Chapter 4

Application of the model

4.1 Introduction

The Sabarmati river was branded as the third most polluted river in the country by the Central Pollution Control board (CPCB) in 2010. Comptroller and Auditor General (CAG) reported in 2012."Present status of Sabarmati shows the presence of fecal-related disease causing pathogens as well as organic pollution at the outskirts of the city limits". In another study conducted by the LD Engineering College in 2012, it was found that the river was unfit for aquatic life with its dissolved oxygen being zero, even 28 km downstream. The studies and the reports indicate that the Sabarmati river water quality is affected by rapid pace of urbanization taking place in this basin. There was a need to investigate the impact of urbanization on the water quality of Sabarmati river. The Water Quality- Urbanization Regression (WQURM) model developed in the present study is applied on the study area of Sabarmati river basin. The Sabarmati river basin is described in this chapter. Then the WQURM model is applied on the Sabarmati river basin.

4.2 Description of Sabarmati river basin

4.2.1 Overview of basin

Sabarmati River is one of the major west flowing rivers of India. The Sabarmati basin extends over the states of Rajasthan and Gujarat having an area of 21,674 Sq. km with maximum length and width of 300 km and 150 km respectively. It lies between 70°58' to 73°51' east and 22°15' to 24°47' north. The basin is bounded by Aravalli hills in the north and north-east, Rann of Kutch in the west and Gulf of Khambhat in the south. The Sabarmati basin extends over parts of Udaipur, Sirohi, Pali and Dungarpur districts of Rajasthan, Sabarkantha, Kheda, Ahmedabad, Mahesana, Gandhinagar and Banaskantha districts of Gujarat. Figure 4.1 shows the geographical location of the basin with terrain features from DEM. The highlighted blue boundary shows the basin extent overlaid on state boundary.

The basin spreads over 15 parliamentary constituencies (2009) and is comprised of 13 in Gujarat and 2 in Rajasthan. In Gujarat, the basin occupies an area of 17,550 Sq. km

accounting to 81% of the total basin area. In Rajasthan, It covers an area of 4,124 Sq. km which accounts for 19% of the total basin area. (India- WRIS, 2014)

The average annual runoff and average annual water potential of the basin is 3.81 BCM. The utilizable surface water in the basin accounts to 1.9 BCM.

Figure 4.1 Sabarmati basin Index map

(Source: India-WRIS, 2014)

4.2.1.1 Topography

The Sabarmati basin is bounded by Aravalli hills in the north and north-east, Rann of Kutch in the west and Gulf of Khambhat in the south. The basin has maximum length and width of about 300 km and 150 km, respectively. The terrain of Sabarmati basin is hilly in the early reaches up to Dharoi dam after which the river flows mostly in plains. The northern part of the basin is marked by hilly terrain while the southern part has large alluvium plain having gentle slope. The spatial variation of different elevation zones in the basin is depicted in Table 4.1

Table 4.1 Elevation zones

Sl. No.	Elevation (m)	Area (Sq.km)	% of Total Area
1	< 5	184.20	0.85
2	5-10	1113.85	5.14
3	10-50	5554.80	25.63
4	50-100	4303.09	19.85
5	100-200	5345.61	24.66
6	200-300	2063.20	9.52
7	300-400	883.49	4.08
8	400-500	612.57	2.83
9	500-750	1206.61	5.57
10	750-1000	396.40	1.83
11	1000-1500	10.18	0.05
(India- WRIS, 2014)			

4.2.1.2 Climate

Sabarmati basin experiences 3 marked seasons - Summer (March-May), Monsoon (June-September) and Winter (October-February). The winter season begins in December and continues till the end of February. January is the coldest month of the year. Clear bright weather, intersperse by brief spells of cloudy weather and accompanied by a little rain caused by western disturbances traversing north India is experienced during this part of the year. Winds blow mainly north-east.

From March onwards, the hot weather sets in and continues till the middle of June. Thunder-storms occur occasionally during this season. The winds are generally north-easterly. The south-west monsoon normally sets in by the middle of June and continues to be active till September. 95% of the annual rainfall occurs during this period. Heavy showers generally occur in association with monsoon depressions from the Bay of Bengal and the Arabian Sea. The south-west monsoon withdraws by about the middle of September and the weather clears up. Pleasant weather prevails till the end of December. From the available data and record,

the basin contains two climatic regions, the northern part of the basin comprises sub-tropical wet climate. The major part of basin comprises tropical wet climate causes mainly due to existence of Aravalli and the Western Ghats. The climate varies from arid in the Saurashtra area to semi- arid in north Gujarat to humid in coastal areas. *(Water Year Book, CWC, 2008-09)*

4.2.1.3 Rainfall

The Average annual rainfall in the Sabarmati basin is 689.90 mm. The southwest monsoon sets in by middle of June and withdraws by the first week of October. The rainfall is mainly influenced by the southwest monsoon. The effect is most pronounced in Vadodara lying on the windward side of the Western Ghats. Monsoon contributes nearly 91-94% of annual precipitation. Average wind speed is the lowest in Udaipur and higher in Ahmedabad district. In general, wind speeds are taken to be moderate over most of the months.

4.2.1.4 Temperature

The maximum temperature in the basin varies from 39°C to 48°C. The temperatures average 11°C – 15°C in winters and as high as 38-47°C in summers. Month of May is generally the hottest month of the summer with mean maximum temperature of 34.4°C. January is the coldest month with mean minimum temperature of 18.76°C. The average annual minimum temperature (1969-2004) is 19.64°C. The average annual maximum temperature for the same period is 33.01°C. The average annual mean temperature for the period is 26.33°C. The higher elevations in the north experience lower temperatures (India- WRIS, 2014).

4.2.2 Sabarmati river and its tributaries

The Sabarmati river is one of the four main rivers which traverse the alluvial plains of Gujarat. It rises in the Aravalli hills in the Rajasthan state at an elevation of 762 meters near the popular shrine of Amba Bhavani. After traversing a course of about 48 km in Rajasthan, the river enters the Gujarat state. At the 51 km of its run, the Wakal river joins it from the left, near village Ghonpankhari.(National Institute of Hydrology,2007). Flowing in a generally south-west and winding among jungle covered hills over a bed strewn with shingles and boulders, at the 67 km of its run, it receives the Sei river from the right near Mhauri and

then the Harnav river the left at about 103 km from the source, before it enters Dharoi reservoir. Emerging from the dam it passes through the plains and is joined on its left at about 170 km from its source by the Hathmati river. Continuing to flow south-westwards, the river passes through Ahmedabad at about 165 km downstream of Dharoi dam. Further 65 km downstream, another tributary, the Watrak river joins it from the left. Flowing for a further distance of 68 km, the river outfalls into the Gulf of Cambay in the Arabian Sea. (Jain S.K, Agrawal P. K, Singh V. P, 2007).

Description of some major tributaries of Sabarmati basin is given below:-

(a) Sei - This is a right bank tributary of Sabarmati river. It rises in the Aravalli hills in Rajasthan and flows in south-west direction for a total distance of 74.89 km before it joins Sabarmati on its right bank. It drains an area of 946 Sq. km.

(b) Wakal - This is a left bank tributary of Sabarmati river. It rises in the Aravalli hills in Rajasthan and flows in south-west direction for a total length of 88.54 km before it joins Sabarmati on its left bank. It drains an area of 1625 Sq km. Menas is its main tributary.

(c) Harnav - This is a left bank tributary of Sabarmati river. It rises in the northern portion of the Kulalia hills of Rajasthan and flows in south-west direction for a total distance of 59.07 km and joins the left bank of Sabarmati. It drains an area of 972 Sq. km.

(d) Hathmati - This is a left bank tributary of Sabarmati river. It rises in south-west foot hills of Rajasthan and Gujarat states and flows in south-west direction for a distance of 118.27 km to meet the Sabarmati on its left bank. Ghuvai and Boroli rivers are the sub-tributaries of Hathmati River. This tributary drains an area of 1526 Sq. km.

(e) Watrak - This is a left bank tributary of Sabarmati river. It rises in the Panchara hills in Dungarpur district of Rajasthan and flows in south-west direction for a distance of 231.69 km and joins Sabarmati on the left bank. Watrak and its tributaries drain an area of 8638 Sq. km.

(f) Shedhi- Shedhi River is a third order stream in the Sabarmati river basin (Figure 1a) and drains into the alluvial plains of central Gujarat. Originating from the eastern hills of Panchmahal district comprising the rocks of Aravalli Super Group, the Shedhi flows for a distance of about 50 km through the alluvial plain and joins the Watrak River at Kheda (Figure 1b). It follows a south-south westerly course and flows parallel to the Mahi River for a stretch of about 15 km in the upstream, however it takes a westerly trend in the lower reaches. Mohar Nadi, a tributary, meets the Shedhi at Nadiad. The lengths of Sabarmati and its tributaries are summarized in Table 4.2 (India-WRIS, 2014).

Table 4.2 Length of major rivers (GIS Calculated)

Sl. No.	Tributaries/ River	Total Flowing length(km)
1	Sabarmati	352.235
2	Sei	74.89
3	Wakal	88.54
4	Harnav	59.07
5	Hathmati	118.27
6	Watrak	231.69
7	Dhamoi	49.70
8	Majam	96.509
9	Meswo	169.552

Source: India-WRIS database

4.2.3 Land use/land cover

Land use is a description of how people utilize the land and socio-economic activity - Urban and agricultural land uses are the most commonly known land use classes. At any one point or place, there may be multiple and alternate land uses, the specification of which may have a political dimension. Land cover is the physical material at the surface of the earth. Land cover include grass, asphalt, trees, bare ground, water, etc. This basin holds a variety of land cover and land use classes.

The distribution of land use/land cover units in Sabarmati basin during 2005-06 is given in Figure 4.2. Major part of the basin is covered with agricultural land with an area of 16186.38 Sq. km (74.68% of the total geographical area). Sabarmati river and its tributaries have contributed to the land cover class Waterbodies by 4.19 %. The built up land (Includes Urban and Rural class) is 1.95% covering an area of 423.14 Sq. km. Forest cover in the basin is 2595.69 Sq. km which accounts for 11.98% of total area. Wasteland in the basin occupies 7.15%, covers an area of 1549.13 Sq. km (Table 4.3). Grassland accounts for 0.05% with an area of 10.72 Sq. km. The other main categories of land use/land cover in the basin are fallow land, scrub land, scrub forest, river/stream/canal, rural, urban mining, swamp/mangrove, etc.

The dominant crops harvested in the basin depend largely on the season and availability of water. The monsoon is the main cultivation season. Major crops grown during the kharif are bajra (pearl millet), cotton, groundnut, jowar, rice, and maize, while minor crops consist of

pulses, millets, and tobacco. During the Rabi season (winter), wheat is the dominant crop. In some areas, crops are also grown during the hot summer season, but this depends entirely on the availability of irrigation water. The main crop during this growing season is bajra (India-WRIS, 2014).

Table 4.3 Land use/ land cover statistics (2005-06)

S. No.	Category	Area (Sq. km)	% of Total Area
1	Built Up land	423.14	1.95
2	Agricultural	16186.38	74.68
3	Forest	2595.69	11.98
4	Grassland	10.72	0.05
5	Wasteland	1549.13	7.15
6	Waterbodies	908.94	4.19

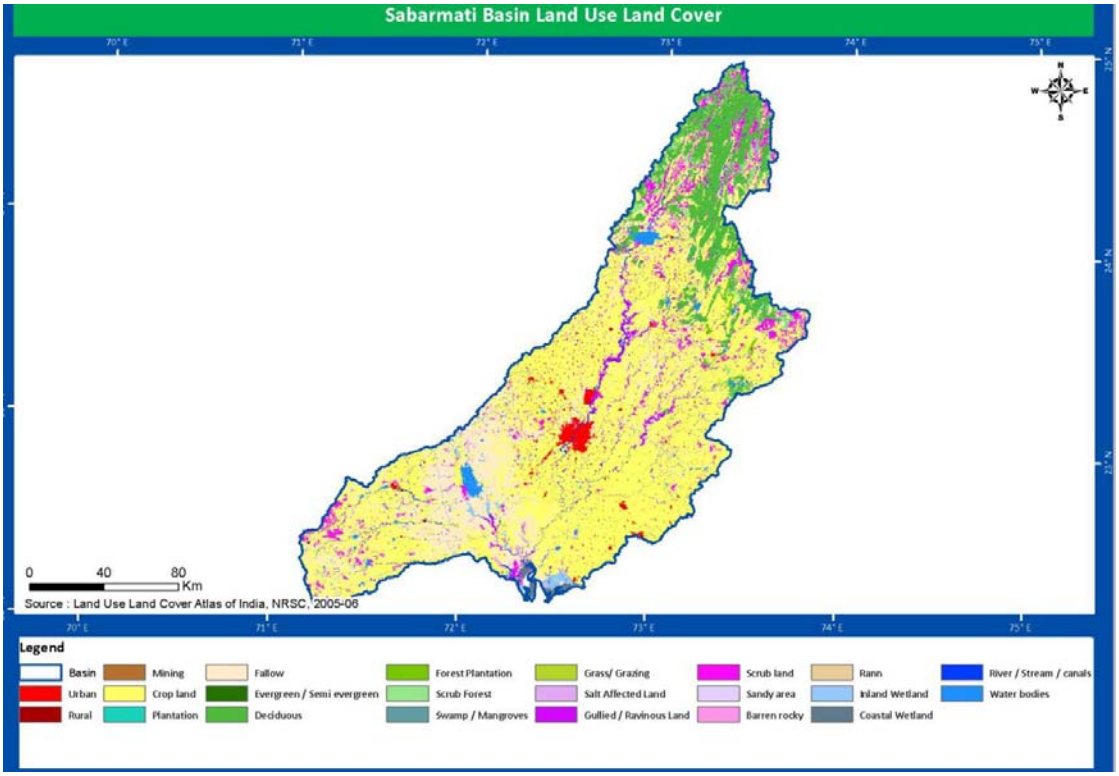

Figure 4.2 Land Use/ Land Cover

(Source: India-WRIS, 2014)

4.2.4 Hydrological units

Hydrological units of a basin comprise sub basins and watersheds. The Sabarmati basin comprises 2 sub basins and 51 watersheds. The sub basins and watersheds are described below.

4.2.4.1 Sub-basins

The basin is divided into 2 sub-basins *viz. Sabarmati Upper* and *Sabarmati Lower Sub-Basin*. They have been further clustered into 51 watersheds each of which represents a different tributary system. The Sabarmati and its tributaries are an interstate river system, flowing through the states of Rajasthan and Gujarat. The drainage network of Sabarmati river consists of 5 major tributaries. The basin is roughly triangular in shape with the Sabarmati river as the base and the source of the Watrak river as the apex point. Sabarmati originates from Aravalli hills at an elevation of 762 m near village Tepur in Udaipur district of Rajasthan. The total length of river from origin to outfall into the Arabian Sea is 371 km and its principal tributaries joining from left are Wakal, Hathmati and Watrak whereas Sei joins the river from right. (India- WRIS, 2014)

4.2.4.2 Watersheds

Two sub-basins have been further bifurcated into 51 watersheds. Sabarmati lower sub basin consists of 17 watersheds with size range of 397.55 - 986.46 Sq. km. Sabarmati upper sub basin consists of 34 watersheds with size range of 313.38 - 828.34 Sq. km. Maximum number of watersheds are falling in Sabarmati upper sub-basin. The number and size range of watershed under each sub-basin is given in Table 4.4. Spatial location of the watersheds in Sabarmati lower sub-basin is shown in Figure 4.3 whereas the location of watersheds in Sabarmati upper sub-basin is shown in Figure 4.4.

Table 4.4 Sub-basin wise watersheds

S. No.	Name of Sub-basin	Area (Sq. Km.)	Size Range of Watershed (Sq. Km.)	No. of Watersheds
1	Sabarmati Lower Sub Basin	8904.02	397.55 - 986.46	17
2	Sabarmati Upper Sub Basin	40575.72	313.38 - 828.34	34

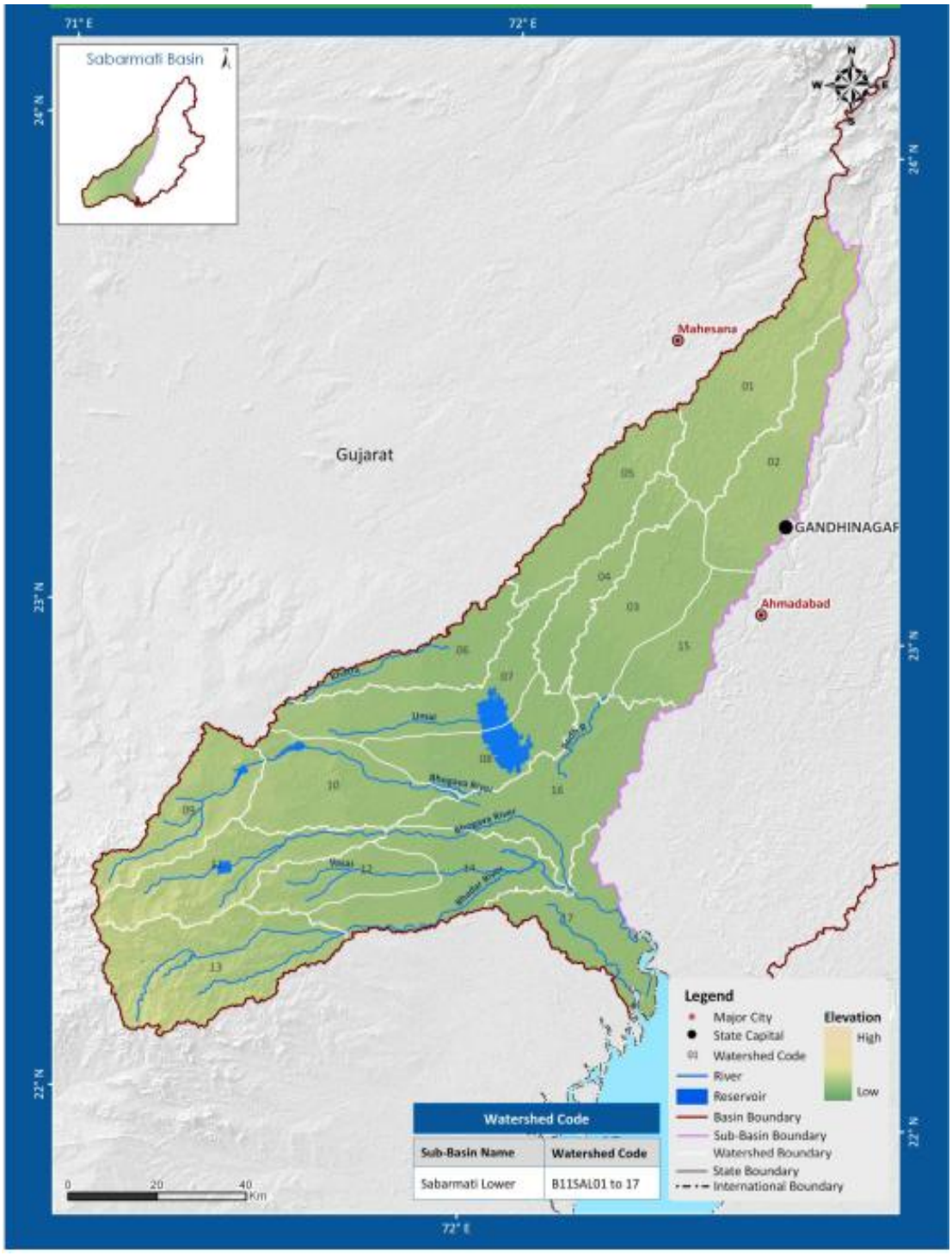

Figure 4.3 Sabarmati lower sub-basin and watersheds

(Source: India-WRIS, 2014)

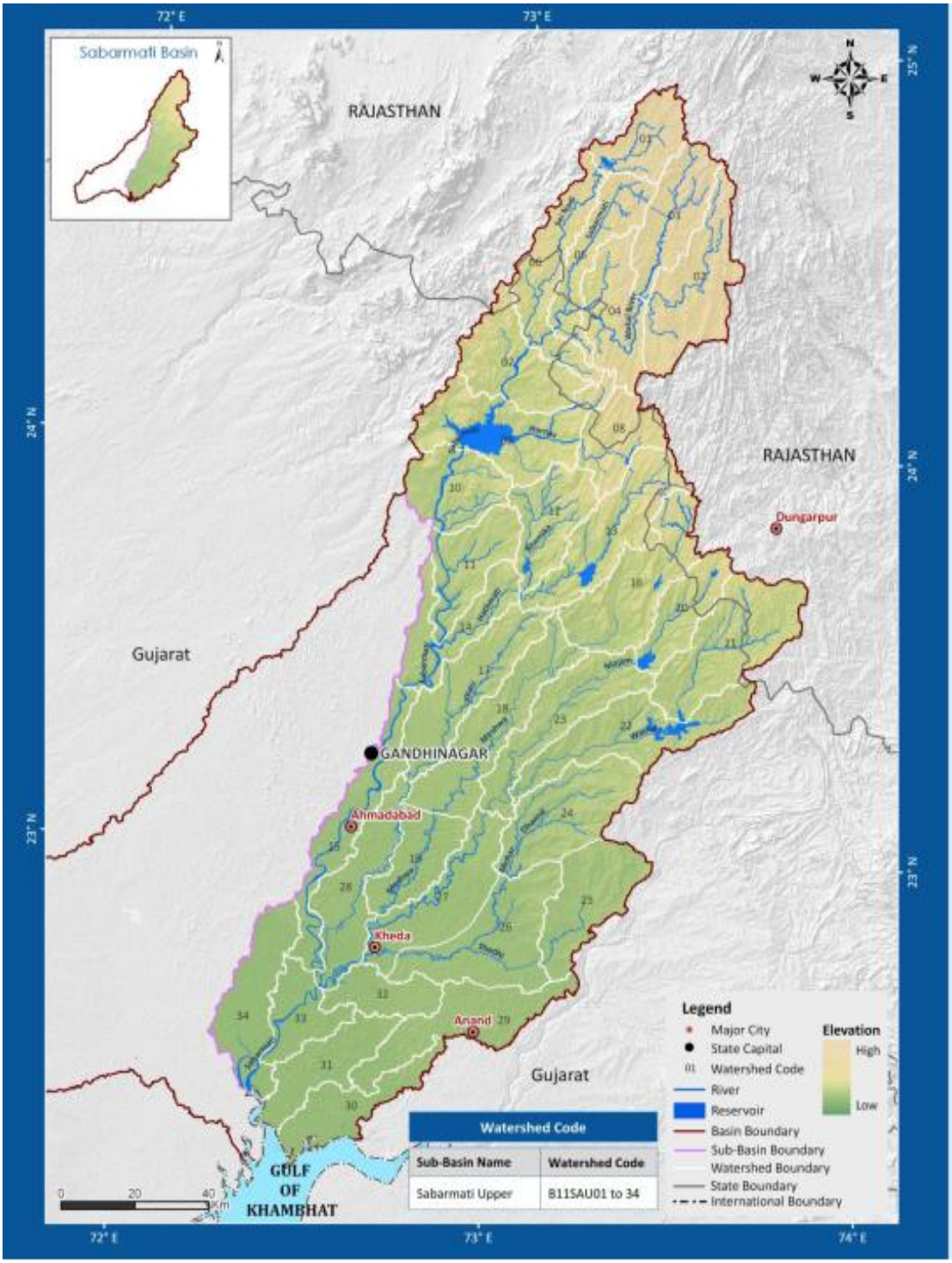

Figure 4.4 Sabarmati upper sub-basin and watersheds

(Source: India-WRIS, 2014)

4.2.5 Pace of urbanisation and increase in urban water Use

Rapid urbanisation is taking place in the basin. About 52% of the population is urban. Nearly 50% of the basin population is concentrated in Ahmedabad and Gandhinagar districts and more than three-fourth of the urban population is residing in the cities of Ahmedabad and Gandhinagar. There is a huge demand for public water supply in these cities, which is bound to increase substantially in future due to demographic trends and rapid growth of urbanisation and income levels. Consequently the amount of wastewater generated and need for much greater treatment facilities and disposal of the treated effluents will be required. At present partially treated effluents are already being utilised for irrigation in the Sabarmati basin, but mixing with river waters is also occurring (ICID, 2005).

4.2.6 Industries in Sabarmati river basin

There are 20 industrial estates operating in the Sabarmati river basin. The industries in the basin include small-scale industries, factories, medium and large industries. There are 2,687 medium and large industries. In addition, there are 45,133 small-scale industries. They include textiles, paper products and printing, leather products, rubber and plastic industries, chemical and chemical products, and are highly water consuming. The region being conducive to cotton growing, number of textile and dyeing industries has come up in the basin particularly in the Ahmedabad district. Dairy farming, processing of milk and its products is an important industry in the region. In addition, industries dealing with chemical, starch, drugs and pharmaceuticals, glass and ceramics, cement etc. have come up in the basin in a big way.

4.2.7 Sabarmati river pollution status

Due to discharge of domestic wastewater and industrial effluents, partially treated/untreated into the tributaries of the river and main Sabarmati river, surface water pollution is rather high (ICID, 2005).

4.3 Data base for Sabarmati river basin

4.3.1 Details of stations selected on Sabarmati river and its tributaries

Five stations have been selected in the Sabarmati river for assessing the water quality and for assessing influence of urbanization on water quality. These five stations have been selected on the river Sabarmati and its tributaries. The stations are selected such that they are located in districts having different levels of urbanization. Station S_1 is located in Ahmedabad district, S_2 is located on Shedhi river, a tributary of Sabarmati river in Kheda district, S_3 is located on the upper reaches of Sabarmati river at Kheroj bridge in Sabarkantha district, S_4 is located in Miroli village of Ahmedabad district and S_5 is located at Mahudi of Gandhinagar district on the upper reaches of Sabarmati river. The stations located on the Sabarmati river and its tributaries: are listed as follows:

1. Station-1 (S_1) –Sabarmati river at V. N Bridge, at Ahmedabad city located in Ahmedabad district.
2. Station-2 (S_2) -Shedhi tributary of Sabarmati river at Kheda city located in Kheda district.
3. Station-3 (S_3)- Sabarmati river at Kheroj bridge at Sabarkantha district in Khedbrahma Taluka, located at latitude 24.23085°N & longitude 73.01773°E.
4. Station-4 (S_4)- Sabarmati river at Miroli village, Dascroi Taluka, Ahmedabad district located at latitude 22.8660°N & longitude 72.5145°E.
5. Station- 5 (S_5) – Hathmati tributary of Sabarmati river Mahudi Jain temple, Mansa Taluka, Gandhinagar district located at latitude 23.5138°N & longitude 72.7361°E.

The map of the Sabarmati river basin along with the stations under study is shown in Figure 4.5

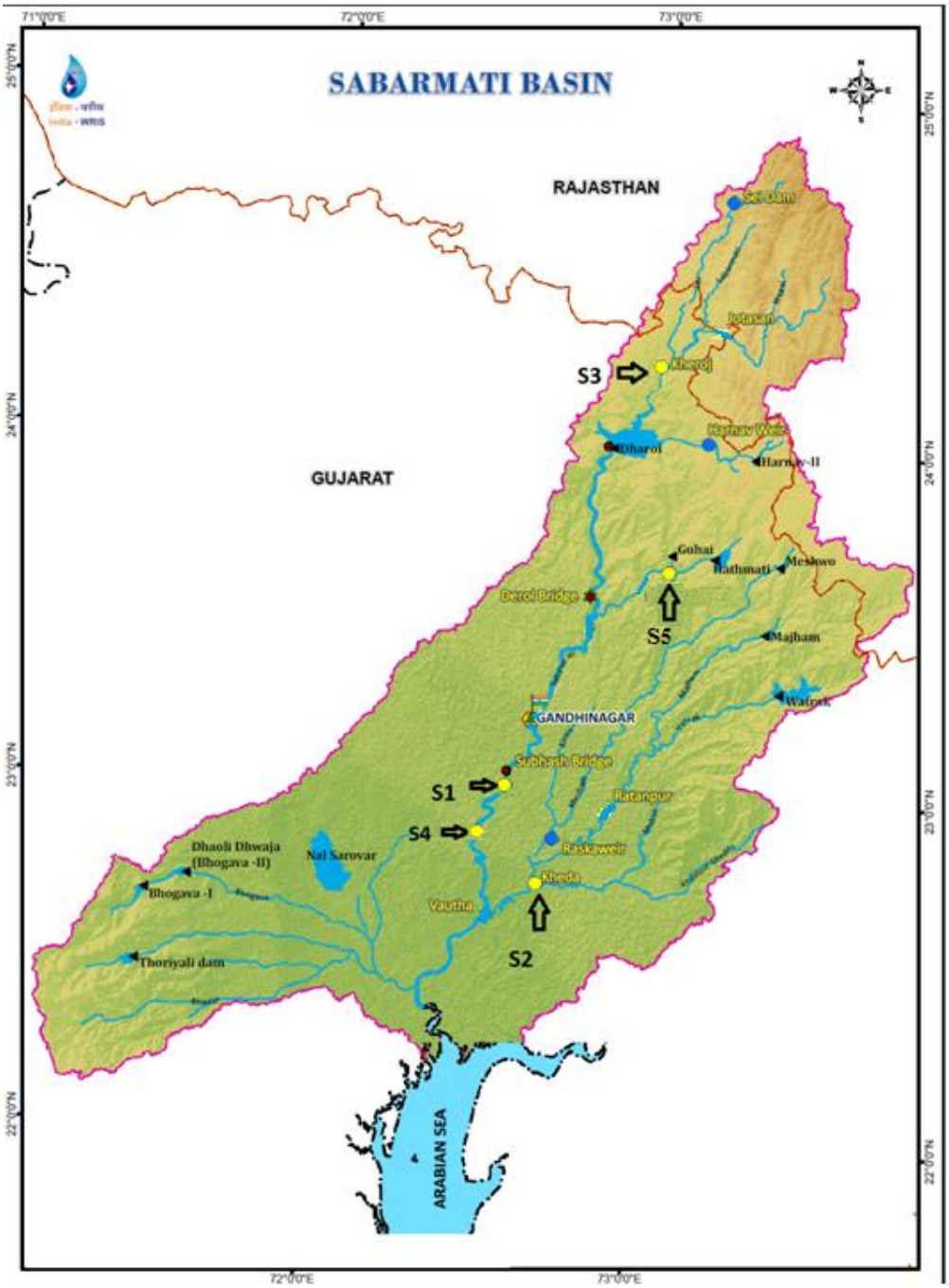

Figure 4.5 Map of Sabarmati river basin showing the location of stations under study

4.3.2 Data base for water quality

Water quality quarterly concentration for the parameters, pH, Dissolved oxygen, BOD, Electrical Conductivity, Nitrate nitrogen and Total Coliform for the stations S_1, S_2, S_3, S_4 and S_5 in the Sabarmati river basin has been collected for the present study from the year 2005 to 2011 from Gujarat Pollution Control Board, Gandhinagar. The data for the parameter concentrations for the stations S_1, S_2, S_3, S_4 and S_5 is shown in Table 4.5 to 4.9.

Table 4.5 Data for the water quality parameters for station S_1 **(**V. N Bridge, Ahmedabad)

Station -S_1							
	Month	pH	DO (mg/l)	BOD mg/l)	EC (μ mhos/cm)	Nitrate Nitrogen (mg/l)	Total Coliform (MPN/100 ml)
2005	Jan	7.1	3.1	75.0	2740.0	0.3	460000.0
	Apr	6.9	0.0	120.0	2740.0	0.3	460000.0
	July	7.6	2.3	63.0	687.0	0.5	1100000.0
	Oct	7.4	5.2	4.3	310.0	0.2	1500.0
2006	Jan	7.1	0.0	293.0	1940.0	0.1	150000.0
	Apr	7.0	0.0	107.0	1770.0	0.1	75000.0
	July	7.6	2.4	50.0	516.0	0.2	430.0
	Oct	7.7	6.0	23.0	680.0	0.1	7500.0
2007	Jan	7.2	4.3	22.0	905.0	0.8	2300.0
	Apr	7.4	0.0	140.0	2350.0	0.0	150000.0
	July	7.5	7.0	21.0	446.0	0.6	930.0
	Oct	7.3	4.2	4.0	548.0	1.9	230.0
2008	Jan	8.6	2.0	2.0	670.0	0.4	43.0
	Apr	7.2	2.6	24.0	1290.0	2.5	4300.0
	July	8.1	0.0	23.0	954.0	0.5	43000.0
	Oct	7.3	3.6	3.0	425.0	0.1	930.0
2009	Jan	7.6	1.2	47.0	1240.0	2.0	1200.0

	Apr	8.3	0.0	138.0	21010.0	1.8	2100.0
	July	7.7	4.8	9.0	407.0	1.6	2100.0
	Oct	7.4	4.7	0.2	224.0	0.2	2400.0
2010	Jan	7.1	1.0	0.3	714.0	2.7	2100.0
	Apr	7.0	0.0	88.0	2280.0	3.1	46000.0
	July	8.1	2.0	100.0	1610.0	0.6	46000.0
	Oct	7.4	5.6	15.0	788.0	1.7	2100.0
2011	Jan	7.3	2.6	48.0	976.0	0.4	930.0
	Apr	7.8	0.0	106.0	2009.0	0.9	1500.0
	July	7.6	0.0	18.0	636.0	0.4	930.0
	Oct	7.8	6.6	3.0	290.0	4.6	1400.0

Table 4.6 Data for the water quality parameters for station S_2 **(**Shedhi at Kheda)

Station -S_2							
	Month	pH	DO (mg/l)	BOD (mg/l)	EC (μ mhos/cm)	Nitrate Nitrogen (mg/l)	Total Coliform (MPN/100 ml)
2005	Jan	7.4	5.9	6.0	741.0	0.5	15000
	Apr	7.5	7.1	7.0	756.0	0.4	11000
	July	8.0	5.4	3.0	200.0	0.3	23000
	Oct	7.6	5.5	3.8	200	0.3	23000
2006	Jan	7.9	7.5	0.8	500	0.2	750
	Apr	8.3	8.8	5.4	1310	1.9	750
	July	8.3	0.5	14	1400	0.2	430
	Oct	8.1	7.3	2.2	806	0.9	1500
2007	Jan	8.1	7.1	5	816	0.9	200
	Apr	8.5	7.1	3.1	820	0.7	140

	July	8.9	4.2	5.1	735	1	450
	Oct	8.3	6	3.2	701	0.5	230
2008	Jan	7.8	5.8	0.8	829	0.4	15
	Apr	8.2	8.8	4	1340	5.1	15
	July	7.9	3.7	19	1200	0.1	43
	Oct	7.8	7	8	892	0.1	21
2009	Jan	8.2	4.9	0.9	735.0	3.4	93.0
	Apr	8.3	2.8	9.0	945.0	2.2	150.0
	July	8.4	8.2	2.0	785.0	0.6	33.0
	Oct	8.0	6.1	1.5	705.0	2.2	50.0
2010	Jan	7.7	7.8	4.0	750.0	0.3	80.0
	Apr	7.3	1.5	10.0	1020.0	0.6	28.0
	July	7.8	7.8	22.0	1100.0	1.1	80.0
	Oct	7.4	6.8	1.6	702.0	0.7	11.0
2011	Jan	7.8	7.9	0.9	810.0	1.1	15.0
	Apr	8.5	7.8	6.0	1300.0	1.7	20.0
	July	8.6	7.3	29.0	1050.0	1.1	50.0
	Oct	7.7	7.3	5.0	708.0	1.4	220.0

Table 4.7 Data for the water quality parameters for station S_3 **(**Kheroj bridge, Sabarkantha)

Station -S_3							
Year	Month	pH	DO (mg/l)	BOD (mg/l)	EC (μ mhos/cm)	Nitrate Nitrogen (mg/l)	Total Coliform (MPN/100 ml)
2005	Jan	7.3	6.3	1.2	540	0.6	90
	Apr	7.8	6.2	1.3	560	0.5	85

	July	8.1	5.9	3	253	0.6	9000
	Oct	8.2	6.9	1.3	590	0.4	93
2006	Jan	8.3	8.6	5.5	466	0.1	75
	Apr	8.7	9.2	8.6	500	0.5	150
	July	8.4	5.8	12	353	0.3	150
	Oct	8.2	8.1	3	558	1.3	20
2007	Jan	8.4	8.2	3	704	0.2	43
	Apr	8.2	7.9	2	655	0.3	40
	July	7.7	2.4	12	292	1.1	75000
	Oct	8	8.4	3	650	0.5	9
2008	Jan	7.1	9.2	8	511	0.7	23
	Apr	7.6	8.1	3	778	2.6	230
	July	7.8	7.4	9	570	0.2	43
	Oct	7.9	7.8	3	631	0.3	240
2009	Jan	8.2	5.3	10	330	2.0	340
	Apr	8.2	5.4	12	465	2.5	260
	July	8.5	5.8	9	471	2.4	750
	Oct	8.3	6.5	5	324	2.2	280
2010	Jan	8.2	5.8	5	264	0.3	350
	Apr	8.2	3.6	6	316	0.9	15000
	July	8.2	2.4	2	497	0.3	430
	Oct	8.3	8.1	2	421	0.3	240
2011	Jan	8.5	6.3	2	150	0.3	230
	Apr	8.3	5.7	3	120	0.5	210
	July	7.7	6.7	4	110	0.6	240
	Oct	8.3	7.5	1	519	0.3	460

Table 4.8 Data for the water quality parameters for station S_4 **(**Miroli village, Ahmedabad district)

Station -S_4							
Year	Month	pH	DO (mg/l)	BOD (mg/l)	EC (μ mhos/cm)	Nitrate Nitrogen (mg/l)	Total Coliform (MPN/100 ml)
2005	Jan	6.9	0.5	19	922	0.2	1100000
	Apr	7.3	0	85	4040	0.3	1100000
	July	7.5	0.7	19	656	0.3	1100000
	Oct	7	0	21	862	0.1	21000
2006	Jan	7.5	0	63	1620	0.2	46000
	Apr	7.8	0	105	3510	0.1	1500000
	July	7.5	0	90	2270	0.2	7500
	Oct	7.4	0	120	2290	0.2	7500
2007	Jan	7.3	0	105	2100	0.5	6500
	Apr	7.4	0	80	2340	1.3	46000
	July	6.9	0	38	2020	0.3	7500
	Oct	7.7	2.7	18	724	0.6	150
2008	Jan	8.6	0	28	2670	0.3	93000
	Apr	7.3	0	72	2000	2.8	4300
	July	7.3	0	30	2930	0.3	4300
	Oct	7.7	0	15	2000	2	43000
2009	Jan	8	0	18	3010	0.5	28000
	Apr	8	0	76	1870	0.5	46000
	July	7.3	0	17	2090	0.5	7500
	Oct	7.3	0	5	1850	0.3	5300
2010	Jan	7.5	0.3	18	825	0.2	9000
	Apr	7.6	0	95	1320	0.3	12000

	July	8	0	40	740	0.5	3000
	Oct	8.2	0.2	5.6	2850	0.5	9600
2011	Jan	7.6	0.4	45	935	0.2	43000
	Apr	7.4	0	103	1580	1.2	24000
	July	7.9	0.2	85	680	2.1	45000
	Oct	8.2	0.1	4	275	0.3	8500

Table 4.9 Data for the water quality parameters for station S_5 **(**Mahudi Jain temple, Gandhinagar district)

Station -S_5							
Year	Month	pH	DO (mg/l)	BOD (mg/l)	EC (μ mhos/cm)	Nitrate Nitrogen (mg/l)	Total Coliform (MPN/100 ml)
2005	Jan	7.9	6.5	4	312	0.3	630
	Apr	8.4	6	5	456	0.4	8450
	July	8.4	6.5	1	173	0.5	150000
	Oct	8	7.9	3.2	450	0.4	430
2006	Jan	8	7.6	1	627	0.8	150
	Apr	8.4	5.2	5.2	723	0.8	2500
	July	8.3	6.4	2	369	0.2	90
	Oct	8.1	7.2	1	154	0.1	40
2007	Jan	7.9	6.2	3.3	255	0.3	320
	Apr	8.2	5.4	6	568	0.3	460
	July	8.2	6	4	450	0.2	430
	Oct	7.6	7	2	128	0.2	210
2008	Jan	7.6	5.9	4	104	0.8	450
	Apr	8	6	5.1	543	0.6	580

	July	8.2	6.1	5.3	340	0.4	620
	Oct	8.4	9	3	125	0.5	430
2009	Jan	8.2	6.8	5.2	348	0.2	350
	Apr	7.9	5.8	6.3	350	0.5	480
	July	8	6	10	210	0.4	80
	Oct	8.3	7	2	240	0.8	490
2010	Jan	7.9	6.1	2	485	2.1	2650
	Apr	8.2	6.5	1	560	2.0	3210
	July	7.6	8.8	1	318	3.2	460
	Oct	8.1	6.9	2	483	0.1	2400
2011	Jan	8.1	7.1	4	506	0.5	430
	Apr	8	6.2	5	2010	0.6	120
	July	8.5	7.5	4	160	0.3	230
	Oct	8.2	6.6	1	377	0.2	230

In this study, the water quality parameter data are collected quarterly because the inflow in the river is varying throughout the year. i.e. summer, winter, monsoon and post- monsoon. So, the quarterly water quality parameter data is representative of the variation of the discharge in the river. Moreover the discharge data on the tributaries and at the stations where the water quality parameter data was collected were not available. Hence, the discharge in the river is not included for analysis in this study.

It is found in most of the literatures that the aggregation of the water quality parameters into Water Quality Index does not require the conversion into a pollution load. Also, in the present study, the correlation between pollution load and urbanization is not aimed at. Hence, there is no need to convert the water quality parameter concentration into pollution load.

4.3.3 Data base for urbanization level of districts in Sabarmati river basin

District-wise data of households by main source of lighting, number of households having specified assets, census houses by predominant material of roof, population size, population density are collected from Census of India, 2011 are shown in Appendix VI - XIII. District-

wise data base of number of Industries in Gujarat is collected from Vibrant Gujarat, Government of Gujarat. Land Use, Land cover pattern, district-wise in Gujarat is collected from National Remote Sensing Centre (NRSC), Hyderabad. The data-base for the urbanization parameters collected for districts: Ahmedabad, Kheda, Sabarkantha, Mehsana, Gandhinagar and Banaskantha are shown in Table 4.10

Table 4.10 Data base for Parameters for measurement of urbanization level of districts located in Sabarmati river basin.

Urbanization Parameters	**District**					
	Ahmedabad	**Kheda**	**Sabarkantha**	**Mehsana**	**Gandhinagar**	**Banaskantha**
Population size	7208200	2298934	208531	2027727	1387478	3116045
Population density (persons/sq.Km)	890	541	328	462	660	290
Industries	24156	8206	8042	7883	8330	397
% of Built up area to total area	3.82	1.19	0.91	2.11	5.2	1.05
Roofing (%)	16.89	8.09	9.83	11.78	13	5.6
Electricity Facility (%)	20.19	16.19	18.06	19.01	18.92	12.73
Educational Facilities	84	19	7	23	39	8
Health services (major Hospitals)	32	2	2	5	3	2
Assets (%)	3.17	0.5	0.52	1.06	0.18	0.26

4.4 System for application

The application of the model developed in the present study has been demonstrated on Sabarmati river basin, India. The model developed in the present study has been calibrated in this section and shown in Table 4.11.

The WQI model developed in this study requires six input water quality parameters, namely, pH, Dissolved Oxygen, BOD, Electrical Conductivity, Nitrate nitrogen and Total Coliform. The weighing factor to be used for each parameter is as shown in Table 3.2.The WQI can be computed using equation 3.2. The output of the WQI model is Water Quality Index for study stations S_1, S_2, S_3, S_4 & S_5 in the Sabarmati river basin.

The UI model developed in this study requires nine urbanization parameters, namely, population size, population density, industries, built-up area, roofing types, electricity facilities, educational facilities, health services and assets. The UI of the districts can be computed using equation 3.4. First, the output of the model is Urbanization Index of various districts lying in the catchment of the stations. There are two cases applicable in the study area, case A2 B1and case A2 B2.

For case A2 B1, i.e, a portion of district falls in the catchment of the Station (A2) and only one district falls in the catchment of Station (B1). Equation 3.5 is used for this case to compute UI of the catchment area of stations. For case A2 B2 i.e, a portion of district falls in the catchment of the Station (A2) and multiple districts fall in the catchment of Station (B2), equation 3.7 is used to compute UI of the catchment area of stations. The final output is the UI of the catchment of the stations.

Table 4.11 System of application for Sabarmati river

Model	Input parameters of the model	System Equation	Value of parameter/station	Output of model
WQI model	pH, Dissolved Oxygen, BOD, Electrical Conductivity, Nitrate nitrogen and Total Coliform	$WQI = \sum_{i=1}^{n} (W_i \, x \, Vr_i)$	No. of water quality parameters, n = 6 W_i as per table 3.2. W_i (pH) = 0.165 W_i (DO) = 0.281 W_i (BOD) = 0.234 W_i (EC) = 0.009 W_i(Nitrate Nitrogen) = 0.028 W_i (TC) = 0.281	WQI of S_1, S_2, S_3, S_4 & S_5 in the Sabarmati river basin
UI model	Popu.size, popu.density, industries, built-up area, roofing types, electricity facilities, educational facilities, health services, assets	$USj = \sum_{i=1}^{n} (P_{i,j})$ $UI_k = US_j \, x \frac{100}{90}$	Total no. of urbanization parameters, n = 9 j = Districts under consideration i.e,Ahmedabad, Kheda, Sabarkantha, Mehsana, Gandhinagar, Banaskantha Stations, k = S_1,S_2,S_3,S_4,S_5	UI of various districts
		Case A2 B1 $UI_k = UI_j \, x \frac{a_{i,j,k}}{A_j}$	i = watershed $a_{i,j,k}$ = watershed area of district j lying in the catchment of station k k =Stations S_2 & S_5	UI of the catchment area of stations k
		Case A2 B2 $UI_k = \sum_{j=1}^{N} \left(\frac{UI_j \, x \, a_{i,j,k}}{A_j} \, x \, \frac{a_{i,j,k}}{A_k} \right) X \, N$	k =Stations S_1 & S_4	