Chapter 5

Results and Discussion

5.1 Introduction

This chapter describes the results obtained from three models developed in this study:

1.Water Quality Index model

2. Urbanization Index model

3. Water Quality - Urbanization Regression model

5.2 Water Quality Index model

In this study, for the formulation of the Water Quality Index model, the equation (3.2) developed in this study is reproduced below:

$$WQI = \sum_{i=1}^{n}(W_i \, x \, Vr_i) \qquad (5.1)$$

5.2.1 Results of Water Quality Index model

The Water Quality Index model developed in this study is applied on the Sabarmati river, India. The quarterly Water Quality Index obtained for stations, S_1,S_2, S_3, S_4 and S_5 from year 2005 to 2011 using equation 3.2 are shown in Table 5.1.

Table 5.1. Water Quality Index for the stations under study

Water Quality Index									
Station- S_1									
	2005	2006	2007	2008	2009	2010	2011	Avg.	Grand Avg.
Jan	44.6	19.3	61.4	61.9	44.6	53.9	44.5	45.6	49.1
Apr	25.4	28.7	19.8	44.6	30.5	28.7	39.9	31.1	
July	33.3	55.8	72.7	33.3	61.4	28.7	44.6	47.1	
Oct	71.7	67.1	71.7	65.2	71.3	67.1	82.4	70.9	
Station- S_2									
	2005	2006	2007	2008	2009	2010	2011	Avg.	
Jan	60.6	82.2	83.1	87.8	88.8	88.8	93.4	83.5	76.4
Apr	61.6	77.5	83.1	88.8	50.3	55.9	85.4	71.8	
July	65.9	50.3	61.9	67.2	93.4	78.4	71.8	69.8	
Oct	61.2	82.2	77.5	78.4	87.8	93.4	83.1	80.5	
Station- S_3									
	2005	2006	2007	2008	2009	2010	2011	Avg.	
Jan	87.8	88.7	93.4	84.1	72.8	77.9	88.4	84.7	79.8
Apr	87.8	71.8	93.4	87.8	78.4	44.7	78.2	77.4	
July	72.2	72.8	33.8	84.1	67.2	59.7	83.9	67.7	
Oct	87.8	93.4	93.4	93.4	83.1	87.8	87.8	89.5	
Station- S_4									
	2005	2006	2007	2008	2009	2010	2011	Avg.	
Jan	33.34	33.34	39.9	33.34	33.34	44.58	33.34	35.9	38.1
Apr	28.66	28.66	33.34	30.04	28.66	28.66	28.66	29.5	
July	33.34	39.9	44.58	44.58	44.58	44.58	39.9	41.6	
Oct	33.34	39.9	50.2	44.58	49.26	49.26	49.62	45.2	

Station- S_5									
	2005	2006	2007	2008	2009	2010	2011	Avg.	
Jan	77.36	87.66	83.52	77.72	82.98	82.04	82.98	82.0	80.6
Apr	71.74	71.74	77.36	71.74	72.68	82.04	77.36	75.0	
July	71.34	87.66	77.36	77.36	73.22	87.66	77.9	78.9	
Oct	82.98	93.82	88.38	87.66	82.4	82.04	87.66	86.4	

5.2.2 Observations on water quality of Sabarmati river

The data of water quality parameters for the stations are shown in chapter 4, Tables 4.5 to 4.9. District map of Sabarmati river basin with stations under study is shown in figure 5.1(a). Watershed map of Sabarmati river basin with stations under study is shown in figure 5.1 (b).The numbers in the figure are catchment numbers.

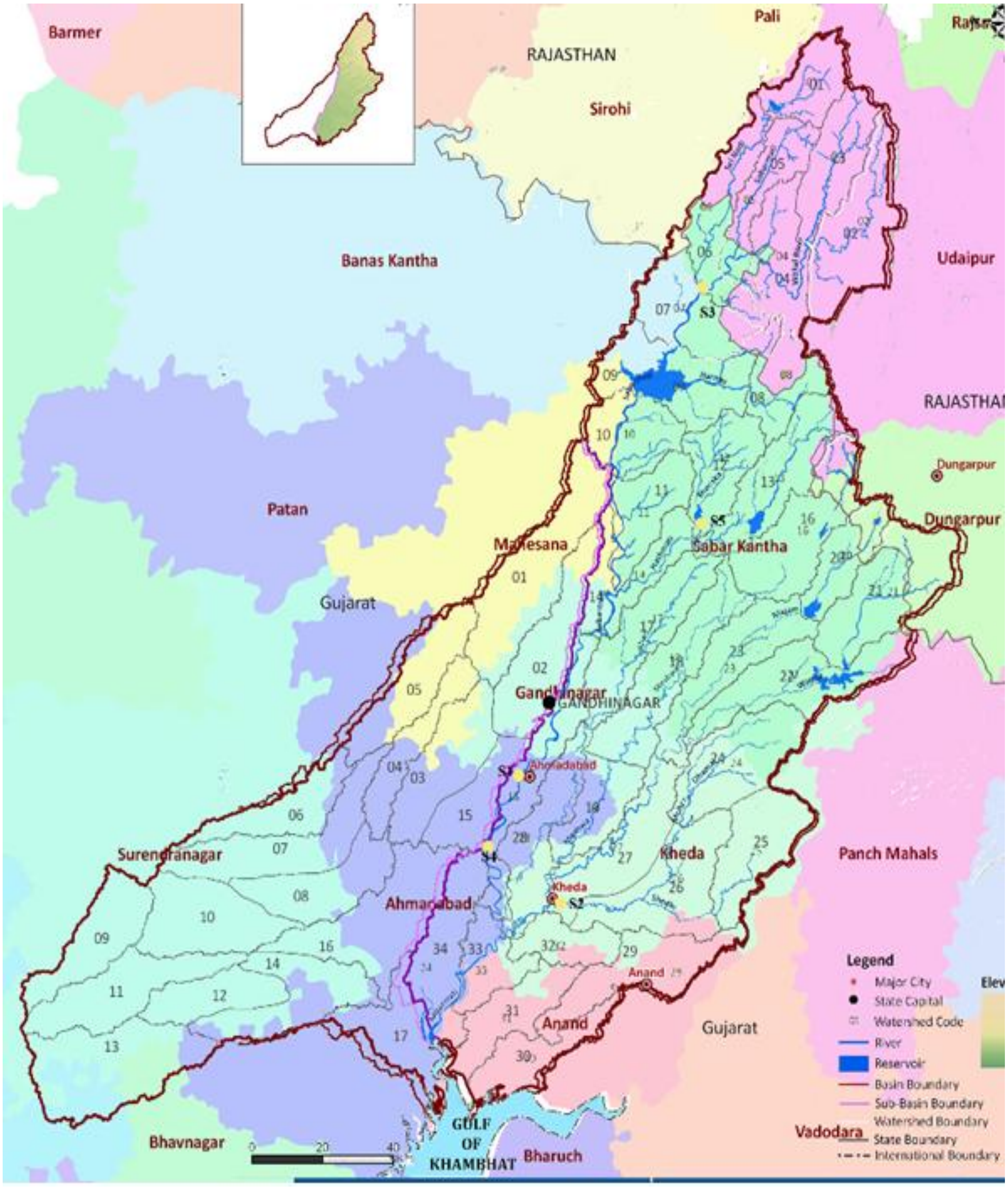

Figure 5.1 (a) District map of Sabarmati river basin with stations under study

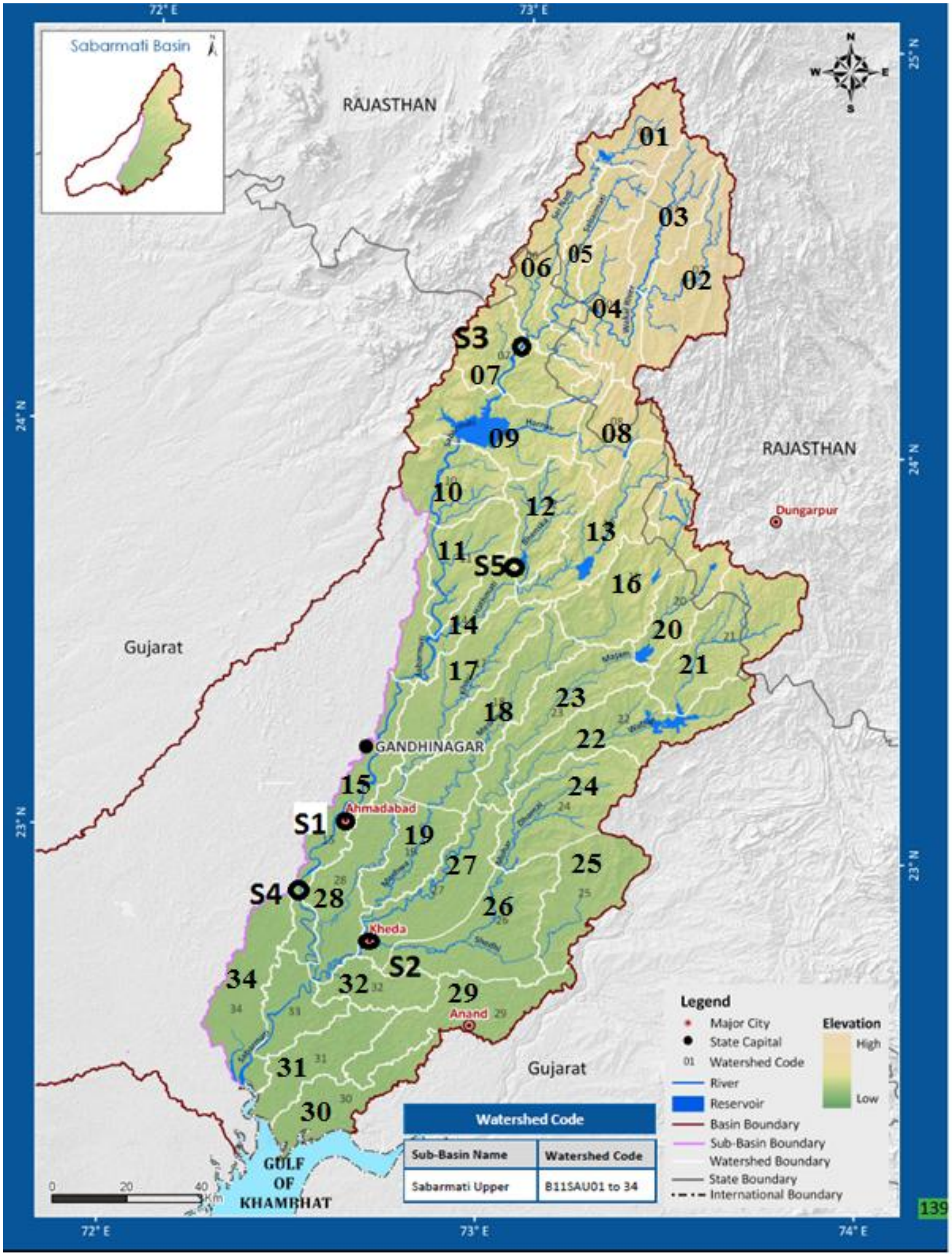

Figure 5.1 (b) Watershed map of Sabarmati river basin with stations under study

Dissolved Oxygen

In the present research, principle pollution indicator DO showed a large variation for station S_1. At S_1, the DO dropped to as low as 0 mg/l for all the years mostly in summer month and at S_4, DO is 0 mg/l for most of the months. This suggests addition of high organic load at this station due to the discharge of domestic sewage and industrial wastewater in the river. In summer, the temperature of the stream increases. With the increase in temperature, the solubility of oxygen in waters decreases. Also the temperature affects the metabolism, growth and reproduction of bacteria responsible for the biodegradation of the organic matter in water. The rate of biodegradation and biological activity increases with the increase in temperature. Hence the oxygen demand in the water increases. At S_1 and S_4 high organic pollution, low flow in the summer coupled with increased temperature caused a zero DO level. At stations S_2, S_3 and S_5, DO levels (mean value = 6.2, 6.6 and 6.7 respectively) for most of the months was found sufficient for aquatic life survival. This is because S_1 and S_4 are located in higher urbanization level in comparison to S_2, S_3 and S_5 which are located in moderately rural area.

pH

In the present study, the pH ranged from 6.9- 8.9. A narrow variation of pH is observed for all stations. This may be due to low variation of free CO2 during these periods (Jayaprakash 1988).

Electrical Conductivity

EC is a measure of TDS in water. In this study, EC values are comparatively low at station S_5 and S_3. EC levels are affected by the land cover pattern, i.e, semi-green area and forest area cause less soil erosion of the top soil. Since the catchment area of S_3 is entirely forest area, the EC values are low at this station. The catchment area of station S_5 is lying in the Sabarkantha district. About 87% of Sabarkantha district is covered with forest plantation, agriculture and cropland. Similarly the catchment area of station S_2 is covering 73 % of Kheda district and about 91 % of Kheda district is covered with forest, agriculture and cropland. Hence less soil erosion in the catchment area of S_5 and S_2 is the cause of low EC values observed at these stations. Higher EC values are observed at station S_1 whereas the highest EC values are reported at station S_4. The catchment area of S_1 covers urbanized districts Ahmedabad, Gandhinagar and Mehsana in addition to less urbanized districts such as

Sabarkantha, Banaskantha and the forest area on the upper reaches of the basin. Whereas, the station S_4 lies on d/s of S_1 covering a slightly more part of Ahmedabad district than S_1. Hence S_1 and S_4 cover a lower forest area than S_2, S_3 and S_5. Also S_1 and S_4 cover relatively dense road networks, high population density and intensive land use which is a cause of higher EC values than S_2, S_3 and S_5. The stations of downstream regions have higher TDS values compared to the upstream ones (Jayaprakash 1988). This is also observed for this basin.

Nitrate- Nitrogen

Nitrate- Nitrogen levels for all the five stations S_1, S_2, S_3, S_4 and S_5 are found to be low, at S_1, 0-4.6 mg/l, at S_2, 0.1-5.1 mg/l, at S_3, 0.1-2.6 mg/l, at S_4, 0.2-2.8 mg/l and at S_5 0.1-3.2 mg/l for all the years. There is no significant variation in the Nitrate- Nitrogen levels at these stations with the urbanization level. This suggests that the natural occurring sources may be the cause of low Nitrate- Nitrogen levels in these stations.

Most probable number

The most probable number (MPN) is the number of organisms that are most likely to have produced laboratory results in a particular test.Most probable number (MPN)/100 ml was found to be very high at S_1 and S_4 i.e, maximum value of 15,00,000 per 100 ml. At S_2, S_3 and S_5 maximum MPN values reported are 23000, 75000 and 150000 respectively. As observed, the MPN values are higher at S_1 and S_4 which are higher in urbanization level in comparison to S_2, S_3 and S_5 which are moderately rural. This is due to higher amount of faecal contaminants at S_1 and S_4 entering into the water due to increased human and animal activities along the banks of the river.

Biochemical Oxygen Demand

At station S_1, high BOD values were observed i.e (2-293) mg/l . At S_2, the BOD values range from (0.8 – 29) mg/l. At S_3, the BOD values range from (1.2 - 12) mg/l. At S_4, high BOD values are reported ranging from 4 mg/l – 120 mg/l. At S_5, the BOD values range from (1 - 10) mg/l. BOD is a key indicator of organic pollution in the waters. At S_1 and S_4, high organic pollution in this area is because of high population, increased growth of industries and higher level of urbanization observed in comparison with low urbanized locations , S_2, S_3 and S_5. At S_2, maximum BOD values were observed in the month of July for most of the years. For S_3, the highest BOD values were observed in the month of July for most of the years. During monsoon, the sewage treatment plants receive a high quantum of sewage which sometimes exceeds their treatment capacity. Hence, untreated or partially treated sewage is discharged into the river leading to increased BOD values observed at S_2 and S_3 mostly in the monsoon periods.

5.2.3 Seasonal variation of Water Quality Index for the stations on Sabarmati river

The seasonal variation of Water Quality Index for the stations S_1, S_2, S_3, S_4 and S_5 is shown in Figure 5.1.1 to 5.1.5. Figure 5.2 shows the Spatial Variation of Water Quality Index for stations at different seasons.

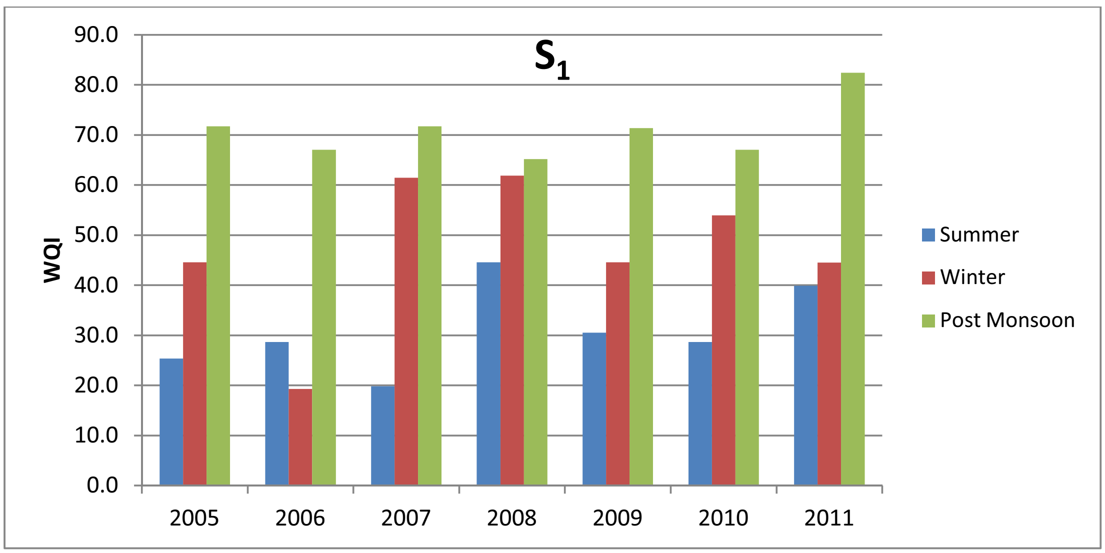

Figure 5.1.1 Seasonal Variation of Water Quality Index for station S_1

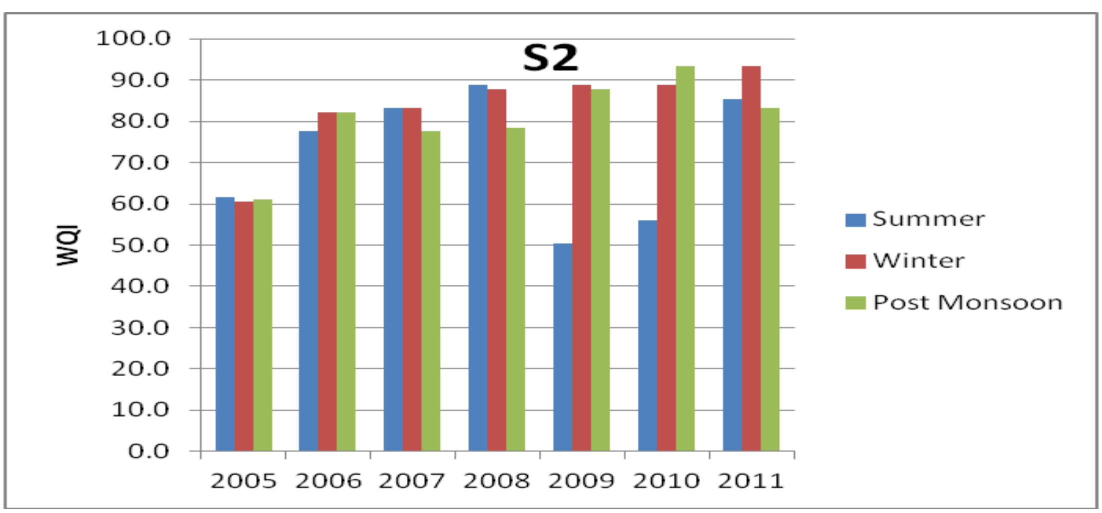

Figure 5.1.2 Seasonal Variation of Water Quality Index for station S_2

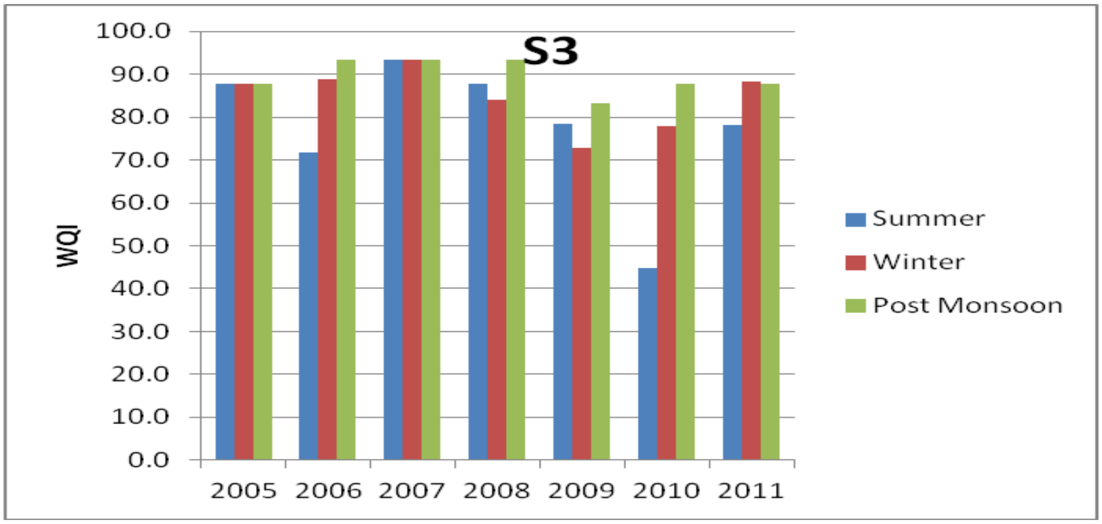

Figure 5.1.3 Seasonal Variation of Water Quality Index for station S_3

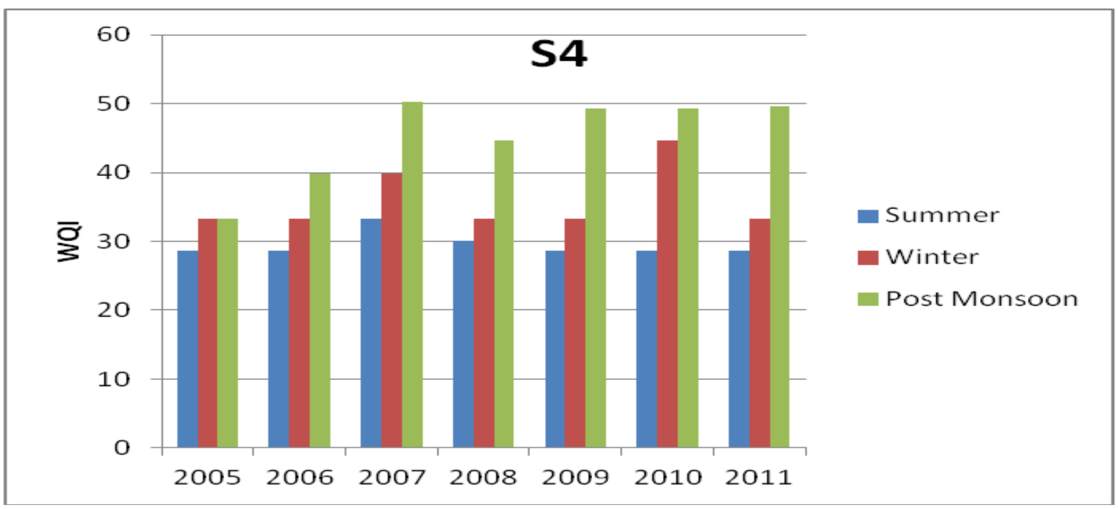

Figure 5.1.4 Seasonal Variation of Water Quality Index for station S_4

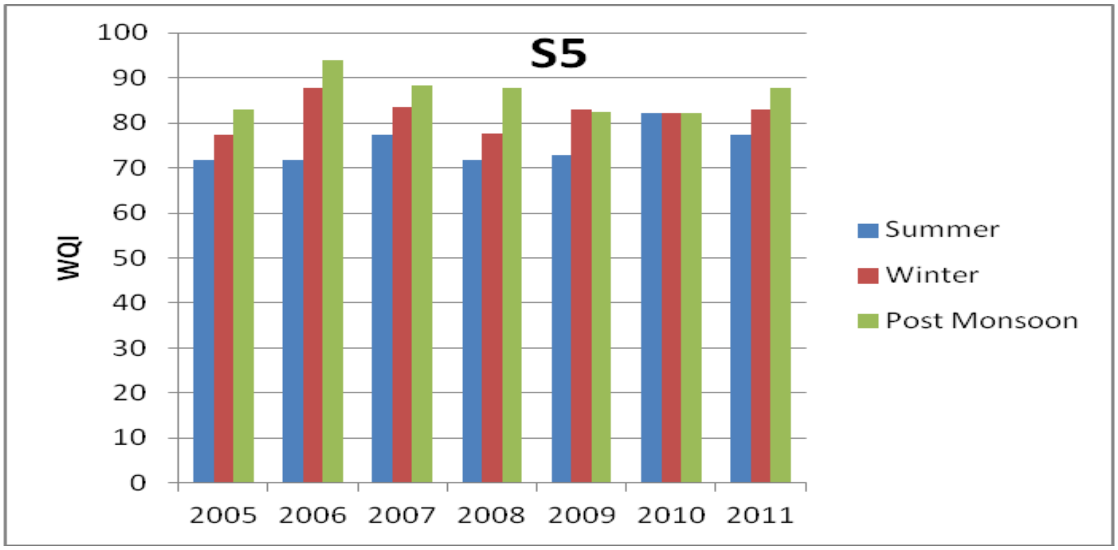

Figure 5.1.5 Seasonal Variation of Water Quality Index for station S_5

From Figure 5.1.1 to 5.1.5, it is observed that the Water Quality Index at S_4 is lowest, followed by S_1, S_2, S_5 and S_3 for all the seasons. The Water Quality Index in summer is lowest for the stations S_2, $S_{3,}$ S_4 and S_5 followed by winter and then post-monsoon for all the years. However for S_1, it is observed that for the year 2006, the value of WQI for winter is less than summer. This is due to the observation that in 2006, BOD, EC and total coliform values are higher than in winter for station S_1. This is indicative of higher organic and faecal pollution that may be caused in winter compared to summer. Hence the value of WQI is lower in winter than in summer for station S_1 in the year 2006.

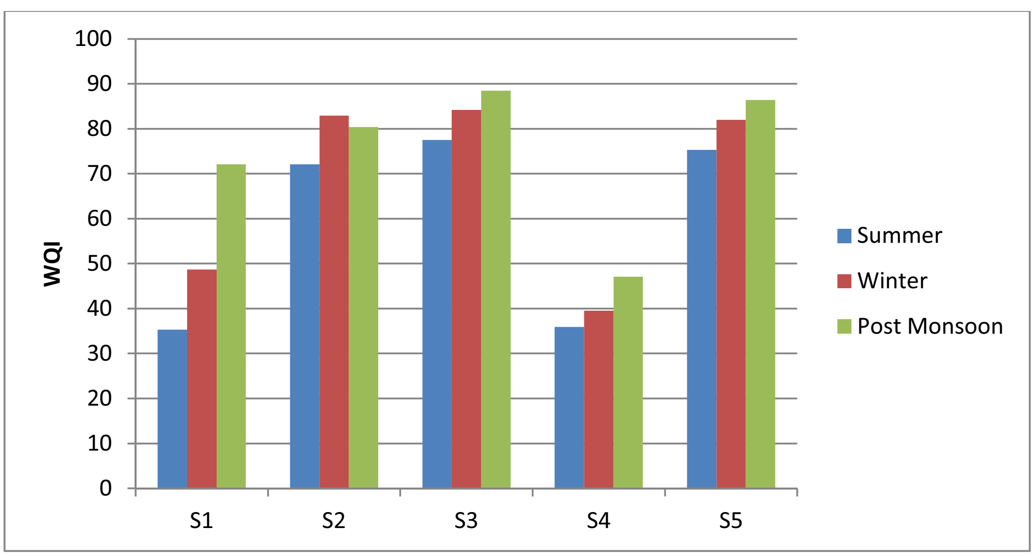

Figure 5.2 Spatial season-wise Variation of Water Quality Index for stations

From Figure 5.2, it can be observed that the S_1 and S_4 have the highest seasonal variation followed by S_2. The least seasonal variation is observed at S_3 and S_5. This seasonal variation is indicative of high urbanization at S_1 and S_4 compared to S_2, S_3 and S_5.

5.3 Urbanization Index model

The Urbanization Index model is developed using four multi-dimensional aspects, namely, Demographic aspect, economic development aspect, spatial Aspect and infrastructural development aspect. Under the four aspects identified, nine indicator parameters of urbanization are selected.

For each of the above urbanization parameters the scale is formed to assign the points from 1 to 10 as shown in Tables 3.4 to 3.12. Urbanization score for each of the district have to be obtained by aggregating the points obtained as above for each urbanization parameter. Urbanization Index is formed by normalizing the urbanization score of the district.

5.3.1 Results of Urbanization Index model

Sabarmati river basin map with districts and stations is shown in figure 5.2.1.

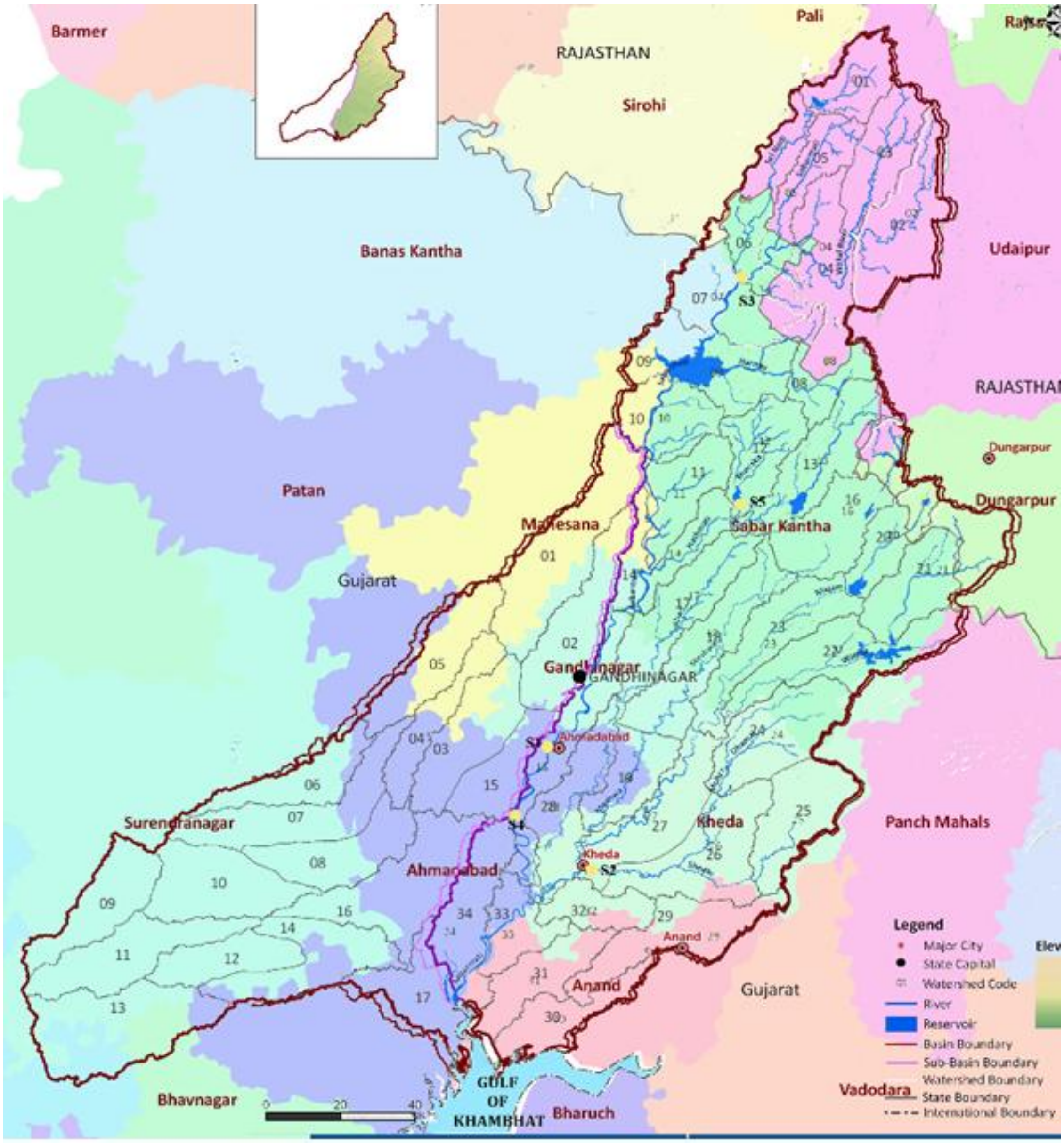

Figure 5.2.1 Sabarmati river basin map with districts and stations

The points for each of the urbanization parameter for the districts, Ahmedabad, Kheda, Sabarkantha, Mehsana, Gandhinagar and Banaskantha falling in the Sabarmati river basin are obtained using the urbanization scale developed in the present study. The points are aggregated and the normalized Urbanization Index for each district is obtained, shown in Table 5.2 using equation 3.4. The results of Urbanization Index for the districts are shown in Table 5.3.

Table 5.2 Urbanization Index computation for the districts under study

Urbanization Parameters	Points for districts					
	Ahmedabad	**Kheda**	**Sabarkantha**	**Mehsana**	**Gandhinagar**	**Banaskantha**
Population size	9	4	4	4	3	5
Population density	5	3	2	3	4	2
Industries	10	5	5	5	5	2
% of Built up area to total area	10	4	4	8	10	4
Roofing	7	3	3	4	5	2
Electricity Facility	5	4	4	4	4	3
Educational Facilities	10	4	4	4	4	4
Health services	10	6	4	6	6	4
Assets	10	3	3	4	10	2
Total Points	**76**	**36**	**33**	**42**	**51**	**28**
Urbanization Index	**84.44**	**40**	**36.67**	**46.67**	**56.67**	**31.11**

Table 5.3 Results of Urbanization Index for the districts under study

Districts	**Urbanization Index of districts**
Ahmedabad	84.44
Kheda	40
Sabarkantha	36.67
Mehsana	46.67
Gandhinagar	56.67
Banaskantha	31.11

5.3.2. Urbanization Index of the catchment of the stations

There are five stations under study in the Sabarmati river basin, namely, S_1, S_2, S_3, S_4 and S_5. To determine the Urbanization Index of the catchment of the each station, the watershed map of the Sabarmati river basin is referred.The watershed map of the Sabarmati river basin is shown in Figure 5.3. Districts and watershed map of Sabarmati river basin with stations under study is shown in Figure 5.4.

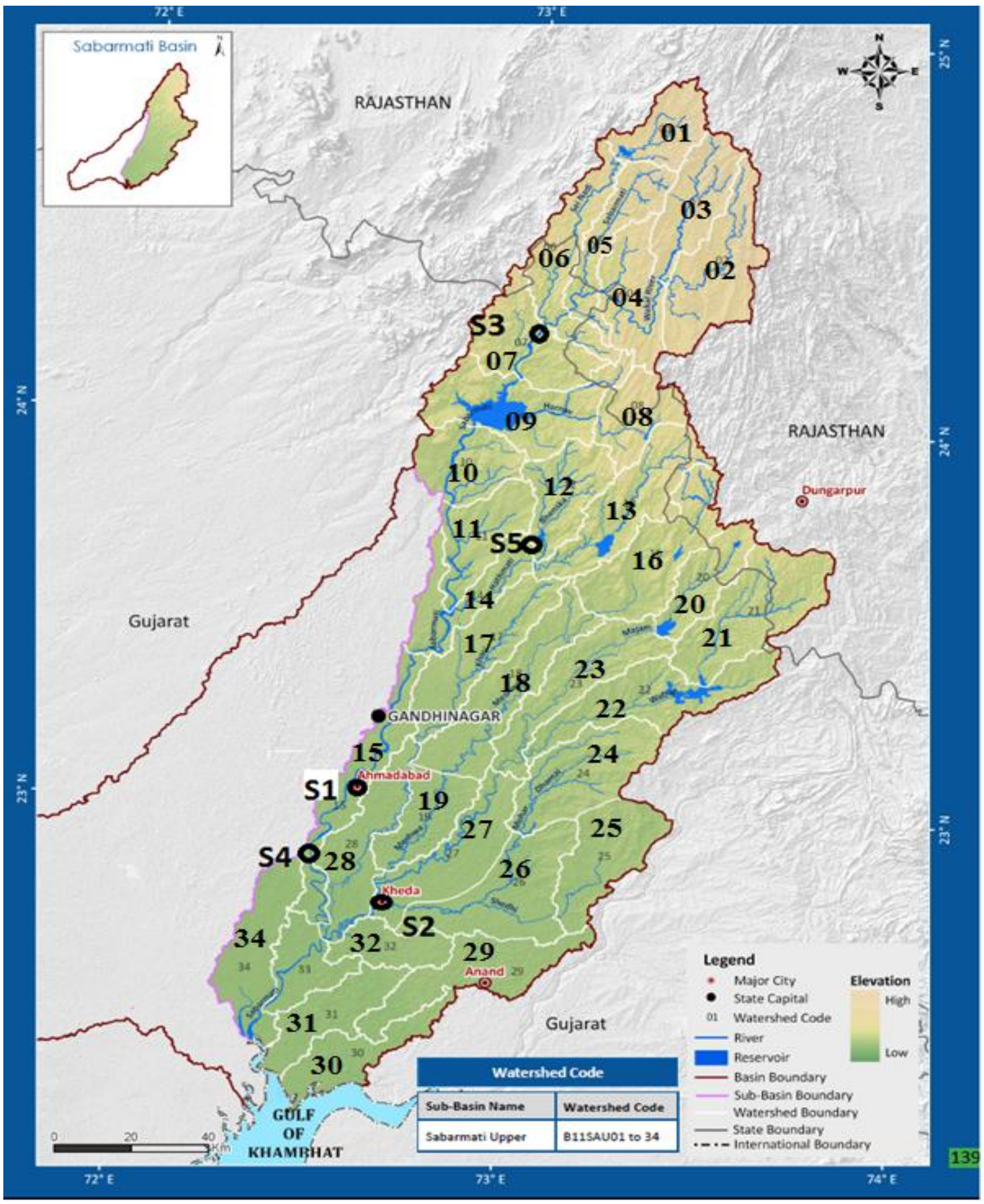

Figure 5.3 Watershed map of Sabarmati river basin with stations under study

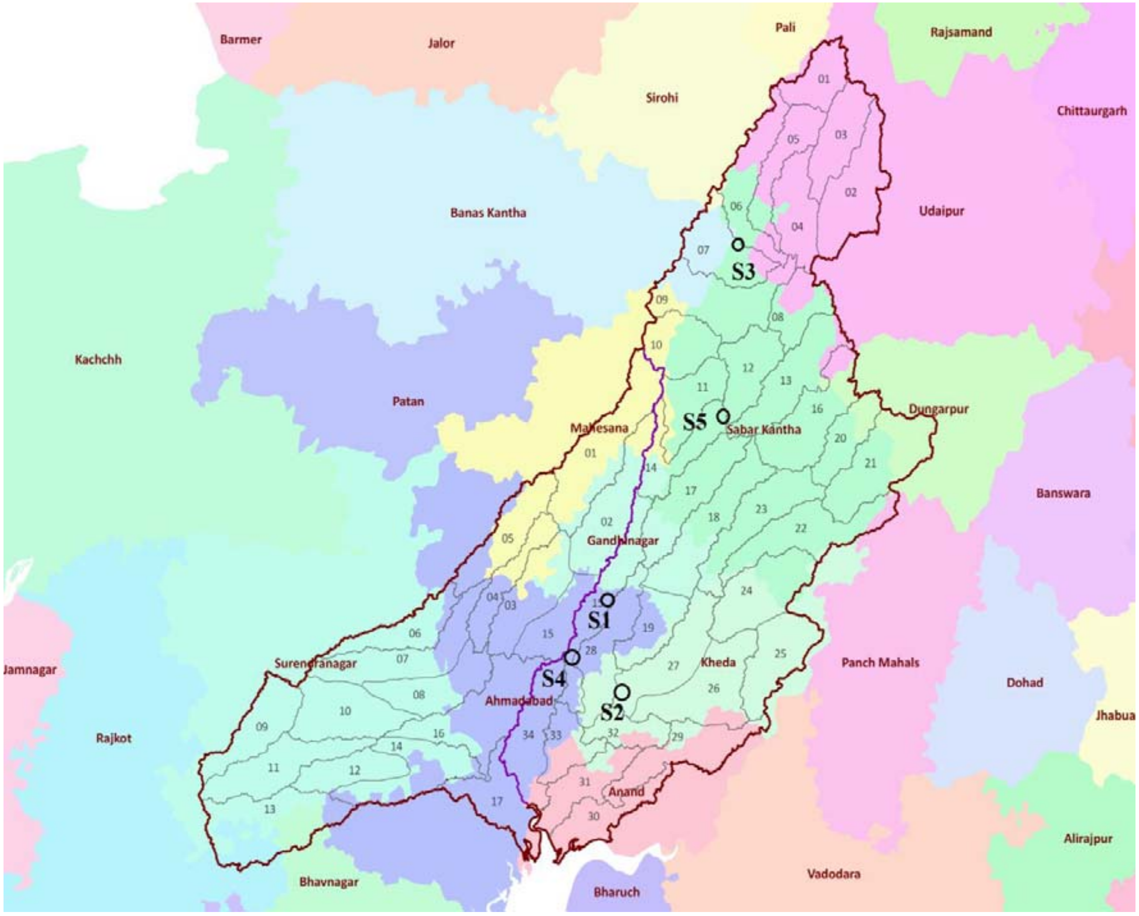

Figure 5.4 Districts and Watershed map of Sabarmati river basin with stations under study

For computation of the Urbanization Index of the catchment of each station under study, a methodology has been developed in this study which is discussed in chapter 3.From the watershed map of the Sabarmati river basin, the area of the watershed falling in the catchment of the station is evaluated and is shown in Table 5.4.

5.3.2.1. Urbanization Index for catchment area of Station S_3

The enlarged Figure showing the watersheds and districts contributing to the station S_3 is shown in Figure 5.5.

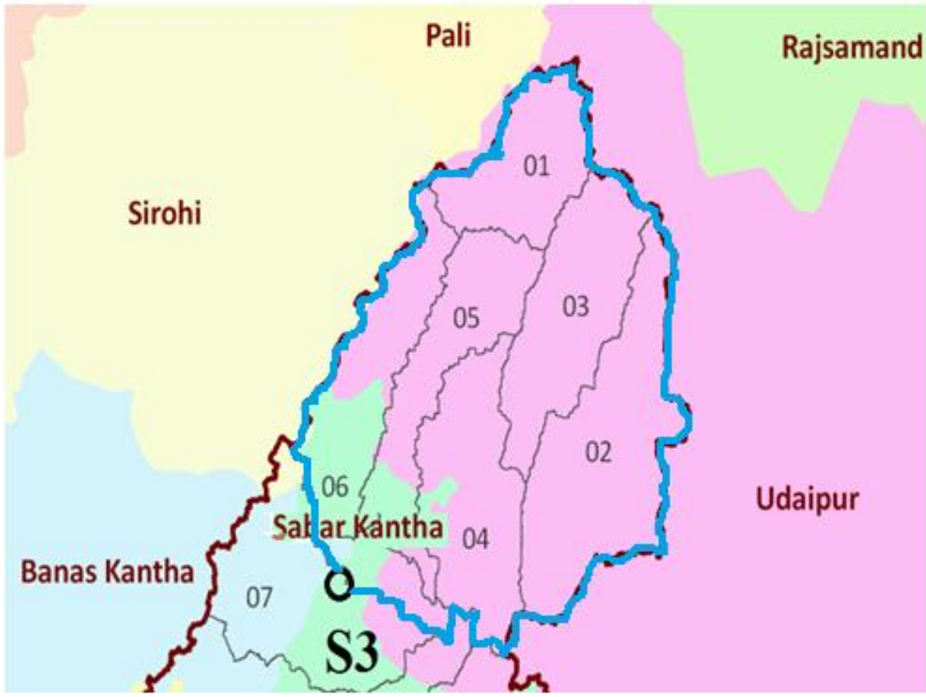

Figure 5.5 Watersheds contributing to the station S_3

From Figure 5.3 and Figure 5.5, for station S_3, it is observed that the catchment area of this station consists of watershed no. 1, 2, 3, 4, 5 and 6. All these watersheds fall under forest area of Udaipur district of the state of Rajasthan. Hence from the urbanization scale developed in the present study, the Urbanization Index for this forest area computed as follows. The urbanization points attained for each of the parameters, namely, population size, population density, number of industries, percentage of built- up area, roofing types , electricity facilities and assets is 1 point each. Zero point is allocated for the health facilities and educational facilities. Hence for the highly rural area of station $S_{3,}$ total points attained are 7 out of maximum 90 points. Normalized Urbanization Index is 7.7.

Hence for $S_{3,}$ Urbanization Index is 7.7.

5.3.2.2. Urbanization Index for the catchment area of station S_5 and S_2

The enlarged Figure showing the watersheds contributing to the station S_5 and S_2 is shown in Figure 5.6 and Figure 5.7 respectively.

Figure 5.6 Watersheds contributing to the station S_5

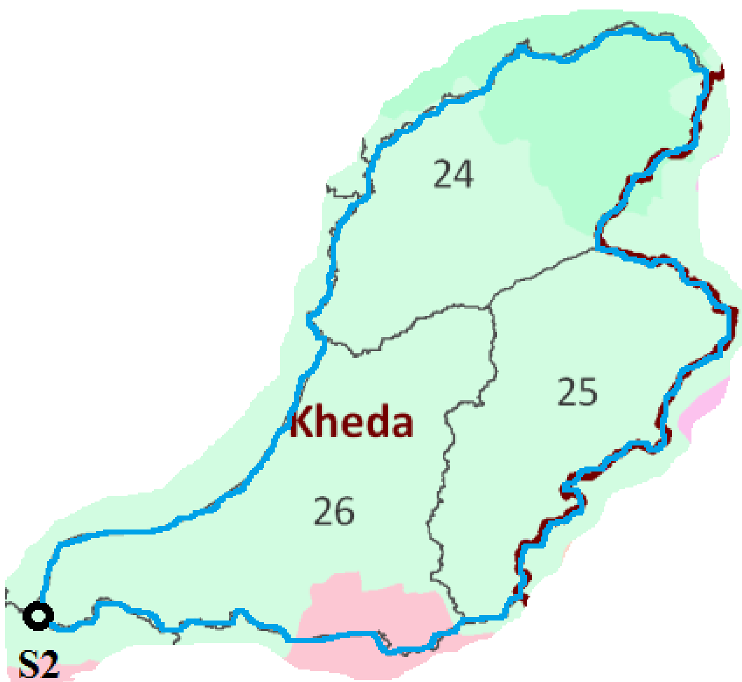

Figure 5.7 Watersheds contributing to the station S_2

The station S_5 is lying on the tributary of Sabarmati river i.e. river Hathmati. From Figure 5.3 and 5.6, for station S_5, it is observed that the catchment area of this station consists of watershed no. 12 and 13.The watershed 12 and 13 (i.e. catchment of station S_5) is falling under only one district. So case A2 B1 for computation of Urbanization Index of station S_5 is applicable and as per the equation 3.5, the Urbanization Index of station, $UI_k = UI_j \times \frac{a_{i,j,k}}{A_j}$

where, UI_k = Urbanization Index of the catchment of station k , i = watershed number, j = district , k = station, $a_{i,j,k}$ = area (Km^2) of the watershed i of district j in the catchment of station k, A_j = Total area (Km^2) of district j .

From Figure 5.3 and 5.7, for station S_2, it is observed that the catchment area of this station consists of watershed no. 24, 25 and 26.The watersheds (i.e. catchment of station S_2) are falling under only one district. So case A2 B1 for computation of Urbanization Index of station S_2 is applicable and as per the equation 3.5, the Urbanization Index of station, $UI_k = UI_j \text{ x } \frac{a_{i,j,k}}{A_j}$

The results of Urbanization Index of the catchment of station S_5 and S_2 is shown in Table 5.7.

5.3.2.3. Urbanization Index for the catchment area of Stations S_1 and S_4

The enlarged Figures showing the watersheds contributing to the station S_1 and S_4 is shown in Figure 5.8 and Figure 5.9 respectively.

From Figure 5.3 and 5.8, for station S_1, it is observed that the catchment area of this station consists of watershed no. 1 to 15.These watersheds (i.e. catchment of station S_1) are falling in various districts (Table 5.4). So case A2 B2 for computation of Urbanization Index of station S_1 is applicable and as per the equation 3.7, the Urbanization Index of station,

$$UI_k = \sum_{j=1}^{N} \left(\frac{UI_j \text{ x } a_{i,j,k} \text{ x } a_{i,j,k}}{A_j \quad A_k} \right) \text{X N}$$

Where, UI_k = Urbanization Index of the catchment of station k , i = watershed number, j = district , k = station, $a_{i,j,k}$ = area (Km^2) of the watershed i of district j in the catchment of station k, N= Total no. of district portions in the catchment of the station, A_j = Total area (Km^2) of district j, A_k = Area of the catchment of station k.

The results of Urbanization Index of the catchment of station S_1 is shown in Table 5.5.

For station S_4, from Figure 5.3 and 5.9, it is observed that the catchment area of this station consists of watershed no. 1 to 15.These watersheds (i.e. catchment of station S_4) are falling in various districts (Table 5.4). So case A2 B2 for computation of Urbanization

Index of station S_4 is applicable and as per the equation 3.7, the Urbanization Index of station,

$$UI_k = \sum_{j=1}^{N} \left(\frac{UI_j \times a_{i,j,k}}{A_j} \frac{\times a_{i,j,k}}{A_k} \right) X\, N$$

The results of Urbanization Index of the catchment of station S_4 is shown in Table 5.6.

Figure 5.8 Watersheds contributing to the station S_1

Figure 5.9 Watersheds contributing to the station S_4

Table 5.4 Area measurements for catchment of the stations

Station	Watershed No. contributing to the station	District in which watershed falls	Watershed area of the district falling in the catchment (Km^2) $a_{i,j,k}$	Area of the district (Km^2) A_j	Ratio of Watershed area to the total area of the district $a_{i,j,k} / A_j$
S_1	1,2,3,4,5, 6	Forest area	---	---	---
	8,12,13	Sabarkantha	1234	7394	0.167
	9	Mehsana	132	4401	0.03
		Sabarkantha	481	7394	0.065
		Banaskantha	64	10743	0.006
	10	Mehsana	203	4401	0.046
		Sabarkantha	266	7394	0.036
	11	Sabarkantha	414	7394	0.056
	7	Banaskantha	251	10743	0.023
		Sabarkantha	226	7394	0.031
	14	Gandhinagar	142	2140	0.066
		Mehsana	60	4401	0.014
		Sabarkantha	72	7394	0.010
	15	Gandhinagar	218	2140	0.102
S_2	24,25,26	Kheda	2886	3953	0.73
S_3	1,2,3,4,5, 6	Forest area	----	----	---
S_4	8,12,13	Sabarkantha	1234	7394	0.167
	9	Mehsana	132	4401	0.03
		Sabarkantha	481	7394	0.065
		Banaskantha	64	10743	0.006
	10	Mehsana	203	4401	0.046
		Sabarkantha	266	7394	0.036
	11	Sabarkantha	414	7394	0.056
	7	Banaskantha	251	10743	0.023
		Sabarkantha	226	7394	0.031
	14	Gandhinagar	142	2140	0.066
		Mehsana	60	4401	0.014
		Sabarkantha	72	7394	0.010
	15	Gandhinagar	218	2140	0.102
		Ahmedabad	113	8107	0.014
S_5	12,13	Sabarkantha	888	7394	0.120

Table. 5.5 Urbanization Index for station S_1

Water-shed No.	District	Watershed area of the district falling in the catchment (Km^2)	Total area of the district (Km^2)	Ratio of Watershed area to the total area of the district	UI of the district	UI of the portions of districts	$\frac{a_{i,j,k} \times UI_j \times a_{i,j,k}}{A_j \times A_k}$
(1)	(2)	(3) $a_{i,j,k}$	(4) A_j	(5) = (3)/(4)	(6) UI_j	(7)= (5)x(6)	(8)=$\frac{(7)x(3)}{\sum(3)}$
1,2,3,4,5,6	Forest area	2292	---	---	---	7.7	2.915
8,12,13	Sabarkantha	1234	7394	0.167	36.670	6.120	1.247
9	Mehsana	132	4401	0.030	46.670	1.400	0.031
	Sabarkantha	481	7394	0.065	36.670	2.385	0.189
	Banaskantha	64	10743	0.006	31.110	0.185	0.002
10	Mehsana	203	4401	0.046	46.670	2.153	0.072
	Sabarkantha	266	7394	0.036	36.670	1.319	0.058
11	Sabarkantha	414	7394	0.056	36.670	2.053	0.140
7	Banaskantha	251	10743	0.023	31.110	0.727	0.030
	Sabarkantha	226	7394	0.031	36.670	1.121	0.042
14	Gandhinagar	142	2140	0.066	56.670	3.760	0.088
	Mehsana	60	4401	0.014	46.670	0.636	0.006
	Sabarkantha	72	7394	0.010	36.670	0.357	0.004
15	Gandhinagar	218	2140	0.102	56.670	5.773	0.208
Total (A_k)		**6055**					5.033
Urbanization Index of the catchment of the station $UI_k = \sum_{j=1}^{N}\left(\frac{UI_j \times a_{i,j,k} \times a_{i,j,k}}{A_j \quad A_k}\right) X\ N$ Where N = total number of district portions = 14							**70.461**

Table. 5.6 Urbanization Index for station S_4

Water-shed No.	District	Watershed area of the district falling in the catchment (Km^2)	Total area of the district (Km^2)	Ratio of Watershed area to the total area of the district	UI of the district	UI of the portions of districts	$\frac{a_{i,j,k} \times UI_j \times a_{i,j,k}}{A_j \times A_k}$
(1)	(2)	(3) $a_{i,j,k}$	(4) A_j	(5) = (3)/(4)	(6) UI_j	(7)= (5)x(6)	(8)=$\frac{(7)x(3)}{\sum(3)}$
1,2,3,4,5,6	Forest area	2292	---	---	---	7.7	2.861
8,12,13	Sabarkantha	1234	7394	0.167	36.670	6.120	1.224
9	Mehsana	132	4401	0.030	46.670	1.400	0.030
	Sabarkantha	481	7394	0.065	36.670	2.385	0.186
	Banaskantha	64	10743	0.006	31.110	0.185	0.002
10	Mehsana	203	4401	0.046	46.670	2.153	0.071
	Sabarkantha	266	7394	0.036	36.670	1.319	0.057
11	Sabarkantha	414	7394	0.056	36.670	2.053	0.138
7	Banaskantha	251	10743	0.023	31.110	0.727	0.030
	Sabarkantha	226	7394	0.031	36.670	1.121	0.041
14	Gandhinagar	142	2140	0.066	56.670	3.760	0.087
	Mehsana	60	4401	0.014	46.670	0.636	0.006
	Sabarkantha	72	7394	0.010	36.670	0.357	0.004
15	Gandhinagar	218	2140	0.102	56.670	5.773	0.204
	Ahmedabad	113	8107	0.014	84.44	1.177	0.022
Total (A_k)		**6168**					4.962
Urbanization Index of the catchment of the station $UI_k = \sum_{j=1}^{N} \left(\frac{UI_j \times a_{i,j,k}}{A_j} \frac{\times a_{i,j,k}}{A_k} \right) \times N$ Where N = total number of district portions = 15							**74.43**

5.4 Results of Urbanization Index in Sabarmati river basin

Results of Urbanization Index of the catchment area of the stations is shown in Table 5.7.

Table 5.7 Results of Urbanization Index of the catchment area of the station

Station	Urbanization Index of the catchment area of the station
S_1	70.46
S_2	29.2
S_3	7.7
S_4	74.43
S_5	4.4

5.5 Results of Water Quality Index and Urbanization Index in Sabarmati river basin

Table 5.8 shows the results obtained for Water Quality Index computed using Water Quality Index model and the Urbanization Index obtained using the Urbanization Index model developed in the present study.

Table 5.8 Results of Water Quality Index and Urbanization Index of the catchment area of the station

Station	Water Quality Index	Urbanization Index of the catchment area of the station
S_1	49.1	70.46
S_2	76.4	29.2
S_3	79.8	7.7
S_4	38.1	74.43
S_5	80.6	4.4

5.6 Correlation between water quality and urbanization

For this study, the water quality parameters have been selected considering the water quality aspect, whereas the urbanization parameters are selected using the urbanization aspect. While selection of the urbanization parameters, it is not viewed to select only those parameters which are directly affecting the water quality. Even though, the correlation has been established between the water quality parameters and Urbanization Index at the stations.

Pearson's Correlation Coefficient (r) was computed between water quality parameters and Urbanization Index of the stations in this study. Table 5.9 shows Water Quality parameters and Urbanization Index correlation data. Table 5.10 shows Correlation matrix for water quality parameters and Urbanization index developed in the present study.

Table 5.9 Water quality parameters and Urbanization Index correlation data

Station	Year	pH	DO (mg/l)	BOD (mg/l)	EC (µhos/cm)	Nitrate Nitrogen (mg/l)	Total Coliform (MPN/100ml)	UI
S_1	2005	7.3	2.7	65.6	1619.3	0.3	505375.0	70.5
	2006	7.4	2.1	118.3	1226.5	0.1	58232.5	
	2007	7.4	3.9	46.8	1062.3	0.8	38365.0	
	2008	7.8	2.1	13.0	834.8	0.9	12068.3	
	2009	7.7	2.7	48.6	5720.3	1.4	1950.0	
	2010	7.4	2.2	50.8	1348.0	2.0	24050.0	
	2011	7.6	2.3	43.8	977.8	1.6	1190.0	
S_2	2005	7.6	6.0	5.0	474.3	0.4	18000.0	29.2
	2006	8.2	6.0	5.6	1004.0	0.8	857.5	
	2007	8.5	6.1	4.1	768.0	0.8	255.0	
	2008	7.9	6.3	8.0	1065.3	1.4	23.5	
	2009	8.2	5.5	3.3	792.5	2.1	81.5	
	2010	7.5	6.0	9.4	893.0	0.7	49.8	
	2011	8.1	7.6	10.2	967.0	1.3	76.3	
S_3	2005	7.9	6.3	1.7	485.8	0.5	2317.0	7.7
	2006	8.4	7.9	7.3	469.3	0.6	98.8	
	2007	8.1	6.7	5.0	575.3	0.5	18773.0	
	2008	7.6	8.1	5.8	622.5	1.0	134.0	
	2009	8.3	5.8	9.0	397.5	2.2	407.5	
	2010	8.2	5.0	3.8	374.5	0.5	4005.0	
	2011	8.2	6.6	2.5	224.8	0.4	285.0	
S_4	2005	7.2	0.3	36.0	1620.0	0.2	830250.0	74.4

	2006	7.3	0.2	54.8	1937.5	0.2	713093.8	
	2007	7.3	0.7	60.3	1796.0	0.7	15037.5	
	2008	7.4	0.3	58.0	2017.1	0.5	366785.1	
	2009	7.7	0.0	29.0	2205.0	0.5	21700.0	
	2010	7.8	0.1	39.7	1433.8	0.4	8400.0	
	2011	7.8	0.2	59.3	867.5	1.0	30125.0	
S_5	2005	8.2	6.7	3.3	347.8	0.4	39877.5	4.4
	2006	8.2	6.6	2.3	468.3	0.5	695.0	
	2007	8.0	6.2	3.8	350.3	0.3	355.0	
	2008	8.1	6.8	4.4	278.0	0.6	520.0	
	2009	8.1	6.4	5.9	287.0	0.5	350.0	
	2010	8.0	7.1	1.5	461.5	1.9	2180.0	
	2011	8.2	6.9	3.5	763.3	0.4	252.5	

Table 5.10 Correlation matrix for water quality parameters and Urbanization Index

	Pearson's correlation coefficient (r)					
	pH	**DO**	**BOD**	**EC**	**Nitrate Nitrogen**	**Total Coliform**
Urbanization Index	-0.76	-0.92	0.81	0.62	-0.02	0.44

From Table 5.10, it is observed that there exists a very high degree of negative correlation between DO and Urbanization Index (r = -0.92). Waste discharges high in organic matter and nutrients in urbanized areas may be the reason of decrease in DO levels with the increase in urbanization levels. The depletion of DO concentrations results due to increased microbial activity (respiration) occurring during the degradation of the organic matter.

Also high degree of positive correlation exists between BOD and Urbanization Index (r = 0.81). This shows that as urbanization increases, the BOD, which is a measure of biodegradable organic matter, decreases.

There is a good negative correlation between between pH and UI (r = -0.76). Lower values of pH can occur in dilute waters high in organic content (Chapman, 1996). This indicates that in urbanized areas as the river has high input of organic matter, the pH decreases. i.e. with the increase in urbanization, the pH decreases.

There is a good positive correlation between EC and UI (r = 0.62). EC values exceed especially in polluted waters, or those receiving large quantities of land run-off (Chapman, 1996). Highly urbanized areas have larger built up areas than low/moderately urbanized areas and therefore larger land run-off. So, the correlation obtained between EC and UI justifies with the fact that as urbanization increases, the EC values increases.Poor correlation exists between Nitrate Nitrogen and UI (r = -0.02) and between Total Coliform and UI (r = 0.44).

5.7 Water Quality- Urbanization Regression model (WQURM)

In the present study, to develop the Water Quality- Urbanization Regression Model, various regression types are considered for fitting from the results of Water Quality Index and Urbanization Index (Table 5.8). The residual plots for various regression types , namely, exponential, logarithmic, power and linear are shown in figure 5.10 to figure 5.13. The trend of various regression types are shown in figure 14 to figure 16. The best fit curve/line is determined from all the above regression types by computing the sum of square of error. The regression showing the least sum of square of errors is selected as the best fit curve and the corresponding equation defines the Water Quality - Urbanization Regression Model (WQURM). Table 5.11 shows sum of square of error obtained for the different regression types.

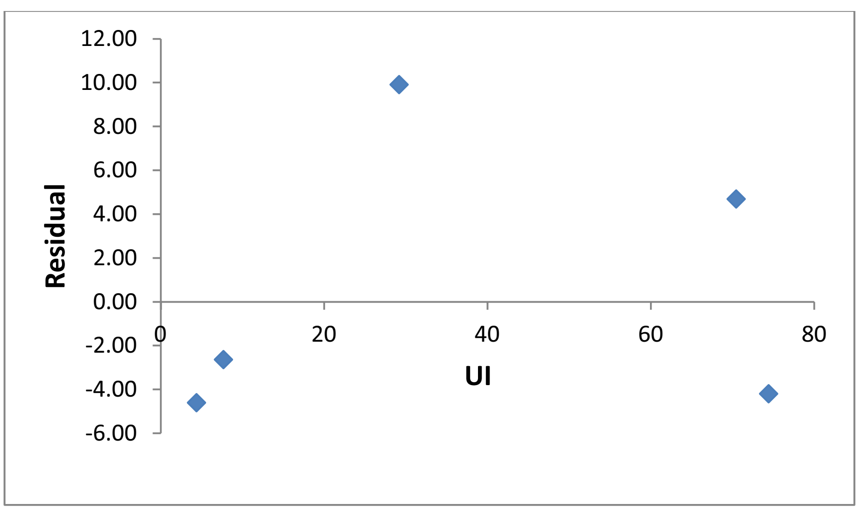

Figure 5.10 Residual plot for exponential regression

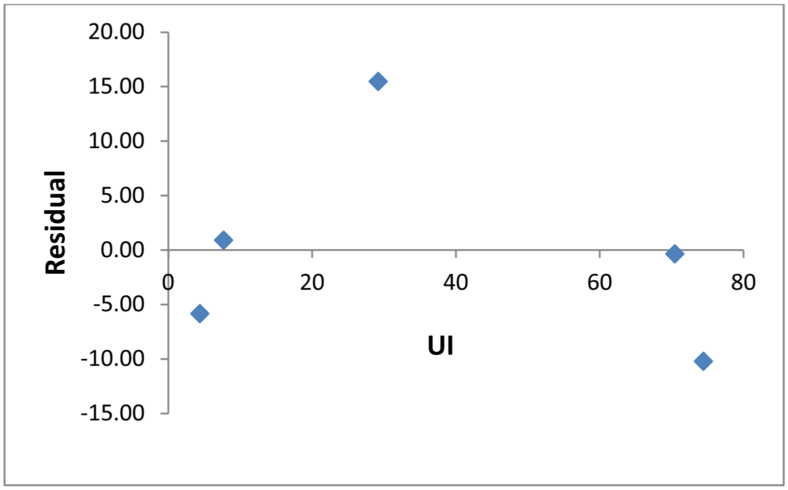

Figure 5.11 Residual plot for logarithmic regression

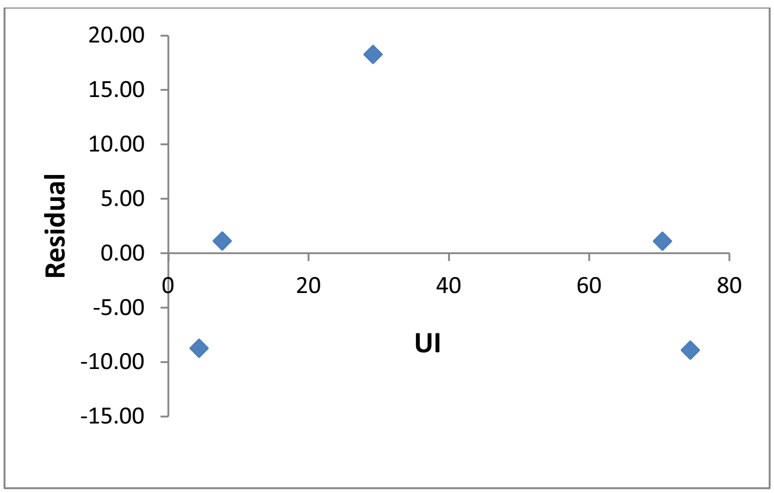

Figure 5.12 Residual plot for power regression

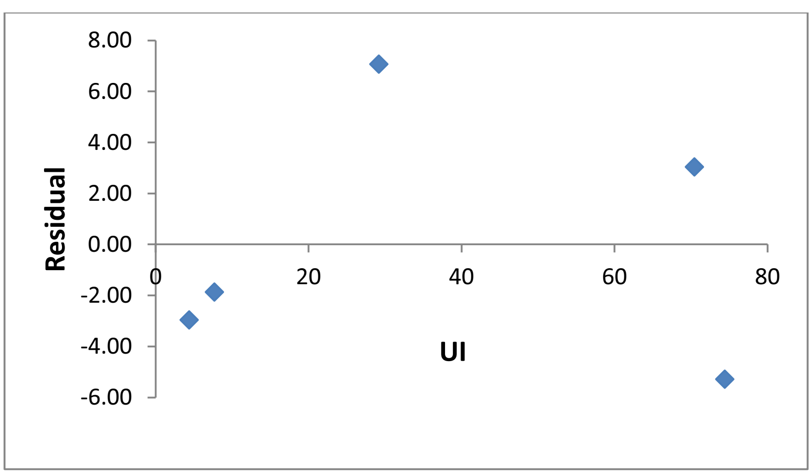

Figure 5.13 Residual plot for linear regression

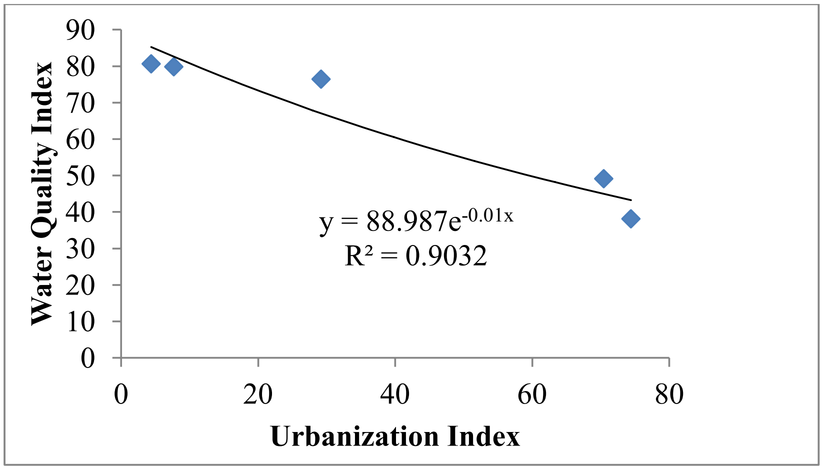

Figure 5.14 Exponential Regression plot

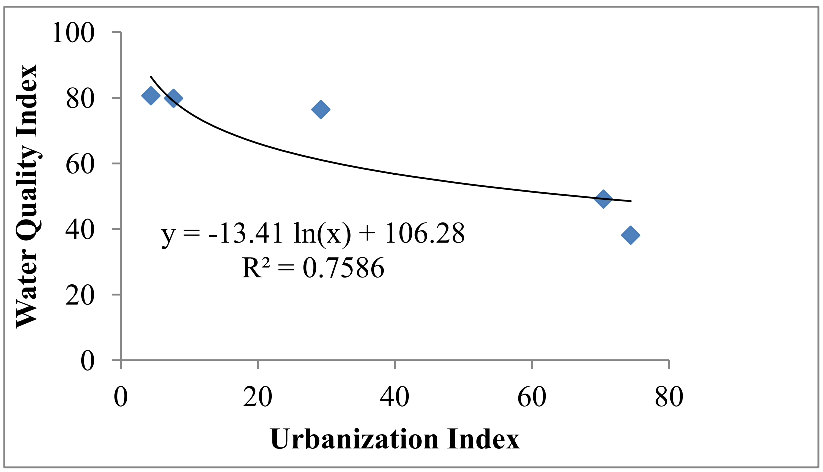

Figure 5.15 Logarithmic Regression plot

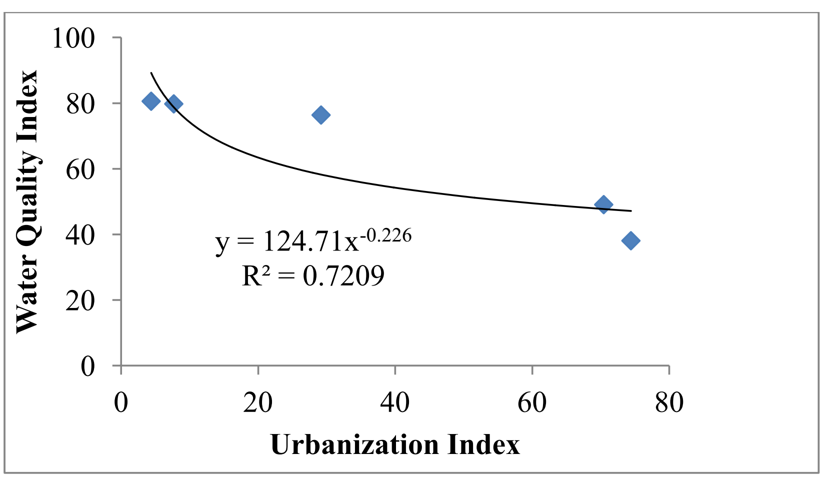

Figure 5.16 Power Regression plot

Table 5.11 Sum of Square of Error for different types of Regression

Sr. No.	Type of Regression	Regression Equation	R^2	Sum of Square of Error
1.	Exponential	$y = 89.042\ e^{-0.01x}$	0.91	166
2.	Logarithmic	$y = -13.48\ \ln(x) + 106.42$	0.76	378.8
3.	Power	$y = 125.06\ x^{-0.227}$	0.72	491.8
4.	Linear	$y = -0.5708x + 86.054$	0.94	99.4

From Table 5.11, it is observed that the Linear regression shows the least sum of square of error and $R^2 = 0.94$. The graph of Water Quality Index and Urbanization Index is plotted for the Water Quality - Urbanization Regression Model (WQURM) using the results of Water Quality Index and Urbanization Index of stations (Table 5.8) and is shown in Figure 5.17. The Figure 5.17 shows the Water - Quality Urbanization Regression Model (WQURM) developed in the present study for a linear regression.

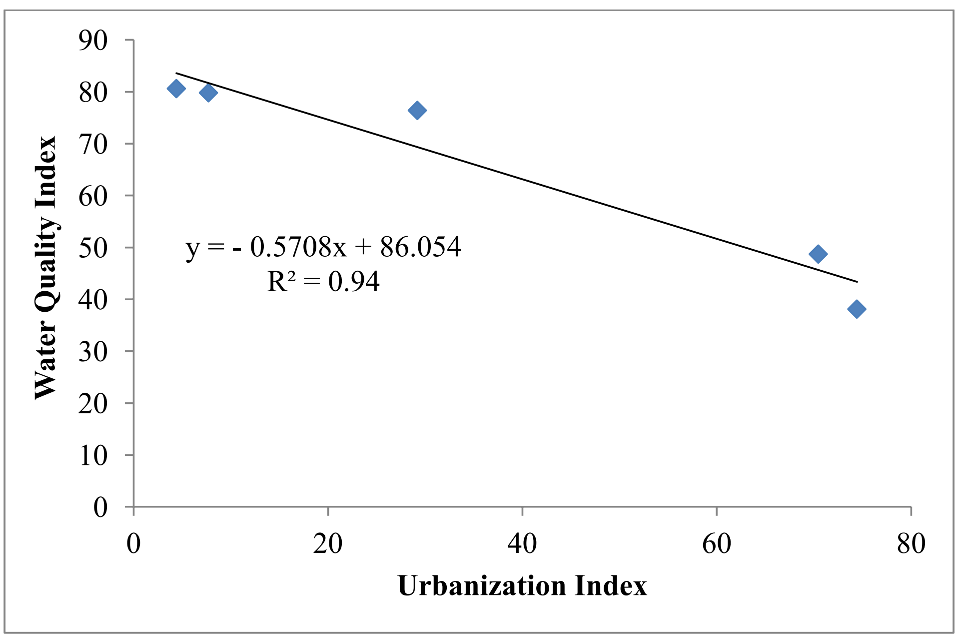

Figure 5.17 Water Quality - Urbanization Regression Model (WQURM) plot for Sabarmati river

From Figure 5.17, a Water Quality - Urbanization Regression Model (WQURM) for the assessment of the impact of urbanization on surface water quality and for the prediction of water quality from urbanization has been developed for the Sabarmati river basin.

The WQURM linear mathematical model is y = -0.5708 x + 86.054, where,

y = Water Quality Index of the station, x = Urbanization Index of the catchment area of the station.

R^2= 0.94 shows a high degree of correlation between the Water Quality Index and Urbanization Index. The trend of the linear Regression line shows a negative correlation between the two parameters. The trend of the regression line shows that as the urbanization increases, the water quality deteriorates with a linear pattern. For a value of Urbanization Index, x = 0, the maximum Water Quality Index, y = 86.054. This is because absolutely pure water does not exist in nature. The river water contains dissolved minerals and gases as a result of its interaction with the atmosphere, organic matter, minerals in rocks, and micro-organisms in the course of its flow on the land.

The data base of urbanization parameters obtained from the Census of India was available for a decade, while the data base of the water quality was available on a quarterly period. Hence, parameter to parameter correlation of water quality and urbanization was not possible to be evaluated. So, multiple regression could not be established for the model.

5.8 Observed versus predicted plot for WQURM

Observed versus predicted plot for the Water Quality - Urbanization Regression Model applied on Sabarmati river is shown in figure 5.18.

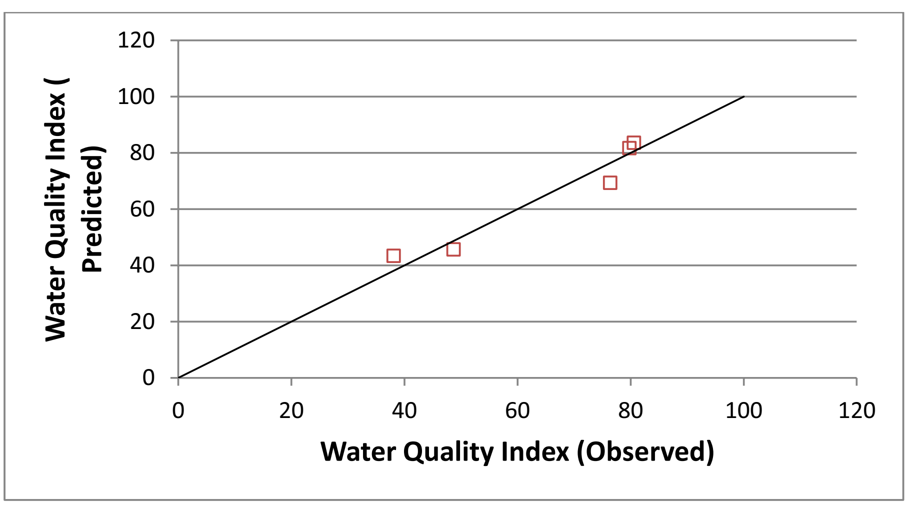

Figure 5.18 Observed versus predicted plot for the Water Quality - Urbanization Regression Model applied on Sabarmati river

In figure 5.18, the observed line passes through zero and has a slope of 45º. The points of predicted values should lie on the linear line. The points are close to the line as observed in figure 5.18 which indicates an accurate prediction.

5.9 Summary of the Results

1) Water Quality Index for the years 2005 to 2011, quarterly have been determined at five stations under consideration in the Sabarmati river basin.

2) The seasonal variation of the water quality at each station and the spatial season-wise variation of the water quality at the stations under consideration in the Sabarmati river basin have been plotted and graphically represented in Figure 5.1.1 to 5.1.5 and Figure 5.2 respectively.

3) It is found that high seasonal variation of water quality is found at the stations which are located in an urbanized area in comparison to the stations having low/ moderate urbanized catchment. The high seasonal variation at the stations located in a high urbanized area is found to be indicative of the influence of urbanization and urban activities towards deteriorating the water quality.

4) As the urbanization parameter data is available district-wise, the Urbanization Index has been found out for each district under consideration in the Sabarmati river basin (Table 5.3).

5) To establish the correlation between water quality and urbanization and to assess the impact of urbanization on water quality, there was a need to determine the urbanization of the catchment area of each water quality station in the basin. Hence, using the methodology evolved to determine the Urbanization Index of the catchment of a station from the Urbanization of the district, the Urbanization Index of the catchment of each station has been obtained (Table 5.7).

6) The Pearson's Correlation Coefficient (r) of each water quality parameter with the Urbanization Index has been computed and shown in Table 5.10.

7) It is found for this study that that there exists a very high degree of negative correlation between DO and Urbanization Index (r = -0.92). Also high degree of positive correlation exists between BOD and Urbanization Index (r = 0.81). There is a good negative correlation between (r = -0.76). There is a good positive correlation between pH and UI and between EC and UI (r = 0.62).

   Poor correlation exists between Nitrate Nitrogen and UI (r = -0.02), and between Total Coliform and UI (r = 0.44).

8) The Water Quality Index of each station under study and Urbanization Index of the catchment of each station obtained in this study is represented in Table 5.8.

9) The Water – Quality Urbanization Regression (WQURM) model developed in this study is applied on the Sabarmati river basin to evaluate the impact of Urbanization on the river water quality quantitatively. Figure 5.17 shows the WQURM model formulated on Sabarmati river basin.

10) From figure 5.17, it can be observed that a linear WQURM model for prediction of the river water quality of Sabarmati river from the Urbanization has been developed. The trend of the WQURM model shows that as urbanization increases, the water quality deteriorates.