff producing characteristics. It includes wetness characteristics, soil texture and water transmission capacity after prolonged wetting. The slope of the soil surface is not considered when assigning hydrologic soil groups (USDA, 2002). Satheeshkumar *et al.,* 2017 generated the HSG map of Pappiradippetti watershed of South India by digitizing soil texture map of the study area.

Conditions for the classification of hydrological soil groups are applied in the ArcGIS interface and HSG map was prepared based on table 3.1. Two hydrologic soil groups, A and B were identified in KCAET Campus from the soil texture map. The silt and silt loam belongs to hydrologic soil group B and sandy loam soil belongs to hydrologic soil group A. As stated by USDA, the HSG A and HSG B have good water transmission rate and low runoff potential. For the hydrologic soil group A and B, the infiltration rate varied from 13 mm h^{-1} to 25 mm h^{-1}. The final map of hydrologic soil group of study area is shown in Fig. 4.5.

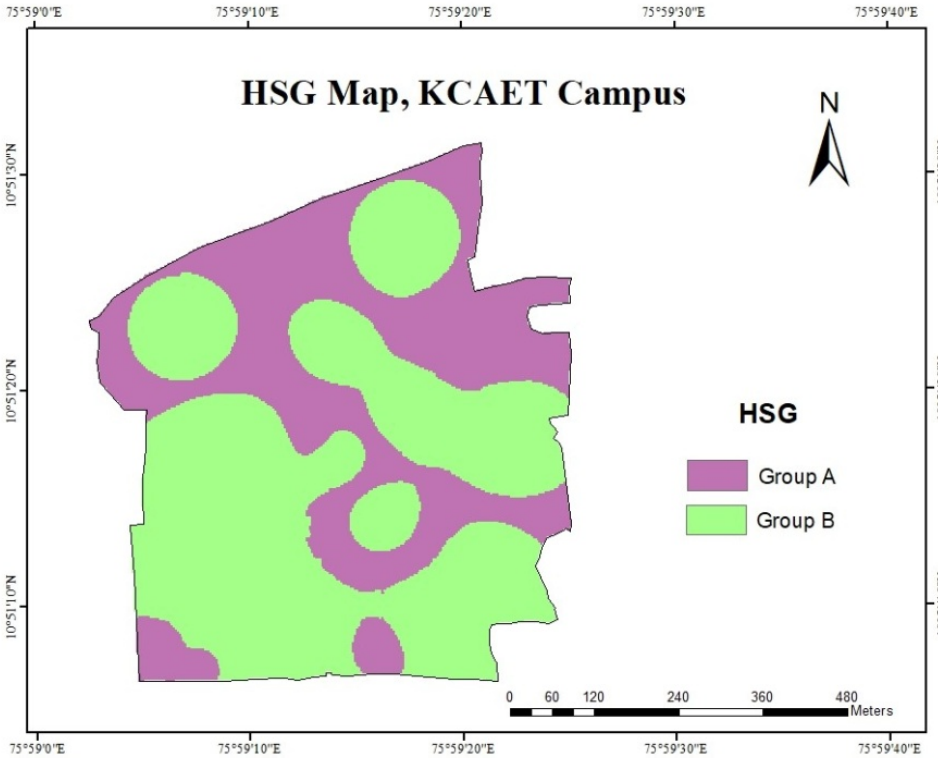

Fig. 4.5: HSG map of the study area

4.3.2 Land use Map

Land use is the key resource for the activities such as agriculture, forestry, settlement, water catchment etc. The free satellite imageries provided in Global Land Cover Facility (GLCP) has been used in many studies have certain limitations as it is not possible to obtain timely data with highest resolution. The purchase of high resolution satellite image is more expensive and may not available sometimes due to security reasons. Google Earth imagery which is open source and provide clear view of land use/ land cover can be utilized. Malarvizhi *et al,* (2016) extracted Google Earth imageries of Vellore in Tamil Nadu and digitized onscreen using GIS software. As suggested by Ghorbani and Pakravan (2013) analysis of land use using visual interpretation with Google Earth imagery showed overall high accuracy.

The land use map of the study area was digitized from the Google Earth imageries of the year 2006 and 2018. Based on the visual interpretation and field verification, land use categories were analyzed and digitized. Mainly 7 land use classes were identified in the area for the year 2006 and 10 land use classes were identified in the study area for the year 2018. Majority of the area was covered by thick vegetation with grass and litter covered in the soil. It comprises around 35.14% of the total area in 2006 which was increased to 46.4% in 2018. The pasture land and some of the agricultural areas were converted to wood covered area in 2018. Other land use classes in the area includes built up areas, open land without any cover, agricultural lands, row crops, agricultural structures such as polyhouses, water harvesting farm ponds, mango orchards, pasture land and coconut plantations. About 7% of the total area was occupied by built up in 2006 whereas the area was then doubled in 2018. Land use/land cover statistics of the study area is shown in Fig 4.8. and 4.9.

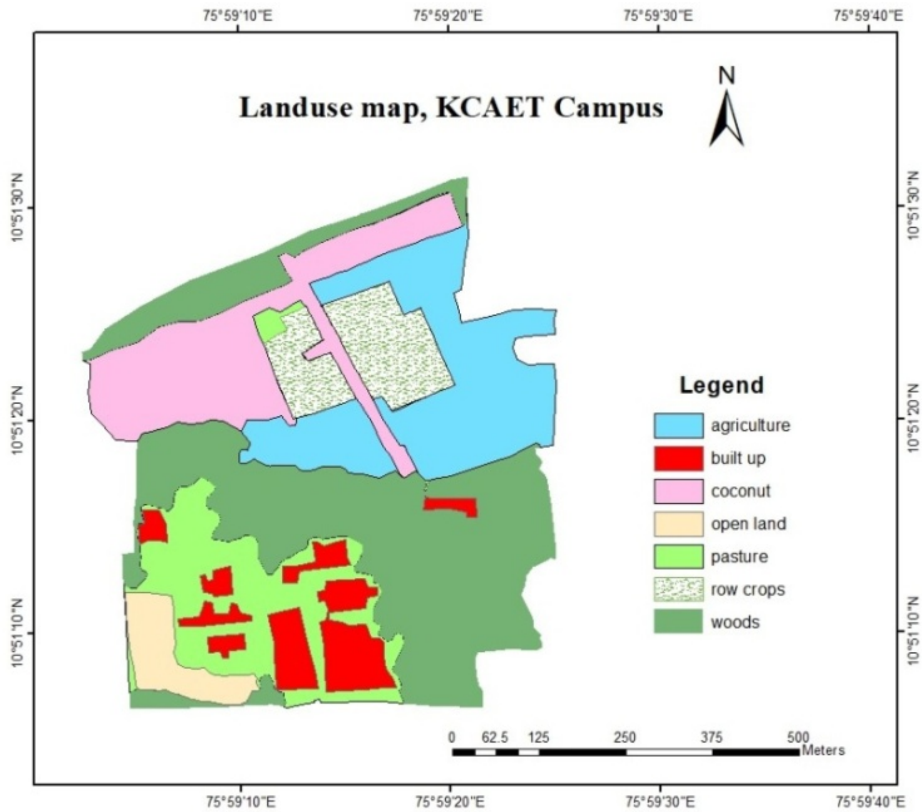

Fig. 4.6: Land use map (2006)

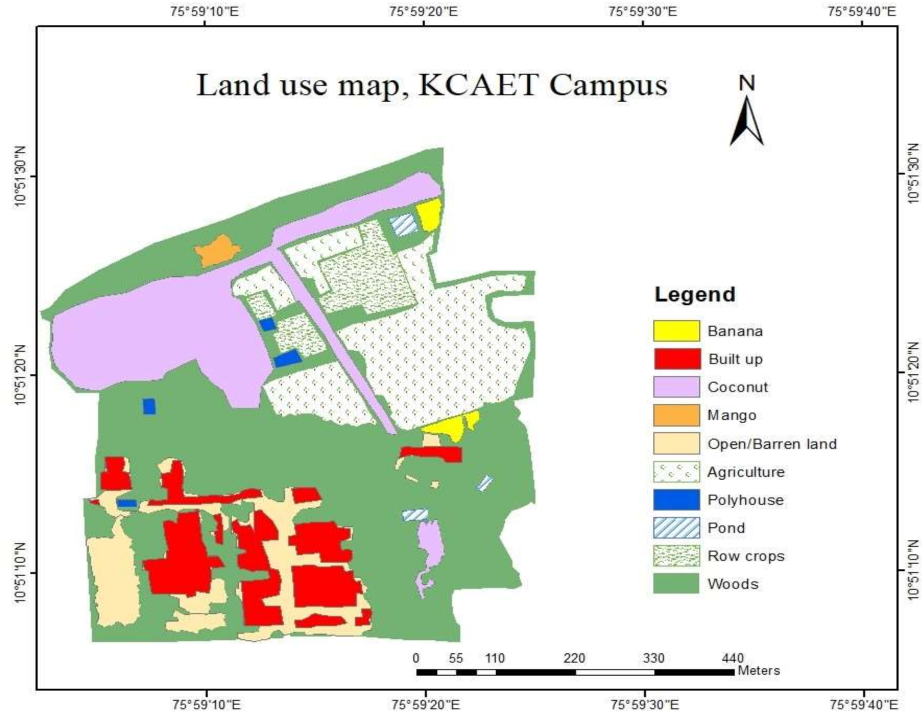

Fig. 4.7: Land use map (2018)

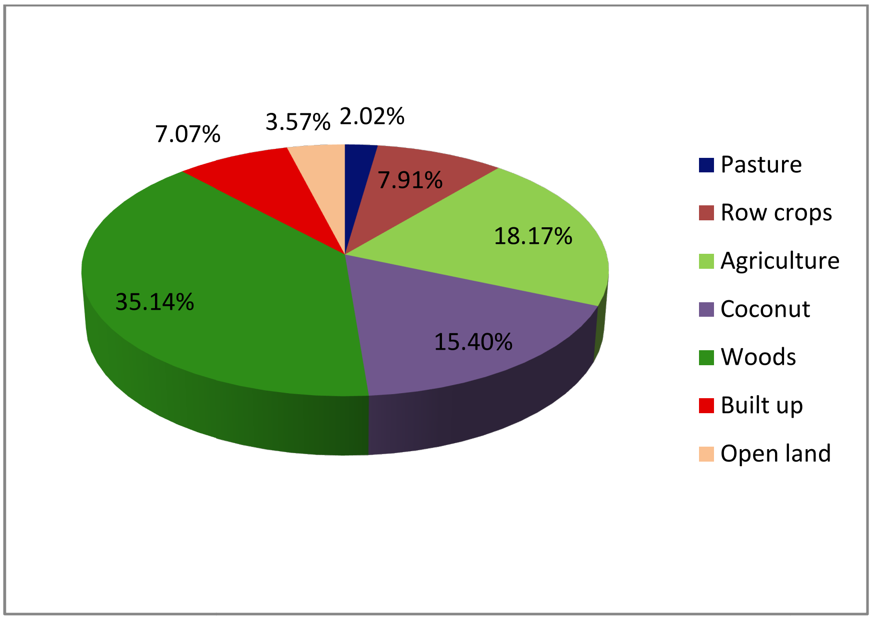

Fig 4.8: Distribution of land use pattern (2006)

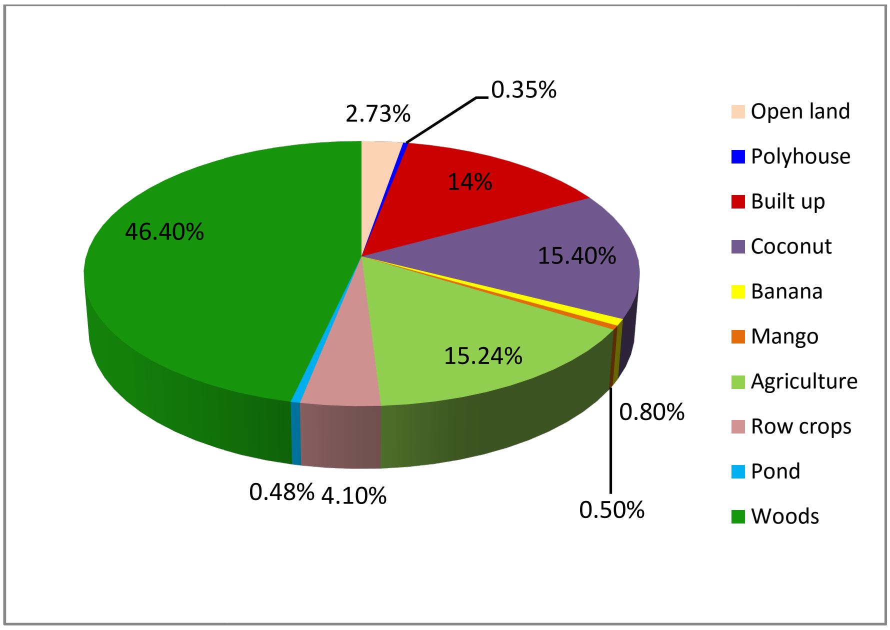

Fig. 4.9: Distribution of land use pattern (2018)

4.4 CURVE NUMBER MAP

The NRCS curve number is a parameter which shows the ability of soils in terms of infiltration of water with respect to antecedent moisture condition (Amutha and Porchelvan, 2009). In another way it is an index which represents the soil cover complex that reflects the response of specific soil under certain conditions to a rainfall event through runoff and infiltration (Elhakeem and Papanicolaou, 2009). Direct runoff estimates are more sensitive to changes in the CN than to rainfall variability. Boughton (1989) has shown that a 15-20% increase in CN almost doubles direct runoff predictions, while a similar extent of CN reduction predicts nearly half of it. The highest curve number was identified as 85 for the built up areas and 82 for the areas with agricultural structures such as polyhouse and lowest CN value was 30 for thick vegetative area under hydrologic soil group A. Composite curve number maps of the year 2006 and 2018 are shown in Fig 4.10 and 4.13 respectively. Curve number maps in the year 2006 and 2018 for AMC conditions I and III (dry and wet conditions) are shown in Fig. 4.11, 4.12 and 4.14, 4.15 respectively.

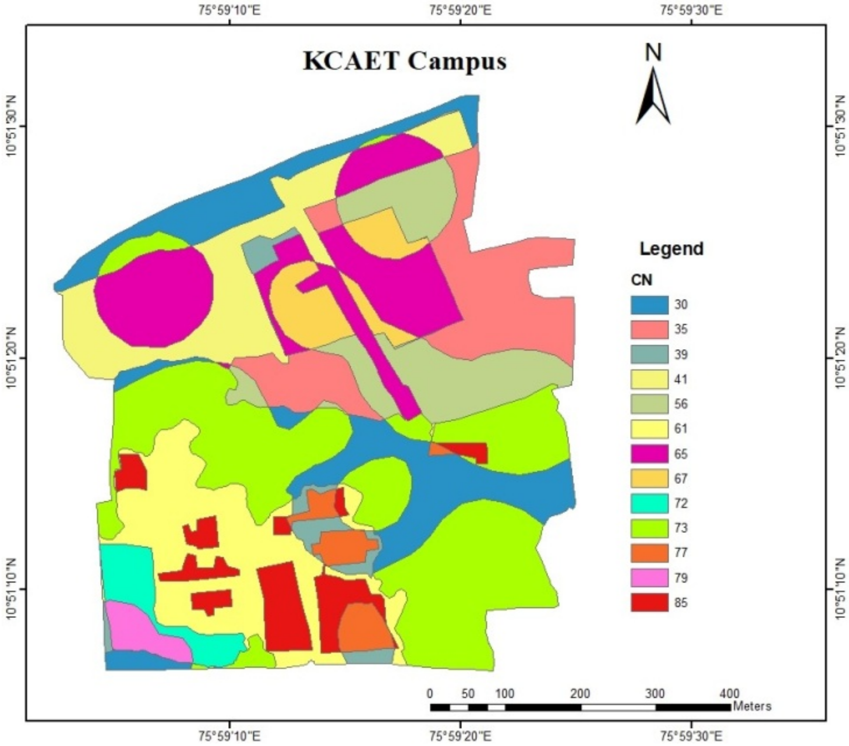

Fig. 4.10: Spatial distribution of CN_{II} values (2006)

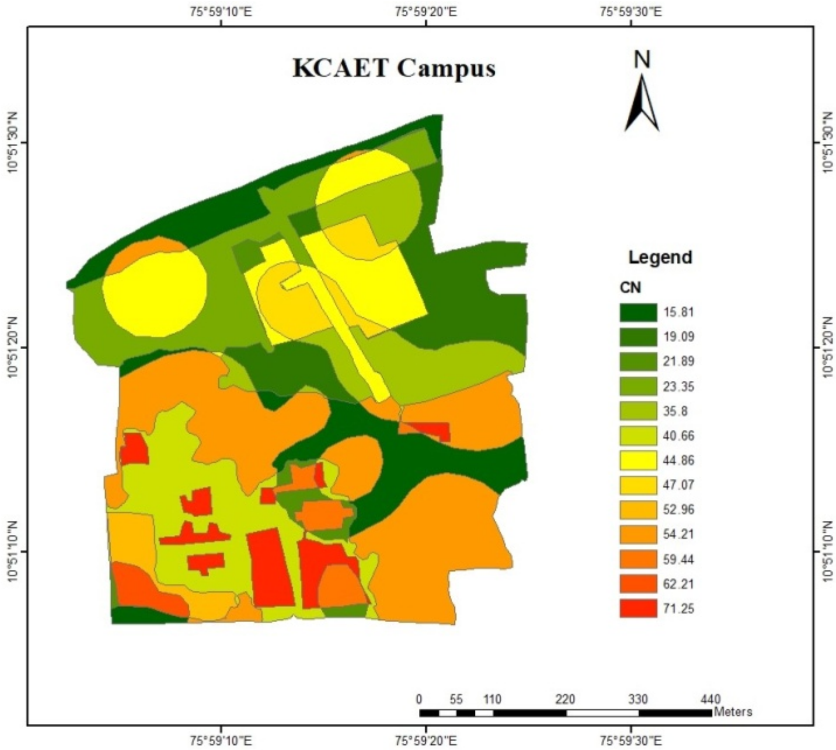

Fig. 4.11: Spatial distribution of CN_I values (2006)

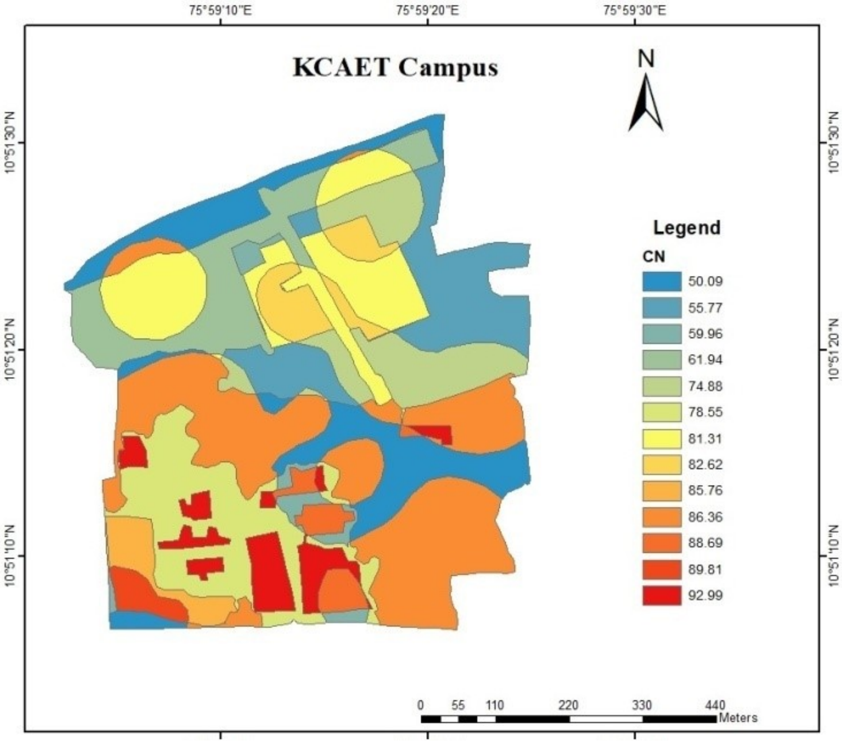

Fig. 4.12: Spatial distribution of CN_{III} values (2006)

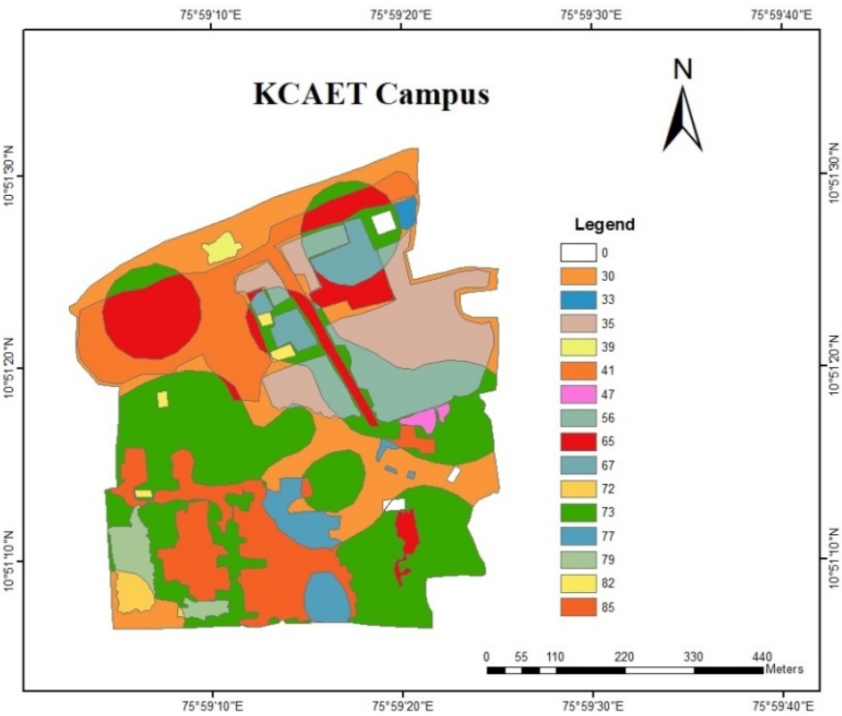

Fig. 4.13: Spatial distribution of CN_{II} values (2018)

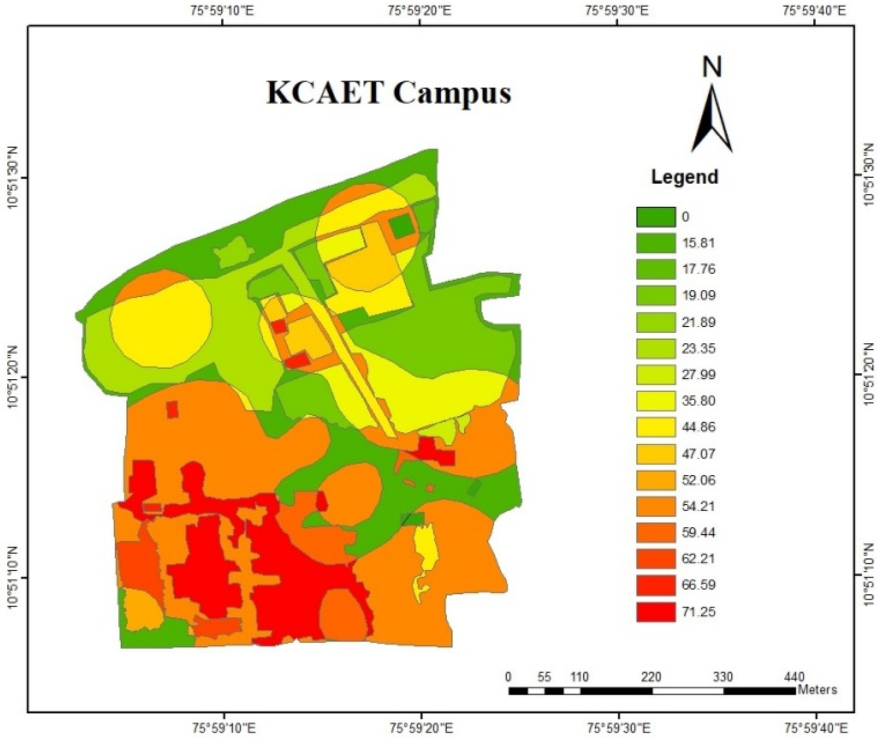

Fig. 4.14: Spatial distribution of CN_I Values (2018)

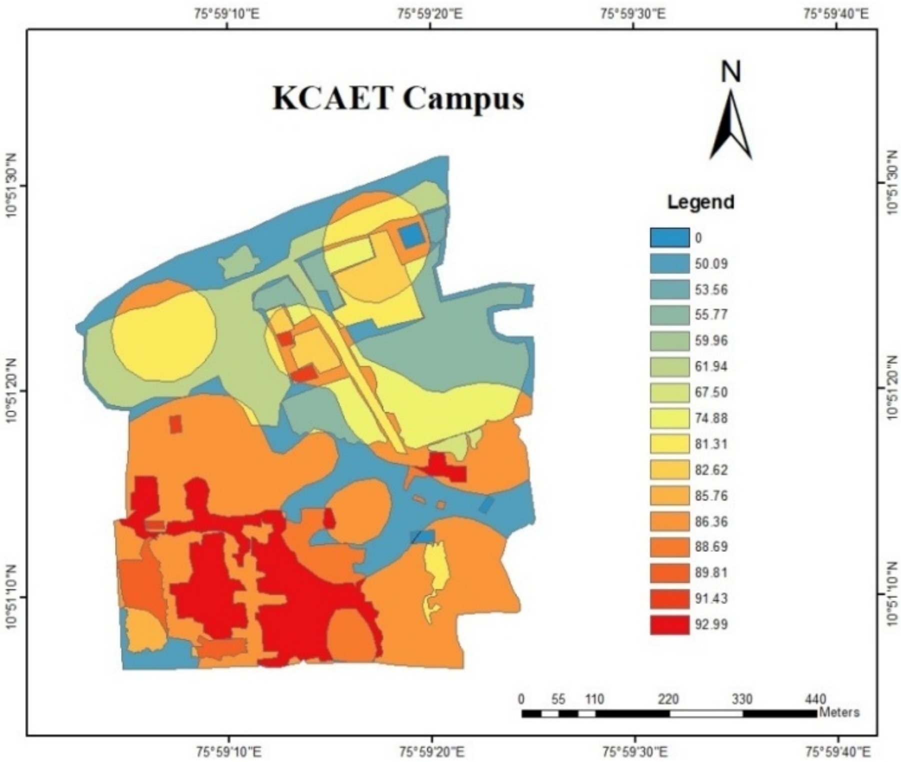

Fig. 4.15: Spatial distribution of CN_{III} Values (2018)

Curve number for each area corresponding to land use classes and HSGs are represented in table 4.3 and table 4.4. Polyhouses occupied the least area and it has curve number value of 72 and 74 for HSG A and B respectively. It can be seen from the table 4.3 and 4.4 that thick vegetation with good grass or litter cover in HSG B has covered more area with an increase of about 7% from 2006 to 2018 and curve number for the area is identified as 73.

Table 4.3: Area for each CN value (2006)

Land use	HSG	CN	Area (m2)	Percentage of area (%)
Pasture	A	39	7477.62	1.92
	B	61	42241.15	10.82
Row crops	A	65	16687.51	4.28
	B	67	14199.90	3.64
Agriculture	A	35	38490.56	9.86
	B	56	32437.16	8.31
Coconut	A	41	32933.82	8.44
	B	65	27154.40	6.96
Woods	A	30	45620.01	11.69
	B	73	91517.03	23.45
Built up	A	77	8652.02	2.22
	B	85	18959.73	4.86
Open land	A	72	4943.50	1.27
	B	79	8972.86	2.30

Table 4.4: Area for each CN value (2018)

Land use	HSG	CN	Area (m²)	Percentage of area (%)
Agriculture	A	35	36220.26	9.28
	B	56	23268.64	5.96
Coconut	A	41	32153.91	8.24
	B	65	28054.89	7.19
Banana	A	33	1311.00	0.34
	B	47	1766.59	0.45
Row crops	A	65	5202.17	1.33
	B	67	10843.30	2.78
Pond	A	0	428.92	0.11
	B	0	1479.92	0.38
Woods	A	30	61610.66	15.79
	B	73	119511.83	30.62
Poly house	A	72	31.66	0.01
	B	74	1391.08	0.36
Built up	A	77	12556.29	3.22
	B	85	41927.72	10.74
Open land	A	72	3371.42	0.86
	B	79	7277.65	1.86
Mango	A	39	1878.54	0.48

Based on table 4.3 and 4.4, the composite curve number was calculated using equation 4.1 (Subramanya, 2008).

$$CN = \frac{\sum A_i * CN_i}{\sum A_i} \qquad (4.1)$$

Where, CN is the composite curve number, A_i is the area for each curve number CN_i and CN_i is the curve number. The composite curve number for the study area for the year 2006 and 2018 was found to be 57.77 and 58.95 respectively. It is the curve number for normal condition (AMC II). Curve numbers for the dry and wet conditions are found out using equations 3.10 and 3.11. For dry (AMC I) and wet conditions (AMC III) the curve numbers for 2006 in the study area are 37.47 and 75.92 respectively. Curve numbers for the year 2018 was 33.61 and 77.08 respectively for dry and wet conditions. The trend of CN I and CN III values with respect to CN II values are shown in Fig 4.16.

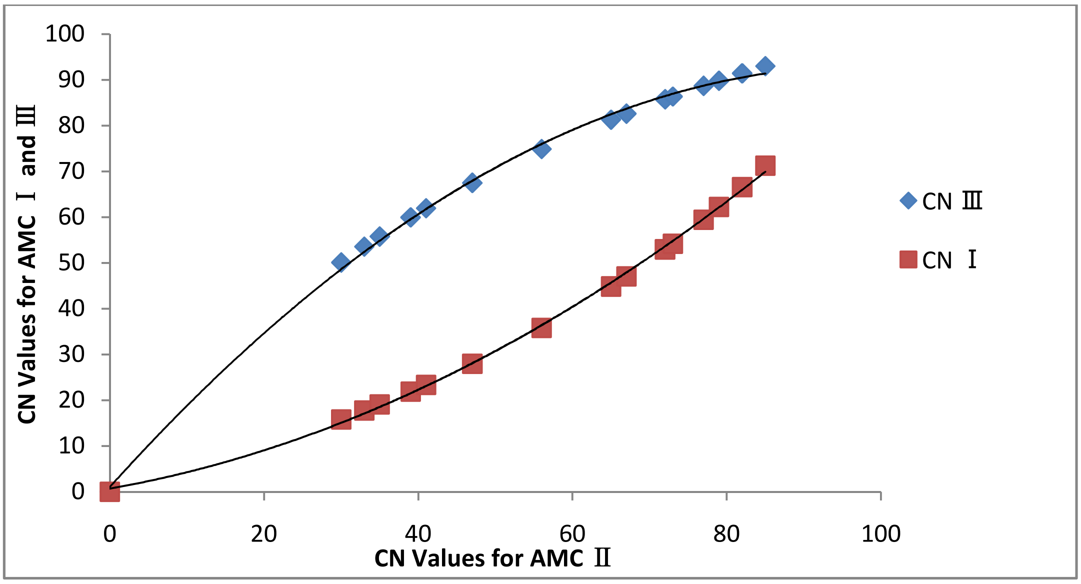

Fig. 4.16: Variation of CN_I and CN_{III} values with CN_{II} Values

4.4.1 Potential Maximum Retention (S)

Needs for functioning of the biodiversity and habitat sustainability are met by the retention of water in the wetlands or depressions contributed by the flood plains. Potential soil water retention of the area was determined on the basis of NRCS CN method in GIS environment and the potential soil water retention map was generated based on the equation 3.12 .

Spatial distribution of S values for the year 2006 and 2018 are shown in Fig 4.17 and 4.18 respectively. The potential maximum retention values of the study area varied from 44 to 592 for 2006 and 2018 respectively. The areas with good vegetative cover and sandy loam soil have higher value of retention capacity. The built up areas and open lands have least potential maximum retention capacity in the study area. Also the sandy loam soil which have high infiltration capacity retains more water than that of soil belongs to hydrologic soil group A. Water harvesting structures such as ponds will have 100% potential for water retention. For composite AMC condition the retention capacity of the year 2006 was 185.67 mm which was then reduced to 176.87 mm in 2018. The potential maximum retention capacity were strongly depending on the amount of rainfall in the previous days.

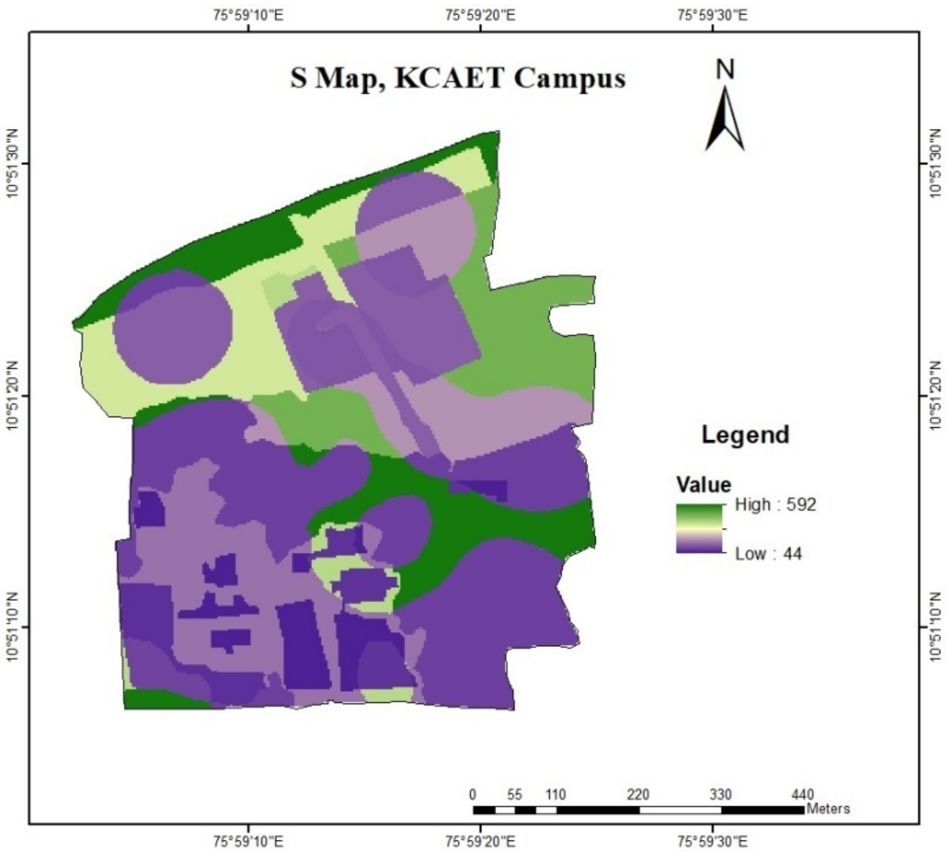

Fig. 4.17: Spatial distribution of potential maximum retention (2006)

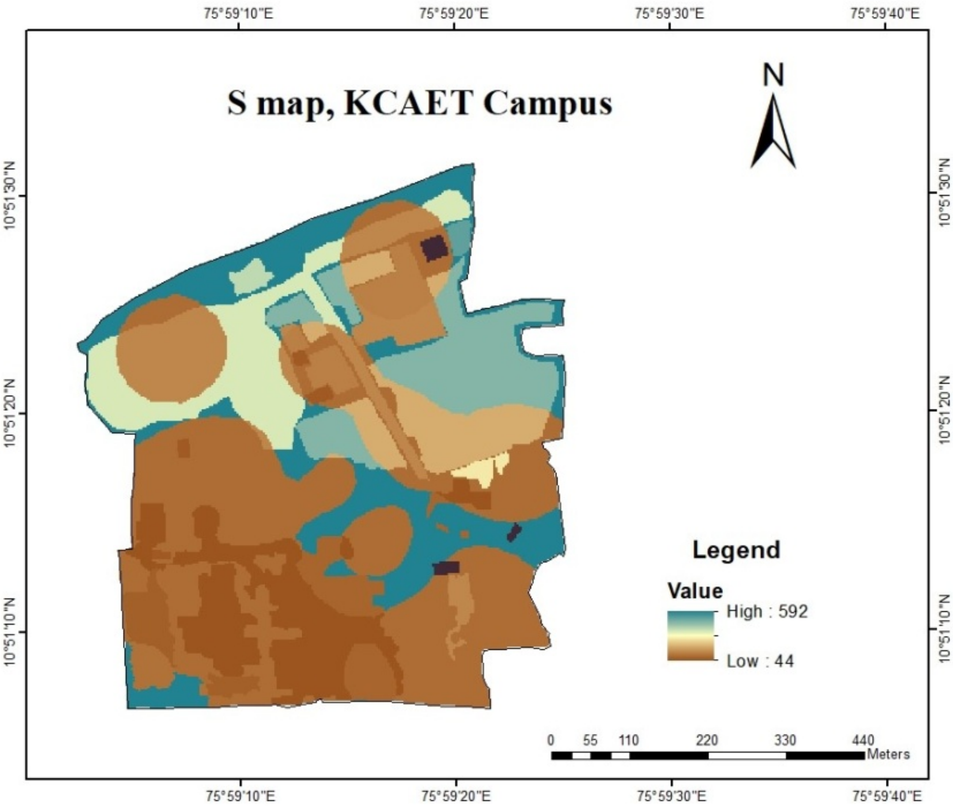

Fig. 4.18: Spatial distribution of potential maximum retention (2018)

Influence of 5 day cumulative moisture condition in potential maximum retention is shown in Fig 4.19. Upto 30 mm of 5 day cumulative rainfall depth, the potential maximum retention values were 403.8 mm and afterwards the retention capacity got reduced to 176.8 mm for higher cumulative rainfall depths. For 5 day cumulative rainfall depth greater than 50 mm, the retention values remained 75.5 mm. Variation of S values with 5 day cumulative rainfall depth shows strong dependence of runoff with antecedent moisture condition. As the cumulative rainfall amount increases, the retention capacity of the soil get reduced. Also the rainfall events with long duration and less intensity will be retained in soil more than that of frequent high intensity rainfall.

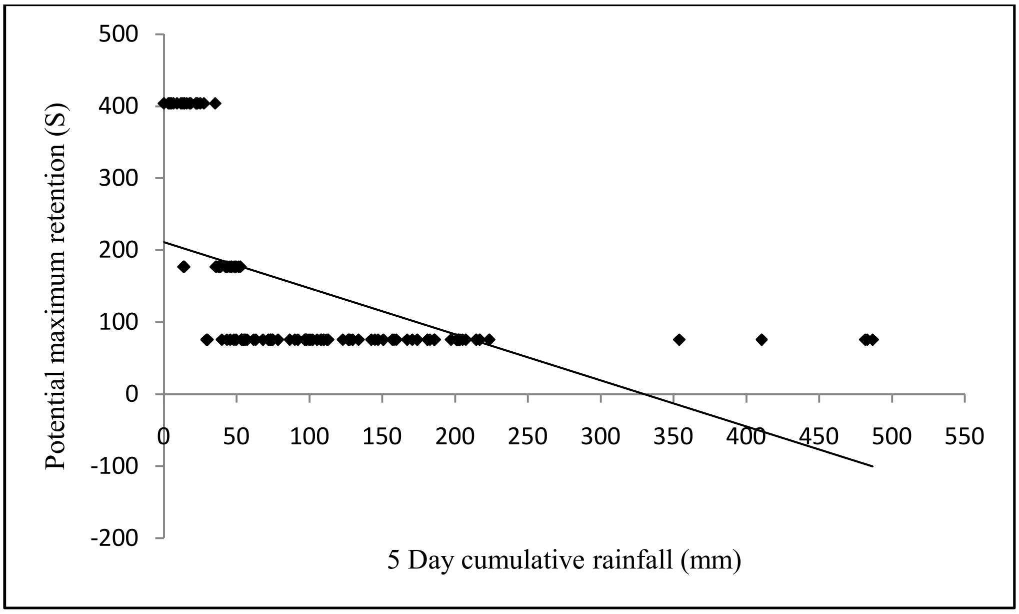

Fig. 4.19: Influence of 5 day Cumulative rainfall on S (2018)

4.4.2 Initial Abstraction (I_a)

Runoff yield is very sensitive to initial abstraction ratio and the amount of water before runoff, such as rainfall interception by vegetation, infiltration etc will constitutes the initial abstractions in an area. Generally it is assumed as a part of potential maximum retention. For the larger channel area and finer soil, the initial abstractions will be lesser. The effect of initial abstraction ratio on runoff estimation increases with decreasing CNs (Yuan *et al.,* 2012). The initial abstraction is taken as 0.2 times of potential maximum retention for the study area. The Initial abstraction map (normal condition) of the year of 2018 is shown for representation purpose in following Fig.4.19. The I_a values varied from 8.8 to 118.4 mm for composite AMC conditions. For the CN values of 38.61 and 77.08, the initial abstraction values was 80.77 mm and 15.10 mm respectively in 2018. As the curve number value increases the I_a values shows a decreasing trend. For higher S values and coarser soil types the initial abstraction values was larger.

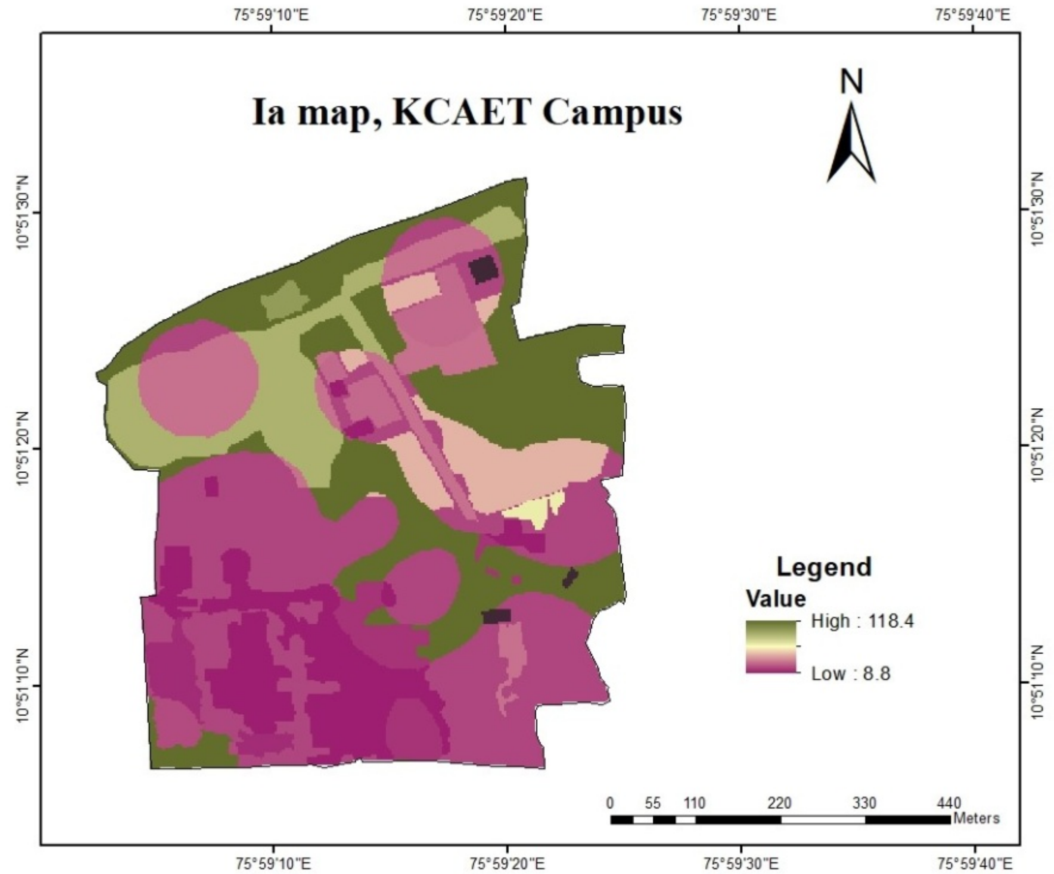

Fig. 4.20: Spatial distribution of Initial abstraction (I_a) - 2018

4.5 ESTIMATION OF DIRECT RUNOFF

The Natural Resource Conservation Services Curve Number (NRCS CN) method was combined with ArcGIS 10.2 to estimate the runoff occurring from the study area. The NRCS CN equation is widely used due to its simplicity and flexibility in estimation of runoff. The thematic layers of potential maximum retention (S) and initial abstraction (I_a) were created, stored and analyzed with ArcGIS 10.2 software. Using NRCS CN method, the runoff of the area was estimated on daily and seasonal basis for daily and seasonal rainfall. The estimated daily runoff for the year 2004, 2005, 2006, 2007 and 2018 is given in Appendix IV.

The runoff map of 30th June 2006 and 20th June 2018 are shown in Fig. 4.21 and Fig. 4.22 respectively for the representation purpose. For the rainfall depth of 58.2 mm the runoff yield produced in 30 June 2006 was 14 mm. The maximum and minimum runoff from different land use and soil type obtained were 0.6 mm to 26.12 mm respectively. Runoff values varied from 0.006 mm to 26.4 mm for rainfall amount of 58.6 mm in 2018 and the average runoff was 15.8 mm. The runoff depth was increased up to 2 mm for almost similar rainfall depth and AMC conditions in 2018 is due to the increase in the curve number value. The curve numbers are strongly based on the land use and soil parameters.

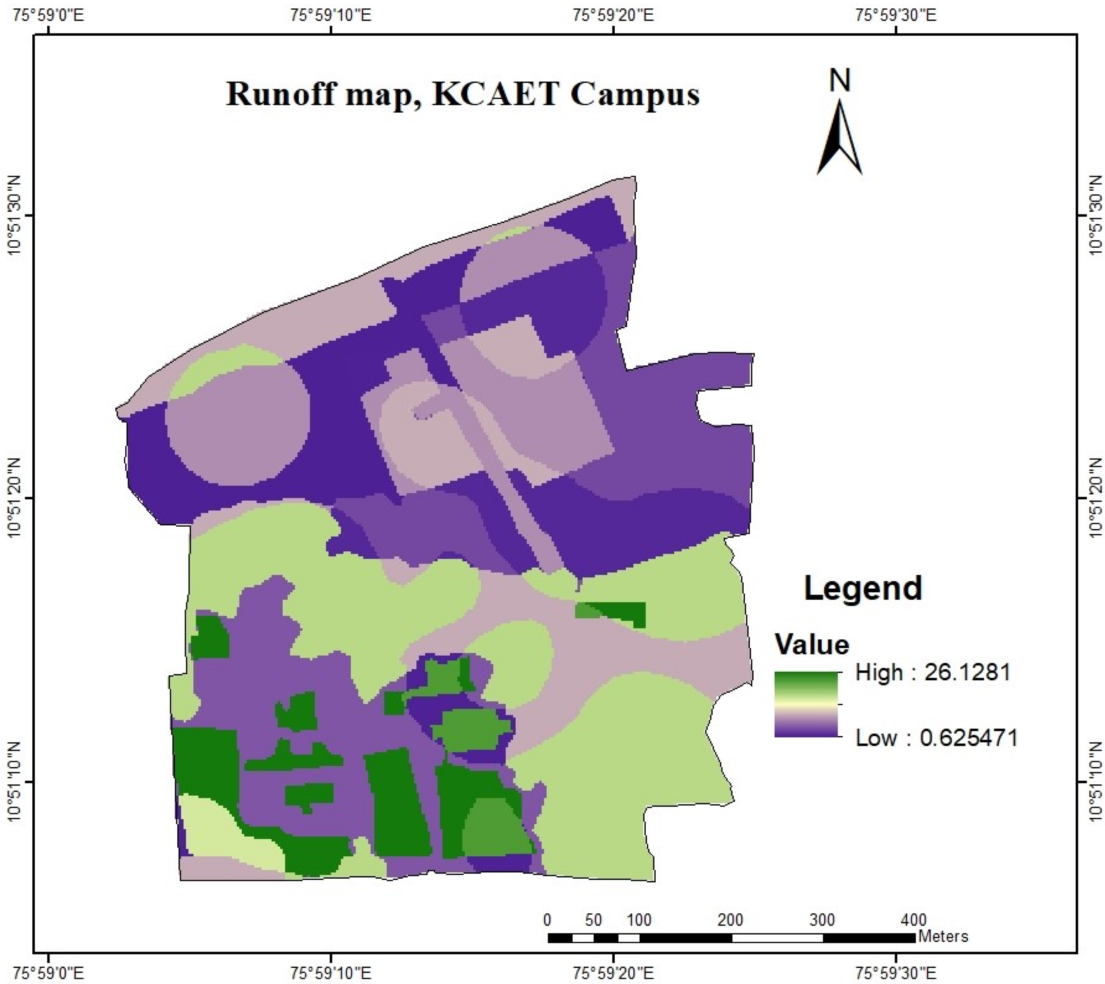

Fig. 4.21: Runoff map for 30 June 2006

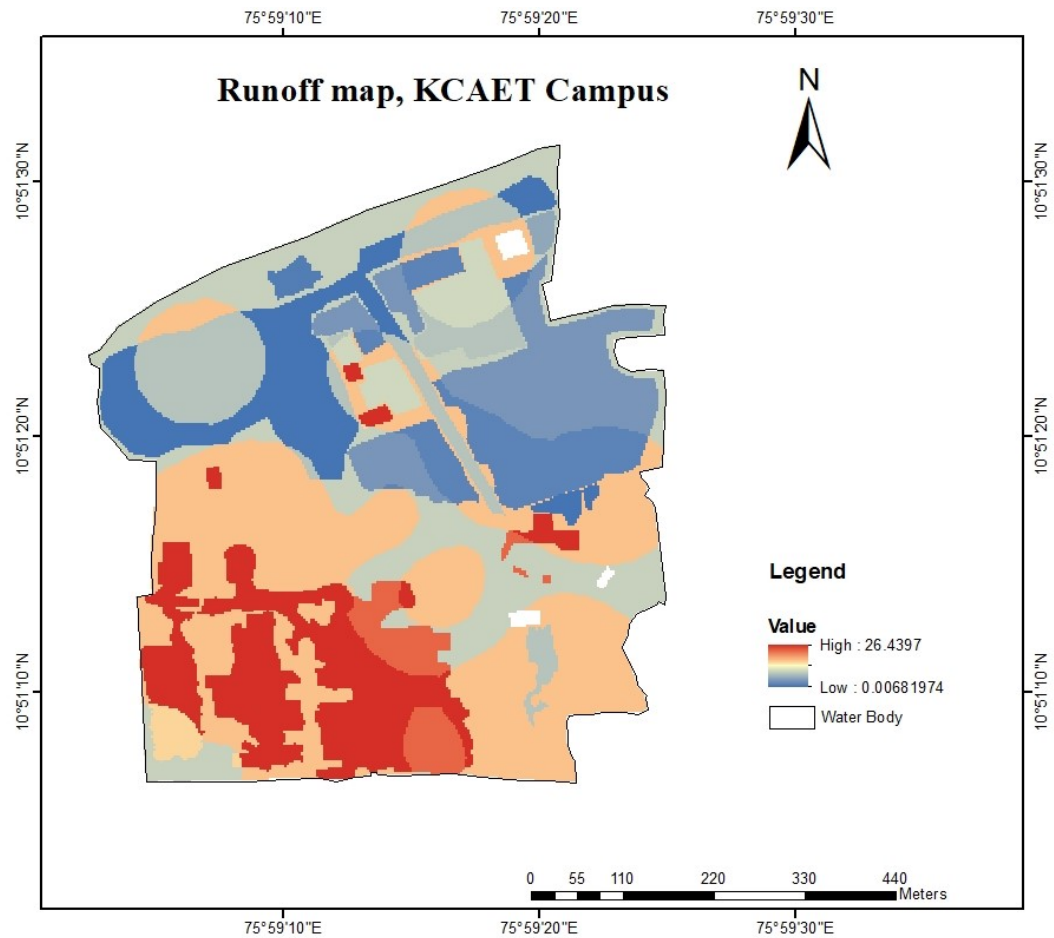

Fig. 4.22: Runoff map for 20 June 2018

Percentage of impervious land use type got increased which resulted in the increase in runoff depth. Rainfall runoff correlation of the study area on the basis of weighted curve numbers is represented in table 4.5. The composite curve number values for normal conditions got increased in 2018 from 57.77 to 58.95 and correlation was developed by taking initial abstraction value as 0.2.

Table 4.5: Rainfall runoff correlation of the study area

Year	AMC	CN	S	Q (taking λ=0.2)
2006	I	37.47	423.87	$\frac{(P-84.77)^2}{P+339}$
	II	57.77	185.67	$\frac{(P-37.13)^2}{P+148.5}$
	III	75.92	80.56	$\frac{(P-16.1)^2}{P+64.4}$
2018	I	38.61	403.86	$\frac{(P-80.77)^2}{P+323}$
	II	58.95	176.87	$\frac{(P-35.3)^2}{P+141.49}$
	III	77.08	75.52	$\frac{(P-15.1)^2}{P+60.42}$

Fig 4.23 represents the correlation between the rainfall and runoff in the study area. R^2 value is obtained was 0.989.

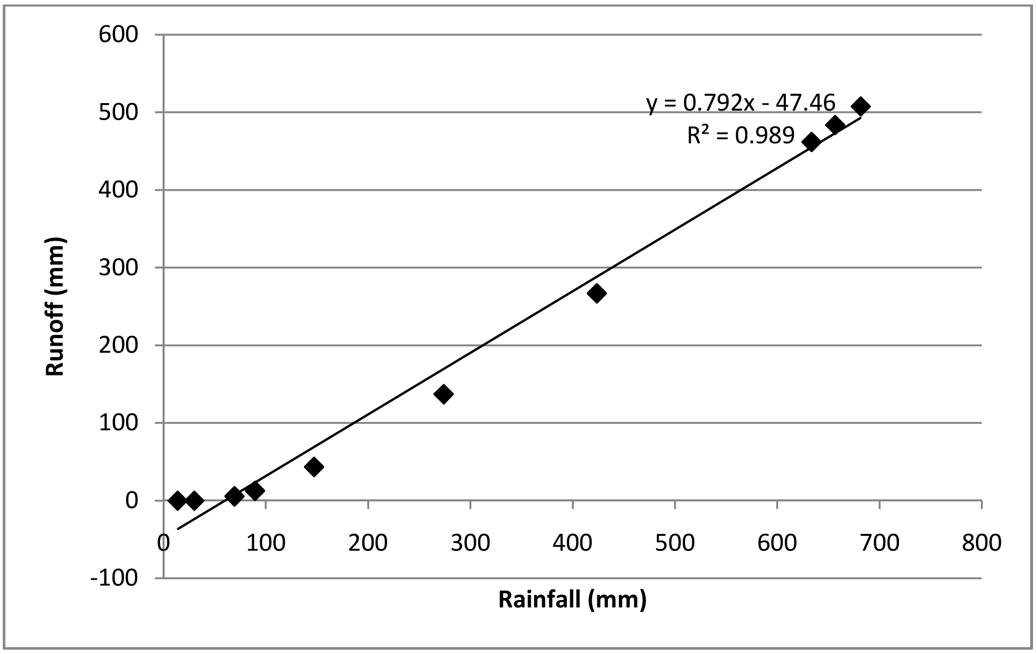

Fig. 4.23: Monthly rainfall runoff correlation

For the assessment of runoff from daily rainfall observations, the rainfall data from the study area was divided for four seasonal classes viz. pre monsoon season (April - May), south west monsoon season (June – September), north east monsoon (October- December) and post monsoon season (January – March). Not much rainfall was observed in the post monsoon season in the study area, hence no runoff was observed for the months of January, February and March.

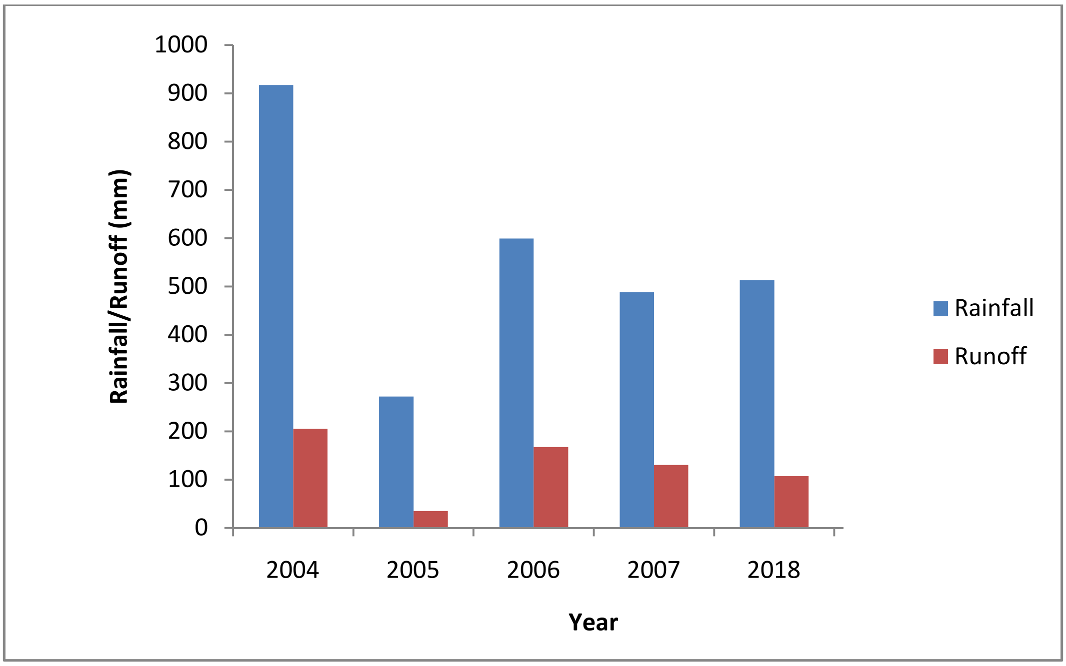

Fig. 4.24: Rainfall - Runoff variation in Pre monsoon

The pre-monsoon or summer rain starts in the middle of April and continues upto May and the rainfall will be of less intense and intermittent. Hence the 5 day cumulative rainfall depth also will be lesser. The antecedent moisture condition will be I or II for most of the days. Amount of rainfall in the pre-monsoon season also shows a decreasing trend. Less than 20% of the total rainfall is produced as runoff in pre monsoon season. From the total rainfall depth of 272 mm in 2005 pre monsoon season, 35 mm was the runoff yield. It was 12.9% of the total rainfall depth.

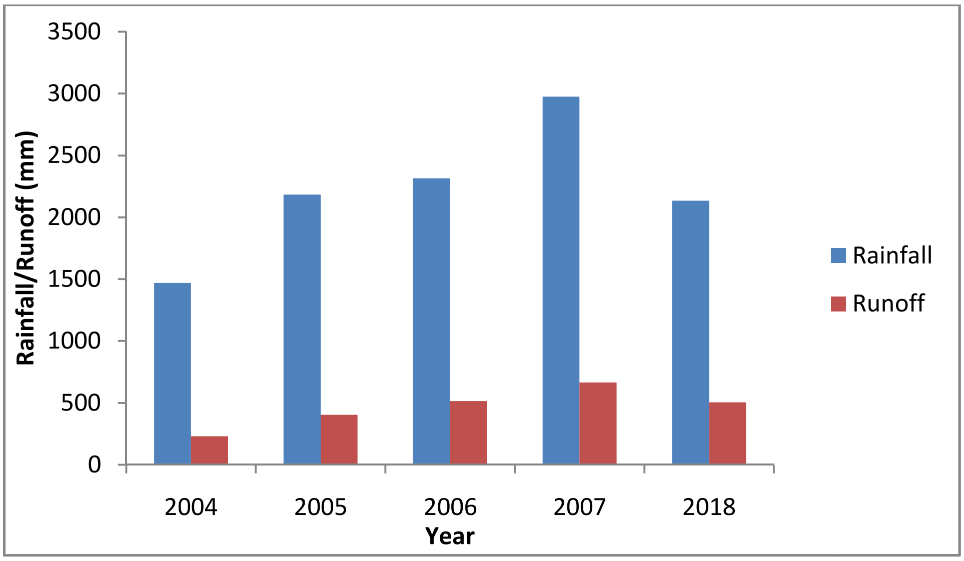

Fig. 4.25: Rainfall – Runoff variation in South West Monsoon

About 60% of the total rainfall depth in Kerala is received from south west monsoon. The maximum amount of rainfall and thereby runoff depth was observed during June and July and the runoff percentage was in the range of 18 to 23. In the year 2018, the rainfall depth in SW monsoon was 2135 mm from which 504 mm runoff depth was observed. About 23% of the total rainfall depth was converted to runoff in the season. The antecedent moisture condition for most of the days in the season was III, therefore the retention capacity was lesser and hence more runoff yield was obtained.

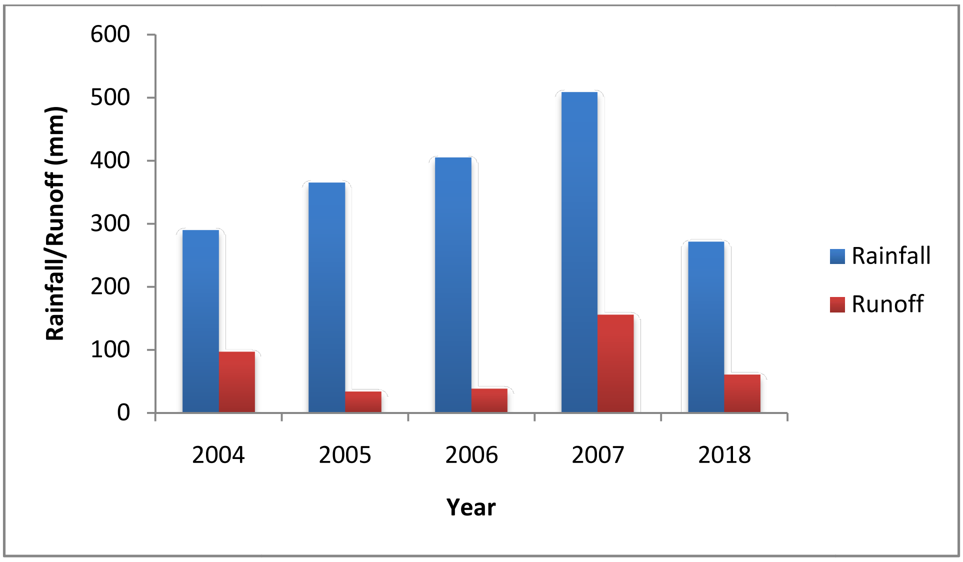

Fig. 4.26: Rainfall – Runoff variation in North East monsoon

The north east monsoon contributes about 30% of the total rainfall. The maximum rainfall was observed during October in the season. Rainfall depth in the particular season was 508.4 in the year 2007 whereas in 2018 it was reduced to 271.6 mm. Also the runoff percentage in this season was less. It ranges from 9% to 20%. In 2005 and 2006, the runoff percentage was 9.5% and 9.3% from 364.9 mm and 404.75 mm respectively. From the rainfall depth of 271.6 mm the runoff produced was 61 mm in 2018.

Yearly rainfall and runoff values obtained from the study area using NRCS CN method is given in table 4.6, and runoff percentage values from the study area varied from 19% to 23%. Also it is showing an increasing trend from 2004 to 2018. 23.92% runoff was observed from 3971.8 mm of rainfall in 2007 and almost similar amount of runoff was observed in 2018 from 2919.8 mm of rainfall. This shows the reduction in annual rainfall depth in the region. Retention capacity of the soil and thereby the ground water recharge has reduced drastically. Decrease in the rainfall amount in pre monsoon season and decrease in ground water recharge may lead to severe drought hence proper water harvesting systems should be designed and implemented. Also the ground water recharge rate should be increased.

Table 4.6: Yearly rainfall - runoff

Year	Rainfall (mm)	Runoff (mm)	Runoff (%)	Volume (m^3)
2004	2675.18	533.02	19.92	208030.95
2005	2819.1	472.48	16.76	184406.03
2006	3320.05	720.48	21.70	281194.94
2007	3971.8	950.13	23.92	370824.42
2018	2919.8	672.68	23.04	262538.87

The spatial severity range of runoff in the study area is shown in Figure 4.27. The runoff severity is categorized into three classes viz. low, medium and high. Areas which has vegetative cover with ground cover with litter or grass and which belongs to HSG A will have low and medium runoff potential compared to land use with impervious structures and which belongs to HSG B. About 28.5% of the area have high runoff potential, 33.7% have medium runoff potential and 37.7% of the total area have low runoff severity range. Major part of the area which belongs to high severity range of runoff have built up and open spaces. Since the water bodies in the study area are water storage structures it does not produced any surface runoff.

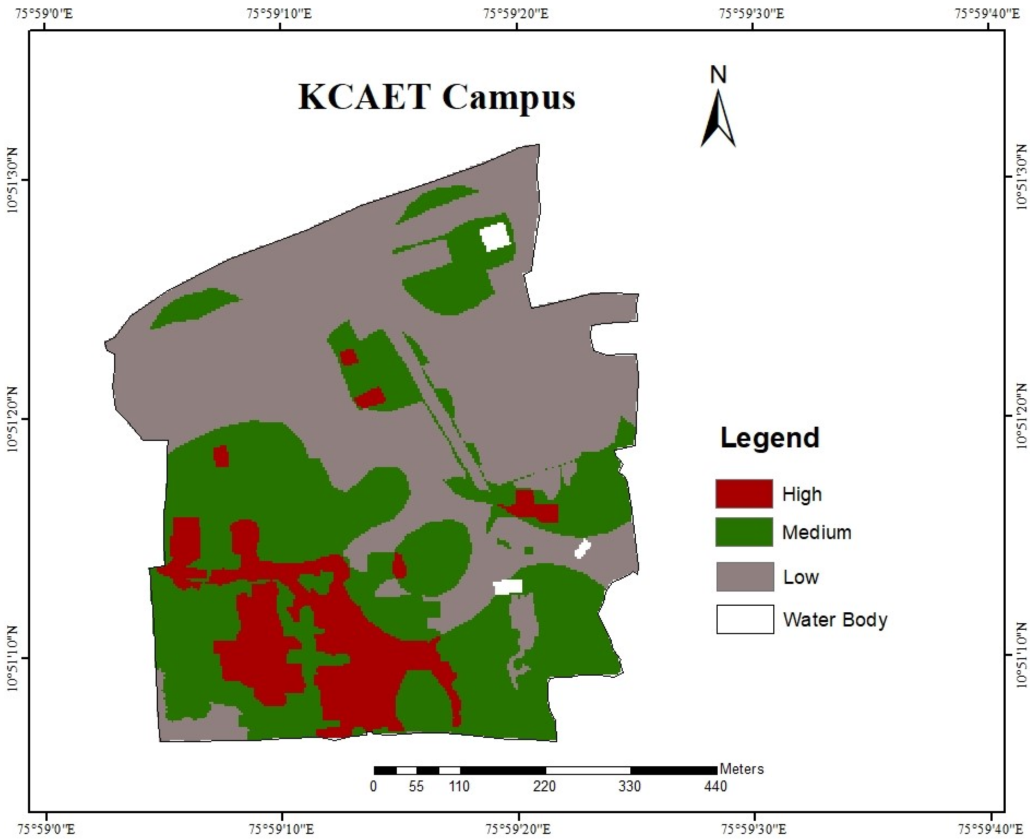

Fig. 4.27: Severity range of runoff

4.6 RAINFALL-RUNOFF CURVE NUMBER BEHAVIOR OF THE AREA

In the NRCS CN method, the critical assumption is that the ratio of actual retention to the potential retention is equal to the actual runoff to the potential runoff (Yu, 2012). Hawkins (1993) studied the asymptotic determination of runoff curve numbers from the measured runoff. He concluded that a systematic correlation exists between the rainfall depth and calculated CN value. The curve numbers approaches a constant value with increase in rainfall depth. The asymptotic CN behavior of the study area with increase in rainfall is shown in Fig 4.28. The results are in agreement with conclusions drawn by Hawkins (1993) and Singh (2015).

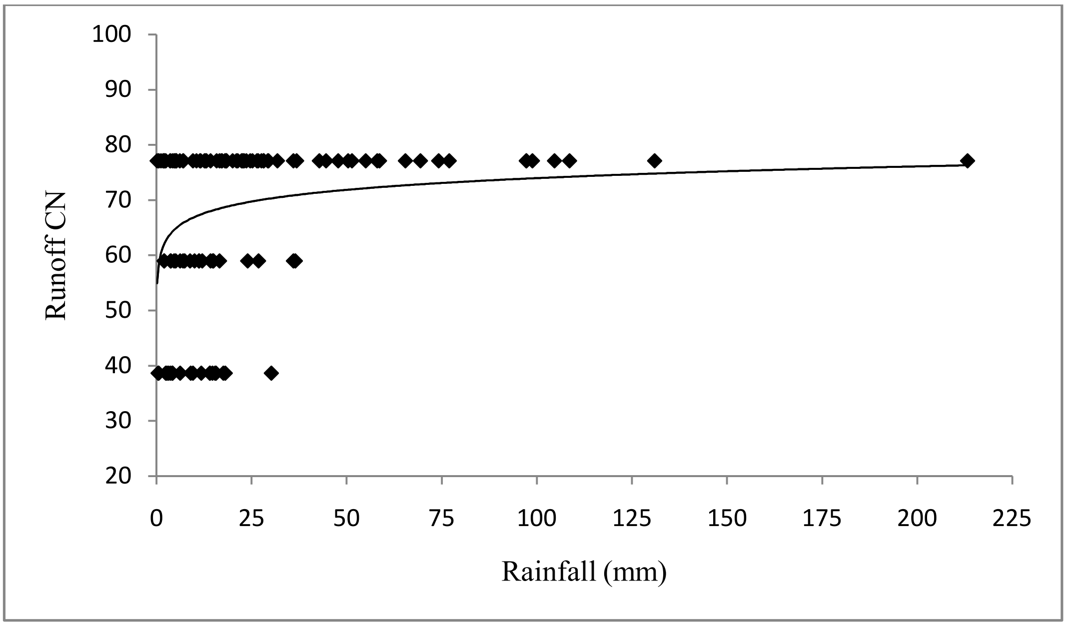

Fig. 4.28: Rainfall – Runoff CN behavior of the area

CHAPTER V

SUMMARY AND CONCLUSION

Water is one of the most essential requirements for economic and social development. Precipitation and runoff are the two important hydrologic variables and principle components in the hydrologic cycle. Surface water that drains of the land into an outlet is called runoff and runoff water has the capacity to detach and transport the soil particles which leads to the severe erosion process. Runoff and subsequent erosion will reduce the productivity and quality of the land. Recent reports reveal that water level in the major aquifers of the world is receding now a day. Both population and temperature rise indicate that the presently available fresh water is under severe pressure and it is anticipated that the situation will become worse during current century.

Keeping the above perspectives in view, this particular study was mainly focused to estimate the runoff from KCAET Campus using remote sensing and GIS techniques, as the conventional methods are time consuming and expensive. The simulated runoff was compared with observed runoff to validate the CN method in estimating runoff from the study area. The analysis was done for the year 2004, 2005, 2006, 2007 and 2018 and validation of the method was done with selected storm events in the study area.

Methodology adopted in this study involves preparation of soil map, land use/land cover map, initial abstraction map (Ia), maximum potential retention map (S) and further processing of these maps/layers in GIS environment to estimate the direct runoff depth. Geodatabase for the NRCS CN method was prepared and analyzed. The land use type of the area was identified and digitized from Google earth imagery of 2006 and 2018. It was found that majority of the area have vegetative cover. About 7% of area was covered with buildings and pavements in 2006 which was then increased to 14 % in 2018. But the percentage of vegetative cover got increased from 35.14 % to 46.4 %. The soil samples were collected from 20 different locations of the study area randomly and soil map was prepared after conducting sieve analysis of the samples. Sandy loam soil dominated the area and belongs to hydrological soil group A. The prepared HSG map and land use maps were intersected in ArcGIS platform. CN values were assigned on the basis of HSG and land use. The composite curve number for the normal condition is 57.77, whereas for wet and dry conditions are 75.92 and 37.47 in 2006. In 2018, the composite curve number for normal condition is 58.95, whereas it is 77.08 and 3.61 for wet and dry conditions respectively. The CN maps for AMC I, AMC II and AMC III for 2006 and 2018 were generated. Daily rainfall for the year 2004, 2005, 2006, 2007 and 2018 was collected from non-recording rain gauge in the study area and runoff maps were generated using NRCS CN method in the GIS environment.

Assessment of rainfall and runoff from the study area was done for four seasons viz. pre-monsoon season (April - May), south west monsoon season (June – September), north east monsoon (October - December) and post monsoon season (January – March). As there was no rainfall during post monsoon, no runoff was observed. The antecedent moisture conditions in most of the days of pre-monsoon season were I and II and the rainfall pattern was well distributed throughout the season. Hence, less than 20% of the total rainfall in the season was converted to runoff. The infiltration rate was higher in this season. More runoff depth was observed during SW monsoon season and upto 23% of total rainfall was converted to runoff. The runoff percentage during NE monsoon was less compared to SW monsoon and it varied from 9% to 20%. In the year 2007, 23.92% was the runoff from 3971.8 mm of rainfall and in 2018, 23.04% was the runoff from 2919.8 mm of annual rainfall.

The spatial variation in severity range of runoff was done by categorizing the runoff prone areas into three classes viz. low, medium and high. About 28.5% of total area comes under high runoff prone area, 33.7% on medium range and 37.3% on low range of runoff. The lowest runoff potential was identified in areas having thick vegetative cover and falling under HSG A. The built up and open lands with HSG B includes the major part of high runoff prone area. Also the influence of 5 day cumulative rainfall on potential maximum retention was analyzed. As the 5 day cumulative rainfall got increased, the runoff percentage also increased and the retention capacity got reduced. When the rainfall depth increased, the runoff curve number value also got increased.

Validation of the model was done using selected storm events in the study area. For the purpose, discharge was measured from compacted area having natural outlet of water flow. Rainfall measurements were done using tipping bucket rain gauge and drop box weir which was designed for runoff measurements in small catchments was used for the runoff measurement. The relative error between observed and simulated values varied from 7 % to 160 % and correlation coefficient, R^2 was 0.929. Runoff estimated using curve number method was comparable with measured runoff for the study area and the result show that the integration of remote sensing and GIS along with curve number method is a powerful tool in estimation of runoff.

Analysis of the results showed that as the runoff percentage is increasing, the retention capacity of the soil is reducing. This leads to the decline of water table resulting in water stress in terms of available fresh water. As the water demand is increasing due to population explosion and resource limitations, it is essential to recharge the ground water using the runoff generated.

Recommendations on future studies

- Make use of AHP (Analytic Hierarchy Process) techniques for the assessment of potential sites for the installation of water harvesting structures and ground water recharging structures and study their impact.
- The runoff yield can be estimated and analyzed using SWAT model and neural networks.
- The assessment can be done in watershed basis and validation of the model can be done with discharge data.

Introduction

Review of Literature

Materials and Methods

Results and Discussion

Summary and Conclusion

References

Appendices