CHAPTER 5
RESULTS AND ANALYSIS

5.1 GENERAL

This chapter shows the outcomes for each particular objective. The outcomes acquired for each of the six objectives are presented in the further sections.

5.2 PREPARATION OF LAND USE/LAND COVER (LULC) MAPS

Objective 1: To study the changes in Land Use/Land Cover (LULC)/ Urban Sprawl over a period, that influences the runoff characteristics of the study area.

The land use/land cover change detection is carried out for the years 1977, 1988, 1993, 1998, 2003, 2008, 2013 and 2018, for almost 4 decades. Prior to determining the final LULC classes, preprocessing of the image has been carried out, image enhancement, study area extraction and post processing was also carried out to rectify the classes, which were not clearly identified.

After carrying out the processing of image, the following results are obtained. The classification of the images for the years 1977, 1988, 1993, 1998, 2003, 2008, 2013 and 2018 are shown in Fig. 5.1, Fig. 5.2, Fig. 5.3, Fig. 5.4, Fig. 5.5, Fig. 5.6, Fig. 5.7, and Fig.5.8 respectively.

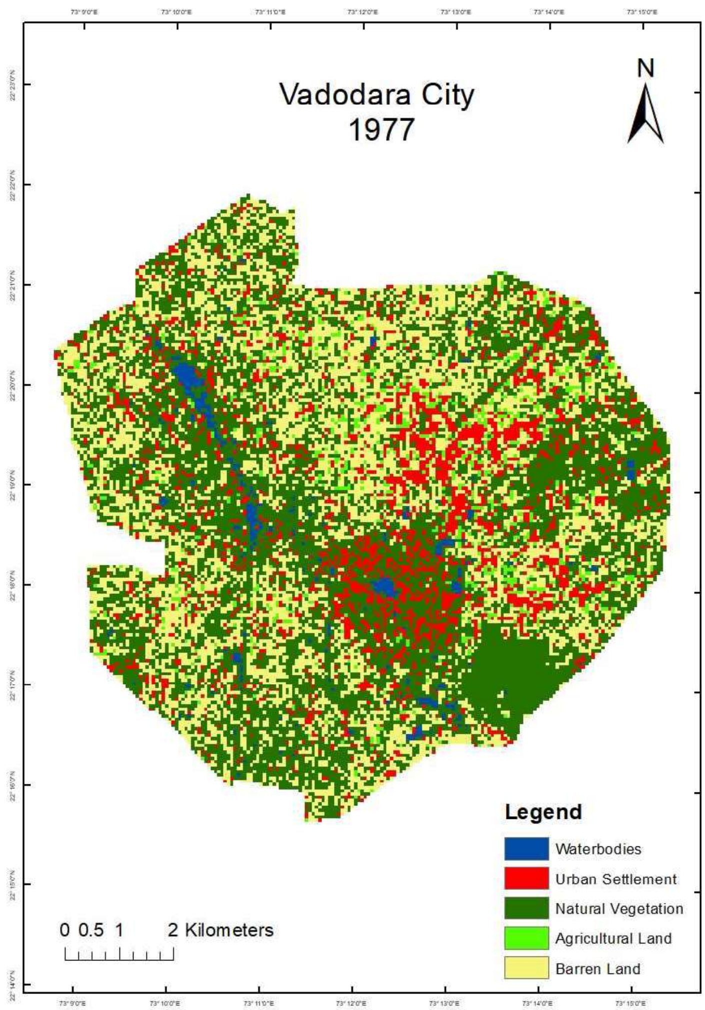


Figure 5.1: LULC Map for Vadodara City in 1977

Fig. 5.1 shows the LULC classification of Vadodara city for the year 1977.

The values of areas of five classes, namely Waterbodies, Urban Settlement, Natural Vegetation, Agricultural Land and Barren Land are given in Table 5.1

Table 5.1: Areas of different LULC classes for 1977

LULC Class	Corresponding Area, Sq. Km.
Waterbodies	1.44
Urban Settlement	11.60
Natural Vegetation	40.82
Agricultural Land	3.93
Barren Land	30.30
Total Area	88.10

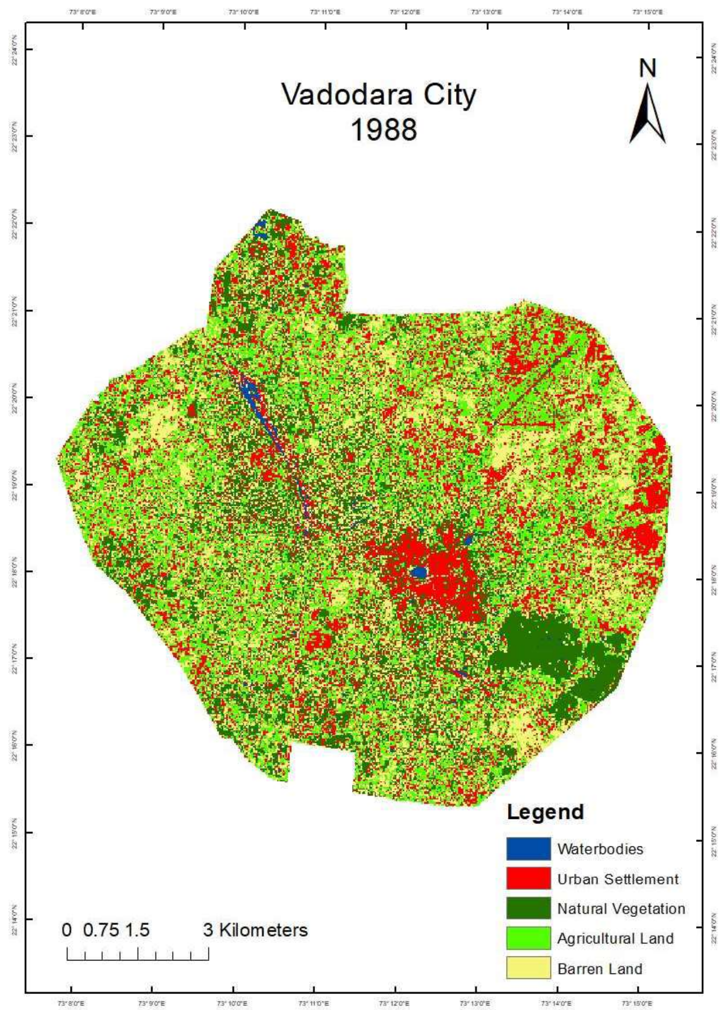


Figure 5.2: LULC Map for Vadodara City in 1988

Fig. 5.2 shows the LULC classification of Vadodara city for the year 1988.

The values of areas of five classes, namely Waterbodies, Urban Settlement, Natural Vegetation, Agricultural Land and Barren Land are given in Table 5.2

Table 5.2: Areas of different LULC classes for 1988

LULC Class	Corresponding Area, Sq. Km.
Waterbodies	0.82
Urban Settlement	24.30
Natural Vegetation	20.06
Agricultural Land	33.94
Barren Land	29.05
Total Area	108.18

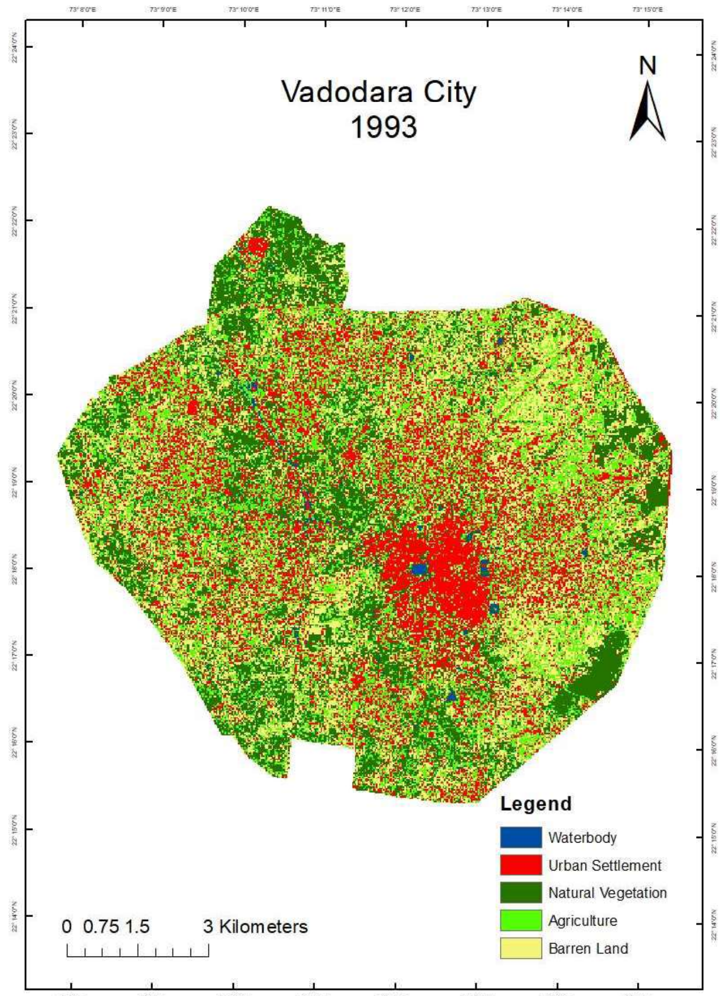


Figure 5.3: LULC Map for Vadodara City in 1993

Fig. 5.3 shows the LULC classification of Vadodara city for the year 1993.

The values of areas of five classes, namely Waterbodies, Urban Settlement, Natural Vegetation, Agricultural Land and Barren Land are given in Table 5.3

Table 5.3: Areas of different LULC classes for 1993

LULC Class	**Corresponding Area, Sq. Km.**
Waterbodies	0.77
Urban Settlement	25.42
Natural Vegetation	25.37
Agricultural Land	28.61
Barren Land	27.99
Total Area	108.18

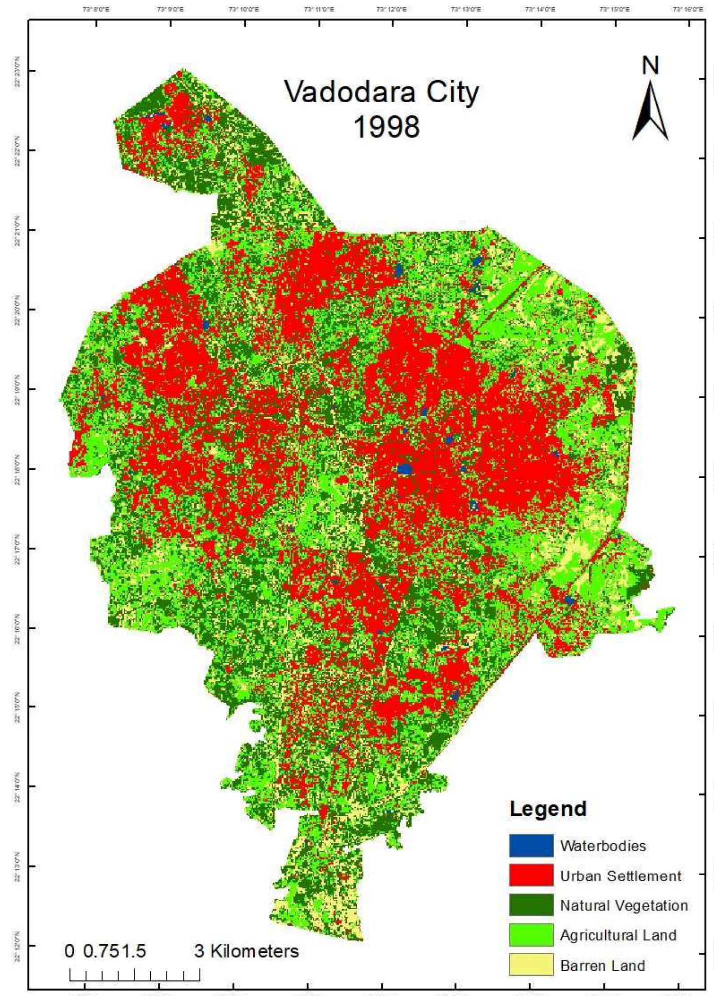


Figure 5.4 LULC Map for Vadodara City in 1998

Fig. 5.4 shows the LULC classification of Vadodara city for the year 1998.

The values of areas of five classes, namely Waterbodies, Urban Settlement, Natural Vegetation, Agricultural Land and Barren Land are given in Table 5.4

Table 5.4: Areas of different LULC classes for 1998

LULC Class	**Corresponding Area, Sq. Km.**
Waterbodies	0.62
Urban Settlement	48.10
Natural Vegetation	38.89
Agricultural Land	44.11
Barren Land	18.24
Total Area	149.96

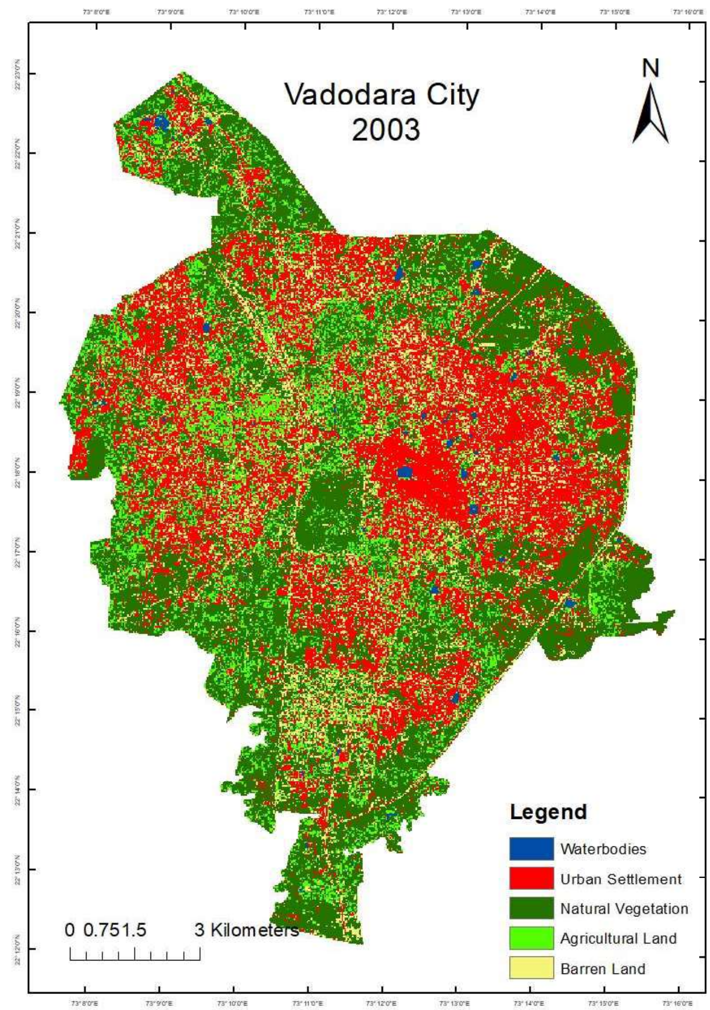


Figure 5.5: LULC Map for Vadodara City in 2003

Fig. 5.5 shows the LULC classification of Vadodara city for the year 2003.

The values of areas of five classes, namely Waterbodies, Urban settlement, Natural Vegetation, Agricultural Land and Barren Land are given in Table 5.5

Table 5.5: Areas of different LULC classes for 2003

LULC Class	Corresponding Area, Sq. Km.
Waterbodies	1.21
Urban Settlement	48.11
Natural Vegetation	59.84
Agricultural Land	23.71
Barren Land	17.08
Total Area	149.96

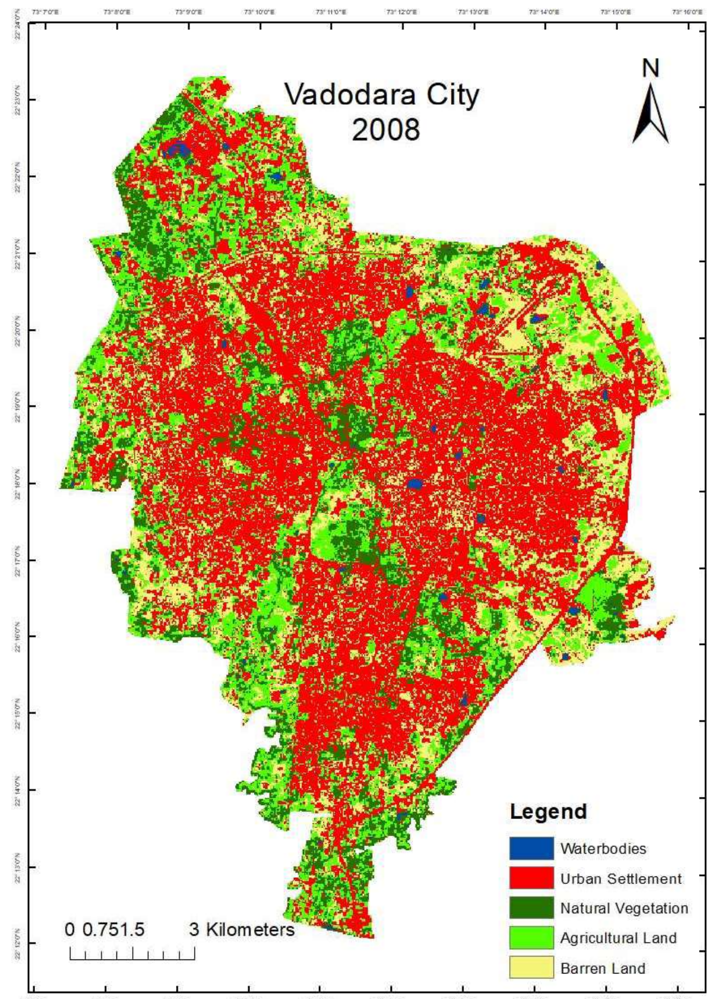


Figure 5.6: LULC Map for Vadodara City in 2008

Fig. 5.6 shows the LULC classification of Vadodara city for the year 2008.

The values of areas of five classes, namely Waterbodies, Urban Settlement, Natural Vegetation, Agricultural Land and Barren Land are given in Table 5.6

Table 5.6: Areas of different LULC classes for 2008

LULC Class	**Corresponding Area, Sq. Km.**
Waterbodies	1.00
Built-up	80.75
Natural Vegetation	18.72
Agricultural Land	35.64
Barren Land	32.63
Total Area	168.75

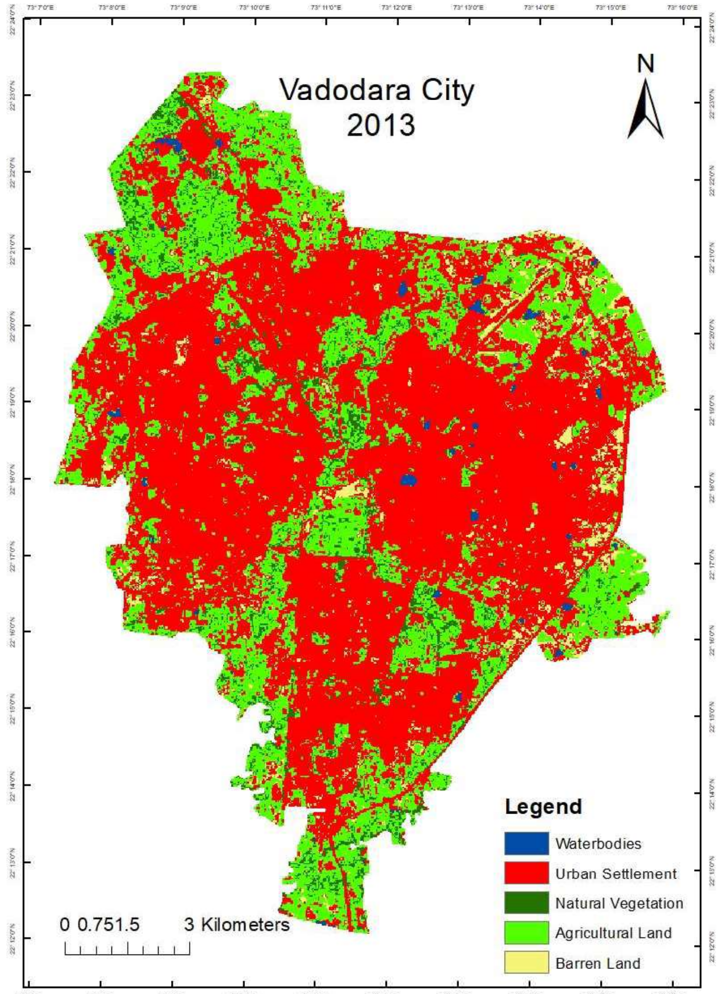


Figure 5.7: LULC Map for Vadodara City in 2013

Fig. 5.7 shows the LULC classification of Vadodara city for the year 2013.

The values of areas of five classes, namely Waterbodies, Urban Settlement, Natural Vegetation, Agricultural Land and Barren Land are given in Table 5.7

Table 5.7: Areas of different LULC classes for 2013

LULC Class	Corresponding Area, Sq. Km.
Waterbodies	1.11
Built-up	106.68
Natural Vegetation	7.94
Agricultural Land	46.53
Barren Land	6.49
Total Area	149.96

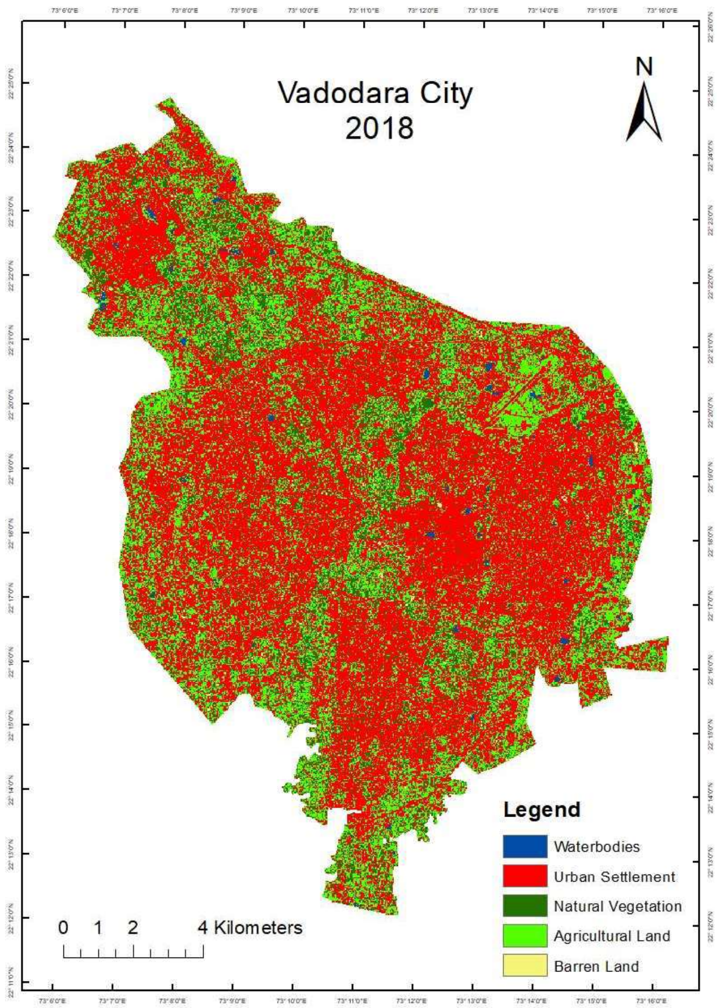


Figure 5.8: LULC Map for Vadodara City in 2018

Fig. 5.8 shows the LULC classification of Vadodara city for the year 2018.

The values of areas of five classes, namely Waterbodies, Urban Settlement, Natural Vegetation, Agricultural Land and Barren Land are given in Table 5.8

Table 5.8: Areas of different LULC classes for 2018

LULC Class	Corresponding Area, Sq. Km.
Waterbodies	1.36
Built-up	122.02
Natural Vegetation	32.70
Agricultural Land	55.92
Barren Land	2.63
Total Area	214.63

Accuracy Assessment of Classified Images

A crucial stage in LULC change analysis is accuracy assessment of a classified image. To ensure that each of the five LULC classes are appropriately represented, 100 sample points were gathered using a stratified random sample technique, considering the relative area of each class.

Images from Google Earth were utilised to collect reference information. The reference information of the year 2018 was utilized to evaluate the accuracy of the classified image. The accuracy evaluation for the image of other years was carried out, assuming the other years to be similar to that of the image of 2018, however with different extents. The confusion (error) matrix's producer and user accuracies, overall accuracy, and Kappa coefficient were used to determine the accuracy evaluation (Congalton and Green 2009; Liu et al. 2007). The link between the categorised map and reference data is indicated by the Kappa coefficient (Lillesand and Keifer 2000). The accuracy of the five LULC classes, both individually and collectively, is calculated using the error matrix. The Jensen and Cowen (1999) equation was used to calculate the Kappa coefficient.

Accuracy assessment determining the accuracy of image classification, is found to be 92% for the overall accuracy of the year 2018 with the Kappa coefficient of 0.89.

5.3 ANALYSIS OF LULC MAPS

A decadal analysis of the LULC maps obtained, is carried out from 1977 to 2018, for four decades namely 1977 – 1988, 1988 – 1998, 1998 – 2008, 2008 to 2018, respectively. The total and respective LULC class areas and their percentages with respect to total areas of land use/land cover by each of the LULC class of Waterbodies, Urban Settlement, Natural Vegetation, Agricultural Land and Barren Land for the years 1977, 1988, 1998, 2008 and 2018 respectively, are shown in Table 5.9.

Table 5.9: Areas and Percentage of LULC classes in Vadodara City 1977 – 2018 (Decadal)

	Area, Sq. Km.					Area, Percentage (%)				
LULC Class	**1977**	**1988**	**1998**	**2008**	**2018**	**1977**	**1988**	**1998**	**2008**	**2018**
Water bodies	1.44	0.82	0.62	1.00	1.36	1.64	0.76	0.41	0.59	0.63
Urban Settlement	11.60	24.30	48.10	80.75	122.02	13.16	22.47	32.07	47.85	56.85
Natural Vegetation	40.82	20.06	38.89	18.72	32.70	46.33	18.54	25.93	11.09	15.24
Agricultural Land	3.93	33.94	44.11	35.64	55.92	4.46	31.37	29.42	21.12	26.05
Barren Land	30.30	29.05	18.24	32.63	2.63	34.40	26.85	12.16	19.34	1.22
Total	88.10	108.18	149.96	168.75	214.63	100	100	100	100	100

Table 5.9 is represented in Fig. 5.9 in the form of pie chart for all LULC classes in the years of 1977, 1988, 1998, 2008 and 2018.

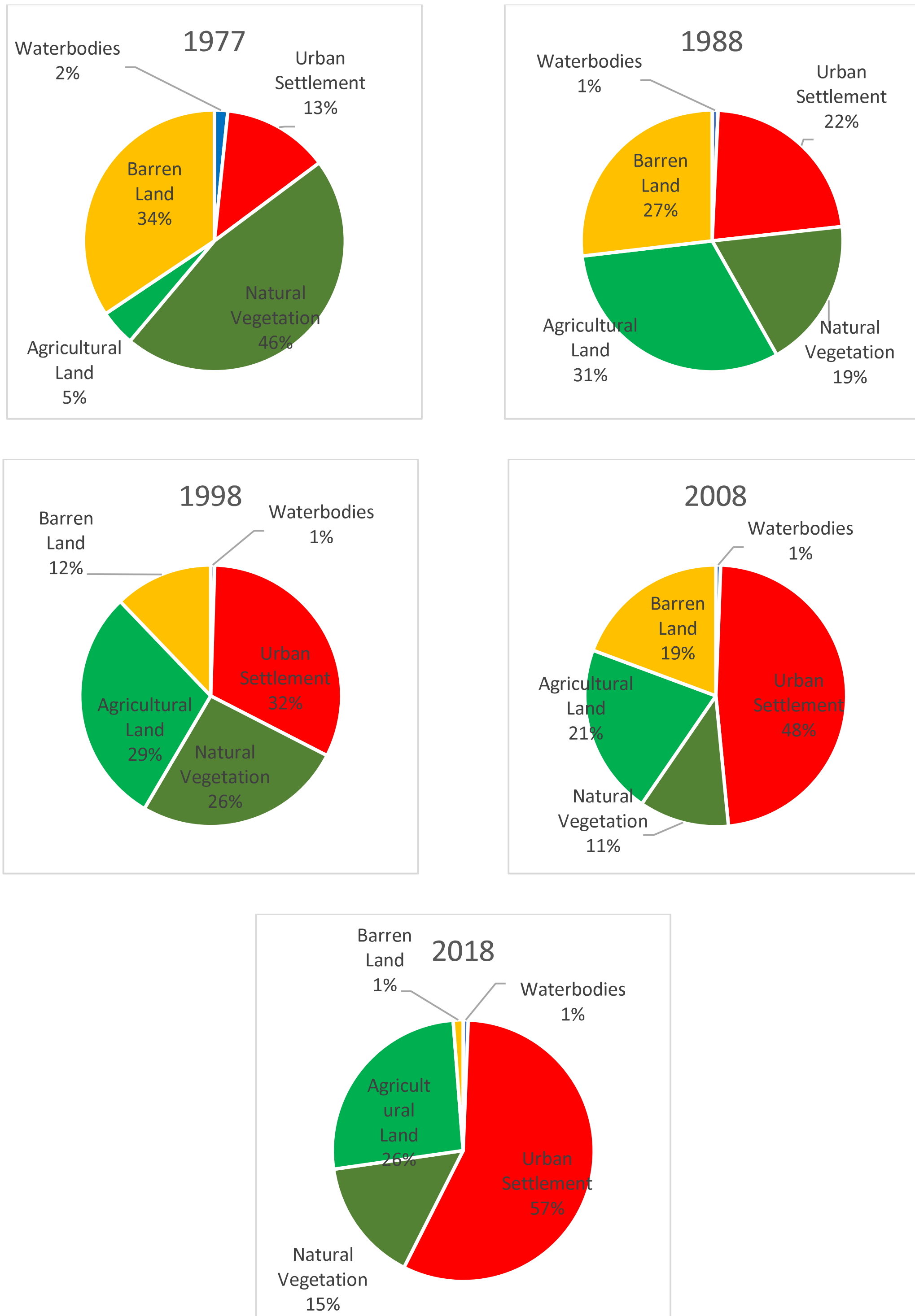
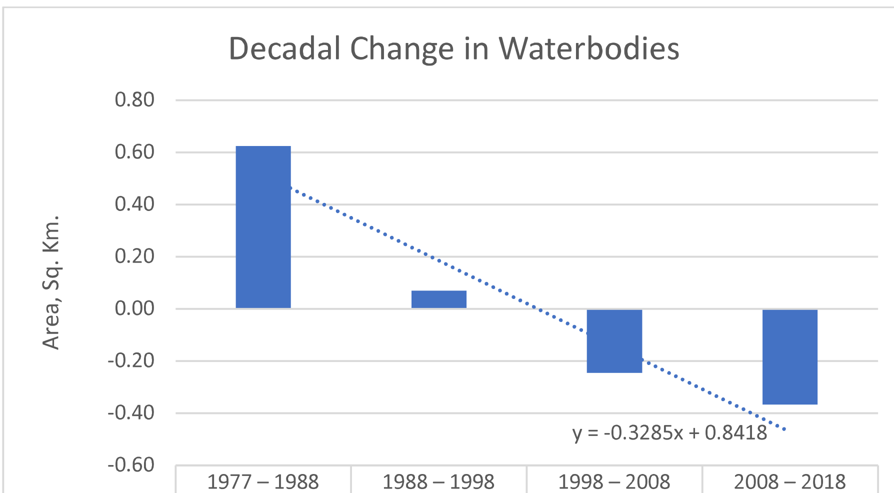


Figure 5.9: Pie Charts showing percentage distribution of classified LULC Areas [1977 – 2018, Decadal]

Fig. 5.9 shows the proportion of areas of different LULC classes for each of the years 1977, 1988, 1998, 2008 and 2018.

The classification of urban settlement shows that there is a significant increase in urban settlement from 13% to 57% of its share in the total area from 1977 to 2018. In 1977 13% of the area was occupied by urban settlement, it increased to 22% in 1988, further increased to 32% in 1998, 47 % in 2008 and 57% in 2018. The classification of natural vegetation in LULC maps shows that the total percentage of area has decreased, from 46 % in 1977 to 15% in 2018. Similarly, for agricultural land, the total percentage of area increased in the first decade i.e. 1977 – 1988 by 27%, then, it decreased at about 11% during 1988 – 2008. After 2008, agricultural land again increased at about 5% during 2008 – 2018. The classification results of barren land shows that, it is decreased by 7% to 14% during 1977 – 1998. From 1998 – 2008, it showed an increase of about 7% and then, in the last decade of 2008 – 2018 it continued to decrease by 18%.

Decadal Change Detection of LULC classes



	1977 – 1988	1988 – 1998	1998 – 2008	2008 – 2018
Waterbodies	0.62	0.07	-0.25	-0.37

Figure 5.10: Decadal Changes in Waterbodies

Fig. 5.10 shows the decadal changes in the LULC class of waterbodies. From

Fig. 5,10, it is observed that waterbodies seem to be in decreasing trend. Only in the first decade of 1977 – 88, it is found to be high up to 2% of total area shared, otherwise the levels are going quite down.

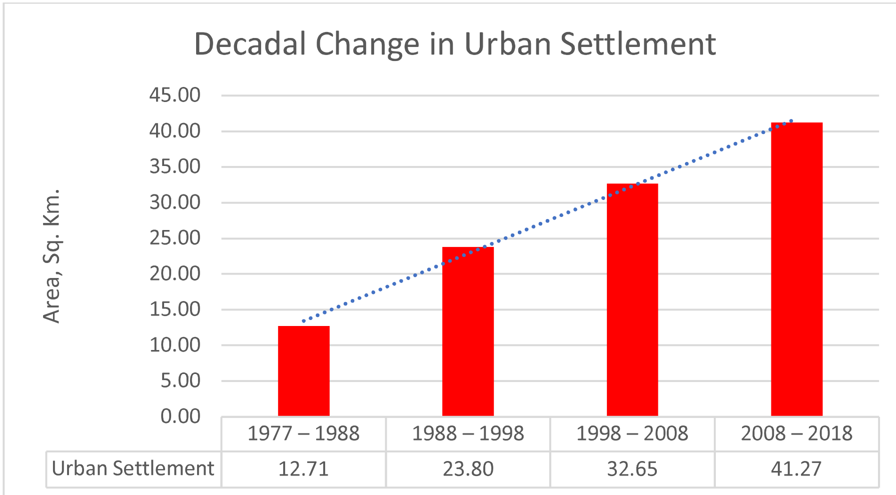


Figure 5.11: Decadal Changes in Urban Settlement

Fig. 5.11 shows the decadal changes in the LULC class of urban settlement.

From Fig. 5.11 it is observed that the urban settlement in the study area is said to be following a highly increasing trend. The maximum growth is observed in the decade of 1998 – 2008, which is 18% of decadal growth i.e. from 32% in 2008 to 48% in 2018.

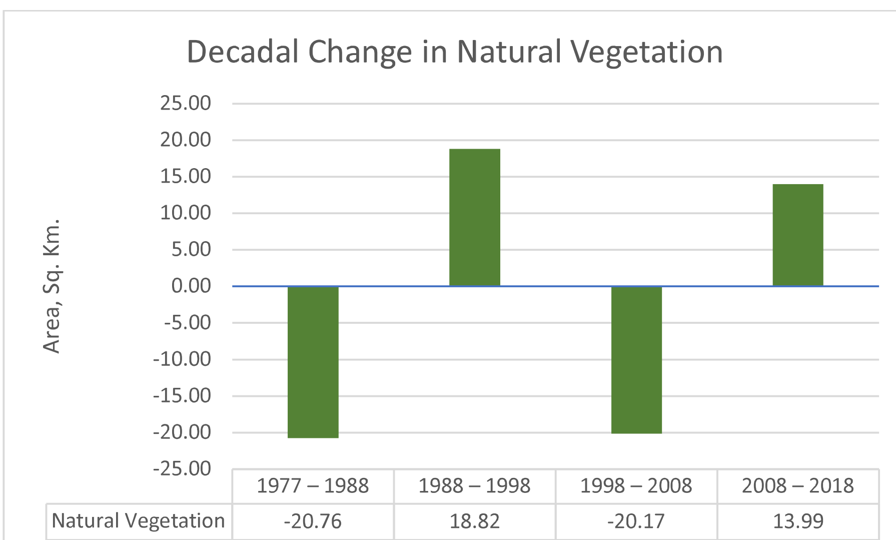


Figure 5.12: Decadal Changes in Natural Vegetation

Fig. 5.12 shows the decadal changes in the LULC class of natural vegetation. From Fig. 5.12, although no kind of trend is observed, the vegetation has seen the highest fall of 27% in the first decade of 1977 –1988 and a subsequent fall of 15% in an alternate decade of 1998 – 2008. In other two decades the vegetation was increased by 7% and 4% but overall, there is a loss of 31% of vegetation from 1977 – 2018, which depicts the decreasing trend.

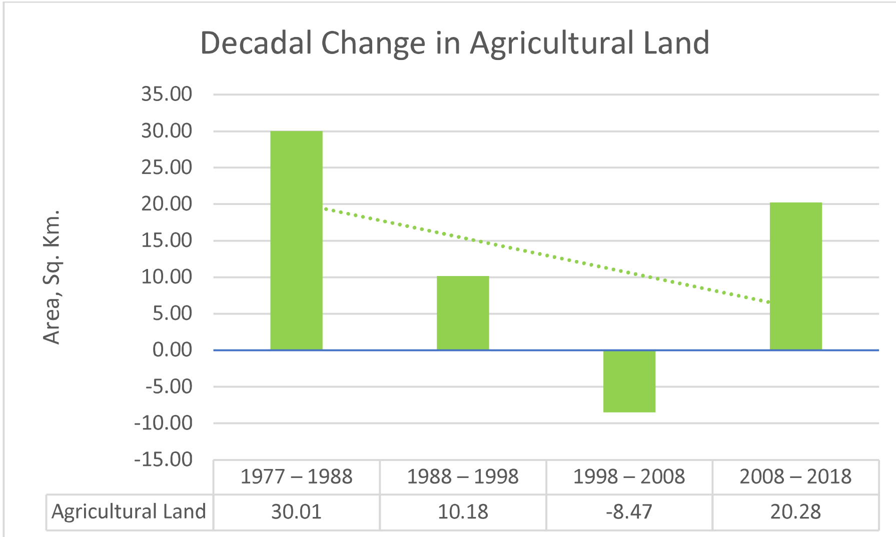


Figure 5.13: Decadal Changes in Agricultural Land

Fig. 5.13 shows the decadal changes in the LULC class of agricultural land. From

Fig. 5.13, the agricultural land is increased by 27% in the first decade and then subsequently decreased by 2% and 8% in the following decade of 1988 – 1998 and 1998 – 2008 respectively. In the last decade, it was increased by 4%.

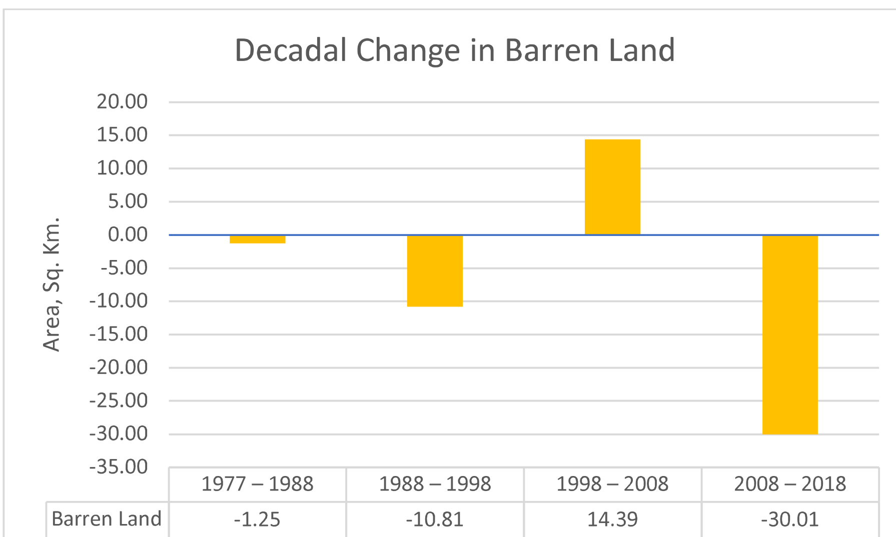


Figure 5.14: Decadal Changed in Barren Land

Fig. 5.14 shows the decadal changes in the LULC class of barren land. In Fig. 5.14 the barren land is decreased by 7% in the first decade, continued to decrease by 15% in the second decade and decreased by 18% in the last decade, except in the decade of 1998 – 2008, it is increased by 7%, with an overall loss of 33% of its area.

Amongst all the LULC classes, the urban settlement is observed to be continually increased. The growth of urban settle is compared with the change in population for all the four decades as shown in Fig. 5.15

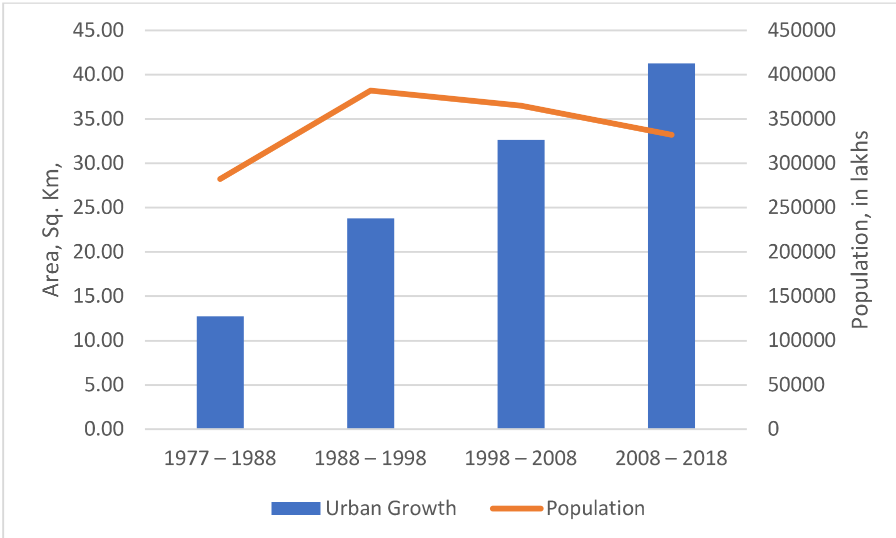


Figure 5.15: Decadal Changes in Urban Settlement and Population

From Fig. 5.15 it is observed that population and urban settlement are gradually increasing in the first two decade. Then in the third and fourth decade, although the population is stable but urban settlement is highly increased. When population and urban settlement goes parallel, it can be said as urban growth, but when urban growth and urban settlement is not proportion, it can be regarded as urban sprawl.

Fig. 5.16 shows the graph of all the LULC classes merged together.

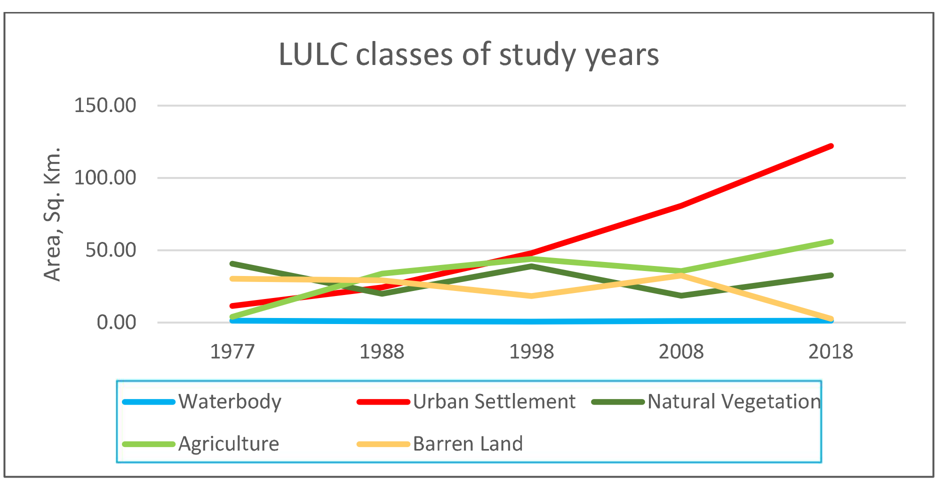


Figure 5.16: Comparison of LULC Classes in study years

From Fig. 5.16, it can be observed that the waterbodies remain stable for almost all the years of 1977, 1988, 1998, 2008 and 2018. The urban settlement is seen to be continuously increased in all the study years, specifically from 1977 to 1998, it is seen gradually increasing, and there is a significant spike observed from 1998 - 2018. Barren land is observed to gradually decrease from 1977 - 1998, but later from 1998 to 2008 there is surge, up to the year 2008 and then after 2008 - 2018, there is a sudden fall. During this period, mainly from 1998 to 2008, where surge is observed in barren land, the natural vegetation and agricultural land are seen to be declining, which puts forth the point that during this decade (1998 – 2008) a lot of construction activities were going on, which led the urban settlement to rise by 18%, highest amongst rise among all the years. During the next decade (2008 – 2018), a constant increase in urban settlement is observed. Although natural vegetation and agricultural land are also observed to be gradually increasing but in a lesser proportion than that of urban settlement.

Fig. 5.17 shows the spatio temporal analysis of LULC maps of Vadodara city.

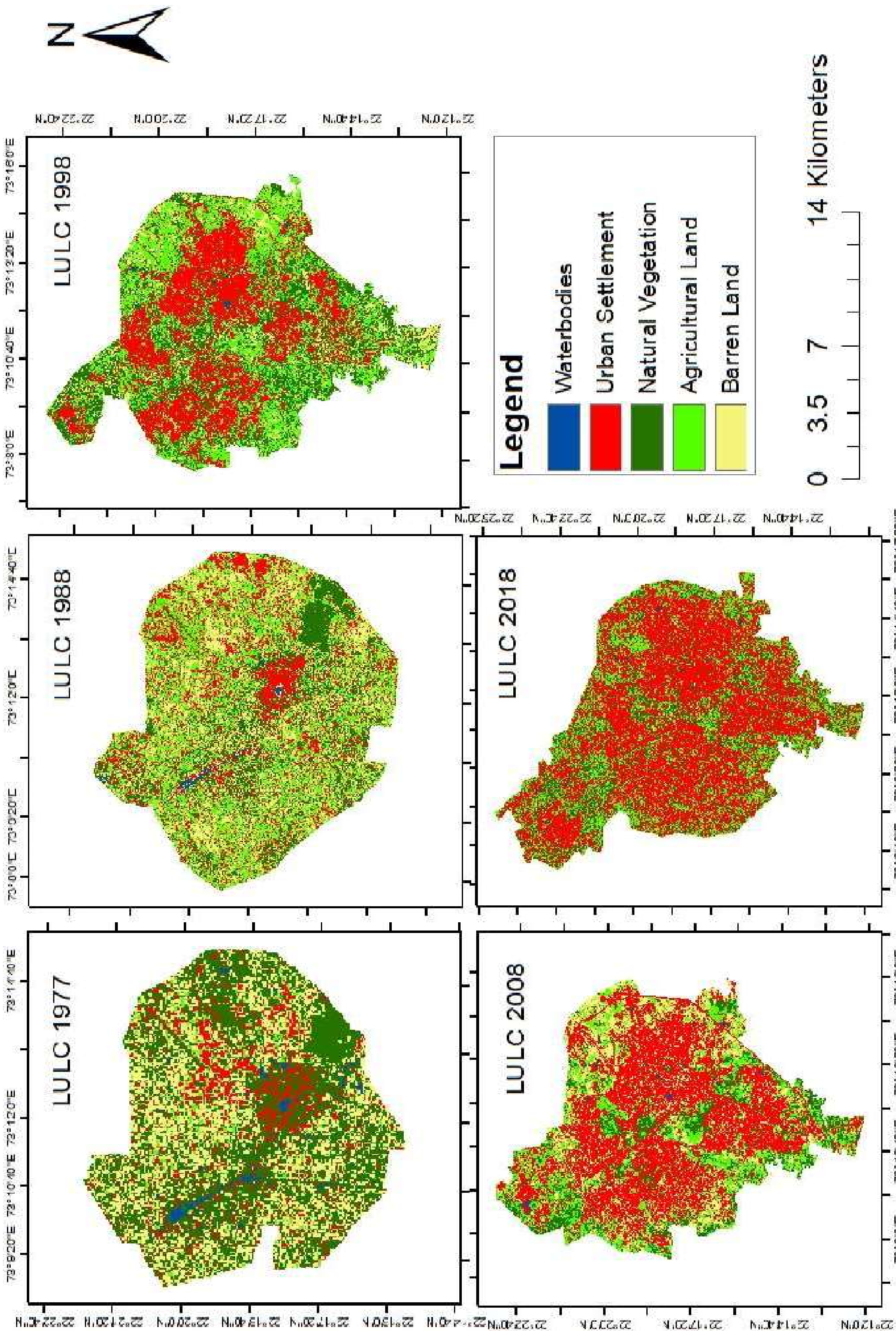


Figure 5.17: Spatio Temporal Analysis of LULC maps of Vadodara City

Fig. 5.17 shows Spatio Temporal Analysis of LULC maps of Vadodara City depicting dominance of urban settlement and shifting of other LULC classes. An increase in urban settlement is observed for the decades of 1977 – 1988, 1988 – 1998, 1998 – 2008 and 2008 – 2018 respectively, for all four decades in varied proportions. The maximum increase of urban settlement is observed from the decade 1998 – 2008, which is around 41 Sq. Km. which is about 47%. The highest amount of loss in natural vegetation took place in 1977 – 1988, which comes out to be 20 Sq. Km., which is about 15%. There is highest agricultural reduction in the decade of 1998 – 2008 i.e. around 8.47 Sq. Km. which is about 10%. Much of the land was barren in the first decades of 1977 – 1988, which are replaced/converted into urban settlement.

Analysis of LULC Maps of Intermediate Years

The changes observed in various LULC classes during the abovesaid respective decades happened in different proportions on a gradual basis. Also, the variations in LULC that occurred in 1993, which is mid-way between the decade 1988 – 1998, 2003, which is mid-way between the decade 1998 – 2008 and in the same manner the LULC changes in 2013, which is mid-way between the decade 2008 – 2018 are analysed and shown in Fig. 5.18

Table 5.10(a) shows the changes in areas that took place in the mid years, 1993, 2003 and 2013, of the decade 1988 – 1998, 1998 – 2008 and 2008 – 2018 respectively.

Table 5.10 (a) Areas (in Sq. Km.) of LULC classes with Intermediate years

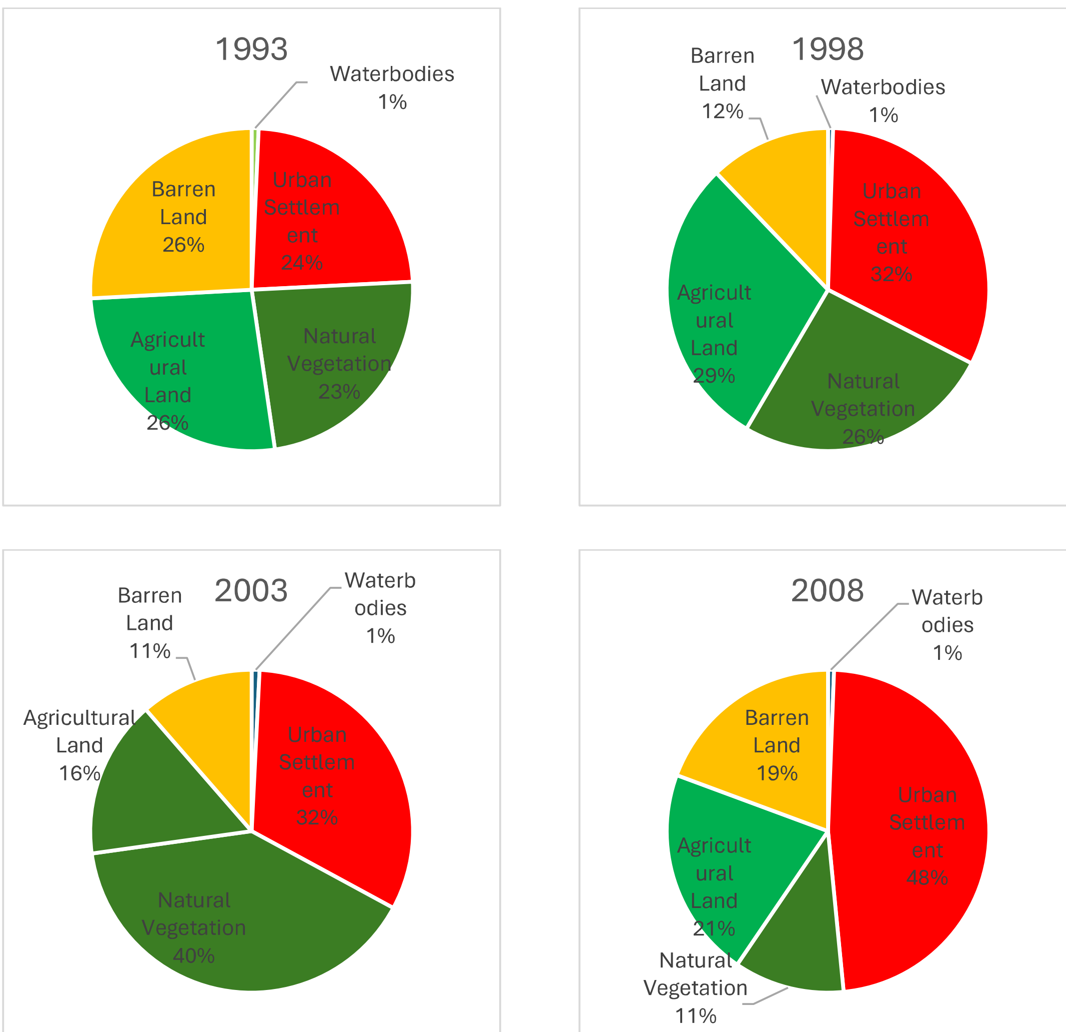
Overall Extent of LULC Areas in Sq. Km. for mid years from 1988 to 2018							
LULC Class	1988	1993	1998	2003	2008	2013	2018
Waterbodies	0.82	0.77	0.75	1.21	1.00	1.11	1.36
Urban Settlement	24.30	25.42	48.10	48.11	80.75	106.68	122.02
Natural Vegetation	20.06	25.37	38.89	59.84	18.72	7.94	32.70
Agricultural Land	33.94	28.61	44.11	23.71	35.64	46.53	55.92
Barren Land	29.05	27.99	18.24	17.08	32.63	6.49	2.63

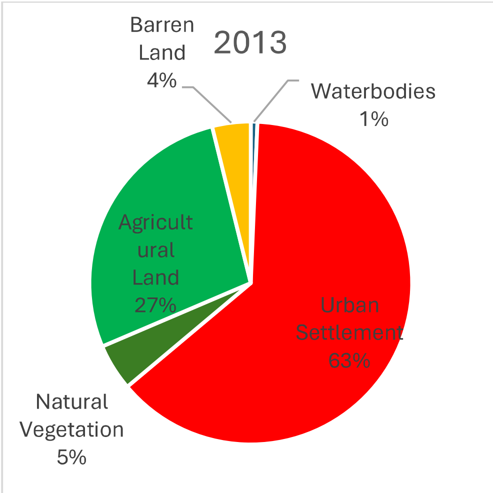
Table 5.10 (b) shows the changes in percentage of areas that took place in the mid years, 1993, 2003 and 2013, of the decade 1988 – 1998, 1998 – 2008 and 2008 – 2018 respectively.

Table 5.10 (b) Percentage Areas of LULC classes with Intermediate years

Percentage, of LULC Areas for mid years in % from 1988 to 2018							
LULC Class	1988	1993	1998	2003	2008	2013	2018
Waterbodies	0.93	0.88	0.85	1.38	1.13	1.26	1.55
Urban Settlement	27.59	28.86	54.60	54.61	91.66	121.08	138.50
Natural Vegetation	22.77	28.80	44.14	67.92	21.25	9.02	37.12
Agricultural Land	38.52	32.48	50.07	26.92	40.46	52.82	63.47
Barren Land	32.98	31.77	20.71	19.39	37.04	7.36	2.98

Fig. 5.18 shows the percentage distribution of areas for the years of 1993, 1998, 2003, 2008, 2013 and 2018.





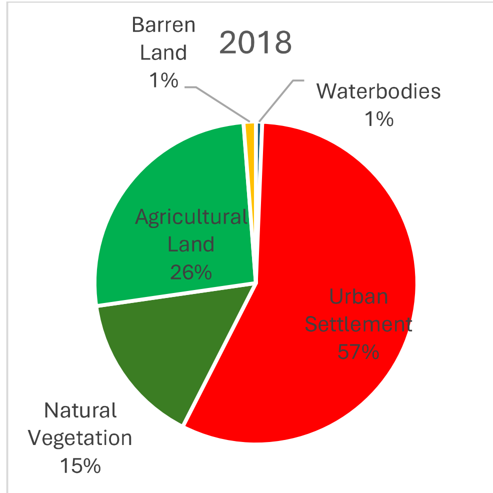


Figure 5.18: Pie Charts showing Percentage Distribution of LULC Areas of the Intermediate Years with Decades

In order to analyse the change in the intermediate years between the decade of 1988 – 1998, 1998 – 2008 and 2008 – 2013. The LULC of the years 1993, 2003 and 2013, which lie mid-way in the above said decade are analysed and compared.

From Fig. 5.18, it is observed that the share of water bodies is up to 1 % in all of the decades and the intermediate years between the last three decades.

In the decade of 1988 – 1998, the LULC map of 1993 is utilized to observe the changes taking place in 1988 – 1993 and 1993 – 1998. It is observed that the urban settlement increased in the mentioned decade by 9% amongst which only 1% increase was observed in 1988 – 1993 and the rest 8% increase was during 1993 – 1998. In the same decade, natural vegetation gradually decreased, agricultural land decreased was 2% which was such that in 1988 – 1993, it reduced to 5% and 1993 – 1998, increased by 3%.

In the decade of 1998 – 2008, the LULC map of 2003 is utilized to observe the changes taking place in 1998 – 2003 and 2003 – 2008. The results show that in this decade the urban settlement was increased by 16%, amongst which only 1% increase is contributed in 1998 – 2003, the remaining 15% increase took place in 2003 – 2008.Similarly the forest was decreased by 15% in the decade amongst which, in first half of the decade the forests were reduced by 14% and then in the second half they were increased to 29%.

In the decade of 2008 – 2018, the LULC map of 2013 is utilized to observe the changes taking place in 2008 – 2013 and 2013 – 2018. The results of which shows that the maximum growth in urban settlement of 15% took place in 2008

– 2013, in the same half natural vegetation and barren land are decreased by 6% and 16% respectively.

Analysing the mid years in the decades of 1988 – 1998 – 2008 -2018, abrupt changes were observed in agricultural land in the year 1993, changes in urban settlement and natural vegetation in 2003 and changes in urban settlement and agricultural land in 2013. The abrupt changes that are observed in the first half of the decade were later reversed in the second half to the same decade.

5.4 CALCULATIONS OF URBAN SPRAWL INDICES AND ANALYSIS

Various sprawl indices have been identified to measure and analyse the urban sprawl The nine different indices, as discussed in methodology, are calculated and analysed hereafter in detail.

1. Land Consumption Ratio (L.C.R)

Table 5.11: Calculations of Land Consumption Rate (L.C.R.)

Year	Built-up Area (A), Sq. Km.	Population (P), lakhs	L. C. R. (A/P)
1977	11.60	4.73	2.452
1988	24.30	7.55	3.218
1998	48.10	11.37	4.229
2008	80.75	15.02	5.375
2018	122.02	18.34	6.652

2. Population Density

Table 5.12 shows the population density calculated for the study years considering the population data of the respective decade.

Table 5.12: Calculation of Population Density

Year	Population Lakhs	Area, Sq. Km.	Population Density (Sq. mt./ person)
1977	4.73	88.1	186.26
1988	7.55	108.18	143.24
1998	11.37	149.96	131.84
2008	15.02	168.75	112.32
2018	18.34	214.63	117.00

In Table, 5.12 the low population density numbers are suggestive of high degrees of urban sprawl. Here 2008 has observed highest degree of sprawl amongst all the other years.

3. Urbanness

Table 5.13: Calculation of Urbanness

LULC Class	Urban Settlement, Sq. Km.	Total Area, Sq. Km	Urbanness
1977	11.60	88.10	0.13
1988	24.30	108.18	0.22
1998	48.10	149.96	0.32
2008	80.75	168.75	0.48
2018	122.02	214.63	0.57

4. Urban Expansion Index (UEI)

UEI is the ratio between the length of a common boundary between past and recent built-up patches and the patch perimeter of the recent built-up patches.

Table 5.14: Calculation of Urban Expansion Index (UEI)

Year	Length, Km.	Perimeter, Km.	L/P	Built up Growth Pattern
1977	11.11	41	0.27	Edge Expansion
1988	13.37	43	0.31	Edge Expansion
1998	18.69	83	0.23	Edge Expansion
2008	21.22	85	0.25	Edge Expansion
2018	24.65	96	0.26	Edge Expansion

Edge expansion patches are the new built-up patches formed as an extension of existing built-up patches.

5. Landscape Expansion Index (LEI)

LEI=100× $A0$ / $A0$+Av

LEI - landscape expansion index

Ao - intersection between the buffer zone and the occupied category

Av - intersection between the buffer zone and the vacant category

Table 5.15: Calculations of Landscape Expansion Index (LEI)

Decade	LEI	Type of Growth
1977 - 1988	67.70	Edge Expansion
1988 - 1998	66.43	Edge Expansion
1998 - 2008	62.67	Edge Expansion
2008 - 2018	60.18	Edge Expansion

6. Average Annual Urban Expansion Rate (AUER)

Table 5.16: Calculations of Average Annual Urban Expansion Rate (AUER)

Decade	AUER
1977 – 1988	7.681
1988 – 1998	7.065
1998 – 2008	5.318
2008 – 2018	4.214

The index yields an estimate depicting the quantum rate at which built-up land of a given region is changing.

7. Urban Growth Coefficient (UGC)

Table 5.17: Calculations of Urban Growth Coefficient (UGC)

Year	Urban Expansion, Sq. Km.	Population Growth, Lakhs	UGC
1977 – 1988	12.71	3.82	3.33
1988 – 1998	23.80	3.76	6.33
1998 – 2008	32.65	3.43	9.52
2008 – 2018	41.27	3.82	10.80

A U.G.C. greater than 1 indicates a sprawling growth, i.e., built-up land is increasing faster than the population in a given area. On the other hand, a UGC of less than 1 signifies densification. Here it signifies a sprawling growth which is increasing in every decade since 1977 – 1988.

8. Urban Expansion Intensity Index (UEII)

Table 5.18: Calculations of Urban Expansion Intensity Index (UEII)

Decade	UEII	Type of Expansion
1977 - 1988	0.59	High-Speed Expansion
1988 - 1998	1.11	Very High-Speed Expansion
1998 - 2008	1.52	Very High-Speed Expansion
2008 - 2018	1.92	Very High-Speed Expansion

From Table 5.18, it is observed that for 1977 – 1988, the UEII value is 0.59, which lies in the range of 1.05–1.92 (high-speed expansion) showing high-speed expansion. For the remaining decades the UEII value is greater than 1.92 which lies in the range of very high-speed expansion.

9. Urban Expansion Differentiation Index (UEDI)

Table 5.19: Calculations of Urban Expansion Differentiation Index (UEDI)

Decade	UEDI	Type of Area
1977 - 1988	4.81	Fast Growing
1988 - 1998	2.53	Fast Growing
1998 - 2008	5.42	Fast Growing
2008 - 2018	1.88	Fast Growing

The analysis of 9 urban sprawl indices calculated in Table 5.10 To 5.19 is as follows:

The LCR ratio is seen increasing in the consecutive decades with a minimum increase of 7.66 in the first decade of 1977 – 1988 and a maximum increase of 12.77 in the last decade 2008 – 2018.

The Population Density is minimum for the year 2008, with a value of 112.32, and maximum in the year 1977, with a value of 186.26. Low population density value means of high degrees of urban sprawl.

The Urbanness that is the built – up area with respect to the total area is found to be rapidly increasing in the consecutive years with a maximum increase of 0.160 from 1998 – 2008 and is maximum, with the value of 0.57 in the year 2018, which is maximum amongst all.

The Urban Expansion Index is calculated for the years of 1977, 1988, 1998, 2008 and 2018, the UEI values for all years are greater than 0.5, which represents the growth pattern as edge expansion.

The Landscape Expansion Index is calculated for the decades of 1977 – 1988, 1988 – 1998, 1998 – 2008 and 2008 – 2018, the values of all decades lie in the range of 50 – 100. The results show type of growth taken place as edge expansion. The same can be visualised in Fig.5.19.

The Average Annual Urban Expansion Rate in the decade of 1977 – 1988 is 28.95, 1988 – 1998 is 37.29, 1998 – 2008 is 41.74 and 2008 – 2018 is 45.06, which depicts that in subsequent decades the built up of land is highly varying with positive trend.

The Urban Growth Coefficient shows that though the population growth is nearly stable but urban expansion is moving at a faster pace than the population growth. The UGC values vary from 3.3 in 1977 to 10.8 in 2018.

The value of UEII, for 1977 – 1988 is 0.59, which lies in the range of 1.05–1.92 showing high-speed expansion. For the remaining decades, the UEII value is greater than 1.92 which lies in the range of very high-speed expansion. The Urban Expansion Intensity Index shows high speed expansion to very high-speed expansion from the decade of 1977 – 1988 to 1988 – 2018 respectively supporting the urban growth coefficient whose values represents the same result.

Lastly the Urban Expansion Differentiation Index (U. E. D. I.) shows that the value of UEDI for the decades are greater than 1, which depicts that the type of area in all decades from 1977 to 2018 are growing very fast.

From all these indices, it is said the city of Vadodara has experienced rapid expansion during the past two decades.

Fig 5.19 shows the spatio and temporal distribution of urban settlement clearly representing the urban sprawl. The sprawl is increasing towards edges of the city is clearly seen in the map.

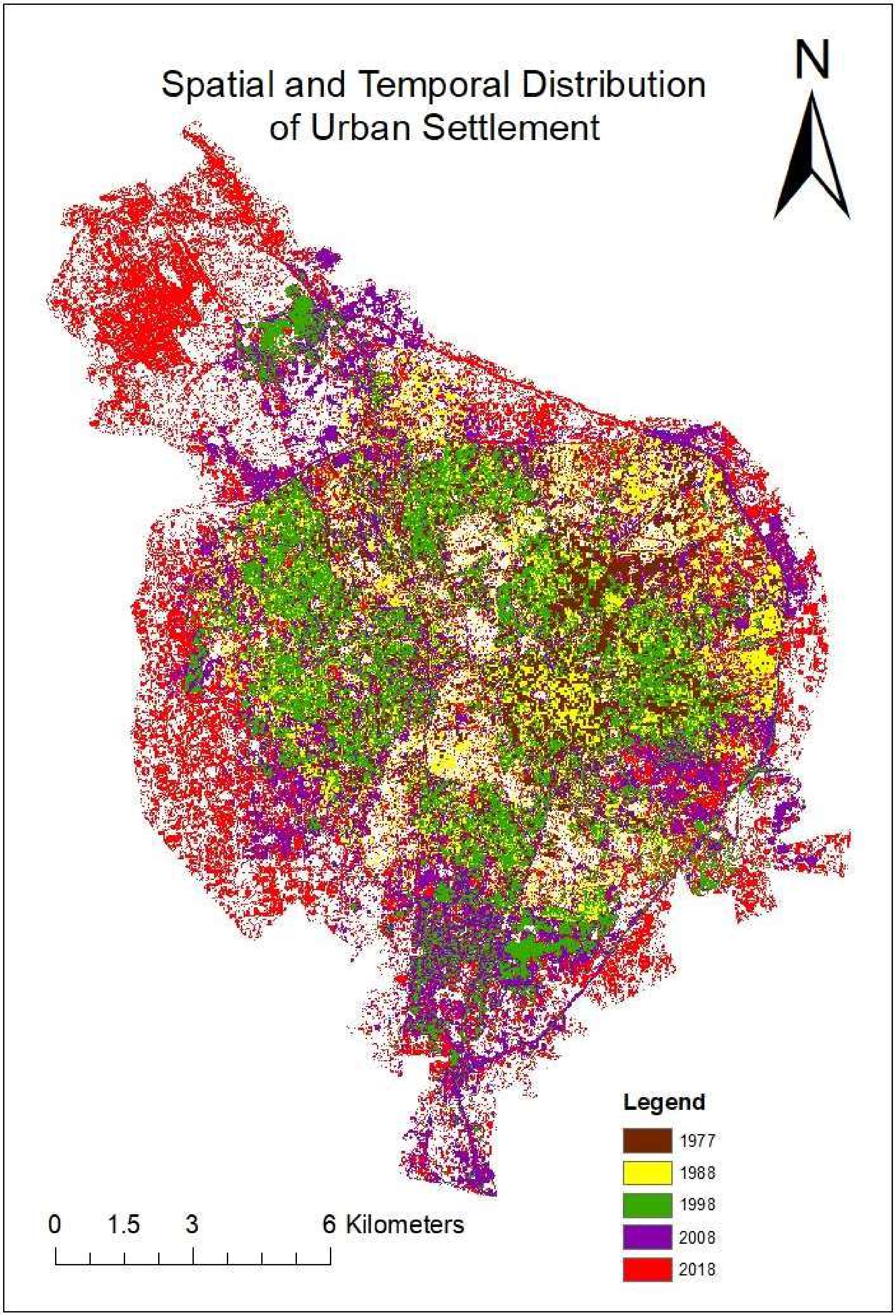


Figure 5.19: Spatio Temporal Distribution of Urban Settlement in Vadodara City

Objective 2: To study and analyse the rainfall over a number of decades in the study area.

5.5 RAINFALL ANALYSIS

The daily and decadal analysis of rainfall has been carried out and the results are shown below:

Analysis of Daily Rainfall Data for Six Decades

The daily rainfall data of Vadodara city are used from 1961 – 2018. The values of daily rainfall data, in mm are divided into six categories namely zero/no rainfall, very low, low rainfall, medium rainfall, heavy rainfall and very heavy rainfall, the ranges of which are given below in Table 5.20. The data series is divided into 6 different decades i.e., 1961-1970, 1971-1980, 1981-1990, 1991-2000, 2001-2010 and 2011-2018. The number of rainy days calculated during these six decades (considering monsoon season only) are given in Table 5.20

Table: 5.20: Decadal Analysis of rainy days from 1961 - 2018

Range	**Class**	**1961-1970**	**1971-1980**	**1981-1990**	**1991-2000**	**2001-2010**	**2011-2018**
No rainfall	No Rainfall	674	673	626	**776**	730	610
0 to 10 mm	Very Low	309	303	270	214	202	186
10 to 20 mm	Low	71	79	72	84	102	58
21 to 30 mm	Medium	39	53	37	37	54	45
31 to 50 mm	Heavy	47	43	27	36	**49**	39
>50 mm	Very High	50	39	38	43	**53**	38

The days with no rainfall, means that there is no measurable precipitation, and the atmosphere remains dry. This can occur due to stable weather conditions, high-pressure systems, or a lack of significant moisture in the air. The range of 0 to 10 mm of rainfall is considered a very low amount of precipitation. This typically results from a steady rain or drizzle over the course of the day. The range more than 50 mm shows that moderate to heavy rainfall and it can have positive effects on soil moisture levels and water reservoirs. However, it may also pose challenges such as flooding in low-lying areas, increased runoff, and potential transportation disruptions. Adequate preparedness and infrastructure are important to manage the impacts of this level of rainfall.

From Table 5.20, it can be analysed that the number of zero/no rainy days for the months of June, July, August and September are decreasing in all the decades are decreasing in all the decades except 1991 – 2000. In 991 – 2000, there a maximum number of zero/no rainfall days amongst all the other decades i.e. 73 days. The number of rainy days with heavy rainfall (31 mm – 50 mm) are 49 days in 2001 – 2010, which is maximum of all. Similarly, the no. of rainy days in very high rainfall (> 50 mm) 53 days during 2001 – 2010. This indicates a shift in the rainfall pattern. Even though the number of days in the range of very heavy rainfall are decreasing, the problem of flooding has not reduced, which indicates that the runoff is not only affected by rainfall but impact of LULC changes is also to be considered.

Trend Analysis of Rainfall Data

Trend Analysis of Annual Rainfall Data

Linear regression analysis is a parametric test and one of the most commonly used methods to detect a trend in a data series. The relationship between two variables (dependent and independent) by fitting a linear equation to the observed data is done by using the scatter plot. A positive slope value indicates an increasing trend, and a negative value indicates a decreasing trend. A numerical measure of this association between the variables is the correlation coefficient, which range between -1 to +1.

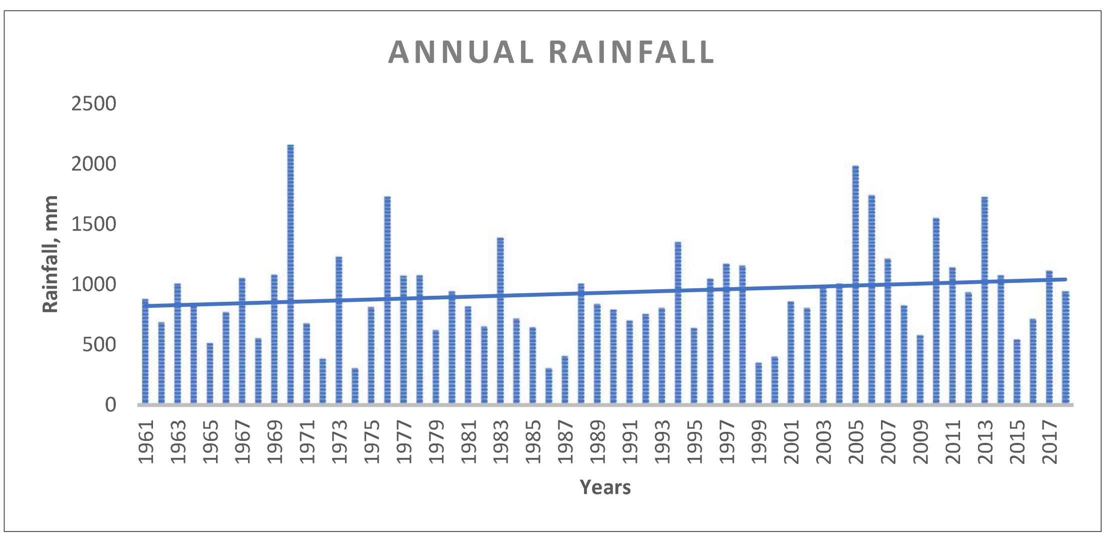


Figure 5.20: Annual Rainfall over Vadodara city

The annual rainfall over Vadodara city showed a long term significant increasing trend which is shown in above Figure 5.20. From the Fig. 5.20 it was observed that after the year 2000, the trend of annual rainfall is increasing significantly. The same was observed in decadal rainfall analysis. Also, in the same trend was observed for daily rainfall data.

Trend Analysis of Seasonal Rainfall Data

For Southwest Monsoon (June–September)

Fig. 5.21 shows the seasonal rainfall values from June to September from 1961 – 2018.

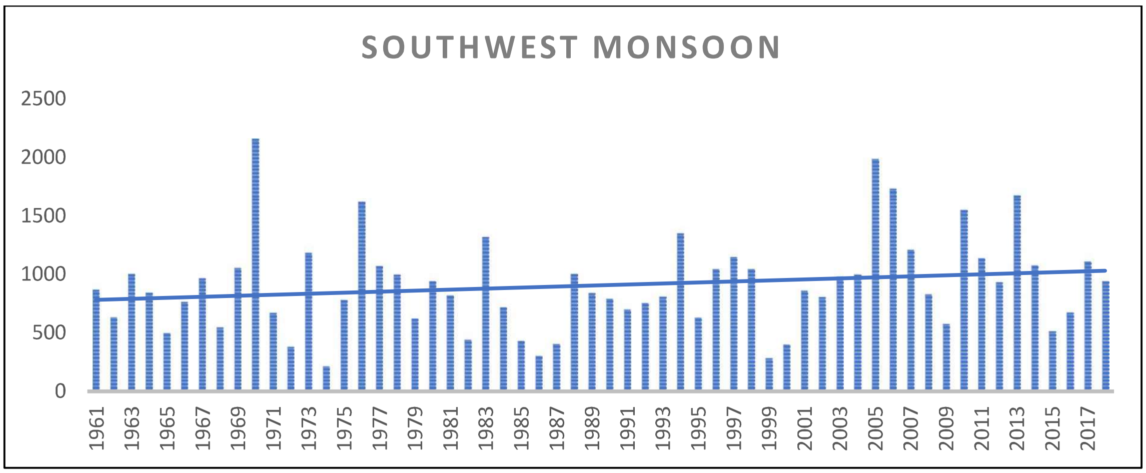


Figure 5.21: Southwest Monsoon Rainfall over Vadodara City

The southwest monsoon rainfall has an overall, increasing trend during study period. The monsoon rainfall with minimum of 217.09 mm and maximum of 2156 mm, amount is observed during 1974 and 1970 the study period.

Mann-Kendall Test and Sen's Slope Estimation

Mann-Kendall Test and Sen's Slope Estimation are two non-parametric test used to detect the presence of a significant trend (upward or downward) in a time series dataset. The results of Mann Kendall (MK) test and Sen's slope test for rainfall data considered from 1961-2018, are analysed for the months of June, July, August, September, analysed for Annual rainfall and for southwest monsoon. The results of the same are shown in below Table 5.21

Table 5.21: MK Trend Test & Sen's Slope Estimator for Rainfall data

Time series	First year	Last Year	Test Z	B
June	1961	2018	-0.14	-0.100
July	1961	2018	1.70	2.436
August	1961	2018	0.40	0.385
September	1961	2018	0.72	0.457
Annual	1961	2018	1.38	3.988
Southwest Monsoon	1961	2018	1.49	4.193

In the Mann-Kendall trend test, the value of Z is a test statistic that measures the strength and direction of a trend in a time series dataset. The sign (positive or negative) and magnitude of the Z statistic provide information about the nature of the trend.

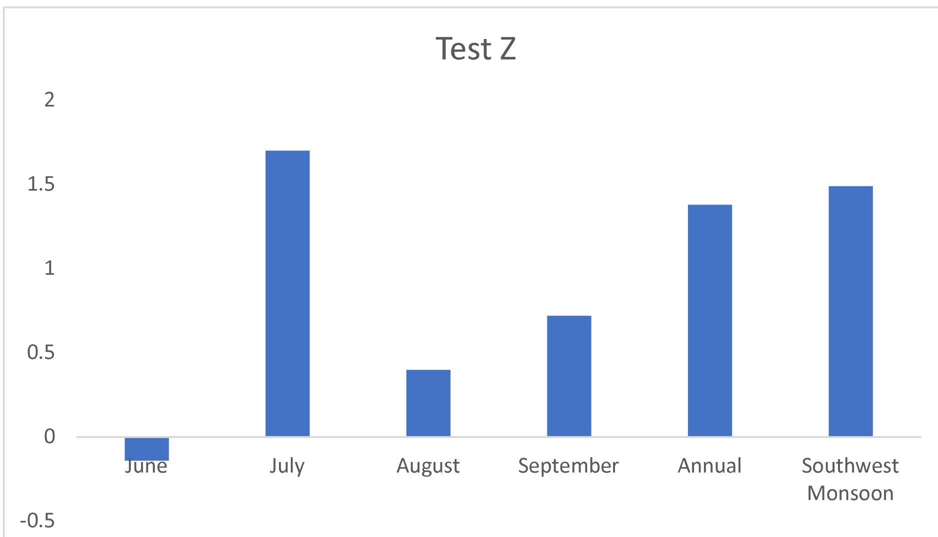


Figure 5.22: Test Z value

Fig. 5.22 shows the test Z value for the study area

A positive Z value indicates an upward (increasing) trend in the data. This means that the data points tend to increase over time. A larger positive Z value corresponds to a stronger upward trend, indicating a more significant increase in the variable being analysed. Similarly, a negative Z value indicates a downward (decreasing) trend in the data. This means that the data points tend to decrease over time. A larger negative Z value corresponds to a stronger downward trend, indicating a more significant decrease in the variable being analysed. Similar, Sen's slope estimator is a statistical method used to estimate the magnitude and direction of a linear trend in a dataset.

From the analysis of Mann Kendall trend test and Sen's slope estimator, from 1961 – 2018, it is observed that in the month of July, the test Z value is 1.7 which is maximum and for month of June the test Z value as -0.14. Which depicts that the rainfall in the month of June is following a decreasing trend and the rainfall in July month is following an increasing trend. Similarly, August is following decreasing trend and September is following an increasing trend.

Analysis of Monthly Rainfall data

The analysis of monthly rainfall data is carried out for the monsoon months which are June, July, August and September for the period of 1961 – 2018, The monthly rainfall data analysis shows that month of June contributes 15%, July contributes 38%, August 31 % and September 16% of the average annual rainfall, The contribution of rainfall of these months is represented in percentage in below Fig. 5.23

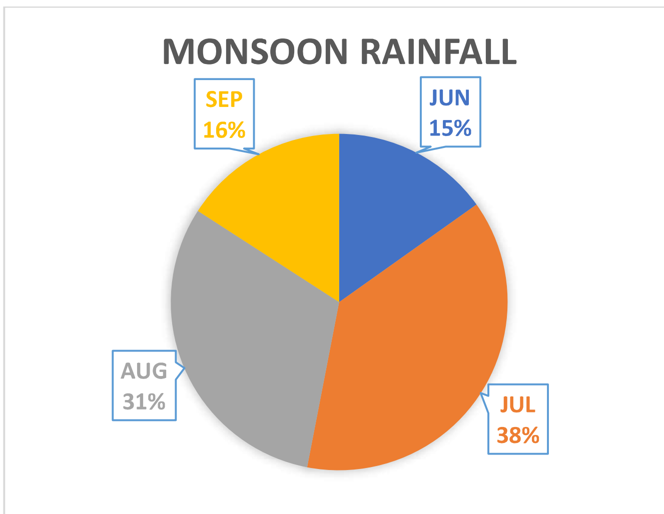


Figure 5.23: Percentage of Annual Rainfall in Monsoon Season

The monthly precipitation of June, July, August, and September can also be regarded as reliable. Nevertheless, the rainfall patterns throughout the monsoon season in the study area exhibit significant regional and temporal disparities, resulting in both floods and droughts across different regions and cities. However, when the rainfall data is aggregated for the entire season or month, it demonstrates a consistent pattern.

Decadal Annual Average Rainfall Analysis

The decadal annual average rainfall during the years 1961 to 2018 is depicted in Fig. 5.24

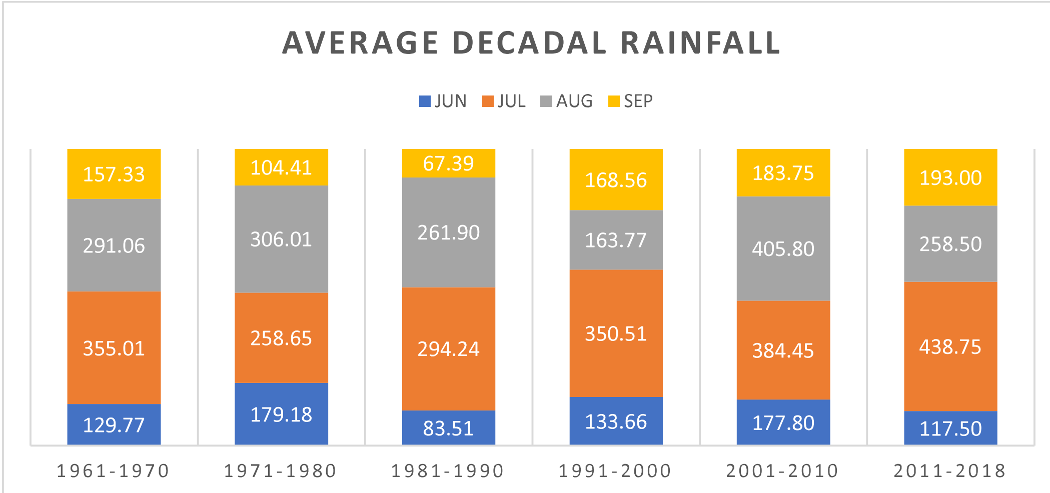


Figure 5.24: Decadal Average Annual Rainfall, mm

The decadal analysis of rainfall shows that the maximum amount of average decadal rainfall is there in the month of July for the decade 2011 – 2018, value of which is 438 mm, and the minimum average annual rainfall is in the month of June during entire study period of 1961 – 2018, whose value is 117.50 mm.

Rainfall Variability

To analyse the rainfall variability the months of June, July, August and September which are the monsoon months are considered in the present study. The basic statistical attributes such as mean, standard deviation (SD), coefficient of variation (CV) of seasonal and annual rainfall series for the period of 58 years (1961-2018) are analysed. The results are shown in Fig. 5.25

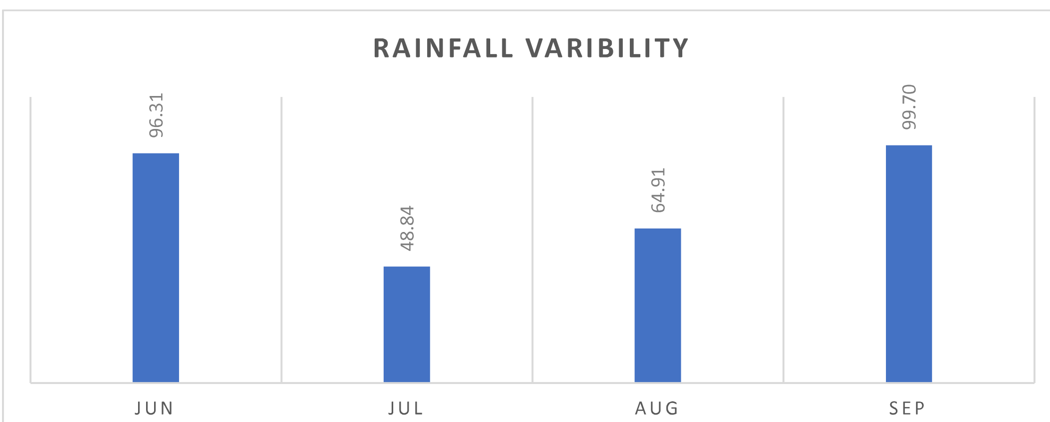


Figure 5.25: Rainfall Variability over the years 1961-2018

The rainfall variability for the month of June, July, August and September as 96.33%, 48.84%, 64.91% and 99.70% respectively, which shows that there is low variability in rainfall during month of July.

The variability in rainfall patterns analysed using CV for the different decade's i.e., 1961-1970, 1971-1980, 1981-1990, 1991-2000, 2001-2010 and 2011-2018 are given in Table 5.22

Table 5.22: Rainfall Variability (in mm) over different decades

Variability	JUN	JUL	AUG	SEP	ANNUAL
1961-1970	89.09	28.48	81.54	74.93	49.00
1971-1980	67.32	64.25	56.23	110.42	47.93
1981-1990	85.72	63.97	49.50	142.45	40.01
1991-2000	104.52	41.77	72.08	107.12	40.13
2001-2010	118.94	43.92	51.95	84.71	39.80
2011-2018	77.85	48.02	56.84	91.95	34.19

The results of variability of rainfall, suggests that the precipitation patterns remain relatively stable or consistent when observed for minimum variability. Conversely, when observed for high variability in rainfall pattern, it implies significant fluctuations in the amount of rain that falls over time, which can lead to more unpredictable weather conditions.

Excess and Deficit Rainfall

Seasonal Excess and Deficit Rainfall

The excess and deficit years are analysed by considering four seasons namely Pre-monsoon (March – May), Monsoon (June – September), Post-monsoon (October – November) and Winter (December – February) from 1961 – 2018. The results are shown in Table 5.23

Table 5.23: Number of Excess and Deficit rainfall years 1961-2018

	Annual Rainfall	**Pre-monsoon (Mar-May)**	**Monsoon (June-Sept)**	**Post Monsoon (Oct-Nov)**	**Winter (Dec-Feb)**
Excess	8	3	8	10	3
Deficit	8	0	7	0	0

From 1961 - 2018, the rainfall excess years are 1970, 1976, 1983 1994, 1997, 2005, 2006 and 2013. The rainfall deficit years are: 1972,1974, 1986, 1987, 1999, 2000, 2009 and 2015. All other remaining years are normal years.

Objective 3: To determine and analyse the runoff in the study area using quantitative techniques like Soil Conservation Services-Curve Number (SCS-CN) method using Remote Sensing and Geographic Information System (GIS).

5.6 COMPUTATIONS AND ANALYSIS OF RUNOFF

The SCS-CN method was initially developed by the Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture (USDA) and is a widely used approach for estimating direct runoff volume in ungauged catchments. In the present study, the curve number (CN) is a key variable which is usually obtained by the look-up table of TR-55. (United States Department of Agriculture (1986). Urban hydrology for small watersheds (PDF). Technical Release 55 (TR-55) (Second ed.). Natural Resources Conservation Service, Conservation Engineering Division.) It is commonly employed in hydrology and stormwater management.

The procedure to compute runoff using SCS – CN method is as follows:

In the first step soil characteristics are identified in the study area. Analysing the soil map obtained for the Vadodara city, it lies in Group C soil type. Soils having low infiltration rates when thoroughly wetted and a low rate of water transmission. The clay content in the soil is on the higher side.

In second step, the land use/ land cover classes are identified and analysed using geospatial techniques. The satellite images used for mapping the LULC changes are taken for the month of March, as it is necessary to take images of the same month, so that comparison of the images is done on approximately similar time scale. The cloud cover was observed to be minimum i.e. less than 10% for the month of march in all images.

In the third step, the month of March in generally considered as transition period from growing season to active season. Growing season is mainly considered from June to October in India. So here in this study AMC dormant is considered the effect on CN values. The AMC is a measure of the initial soil moisture conditions before a rainfall event. It is classified into three levels: I, II, and III. The AMC is typically based on recent precipitation history and soil moisture content. From the precipitation data the values of Antecedent Moisture in mm are calculated and then the rainfall data is classified into AMC type either I or II or III. By considering the antecedent moisture conditions, one can predict how much rainfall will infiltrate into the soil, how much will be stored, and how much will contribute to runoff. These classes are based on the 5 – day antecedent rainfall (i.e. the accumulated total rainfall preceding the runoff under consideration).

In the fourth step, the various curve numbers for different land use classes have been identified using Table 4.3 and Table 4.4. and the Curve Numbers that will be used study for the land use/ land cover classes, namely waterbodies, urban settlement, natural vegetation, agricultural area and barren land. Table 5.24 shows the CN values of LULC classes under AMC – II, known as CN – II.

Table 5.24: CN values for LULC Classes (CN – II)

Land Use Class	Identified CN – II
Waterbody	100
Urban Settlement	90
Natural Vegetation	60
Agriculture	88
Barren Land	86

For AMC – I

$$\mathbf{CN - I = CN - II / (2.281 - 0.01281\ CN - II)}$$

For AMC – III

$$\mathbf{CN - III = CN - II / (0.427 + 0.00573\ CN - II)}$$

For the rainfall data lying under the AMC – I and AMC – III, CN – I and CN – III respectively. But before computing CN – I and CN – III values the CN – II values are converted in to Weighted CN – II.
The Weighted Curve Number (WCN) is a concept in hydrology that combines the effects of different land use/ land cover types within an area to calculate an overall Curve Number (CN) that represents the composite runoff potential. The weighted CN – II is obtained by multiplying the respective land use/ land cover area with the originally identified CN – II values and dividing it by the total area of that particular year land use/ land cover class.

Table 5.25 to Table 5.29 shows the values of weighted curve numbers obtained based on land use/land cover, for study years.

WCN = ∑ (Area of individual land use * CN – II of that land use)
= (1.44 * 100) + (11.60 * 90) + (40.82 * 60) + (3.93*88) + (30.30 * 86)
= 74.80

Table 5.25: Weighted CN for the year 1977

Year	LULC Class	CN II	Area Sq. Km.	CN II * Area of LULC	WEIGHTED CN
1977	Waterbodies	100	1.44	144.36	**74.80**
	Urban Settlement	90	11.60	1043.60	
	Natural Vegetation	60	40.82	2449.22	
	Agricultural Land	88	3.93	345.95	
	Barren Land	86	30.30	2606.21	
	Total Area		88.10		

Table 5.26: Weighted CN for the year 1988

Year	LULC Class	CN II	Area Sq. Km.	CN II * Area of LULC	WEIGHTED CN
1988	Waterbodies	100	0.82	81.99	82.81
	Urban Settlement	90	24.30	2187.32	
	Natural Vegetation	60	20.06	1203.71	
	Agricultural Land	88	33.94	2986.63	
	Barren Land	86	29.05	2498.39	
	Total Area		108.18		

Table 5.27: Weighted CN for the year 1998

Year	LULC Class	CN II	Area Sq. Km.	CN II * Area of LULC	WEIGHTED CN
1998	Waterbodies	100	0.62	61.83	81.19
	Urban Settlement	80	48.10	4328.88	
	Natural Vegetation	60	38.89	2333.12	
	Agricultural Land	88	44.11	3882.07	
	Barren Land	86	18.24	1568.74	
	Total Area		149.96		

Table 5.28: Weighted CN for the year 2008

Year	LULC Class	CN II	Area Sq. Km.	CN II * Area of LULC	WEIGHTED CN
2008	Waterbodies	100	1.00	99.54	85.54
	Urban Settlement	80	80.75	7267.81	
	Natural Vegetation	60	18.72	1123.15	
	Agricultural Land	88	35.64	3136.64	
	Barren Land	86	32.63	2806.52	
	Total Area		168.75		

Table 5.29: Weighted CN for the year 2018

Year	LULC Class	CN II	Area Sq. Km.	CN II * Area of LULC	WEIGHTED CN
2018	Waterbodies	100	1.36	136.17	84.92
	Urban Settlement	80	122.02	10981.80	
	Natural Vegetation	60	32.70	1962.25	
	Agricultural Land	88	55.92	4921.01	
	Barren Land	86	2.63	225.78	
	Total Area		214.63		

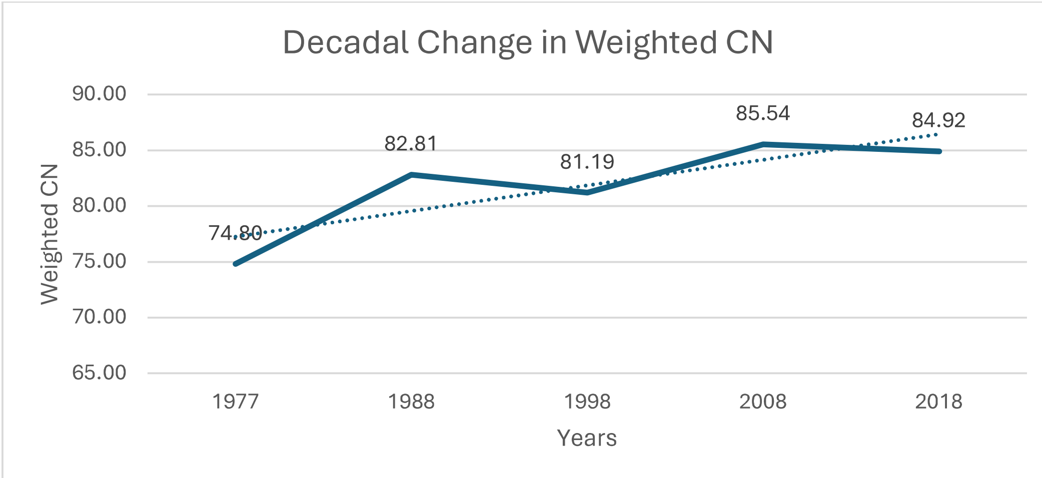


Figure 5.26: Decadal Change in Weighted CN for the study years.

Fig. 5.26 shows the values of weighted CN, obtained from Table 5.25 to 5.29 respectively for the years of 1997, 1998, 1998, 2008 and 2018. The weighted curve number is observed to be increasing in the consecutive years. Based on these curve numbers further calculation of the runoff is carried out for the study years. The Weighted Curve Number is obtained for AMC type II. So, using equations of CN-I and CN - III, Curve Number for AMC type I and AMC type III are calculated, and CN for AMC type II will remain same as that of Weighted CN, which is known as corrected CN. After the calculations of corrected CN, for each of the rainfall, runoffs are calculated for the study period from 1977 – 2018.

The annual one day daily maximum runoff against the annual one-day maximum rainfall (AODMR) is used for the purpose of analysis. The maximum rainfall & runoff will determine more accurately the runoff properties. So, the annual one-day maximum value is considered for analysis. The annual one day daily maximum runoff values are plotted against the annual one-day maximum rainfall, shown in below Fig.5.27

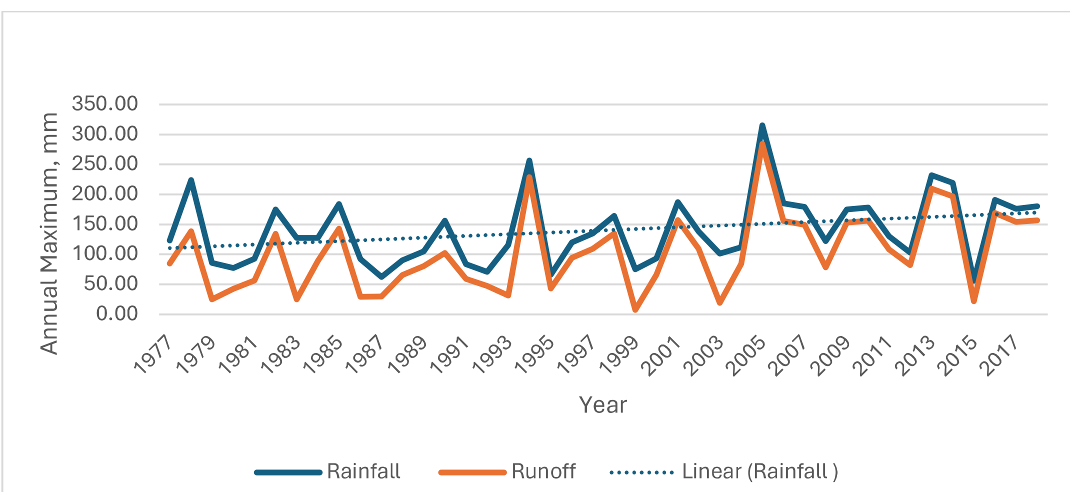


Figure 5.27: Annual One Day Maximum Rainfall – Runoff [1977 – 2018]

Decadal analysis of Runoff against maximum AODMR

From Fig 5.28 to Fig. 5.31, the analysis of one day maximum rainfall – runoff is done for the decades of 1977 – 1987, 1988 – 1997, 1998 – 2007, 2008 – 2018 respectively.

Fig. 5.28 shows the analysis if one day maximum rainfall – runoff for the decade of 1977 – 1987, Fig. 5.29 shows the analysis if one day maximum rainfall – runoff for the decade of 1988 – 1997.

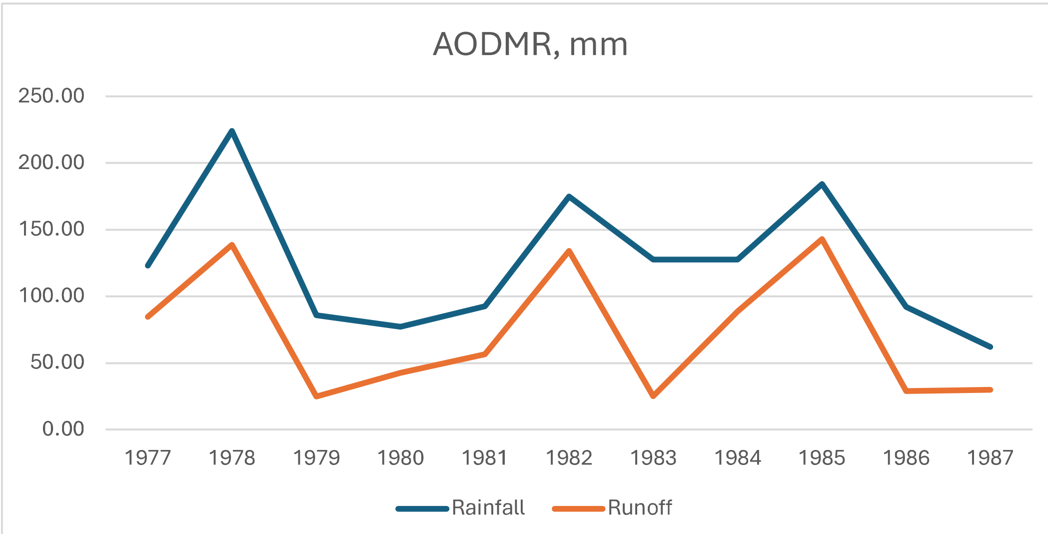


Figure 5.28: Annual One Day Maximum Rainfall – Runoff [1977 – 1987]

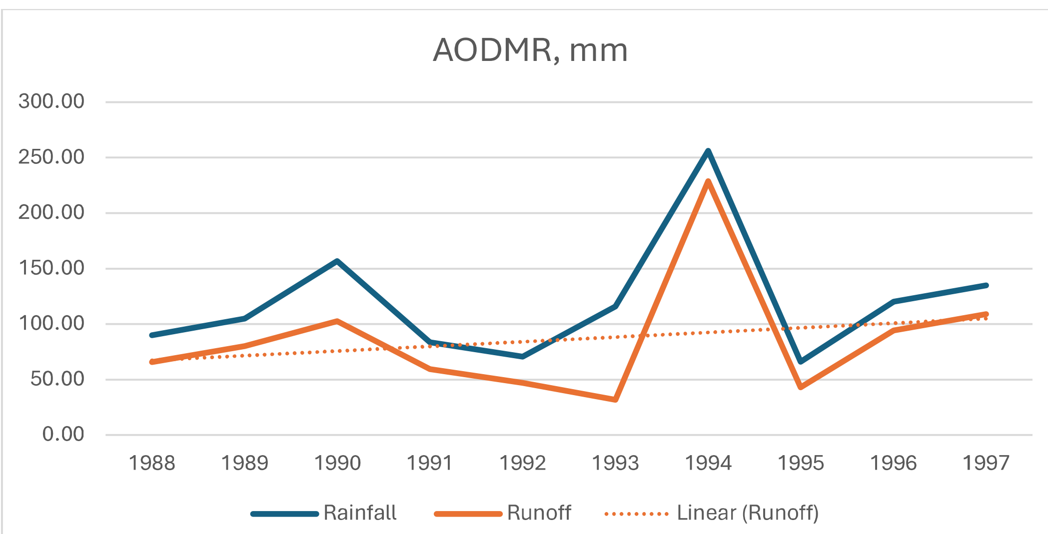


Fig. 5.29: Annual One Day Maximum Rainfall – Runoff [1988 – 1997]

From Fig. 5.28 and Fig. 5.29, it is observed that, the maximum amount of rainfall/ maximum AODMR during the first decade considered is 224 mm and minimum of AODMR is 77 mm and the corresponding runoff comes out to be 138 mm and 42 mm, which is 62% and 55%. Similar analysis when carried out for 1988 – 1997, the maximum AODMR is 256 mm and the minimum AODMR is 66 mm corresponding which the runoff values are 228 mm and 43 mm respectively. The percentage of runoff corresponding to maximum of AODMR and minimum of AODMR comes out to be 89% and 65%.

Fig. 5.30 shows the analysis if one day maximum rainfall – runoff for the decade of 1998 – 2007, Fig. 5.31 shows the analysis if one day maximum rainfall – runoff for the decade of 2008 – 2018.

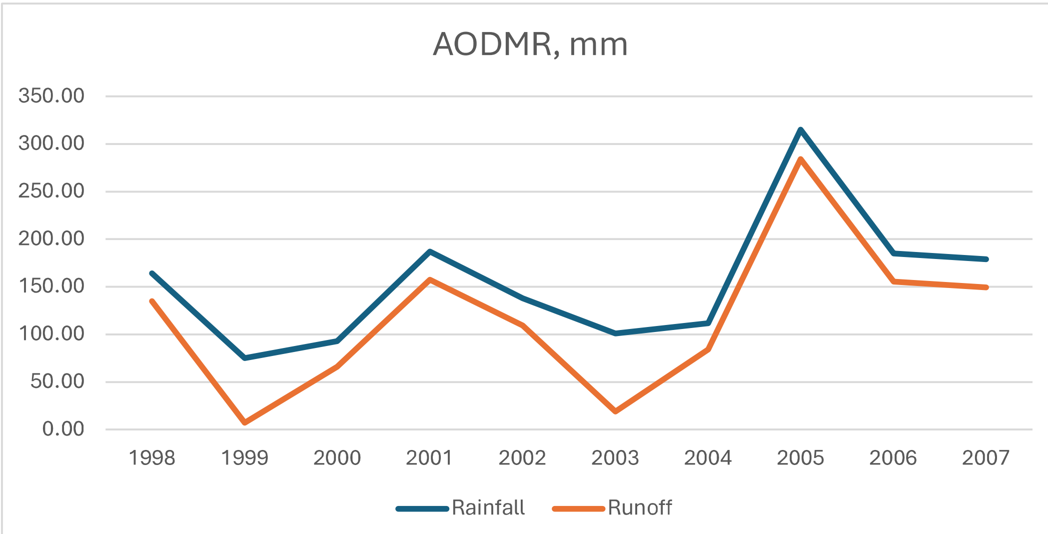


Figure 5.30: Annual One Day Maximum Rainfall – Runoff [1998 – 2007]

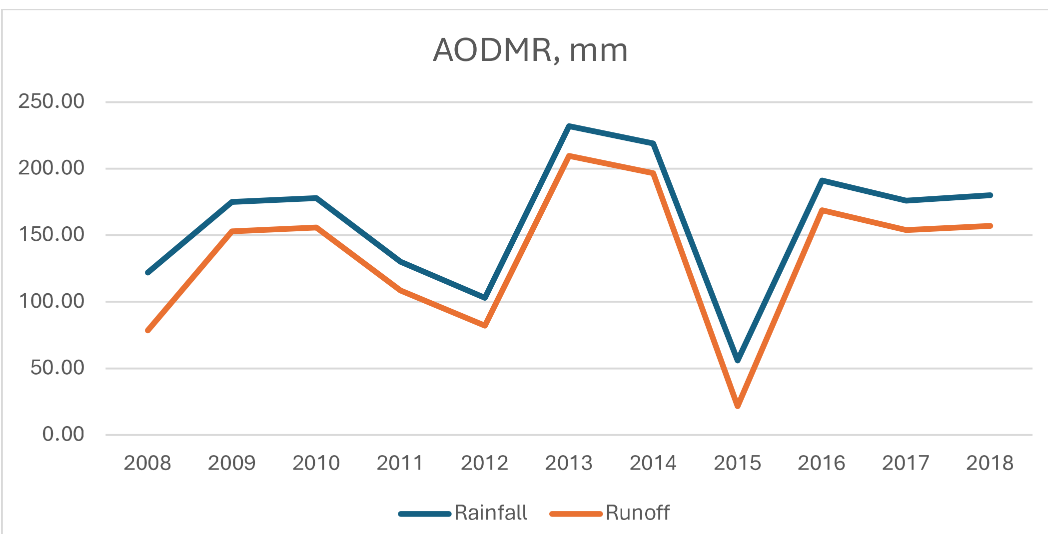


Figure 5.31: Annual One Day Maximum Rainfall – Runoff [2008 – 2018]

From Fig. 5.30 and Fig 5.31, it is observed that, the maximum amount of rainfall/ maximum AODMR during the 1998 - 2007 is 315 mm and minimum of AODMR is 93 mm and the corresponding runoff comes out to be 284.23 mm and 66 mm, which is 90% and 71%. Similar analysis when carried out for 2008 – 2018, the maximum amount of rainfall/ maximum AODMR is 232 mm and minimum of AODMR is 103 mm and the corresponding runoff comes out to be 209.54 mm and 82 mm. The percentage of runoff corresponding to maximum of AODMR and minimum of AODMR comes out to be 91% and 80%.

It is clearly evident that around 30% of additional runoff can be observed when compared with the year 1977 and 2018, which may be directly attributed to the changes in LULC and Urban Sprawl.

Analysis of Decadal Total Runoff

Table 5.30 shows the total decadal runoff against rainfall for the decades of 1977 – 1988, 1988 – 1997, 1998 – 2007, 2008 – 2018. The graphical presentation of this table is shown in Fig. 5.32

Table 5.30: Decadal Total Rainfall – Runoff

Decade	1977 – 1987	1988 – 1997	1998 – 2007	2008 – 2018
Total Rainfall, mm	6466.78	6684.00	7455.60	7186.00
Total Runoff, mm	2206.10	3127.79	3866.96	4115.54
Percentage Runoff	34.11	46.80	51.87	57.27

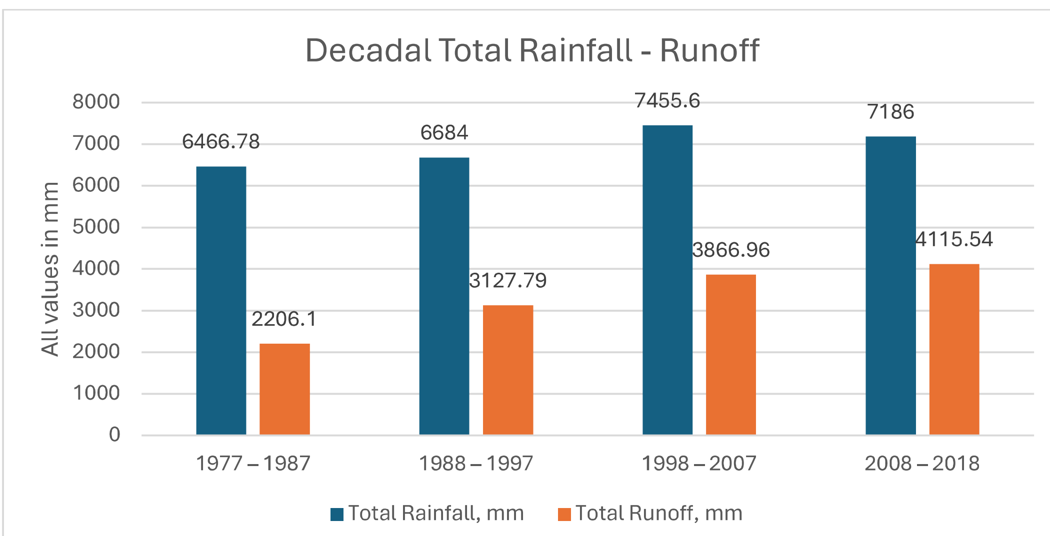


Figure 5.32: Changes Decadal Total Rainfall and Runoff

From Fig. 5.32, it is observed that for the same range of decadal total rainfall values i.e. 6466 mm in 1977 - 1987 and 6684 mm in 1988 – 1997, with the change of time in decade, the runoff value is 2206 mm and 3127 mm. respectively which is seen to be increasing. Similarly, for the same range of decadal total rainfall values i.e. 7455 mm in 1998 – 2007 and 7186 mm in 2008

- 2018, the runoff observed is 3866 mm and 4155 mm respectively, seen to be increasing.

Table 5.31 shows the total decadal runoff against rainfall for the decades of 1977 – 1988, 1988 – 1997, 1998 – 2007, 2008 – 2018. The graphical presentation of this table is shown in Fig. 5.33

Table 5.31: Decade-wise analysis of rainfall and runoff

Decade	1977 – 1987	1988 – 1997	1998 – 2007	2008 – 2018
Total Rainfall, mm	6466.78	6684.00	7455.60	7186.00
Total Runoff, mm	2206.10	3127.79	3866.96	4115.54
Percentage Runoff	34.11	46.80	51.87	57.27

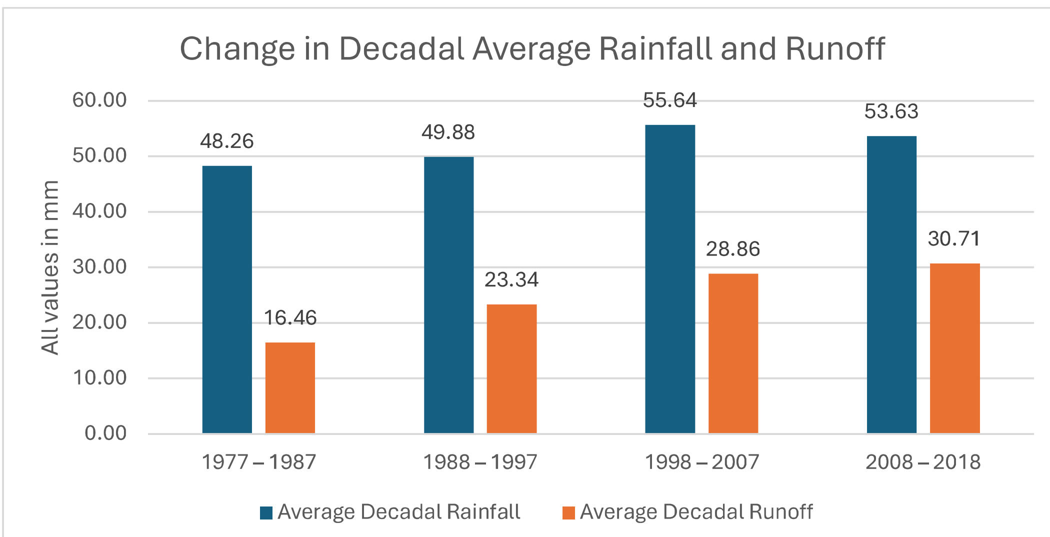


Figure 5.33: Changes in Average Decadal Rainfall and Runoff

From Fig. 5.33, it is observed that for the same range of average decadal rainfall values i.e. 48 mm in 1977 - 1987 and 49 mm in 1988 – 1997, with the change of time in decade, the runoff value is 16 mm and 23 mm. respectively which is seen to be increasing. Similarly, for the same range of decadal total rainfall values i.e. 55 mm in 1998 – 2007 and 53 mm in 2008 - 2018, the runoff observed is 28 mm and 30 mm respectively, seen to be increasing. Comparing the third decade i.e. 1998 – 2007 with the fourth decade 2008 – 2018, although the average rainfall in third decade is higher than the fourth decade, the runoff of the fourth decade is higher than that of the third decade. This firmly prompts that rainfall is not directly proportion to the runoff instead, there are some factors changing with respect to time, nothing other than the land use/ land cover of the area. This increasing trend which is observed may be due to LULC/ Urban Sprawl changes.

Objective 4: To analyse the Impact of Land Use/ Land Cover changes on Runoff in the study area.

5.7 ANAYSIS OF IMPACT OF LULC ON RUNOFF

To analyse the impact of land use/ land cover changes on runoff three scenarios have been considered, where in for each of the years of 1977, 1988, 1998, 2008 and 2018, five maximum daily rainfall events of each year have been considered to compute and analyse the runoff. The purpose of considering these five values of maximum rainfall is that those values are most likely to affect the runoff in the area.

Scenario 1 – Considering 1977 as a base year and superimposing the LULC maps of 1988, 1998, 2008 and 2018 on the base map and considering the extent of area to be same as that of 1977, the changes in runoff values are analysed. The changes in runoffs will definitely occur due to the changes in LULC for different years.

By superimposing the maps of 1988, 1998, 2008 and 2018 on the map of 1977, the results obtained for CN values are as shown in Table 5.32.

Table 5.32: Changes in CN values based on change in LULC classes for base map of 1977

Base Year	CN_1977	CN_1988	CN_1998	CN_2008	CN_2018
1977	87.42	90.98	91.94	93.89	93.38

Table 5.32 shows that from 1977 to 2018, for every decade the CN values which depend on land use/land cover is increasing. The reason of increase in CN value is purely that the pervious areas are getting converted to impervious areas. The increase in CN is reflected in the runoff, in Table 5.33.

Table 5.33: Maximum five rainfall – runoff events, Base Year 1977

Base Year	Rainfall	Runoff, mm 1977	Runoff, mm 1988	Runoff, mm 1998	Runoff, mm 2008	Runoff, mm 2018
1977	**123.10**	**84.58**	**94.87**	**97.72**	**103.63**	**102.09**
1977	**122.80**	**84.30**	**94.58**	**97.43**	**103.34**	**101.80**
1977	**60.00**	**28.10**	**35.44**	**37.60**	**42.32**	**41.07**
1977	52.20	21.86	28.55	30.56	34.99	33.80
1977	40.00	12.86	18.27	19.97	23.80	22.76

The graphical presentation of Table 5.33 is given in Fig. 34

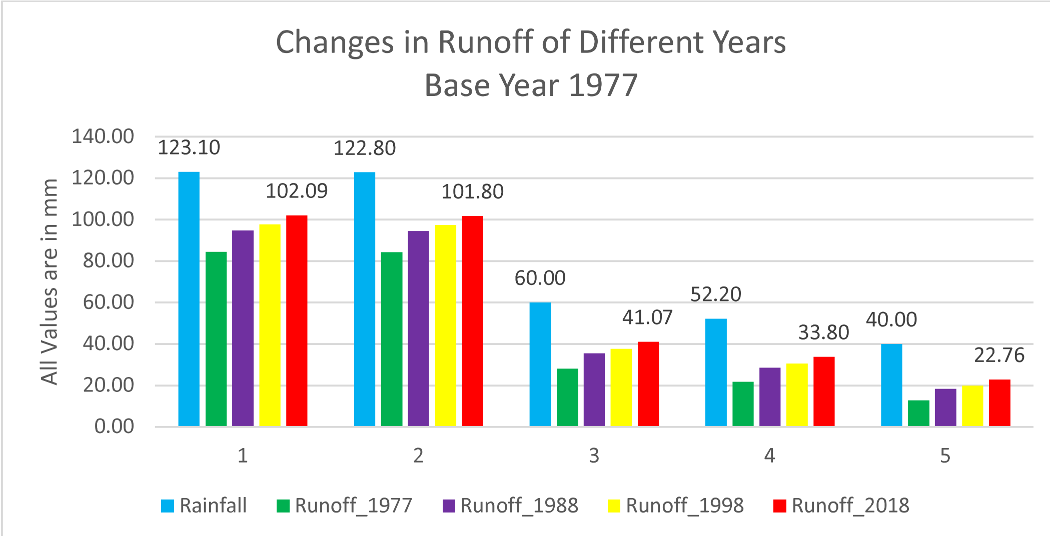


Figure 5.34: Changes in Runoff of different years with Base year 1977

From Fig. 34, it is observed that for 123.10mm of rainfall, the runoff percentages are 68%, 77%, 79%, 84% and 83% respectively for the years 1977, 1988, 1998, 2008 and 2018. These values show that the runoff is varying from 60% to 84%, with an increasing trend, which shows that the runoff values are increasing due to the change in LULC.

Scenario 2 – Considering 1988 as a base year and superimposing the LULC maps of 1998, 2008 and 2018 on the base map, the changes and considering the extent of area to be same as that of 1988, the changes in runoff values are analysed. The change in runoff will definitely occur due to the changes in LULC for different years.

By superimposing the maps of 1998, 2008 and 2018 on the map of 1988 the results of CN values are as shown in Table 5.34

Table 5.34: Changes in CN values based on change in LULC classes for base map of 1988

Base Year	CN_1988	CN_1998	CN_2008	CN_2018
1988	91.86	91.72	93.81	93.34

Above Table 5.34 shows that from 1988 to 2018, the CN value is increasing for 1998, 2008 and 2018. The increase in CN is reflected in the runoff, in Table 5.35

Table 5.35 Maximum five rainfall – runoff events taking base year 1988

Base Year	**Rainfall**	**Runoff, mm 1988**	**Runoff, mm 1998**	**Runoff, mm 2008**	**Runoff, mm 2008**
1988	**90.00**	**65.52**	**65.14**	**70.98**	**69.63**
1988	**62.00**	**39.25**	**38.92**	**44.03**	**42.83**
1988	55.00	21.56	21.13	28.20	26.46
1988	52.20	32.90	32.58	37.43	36.29
1988	47.00	32.90	32.58	37.43	36.29

The graphical presentation of table is given in Fig. 5.35

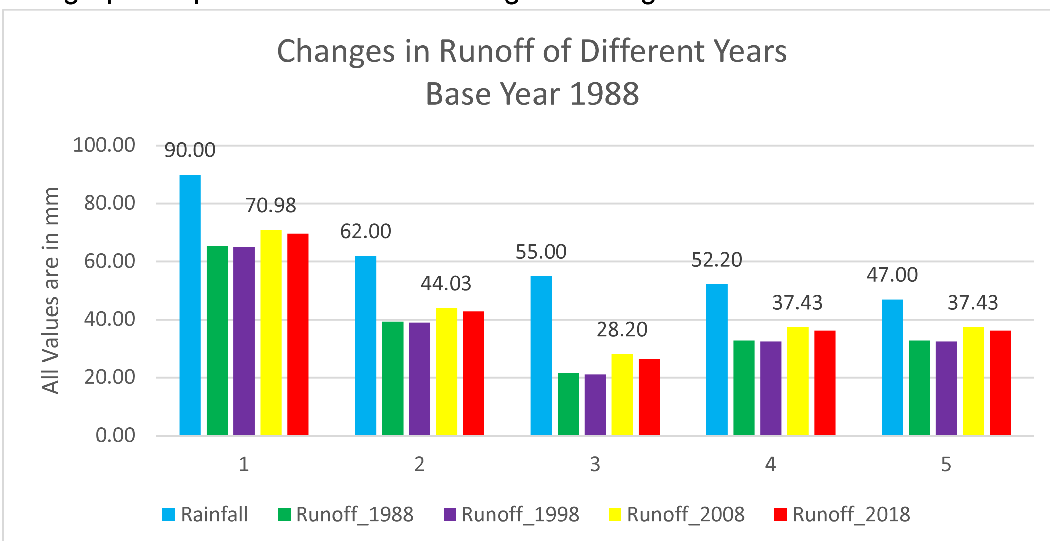


Figure 35: Changes in Runoff of different years with Base Year 1988

From Fig. 5.35, it is observed that for 90.00mm of rainfall, the runoff percentages are 73%, 73%, 78% and 87% respectively for the years 1988, 1998, 2008 and 2018., Similarly, for 62 mm of rainfall, the runoff percentages are 63%, 62%, 71% and 70% respectively for the years 1988, 1998, 2008 and 2018. These values show that the runoff is varying from 60% to 87%, with an increasing trend, which shows that the runoff values are increasing due to the change in LULC.

Scenario 3 – Considering 1998 as a base year and superimposing the LULC maps of 2008 and 2018 on the base map, the changes and considering the extent of area to be same as that of 1998, the changes in runoff values are analysed. The change in runoff will definitely occur due to the changes in for different years.

By superimposing the maps of 2008 and 2018 on the map of 1998 the results of CN values are as shown in Table 5.36.

Table 5.36: Changes in CN values based on change in LU/LC classes for base map of 1998

Base Year	CN_1998	CN_2008	CN_2018
1998	91.00	93.44	93.18

Above Table 5.36 shows that from 1998 to 2018, the CN value is increasing for 2008 and 2018. The increase in CN is reflected in the runoff in Table 5.37

Table 5.37: Maximum five rainfall – runoff events taking base year 1998

Base Year	Rainfall	Runoff, mm 1998	Runoff, mm 2008	Runoff, mm 2008
1998	164.00	134.81	142.62	141.79
1998	158.00	128.93	136.68	135.86
1998	75.00	49.15	55.45	54.76
1998	73.00	26.82	35.77	34.72
1998	49.00	25.82	30.99	30.41

The graphical presentation of table is given in Fig. 5.36

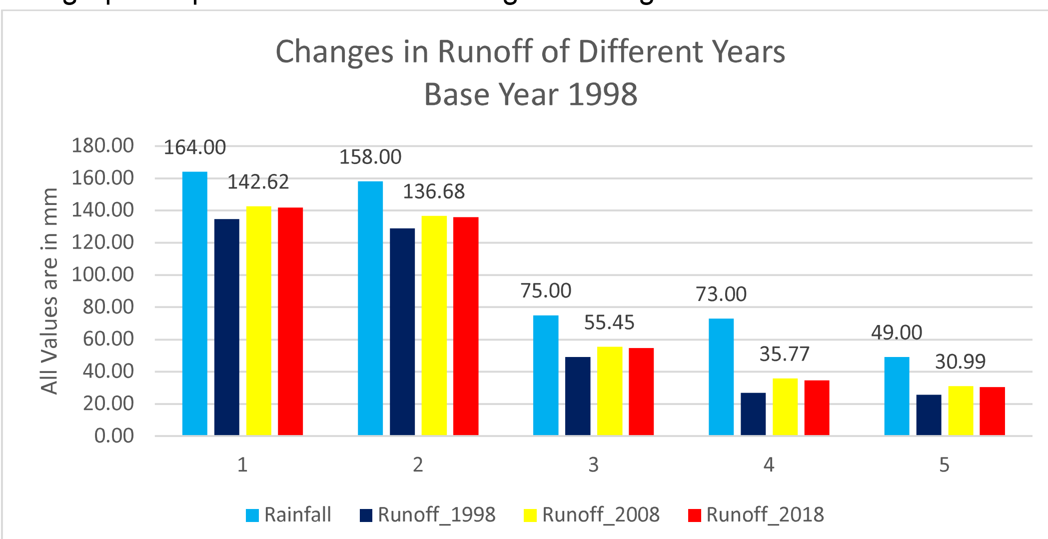


Figure 5.36: Changes in Runoff of different years with Base Year 1998

From Fig. 5.36, it is observed that for 164 mm of rainfall, the runoff percentages are 82%, 86%, and 86% respectively for the years 1998, 2008 and 2018., Similarly, for 158 mm of rainfall, the runoff percentages are 81%, 86% and 86% respectively for the years 1998, 2008 and 2018. For 75 mm of rainfall, the runoff percentages are 65%, 73% and 73% respectively for the years 1998, 2008 and 2018. These values show that the runoff is varying from 65% to 87%, with an increasing trend, which shows that the runoff values are increasing due to the change in LULC.

Alternative Approach

Further to analyse the impact of land use/ land cover changes on runoff, by keeping the rainfall value same as that of the base year and swapping the LULC of other years with the base year, for ex. If the base year is 1977, daily maximum rainfall of the year 1977 is kept constant, swapping the LULC map of 1977 with the maps of 1988, 1998, 2008 and 2018.

Scenario 4: Considering 1977 as a base year, daily maximum rainfall of base year, the runoff of base year is compared to the runoff of the years 1988, 1998, 2008 and 2018 respectively by swapping their LULC maps.

Table 5.38 shows the runoff values computed for the consecutive years, keeping 1977 as base year.

Table 5.38: Five maximum daily rainfall events and LULC of 1977 and Runoff against various LULC

Year	**Rainfall, mm**	**Runoff_1977, mm**	Runoff_1988, mm	Runoff_1998, mm	Runoff_2008, mm	Runoff_2018, mm
1977	**123.10**	**84.58**	**97.49**	**94.93**	**101.75**	**100.77**
	122.80	**84.30**	97.20	94.64	101.45	100.48
	63.00	**0.10**	4.93	3.29	8.59	7.65
	60.00	**28.10**	37.43	35.48	40.79	40.01
	52.20	**21.86**	30.39	28.59	33.54	32.81

For the maximum rainfall of 1977, the runoff variations in different years are shown in Fig. 5.37

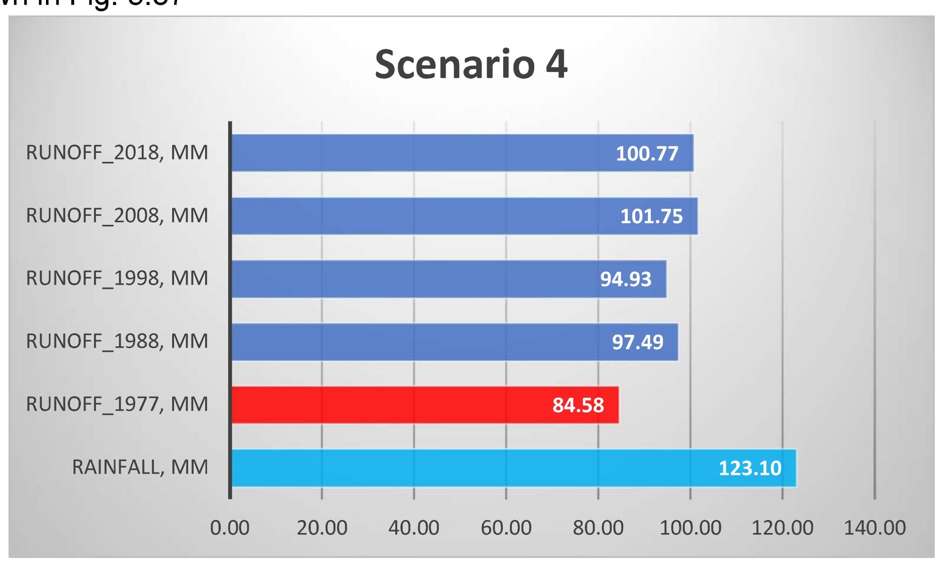


Figure 5.37: Daily Runoff values for study years, Base Year 1977

In Fig. 5.37, for 123.10 mm of rainfall, for base year 1977, the runoff value is obtained as 84.58 mm, which is 64% of rainfall. When the LULC for the year 1988 is taken into account, the runoff comes out to be 97.49 mm, which is 78% of rainfall. For LULC of year 1998, the runoff value comes out to be 94.93 mm, which is 76% of rainfall, for LULC of year 2008, runoff value is 101.75 mm and for year 2018, runoff value is 100.77mm, which is 82% and 81% of rainfall respectively.

The runoff percentages are observed to be varying from varying from 64%, 78%, 76%, 82% and 81% for the years of 1977, 1988, 1998,1998, 2008 and 2018, clearly representing that the runoff values are increasing.

Scenario 5: Considering 1988 as a base year, daily maximum rainfall of base year, the runoff of base year is compared to the runoff of the years 1977, 1998, 2008 and 2018 respectively by swapping their LULC maps.

Table 5.39 shows the runoff values computed for the consecutive years, keeping 1988 as base year.

Table 5.39: Five maximum daily rainfall events and LULC of 1988 and Runoff against various LULC of study years

Year	Rainfall, mm	Runoff_1977, mm	Runoff_1988, mm	Runoff_1998, mm	Runoff_2008, mm	Runoff_2018, mm
1988	**90.00**	54.04	**65.52**	63.21	69.44	68.54
	62.00	29.74	**21.56**	21.56	26.21	25.11
	55.00	7.49	**32.90**	14.50	36.13	35.37
	52.20	21.86	**14.85**	14.85	18.79	17.85
	47.00	17.89	**25.81**	24.11	28.79	28.09

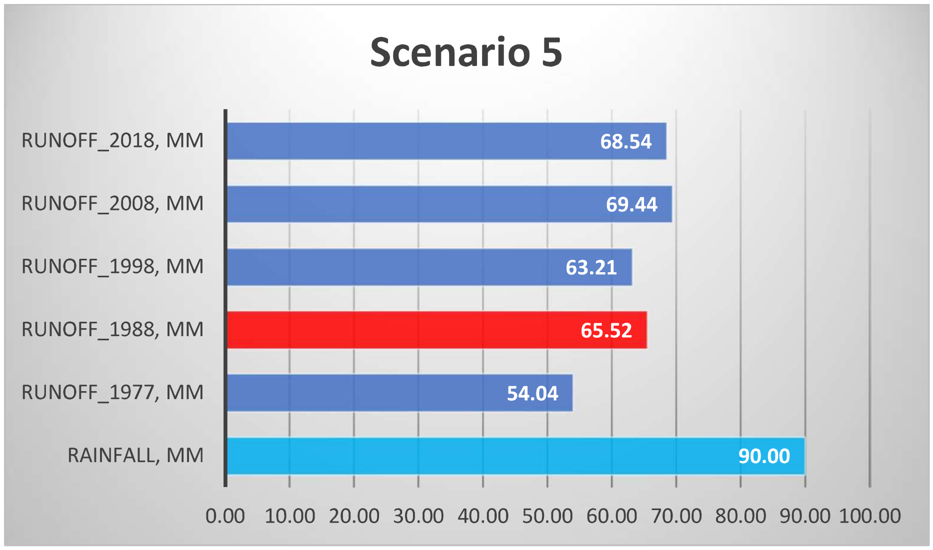


Figure 5.38: Daily Runoff values for study years, Base Year 1988

In Fig.5.38, the runoff percentages are observed to be varying from varying from 60%, 72%, 70%, 76% and 75 for the years of 1977, 1988, 1998,1998, 2008 and 2018, clearly representing that the runoff values are increasing.

Scenario 6: Considering 1998 as a base year, daily maximum rainfall of base year, the runoff of base year is compared to the runoff of the years 1977, 1988, 2008 and 2018 respectively by swapping their LULC maps.

Table 5.40 shows the runoff values computed for the consecutive years, keeping 1998 as base year.

Table 5.40: Five maximum daily rainfall events and LULC of 1998 and Runoff against various LULC of study Years.

Year	**Rainfall, mm**	Runoff_1977, mm	Runoff_1988, mm	**Runoff_1998, mm**	Runoff_2008, mm	Runoff_2018, mm
1998	**164.00**	123.53	137.56	**134.81**	142.07	141.05
	158.00	117.76	131.66	**128.93**	136.14	135.12
	75.00	40.77	51.32	**49.15**	55.00	54.15
	73.00	16.85	29.75	**26.82**	35.07	33.82
	49.00	19.40	27.56	**25.82**	30.61	29.89

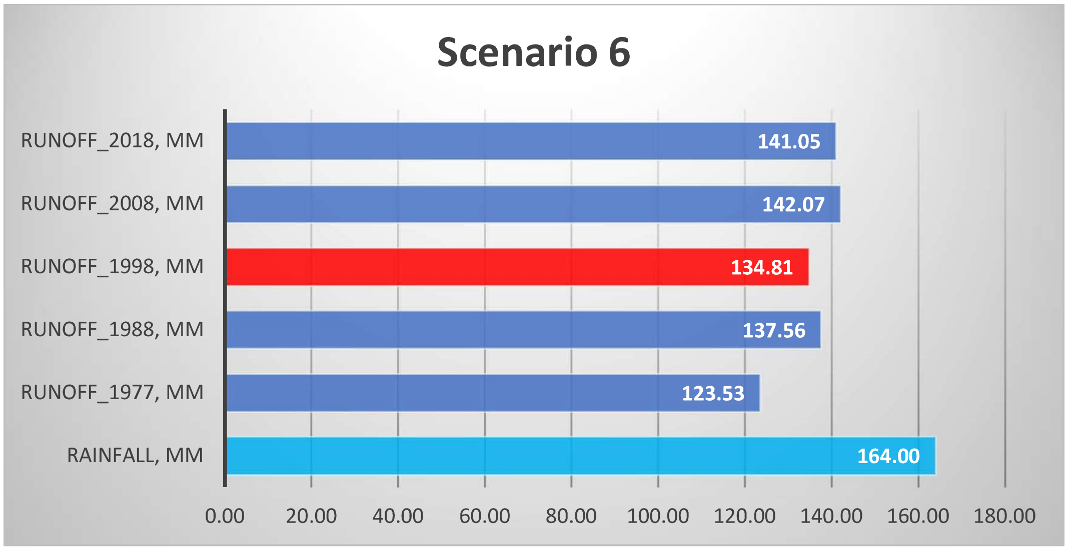


Figure 5.39: Daily Runoff values for study years, Base Year 1998

In Fig.5.39, the runoff percentages are observed to be varying from varying from 75%, 83%, 81%, 86% and 85% for the years of 1977, 1988, 1998,1998, 2008 and 2018, clearly representing that the runoff values are increasing.

Scenario 7: Considering 2008 as a base year, daily maximum rainfall of base year, the runoff of base year is compared to the runoff of the years 1977, 1988, 1998 and 2018 respectively by swapping their LULC maps.

Table 5.41 shows the runoff values computed for the consecutive years, keeping 2008 as base year.

Table 5.41: Five maximum daily rainfall events and LULC of 2008 and Runoff against various LULC of study Years.

Year	**Rainfall, mm**	Runoff_1977, mm	Runoff_1988, mm	Runoff_1998, mm	**Runoff_2008, mm**	Runoff_2018, mm
2008	**122.00**	51.01	70.95	66.46	**78.31**	76.61
	116.00	77.92	90.58	88.07	**94.77**	93.82
	81.00	2.32	12.22	9.49	**17.82**	16.42
	63.00	30.56	40.17	38.17	**43.60**	42.81
	44.00	1.17	0.49	0.10	**1.90**	1.49

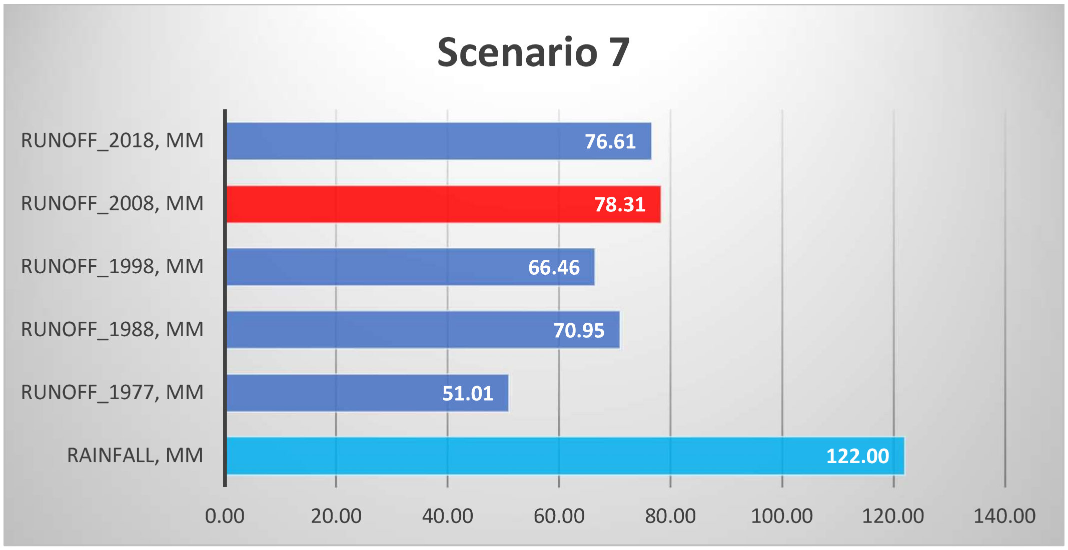


Figure 5.40: Daily Runoff values for study years, Base Year 2008

In Fig. 5.40 the runoff percentages are observed to be varying from varying from 41%, 57%, 54%, 53% and 62% for the years of 1977, 1988, 1998,1998, 2008 and 2018, clearly representing that the runoff values are increasing.

Scenario 8: Considering 2018 as a base year, daily maximum rainfall of base year, the runoff of base year is compared to the runoff of the years 1977, 1988, 1998 and 2008 respectively by swapping their LULC maps.

Table 5.42 shows the runoff values computed for the consecutive years, keeping 2018 as base year.

Table 5.42: Five maximum daily rainfall events and LULC of 2018 and Runoff against various LULC of study Years.

Year	**Rainfall, mm**	Runoff_1977, mm	Runoff_1988, mm	Runoff_1998, mm	Runoff_2008, mm	**Runoff_2018, mm**
2018	**180.00**	138.98	153.33	150.54	145.69	**156.88**
	97.00	60.38	72.23	69.85	65.80	**75.32**
	75.00	1.28	9.52	7.14	3.99	**13.25**
	62.00	29.74	39.26	37.27	33.98	**41.88**
	56.00	24.86	33.80	31.92	28.82	**36.30**

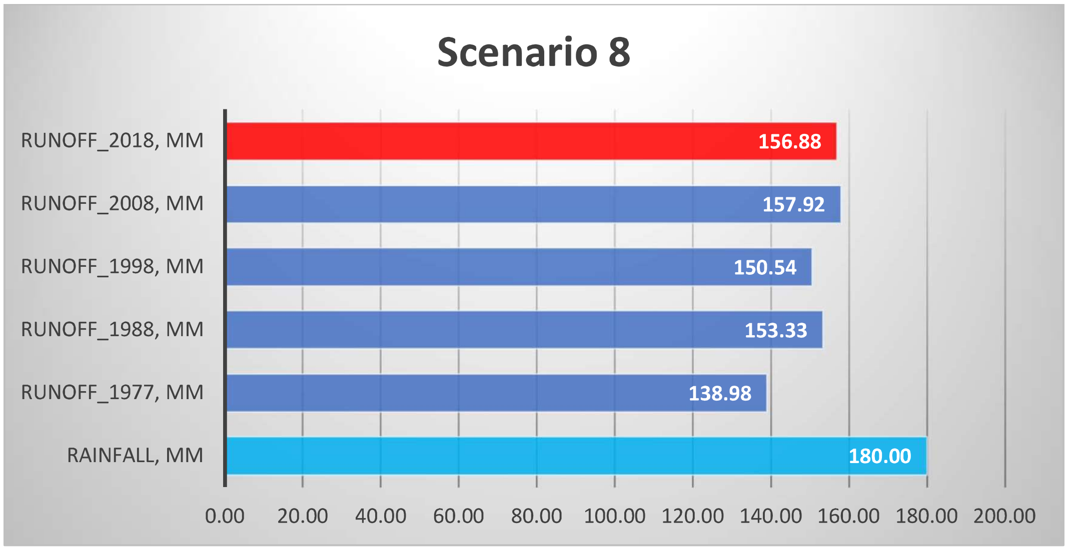


Figure 5.41: Daily Runoff values for study years, Base Year 2018

In Fig.5.41, the runoff percentages are observed to be varying from varying from 76%, 85%, 83%, 80% and 86% for the years of 1977, 1988, 1998,1998, 2008 and 2018, clearly representing that the runoff values are increasing.

Objective 5: To determine rainfall and runoff for various recurrence intervals i.e., for 2, 5, 10, 15, 20, 25, 50, 75 and 100 years return period.

5.8 DETERMINATION OF RAINFALL AND RUNOFF FOR VARIOUS RECURRENCE INTERVALS

The Intensity Duration Frequency (IDF) curves are used to determine rainfall and runoff for various recurrence intervals for various return periods like 2, 5, 10,15, 20, 25, 50, 75 and 100 years.by using the Gumbel distribution method The IDF curves are also developed using various other empirical equations.

Table 5.43: Rainfall Intensity in mm/hr. at various rainfall durations and return periods for Vadodara station by Gumbel's Extreme Value Distribution

Duration (hours)	Return Period T (Years)								
↓	2	5	10	15	20	25	30	50	75	100
1H	45.54	63.01	74.58	81.11	85.68	89.20	92.06	100.04	106.34	110.80
2H	28.69	39.69	46.98	51.09	53.97	56.19	57.99	63.02	66.99	69.80
6H	13.79	19.08	22.59	24.56	25.95	27.01	27.88	30.30	32.21	33.56
12H	8.69	12.02	14.23	15.47	16.35	17.02	17.56	19.09	20.29	21.14
24H	5.47	7.57	8.96	9.75	10.30	10.72	11.06	12.02	12.78	13.32

Preparation of IDF Curves by using data shown Table 5.43., Intensity Duration Frequency curves are plotted for various return periods as shown in Fig. 5.42

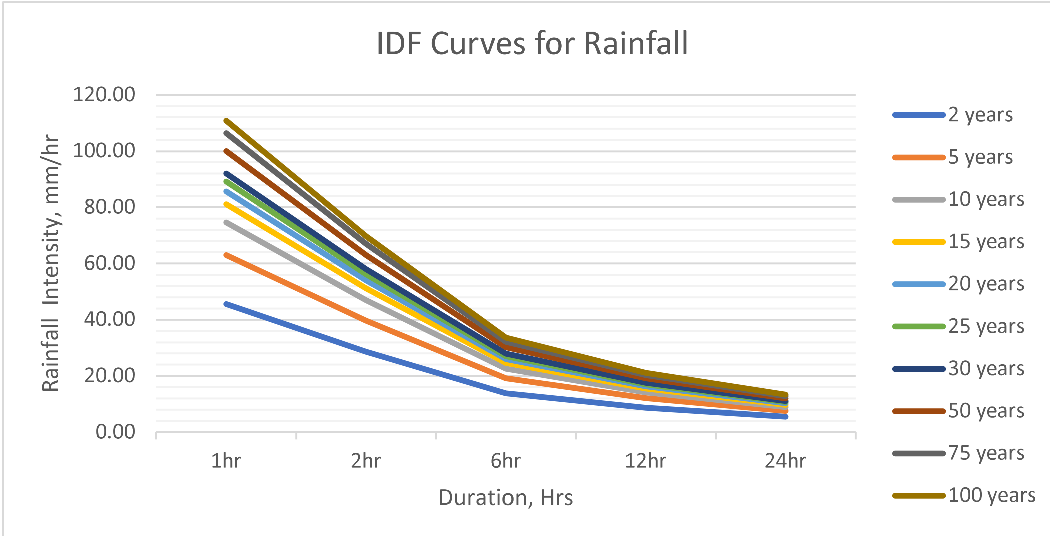


Figure 5.42: Intensity Duration Frequency Curve by GEV Distribution

Fig. 5.42 shows that the rainfall intensity decreases as the duration of rainfall is increased.

IDF Curves by Empirical Equations

The IDF curves are constructed by using equations: Talbot, Bernard, Kimijima and Sherman. Least square method is applied to determine the parameter of four empirical IDF equations used to represent intensity duration relationships. The value of parameter in the Rainfall IDF equations were chosen on the minimum of Root Mean Square Error (RMSE) between the IDF relationship produced by the frequency analysis and that simulated by the IDF equations.
The parameters of Sherman equations are as below in Table 5.44

Table 5.44: The parameters of Sherman equations

Return Period T, Years	a	b	e
2	49.23	0.00	0.67
5	60.14	0.00	0.67
10	60.14	0.00	0.67
15	78.01	0.00	0.67
20	82.66	0.00	0.67
25	86.00	0.00	0.67
30	88.93	0.00	0.67
50	96.83	0.00	0.67
75	103.00	0.00	0.67
100	107.50	0.00	0.67

Table 5.45: Constant parameters with empirical equations at Vadodara station with 100 years return period.

Function	a	b	e	RMSE
Tablot	206.11	0.93	-	4.618
Bernard	107.53	-	0.67	7.119
Kimijima	107.48	0.00	0.67	0.163
Sherman	107.50	0.00	0.67	0.159

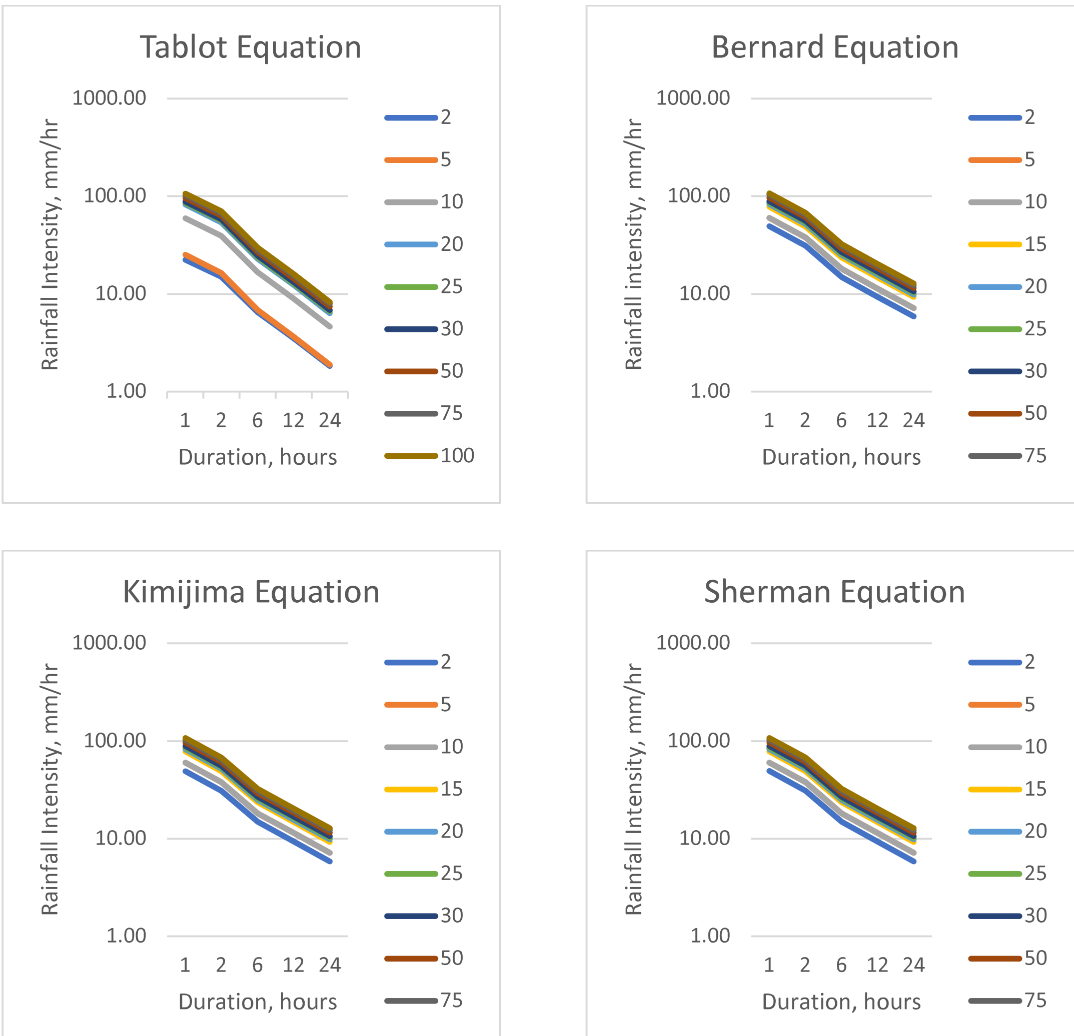


Figure 5.43: Rainfall Intensity Duration Frequency (IDF) curves using empirical equations.

Comparison of the results for the four empirical methods shows that Sherman equations may fit well at the Vadodara station that has Root mean square error (RMSE) only 0.159 mm/hour and its relative coefficient R is approximated 0.99. The results show that the Sherman equations are an acceptable fit to the IDF relationship in Vadodara. This indicated that the empirical formula given by Kimijima and Sherman obtained to estimate intensity in the study area is good for short durations. These IDF Curves and Empirical Equations will help for calculation of peak discharge into Minor Irrigation Tanks and also useful for planning and designing of any water resource management project.

Calculation of Runoff Intensity

To compute Runoff Intensity in mm/hr. at various durations and return periods, a rainfall runoff model is prepared. Various models were developed, but the linear model was best suited for this purpose.

Now using the rainfall and runoff data, a linear model was developed for the dataset of 70% – 30% (Training - Validation).
The linear model equation is:

Y = mx + c, where Y = Runoff and x = Rainfall

To check the accuracy of the model developed, coefficient of correlation is calculated which is, for training and validation, 0.92 and 0.99, respectively.

Table 5.46: Constants obtained using linear model

	Coefficients
Intercept	-50.808
Rainfall	1.033

In the below Table 5.47, the runoff intensities calculated are shown.

Table 5.47: Runoff Intensity in mm/hr. at various durations and return periods for Vadodara station

Duration (hours)	**Return Period T (Years)**									
↓	2	5	10	15	20	25	30	50	75	100
1H	29.43	47.48	59.43	66.17	70.89	74.53	77.49	85.73	92.24	96.85
2H	18.54	29.91	37.44	41.69	44.66	46.95	48.81	54.01	58.11	61.01
6H	8.91	14.38	18.00	20.04	21.47	22.57	23.47	25.96	27.94	29.33
12H	5.61	9.06	11.34	12.62	13.53	14.22	14.78	16.36	17.60	18.48
24H	3.54	5.71	7.14	7.95	8.52	8.96	9.31	10.30	11.09	11.64

For 1 hour duration, the rainfall intensity comes out to be as 45.54, 63.01, 74.58, 89.20, 100.04 and 110.80 mm/hr. for 2, 5, 10, 25, 50 and 100 years return periods respectively. Simultaneously, for 1 hour duration, the runoff intensity comes out to be 29.43, 47.48, 59.43, 74.53, 85.73 and 96.85 mm/hr. for 2, 5, 10, 25, 50 and 100 year return periods respectively.

Similarly, for the durations of 2H, 6H, 12H and 24H, rainfall and runoff intensities are computed, and it is observed that, as time duration increases, the rainfall intensity in mm/hr. is decreased and the amount of rainfall, in mm is increased with increase of return periods from 2, 5, 10, 25, 50 and 100 years. Fig. 5.44 shows the runoff intensities in mm/hr.

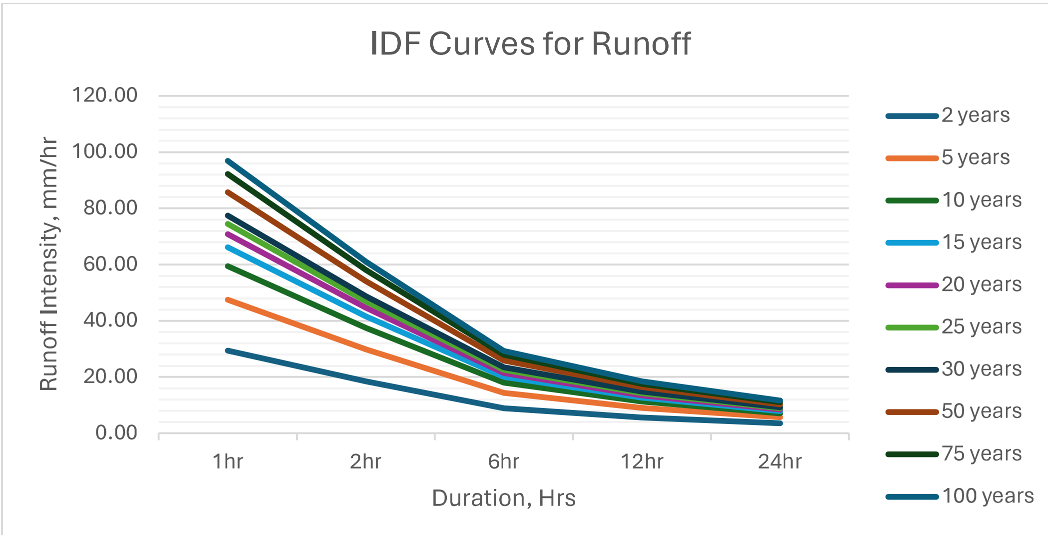


Figure 5.44: Intensity Duration Frequency Curve for Runoff

Objective 6: To predict probable Land Use/ Land Cover changes in the study area

5.9 ESTIMATION OF LULC CHANGES

Table 5.48 shows the LULC of the different classes namely waterbodies, urban settlement, natural vegetation, agricultural land and barren land obtained for the years of 1977, 1988, 1998, 2008 and 2018.

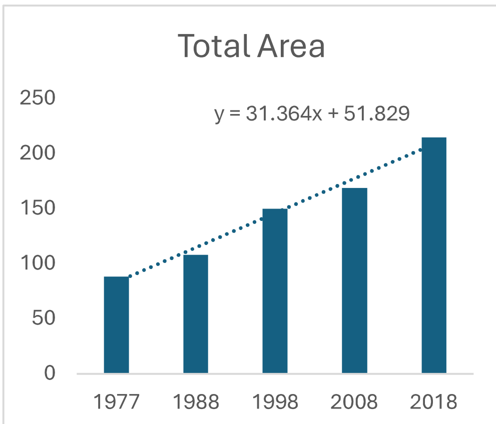
Table 5.48: Areas (Sq. Km.) of LULC classes of the study years

LULC Class	**1977**	**1988**	**1998**	**2008**	**2018**
Water bodies	1.44	0.82	0.62	1.00	1.36
Urban Settlement	11.60	24.30	48.10	80.75	122.02
Natural Vegetation	40.82	20.06	38.89	18.72	32.70
Agricultural Land	3.93	33.94	44.11	35.64	55.92
Barren Land	30.30	29.05	18.24	32.63	2.63
Total Area	88.10	108.18	149.96	168.75	214.63

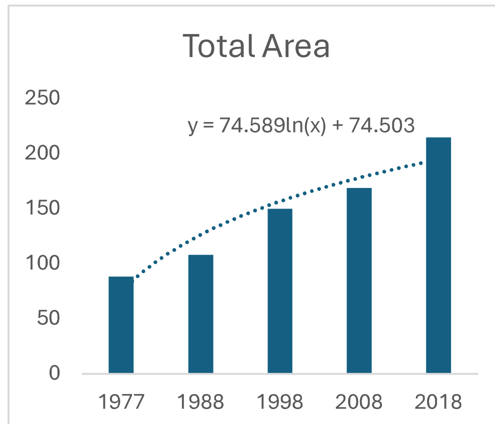
To predict probable LULC changes in the study area, various statistical models namely linear, logarithmic, polynomial, exponential and power models have been used. Using these models, various equations are developed. Using these equations, each of the LULC class and also the change in total area has been estimated for 2028, 2038 and 2048.

Models for Total Area Estimation

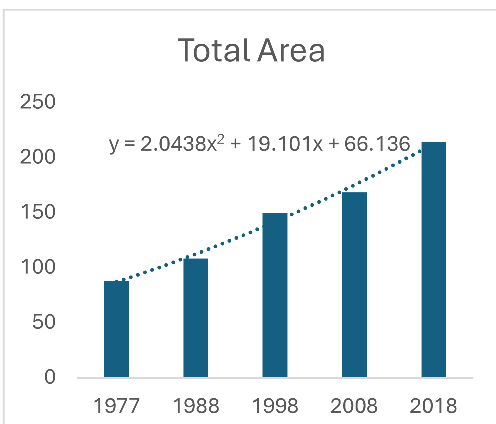
Results Obtained for Total Area Estimation Models



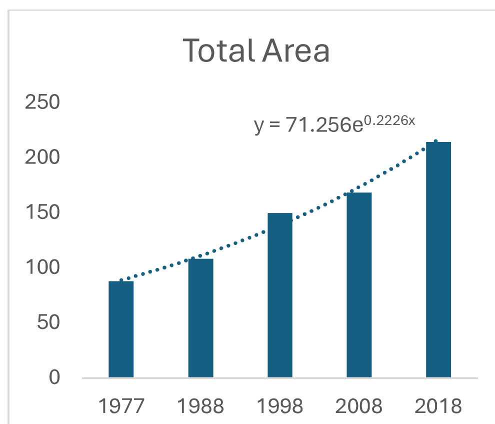
(a) Linear



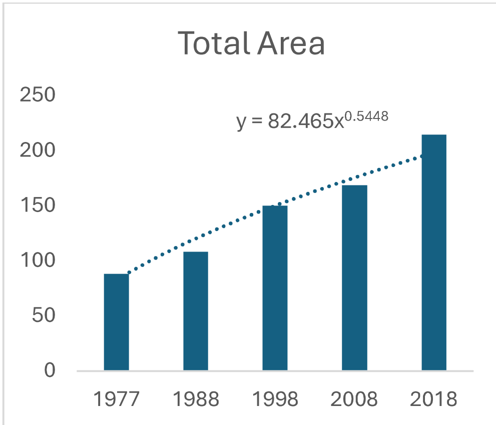
(b) Logarithmic



(c) Polynomial



(d) Exponential



(e) Power

Figure 5.45: Different models obtained for Total Area Estimation

Fig. 5.45 shows the various models generated using the statistical tool. The equation obtained using these models is shown below in Table 5.48

Table 5.49 shows the equations of various models used to obtain the estimations for total area. Using these equations, the predictions are estimated in Table 5.51

Table 5.49: Developed equations for various model for Total Areas estimation

Total Area	Equation
Linear	y = 30.997x + 53.459
Log	y = 53.472ln(x) + 83.517
Power	y = 85.366x0.4647
exponential	y = 66.132e0.2664x
Polynomial	y = 10.917x2 - 12.672x + 89.85

Table 5.50 shows the calculations of total area using the equations obtained in previous tables.

Table 5.50: Calculations of Total Areas using various models

	1977	**1988**	**1998**	**2008**	**2018**
Total Area, LULC	88.1	108.2	150.1	168.7	214.6
Linear	84.4	115.4	146.4	**177.4**	**208.4**
Logarithmic	83.5	120.6	142.3	157.6	169.6
Exponential	86.3	112.7	147.1	191.9	250.5
Polynomial	**88.1**	**108.2**	**150.1**	213.8	299.4
Power	85.4	117.8	142.2	162.6	180.3

Table 5.50 shows the results of models by using these equations. According to these models the areas obtained by using polynomial equations show results similar to the actual values in the first two decades whereas in the last two decades, it is observed

in linear models. However, the estimation of total area has been carried out for all the models and is represented in Table 5.51

Table 5.51: Predicted total LULC for the Total Areas

Year	2028	2038	2048
Linear	**239.4**	**270.4**	**301.4**
Logarithmic	179.3	187.6	194.7
Polynomial	**482.9**	**624.8**	**788.5**
Exponential	327.0	426.8	557.1
Power	196.3	210.9	224.4

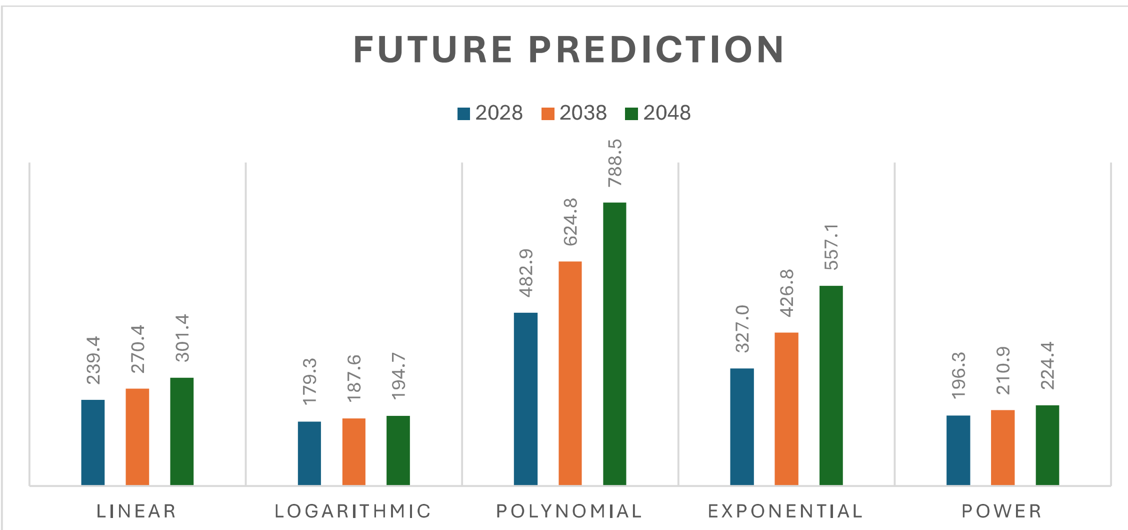
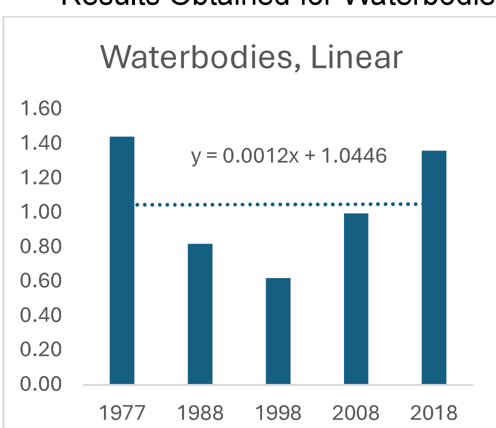


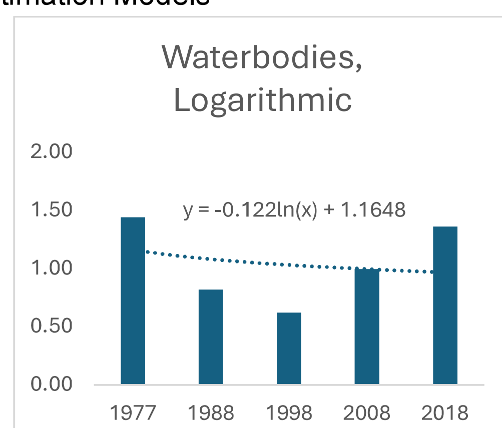
Figure 5.46: Graphs of prediction of Total Area by various models

Models for Waterbodies Estimation

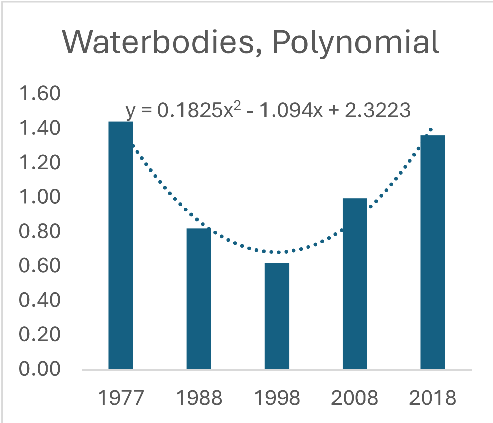
Results Obtained for Waterbodies Estimation Models



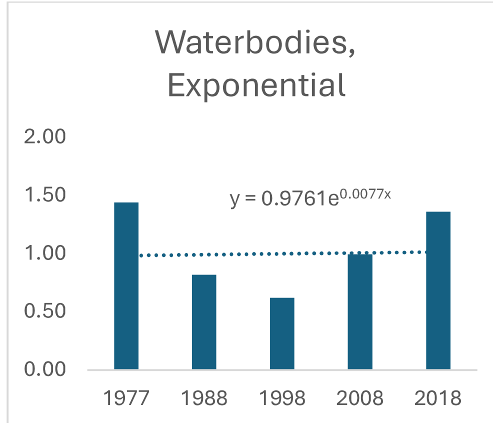
(a) Linear



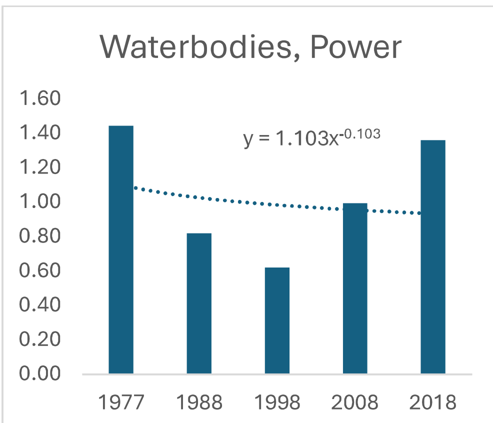
(b) Logarithmic



(c) Polynomial



(d) Exponential



(e) Power

Figure 5.47: Different models obtained for estimation of Waterbodies

Fig. 5.47 shows the various models generated using the statistical tool. The equation obtained using these models is shown below in Table 5.52

Table 5.52 shows the equations of various models used to obtain the prediction for Waterbodies. Using these equations, the predictions are estimated in Table 5.54

Table 5.52: Developed equations for various model for Waterbodies estimation

Water Bodies	Equation
Linear	y = 0.0012x + 1.0446
Logarithmic	y = -0.122ln(x) + 1.1648
Polynomial	y = 0.1825x2 - 1.094x + 2.3223
Exponential	y = 0.9761e0.0077x
Power	y = 1.103x-0.103

Table 5.53 shows the calculations of Waterbodies using the equations obtained in previous tables.

Table 5.53: Calculations of Waterbodies using various models

	1977	1988	1998	2008	2018
Waterbodies	1.44	0.82	0.62	1.00	1.36
Linear	1.046	1.047	1.048	**1.049**	**1.051**
Logarithmic	1.165	1.080	1.031	0.996	0.968
Polynomial	**1.411**	**0.864**	**0.683**	0.866	1.415
Exponential	0.984	0.991	0.999	1.007	1.014
Power	1.103	1.027	0.985	0.956	0.935

Table 5.53 shows the results of models by using these equations. According to these models the areas obtained by using polynomial equations show results similar to the actual values in the first two decades whereas in the last two decades, it is observed in linear models.

However, the estimation of waterbodies has been carried out for all the models and is represented in Table 5.54 The graph of the same is shown in Fig. 5.55.

Table 5.54: Predicted LULC for the Waterbodies.

Waterbodies	2028	2038	2048
Linear	**1.052**	**1.053**	**1.054**
Logarithmic	0.946	0.927	0.911
Polynomial	**2.328**	**3.607**	**5.250**
Exponential	1.022	1.030	1.038
Power	0.917	0.903	0.890

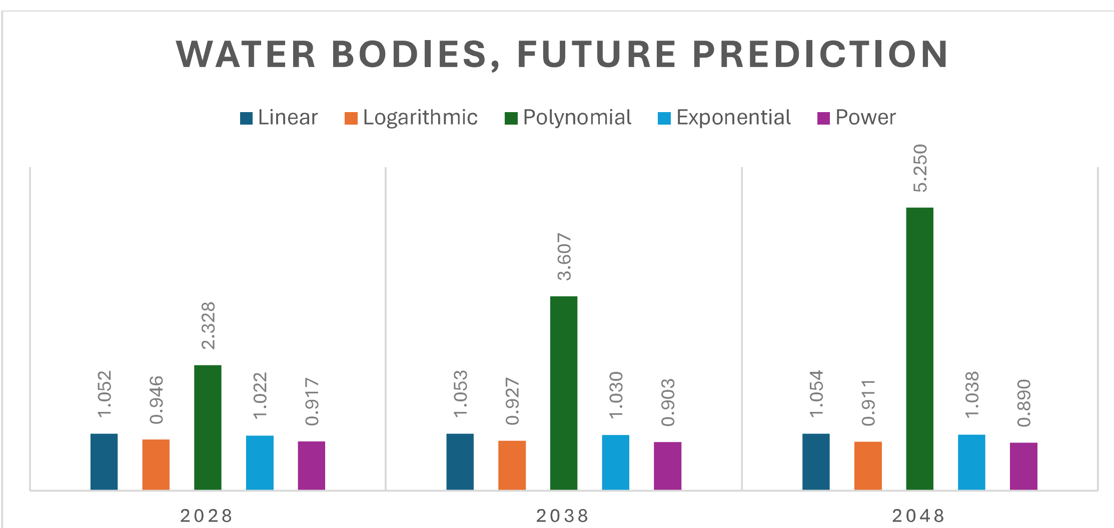
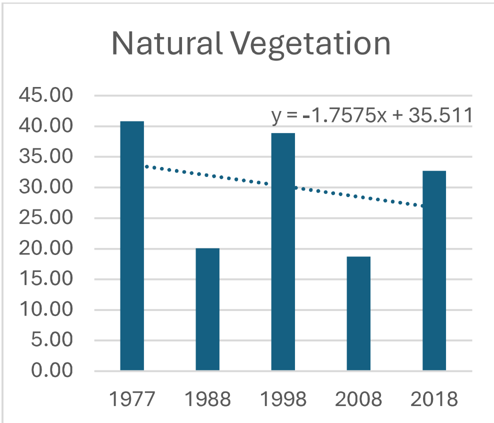


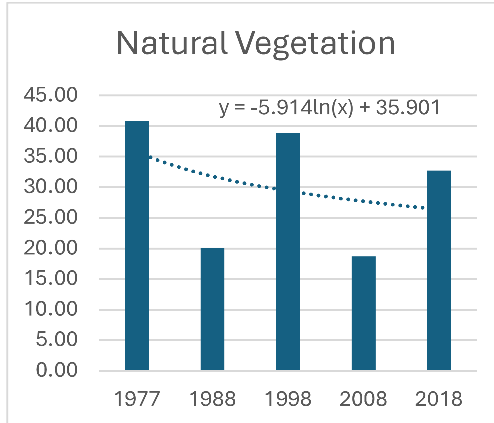
Figure 5.48: Graphs of prediction of Waterbodies by various models.

Models for Natural Vegetation Estimation

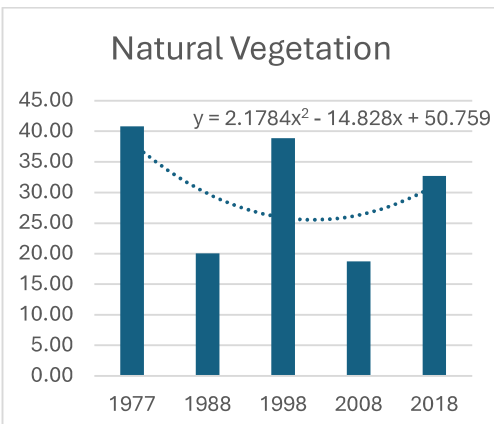
Results Obtained for Natural Vegetation Estimation Models



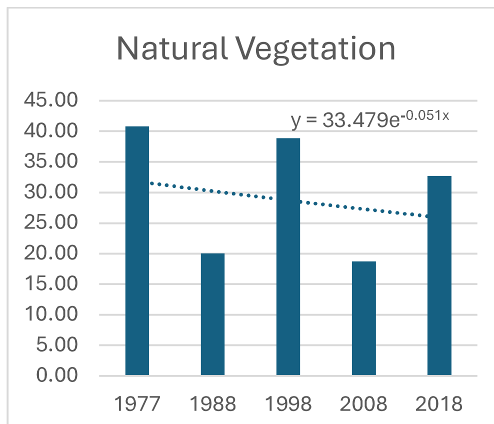
(a) Linear



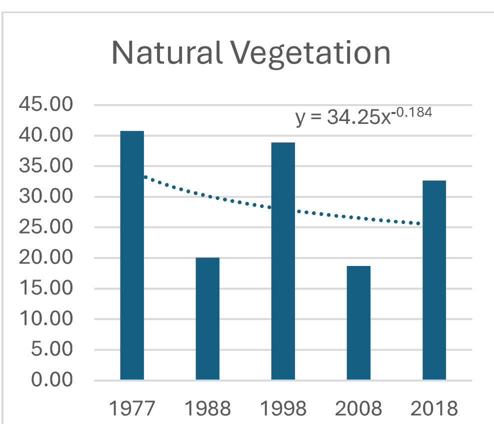
(b) Logarithmic



(c) Polynomial



(d) Exponential



(e) Power

Figure 5.49: Different models obtained for estimation of Natural Vegetation

Fig. 5.49 shows the various models generated using the statistical tool. The equation obtained using these models is shown below in Table 5.55

Table 5.55: Developed equations for various model for Natural Vegetation estimation

Natural Vegetation	Equations
Linear	$y = -1.7575x + 35.511$
Logarithmic	$y = -5.914\ln(x) + 35.901$
Polynomial	$y = 2.1784x^2 - 14.828x + 50.759$
Exponential	$y = 33.479e^{-0.051x}$
Power	$y = 34.25x^{-0.184}$

Table 5.56: Calculations of Natural Vegetation using various models

Year	1977	1988	1998	2008	2018
Natural Vegetation	40.82	20.06	38.89	18.72	32.70
Linear	33.75	32.00	30.24	28.48	26.72
Logarithmic	35.90	31.80	29.40	27.70	26.38
Polynomial	**38.11**	**29.82**	**25.88**	**26.31**	**31.09**
Exponential	31.81	30.23	28.73	27.30	25.94
Power	34.25	30.15	27.98	26.54	25.47

Table 5.56 shows the results of models by using these equations. According to these models the areas obtained by using polynomial equations show results similar to the actual values. So polynomial equations should be used for prediction of Natural Vegetation.

Although polynomial shows the best results the predicted, every model is used for prediction of the Natural Vegetation class as shown in Table 5.57. The graph of the same is shown in Fig. 5.50

Table 5.57: Predicted total LULC for the Natural Vegetation

Year	2028	2038	2048
Linear	24.97	23.21	21.45
Logarithmic	25.30	24.39	23.60
Polynomial	**40.22**	**53.72**	**71.57**
Exponential	24.65	23.43	22.26
Power	24.63	23.94	23.36

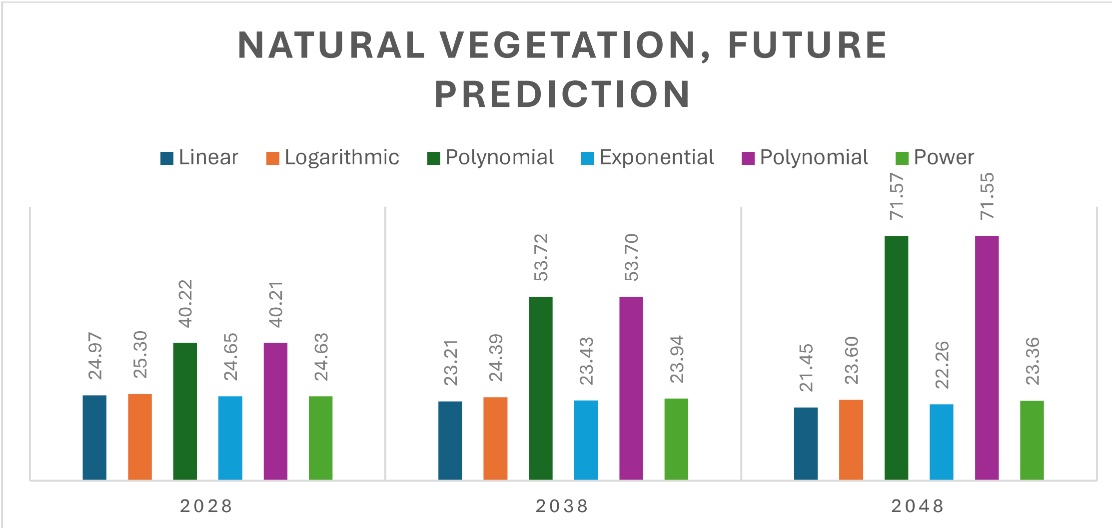
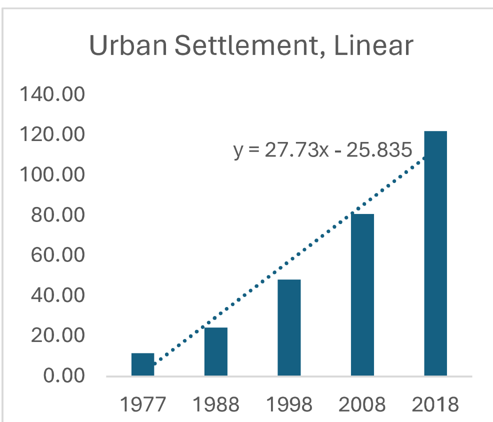


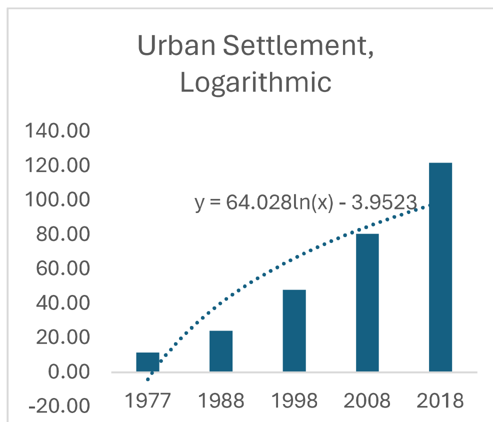
Figure 5.50: Graphs of prediction of Natural Vegetation by various models.

Models for Urban Settlement Estimation

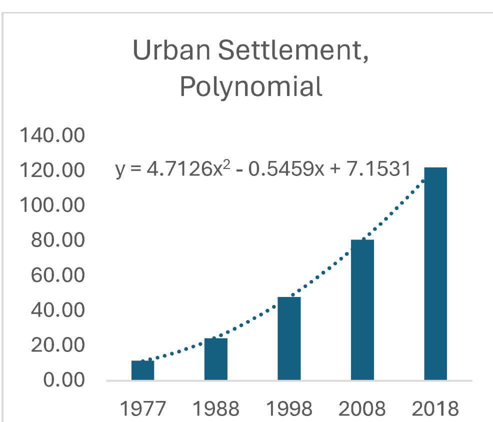
Results Obtained for Urban Settlement Estimation Models



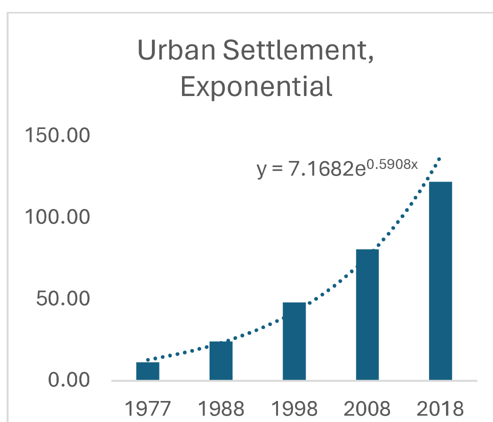
(a) Linear



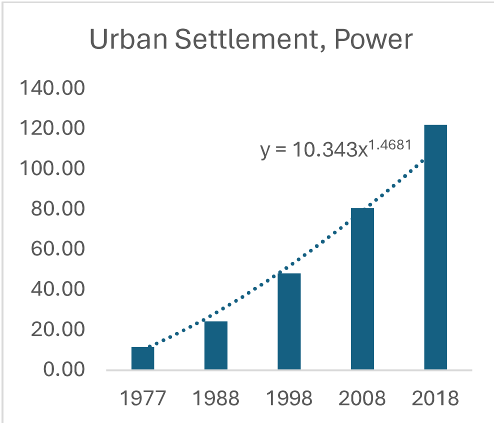
(b) Logarithmic



(c) Polynomial



(d) Exponential



(e) Power

Figure 5.51: Different models obtained for estimation of Urban Settlement

Fig. 5.51 shows the various models generated using the statistical tool. The equation obtained using these models is shown below in Table 5.58

Table 5.58: Developed equations for various model for Urban Settlement estimation

Urban Settlement	Equation
Linear	y = 27.73x - 25.835
Logarithmic	y = 64.028ln(x) - 3.9523
Polynomial	$y = 4.7126x^2 - 0.5459x + 7.1531$
Exponential	$y = 7.1682e^{0.5908x}$
Power	$y = 10.343x^{1.4681}$

Table 5.59: Calculations of Urban Settlement using various models

Year	1977	1988	1998	2008	2018
Urban Settlement	11.60	24.30	48.10	80.75	122.02
Linear	1.90	29.63	57.36	85.09	112.82
Logarithmic	3.95	40.43	66.39	84.81	99.10
Polynomial	**11.32**	**24.91**	**47.93**	**80.37**	**122.24**
Exponential	12.94	23.37	42.18	76.16	137.50
Power	10.34	28.61	51.88	79.14	109.82

Table 5.59 shows the results of models by using these equations. According to these models the areas obtained by using polynomial equations show results similar to the actual values. So polynomial equations may be used for prediction of Urban Settlement.

However, the estimation of Urban Settlement has been carried out for all the models and is represented in Table 5.60 The graph of which is shown in Fig. 5.52

Table 5.60 shows the predicted Urban Settlement class.

Table 5.60: Predicted total LULC for the Urban Settlement

Urban Settlement	2028	2038	2048
Linear	140.55	168.28	196.01
Logarithmic	110.77	120.64	129.19
Polynomial	**173.53**	**234.25**	**304.39**
Exponential	248.25	448.21	809.21
Power	143.52	179.97	218.95

Analysing the Table 5.60, the urban settlement in Vadodara city for the years 2028, 2038 and 2048 is estimated to be around 175, 235 and 305 Sq. Km. Therefore, the percentage change in future 10 years, 20 years and 30 years with base year as 2018 is estimated as 41%, 91% and 149% increase in urban settlement. This increase will have the direct impact on the increase in runoff.

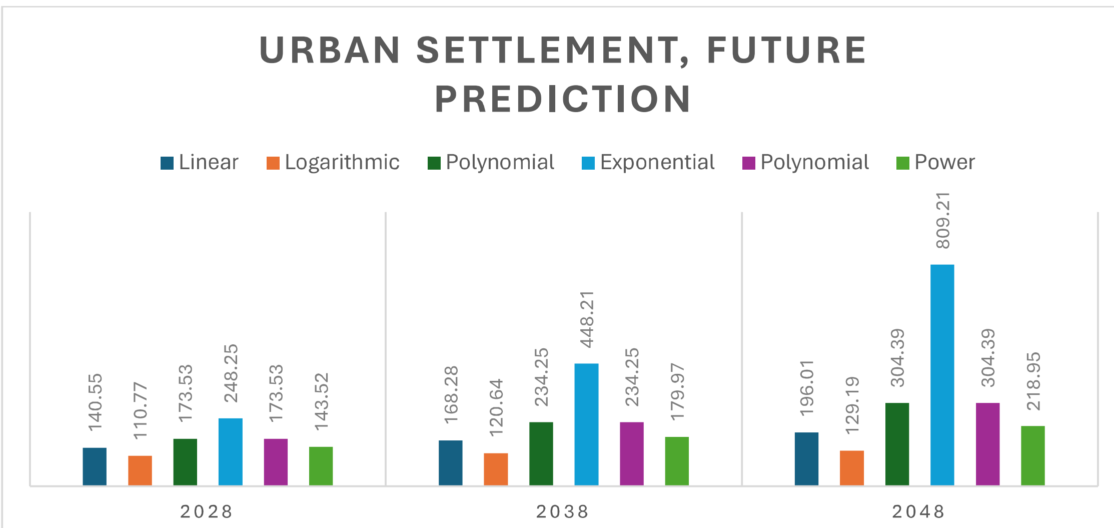


Figure 5.52: Graphs of prediction of Urban Settlement by various models

Analysing the Table 5.60, the urban settlement in Vadodara city for the years 2028, 2038 and 2048 is estimated to be around 175, 235 and 305 Sq. Km. Therefore, the percentage change in future 10 years, 20 years and 30 years with base year as 2018 is estimated as 41%, 91% and 149% increase in urban settlement. This increase will have the direct impact on the increase in runoff.

Analysis of Total Area Predictions

The total areas in Vadodara city for the years 2028, 2038 and 2048 is estimated to be around 483, 625 and 790 Sq. Km. Therefore, the percentage change in future 10 years, 20 years and 30 years with base year as 2018 is estimated as the range of 11%, 26% and 41% increase in total areas.

Analysis of Urban Settlement Predictions

From the estimated models, the urban settlement in Vadodara city for the years 2028, 2038 and 2048 is estimated to be around 175, 235 and 305 Sq. Km. Therefore, the percentage change in future 10 years, 20 years and 30 years with base year as 2018 is estimated as 41%, 91% and 150% increase in urban settlement. This increase will have the direct impact on the increase in runoff.