An assessment of groundwater quality in South-West zone of Surat city

Ankit N. Chaudhari, Darshan J. Mehta and Dr. Neeraj D. Sharma

ABSTRACT

Groundwater quality alludes to the state of the water that is arranged under the Earth's surface. Groundwater can accumulate in breaks in subsurface rocks and the centre of soil particles. Since various blends can break down in water and others can be suspended in water, there is a potential for pollution with harmful mixes including significant particles like Electrical Conductivity (EC), Total Dissolved Solids (TDS), and many others, such as Ca, Cl, F, Mg, NO_3, SO_4, and Total Hardness. This study examines groundwater quality in the study area of the South-West zone of Surat city, Gujarat. The South-West zone of Surat city is situated on the shoreline, causing the groundwater of the concerned area to be highly affected by seawater intrusion. The present study determines the Ground Water Quality Index (GWQI) from the year 2006 to 2015. It also predicts the approximate groundwater quality for the next 10 years. The outcome of this study suggests the need for certain improvement in groundwater quality by an appropriate method such as Managed Aquifer Recharging (MAR). It will be beneficial for the people mainly dependent on the groundwater, particularly living near the coastal region.

Key words | groundwater, groundwater quality index, salinity, Surat city

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HIGHLIGHTS

- To analyze the groundwater quality in the South-West zone of Surat City.
- To determine the Groundwater Quality Index for the years 2006–2015.
- To predict the approximate groundwater quality for the next 10 years.
- Improved outcomes of this study are very useful for those people who have only resources of groundwater.
- The Groundwater Quality Index is one of the most effective tools to rate the quality of groundwater.

INTRODUCTION

Water is the precious gift of nature to human beings. By assessing the physical, chemical, and biological characteristics of water, we can conclude its quality. Due to increased population, industrialization, utilization of composts in farming, and man-made actions, water is being polluted more than ever before. The main sources of water for domestic and drinking purposes are surface water and groundwater (Midhun Dominic & Shino Chacko 2016). India's western coast is not as wide as its eastern counterpart, and the Arabian Sea to the west is more saline than the Bay of Bengal to the east. The major portion of the water used for various purposes in the coastal belts comes from groundwater. Over the past two decades, water levels in several areas of the country have been falling rapidly because of an increase in extraction (Aryal *et al.* 2020),

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and groundwater is contaminated by many sources of pollution (BOBBA 2002).

The Water Quality Index (WQI) was first developed by Horton (1965) based on weighted arithmetical calculation. Many researchers (Brown *et al.* 1972; Bawoke & Anteneh 2020) developed various WQI models based on weighing and rating of different water quality parameters, which is derived by the weighted arithmetic method. The WQI is a dimensionless number with values positioning somewhere in the range of 0 and 100. The WQI is an extraordinarily advanced rating articulation that communicates generally water quality status, viz. excellent, good, and poor, and so forth. Consequently, the WQI is being utilized as a significant tool to think about the nature of groundwater and its administration in a specific region (Bhuvana Jagadeeswari & Ramesh 2012); and the choice of suitable monetarily possible treatment interaction to adapt to the quality issues of concern. It portrays the composite effect of various water quality boundaries and imparts water quality data to general society and legislative policy-makers to shape a solid approach and actualize water quality projects (Kalavathy *et al.* 2011) by the public authority (Ram *et al.* 2021). Groundwater quality investigation influences the commitment of explicit groundwater quality limits remarkably towards groundwater quality degradation, though due respect should be given to observation and assessment of such responsible factors and the total single operand result, such as the Index or decision limit, should be conveyed for the dynamic (Mehta *et al.* 2018). The Ground Water Quality Index (GWQI) is one of the most effective tools to rate the quality of groundwater.

Various chemical parameters are analyzed in this study such as pH, electrical conductivity, total dissolved solids, alkalinity, total hardness, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chloride, fluoride, nitrate, copper, manganese, silver, zinc, iron, and nickel. These were analyzed to estimate the groundwater quality in the latest published research study (Ram *et al.* 2021) on the GWQI for Mahoba district in the south-western district of Uttar Pradesh. This examination assumed that the current study area fundamentally has stone and antacid rock, explicitly in southern parts, which is responsible for leaching of fluoride into groundwater.

In the more recent study on Surat district, the Water Quality Index pre-Monsoon and Post-Monsoon by is calculated considering several chemical parameters by using Horton's method (1965) to assess the Ground Water Quality Index (GWQI) (Bind & Kanchan 2020). The author identified the contaminant ratio in the study area by using geospatial techniques and recommended some suggestions to improve the quality of water, but as a conjectural observation study limited to the current scenario and connectively it is not considered recharge of groundwater.

In the present study, the authors examined groundwater quality data and estimated the possible effect of artificial recharging on these parameters by the managed aquifer recharging (MAR) method in order to ascertain potential improvement in the groundwater quality index (GWQI). MAR can be utilized in mix with other supportable urban water approaches; for example, wastewater harvesting, storm-water collecting, saline groundwater interruption, and flood alleviation (Omosuyi & Oseghale 2012). Critically, MAR has a fundamental supporting part in accomplishing the targets for delicate metropolitan water plans, coordinated water cycles, sustainable drainage systems, low effect improvement, and green infrastructure by giving the huge volume of storage capacity with regards to water in urban areas. In the context of the above scenario, present study focuses on the water quality parameters of the groundwater in the area of Surat City, Gujarat, India.

OBJECTIVE OF THE STUDY

The objective of this study is to analyze the ground water quality using the Ground Water Quality Index (GWQI) in the South-West zone of Surat City and also predict the approximate groundwater quality for the next 10 years.

STUDY AREA

The city of Surat is situated at latitude 21°069 to 21°159 N and longitude 72°459 to 72°549 E on the banks of the Tapti River with the coastline of the Arabian Sea to the west, as shown in Figure 1. Surat city has 7 different zones including the South-West zone, as shown in Table 1. The South-West zone of Surat city is located on latitude 21.050 and longitude 72.684 on the shoreline of the Arabian Sea.

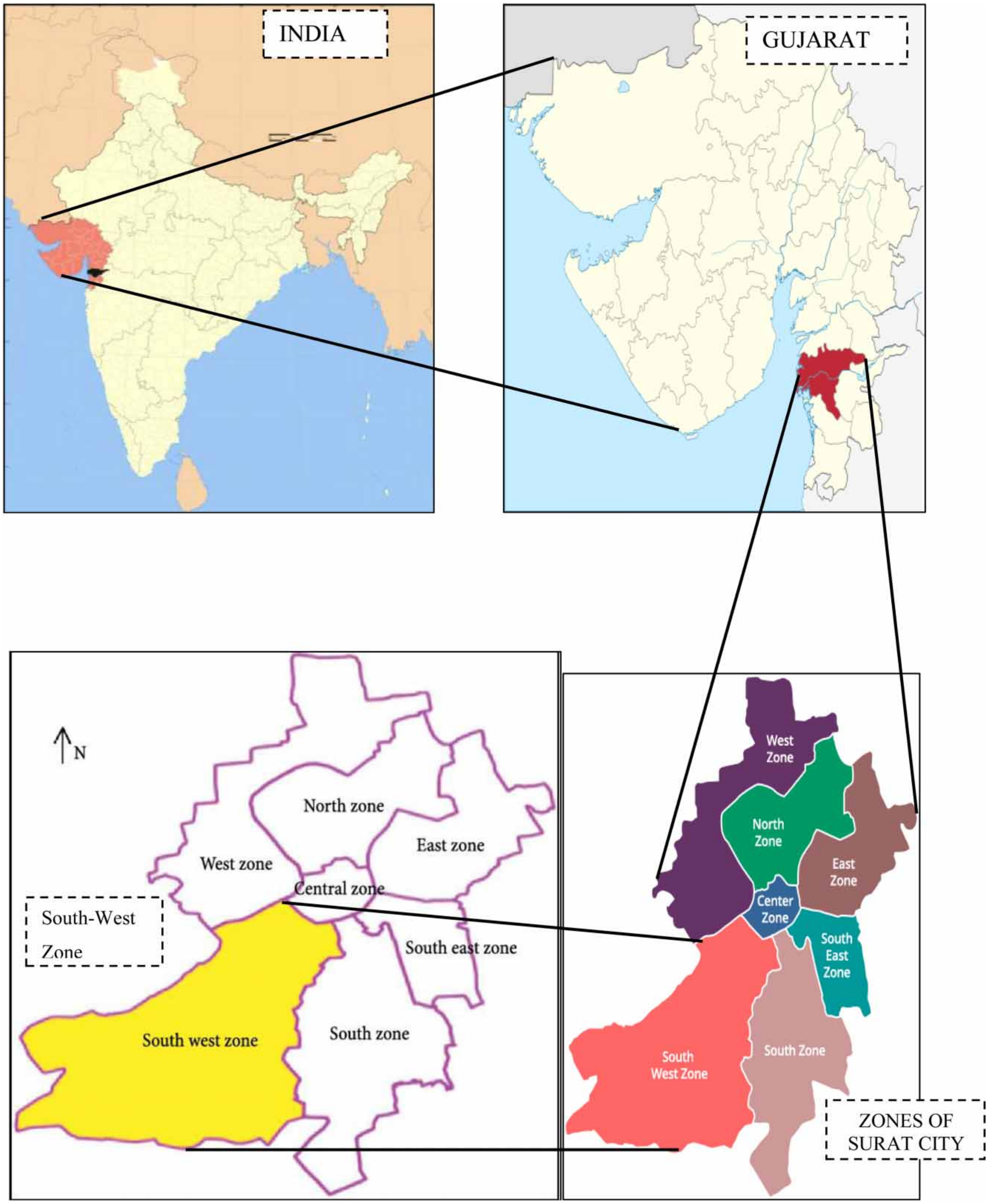

Figure 1 | Location of study area. (*Source*: Google Image).

Within the study domain, one of the major effects of tidal waves has been the degradation of groundwater quality. The study area situated on the shoreline of Dumas region of the Surat district, Arabian Sea, comprises a seaside plain with a fine, salt-influenced soil surface. The study zone also includes small villages, such as Abhva, Panas, Khajod, Bhatpor, and

Table 1 | Zone wise population and geographical area of Surat City

Sr. No	Zone	Area (sq. km)	Population Census 2011	Density per sq. km.	Decade growth 2001–2011 (%age)	Details of slum		Total no. of census houses	Total no. of households
						Slum house hold	Slum population		
1	Central	8.18	408760	49971	− 1.18	9889	49323	153638	80939
2	South West	111.912	347447	3105	43.30	7502	33982	114734	72437
3	South	61.764	695028	11253	70.36	17887	76025	251079	167629
4	South East	19.492	748304	38390	88.37	30051	147050	221643	155732
5	East	37.525	1137138	30303	59.82	21334	90992	313105	234327
6	North	36.363	705163	19392	69.36	13541	58293	201978	141898
7	West	51.279	424986	8288	48.00	5665	25993	130068	93344
Total		**326.515**	**4466826**	**13680**	**55.29**	**105869**	**481658**	**1386245**	**946306**

some more. Individuals who live there have the solitary resource of groundwater for drinking and domestic uses. Hence, the area is selected to investigate the quality of groundwater in the region. Groundwater quality in the study area has been contaminated to some extent by the presence of Electrical Conductivity (EC), Total Dissolved Solids (TDS), and chlorides at prevailing high concentrations including other major Ions. Groundwater quality degradation includes overexploitation of concentration of various chemical parameters leading to increased salinity as well as hardness.

DEMOGRAPHIC DETAILS

Urbanization, characterized as the increasing share of a country's population living in urban areas and subsequently a declining share living in rural areas (Satterthwaite *et al.* 2010), is quite possibly the most extreme type of human-induced land-use change resulting from the perplexing activities of different physical and economic factors. Urbanization leads to increased pressure on freshwater resources as individuals become more concentrated in one region through the change of once natural landscapes to urban a water-impermeable lands, which limits accessible freshwater resources (Sun *et al.* 2013). Presently, urban uses represent an average of 10–20% of the all-out water withdrawals in developing world basins, with demand increasing rapidly as an immediate consequence of population growth in urban areas (Srinivasan *et al.* 2013). This can be attributed to the fact that most of the growth in the world's population is taking place in urban areas in low and middle-income nations, and this is likely to continue. (Okello *et al.* 2015).

Groundwater is being extensively used to enhance the accessible surface water to meet this steadily expanding water demand, especially in the study area, where groundwater is a major source of drinking water for urban people who live in the closest town. Despite this, there is minimal quantitative data on groundwater resources on the landmass, with groundwater storage capacity being subsequently precluded from freshwater accessibility appraisal reports. While considering groundwater resources in areas lining oceans, coastal aquifers are a vital source of freshwater (Priyantha Ranjan *et al.* 2006). Freshwater stored in coastal aquifers is particularly susceptible to degradation due to its proximity to salty seawater, as well as higher population densities of coastal zones that lead to intensive water demand (Okello *et al.* 2015). Climate variations (that cause fluctuations in sea level) and groundwater pumping additionally force dynamic hydrologic conditions, which are related to the conveyance of disintegrated salts through water thickness salinity relationships.

DATA COLLECTION

Groundwater data collected from (India-WRIS n.d.) website for Sultanabad water measurement station from the year of 2006 to 2015, which represents the present study area, as shown in Table 2. Various (chemical parameters) data

Table 2 | Chemical parameters data collection from 2006 to 2015

IParameters	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Ca (mg/l)	40	68	64	52	92	64	80	36	44	44
Cl (mg/l)	234	341	284	206	178	163	135	152	128	135
Electrical conductivity (μs/cm)	1,540	1,815	1,668	1,425	1,250	1,505	1,230	1,304	1,074	1,140
F (mg/l)	0.2	0.15	0.12	0.14	0.17	0.15	0.35	0.3	0.2	0.35
Mg (mg/l)	77.85	80	71	90	41	58	63	63	60.84	60.84
NO_3 (mg/l)	40	19	22	46	37	34	26	17	28	32
SO_4 (mg/l)	32	75	83	14	36	50	79	86	37	54
Total hardness (mg/l)	420	500	450	400	400	400	410	350	360	360
TDS (mg/l)	1,031.8	1,216.05	1,117.56	954.75	837.5	1,008.35	824.1	873.68	719.58	763.8

Source: India-WRIS.

such as Ca: Calcium, Cl: Chlorine, EC: Electrical Conductivity, F: Fluoride, Mg: Magnesium, NO_3: Nitrate, SO_4: Nitrate, and TDS: Total Dissolved Solids were used to determine the Ground Water Quality Index (GWQI).

METHODOLOGY

In India, 7525 Groundwater quality measurement stations are being used to collect the water quality data across the country. Out of these, 668 stations are situated in different regions of Gujarat state. Currently, Surat city has 39 stations in the district and only one of them is situated in the study zone (Figure 2), which is Sultanabad station (India-WRIS n.d.).

Groundwater quality index (GWQI)

Water quality index is a rating strategy that considers the composite impact of individual water quality boundaries on the general nature of water for human utilization. A numerical instrument, the GWQI, can be utilized to charge enormous amounts of water quality information into a single number presenting the general water quality (Sharma & Patel 2010).

Calculation of groundwater quality index (GWQI)

A. The first step to develop the GWQI is to assign a weight or weightage factor (Gwi) to each parameter with a relative importance on the overall quality of water. The value of 5 is assigned to F, Cl, So_4 and TDS, which is the maximum weightage, the value of 3 is assigned to Ca, Mg and Total Hardness, the value of 1 and 2 is assigned to NO_3 and EC respectively, which reflect their importance on groundwater quality.

B. The second step is to determine Relative Weight (Gwr); calculating the ratio of Gwi and Total Gwi and the result of that is called the Relative Weight

$$\mathrm{Gwr} = \frac{Gwi}{\sum Gwi}$$

C. In the third step, a quality rating scale for every parameter was allocated by isolating the parameter's focus in each water test by its separate norm (Si), as indicated by the rules set out by the Bureau of Indian Standards (Standards), and afterwards multiplying the outcome by 100 (Environment)

$$\mathrm{qi} = \left(\frac{Ci}{Si}\right) \times 100$$

where,

- qi = quality rating
- Ci = concentration of every chemical parameter in each water in mg/L,
- Si = drinking water standard of India for each chemical parameter as indicated in the BIS 10500-2012

D. Compute the GWQI

Figure 2 | Location of well site and Water Quality Monitoring Station. (*Source*: Google Earth).

To compute the GWQI, the *SI*i is first determined for each chemical parameter as,

$$\mathrm{SIi} = \mathrm{Gwr} \times \mathrm{qi}$$

$$\mathrm{GWQI} = \Sigma \mathrm{SIi}$$

where, *SI*i is the sub-index of the i parameter and qi is the quality rating dependent on the concentration of the *i* parameter. The computed GWQI estimates were then relegated to one of five levels of water quality (Table 3) ranging from 'excellent' to 'unacceptable for drinking'.

Managed aquifer recharge (MAR)

Managed aquifer recharge (MAR) is the intentional recharge of water to suitable aquifers for subsequent recovery or to achieve environmental benefits. The process managed to assure adequate protection of human health and the environment. Common reasons for using MAR to support sustainable urban water management: selection of suitable sites for MAR and choice of method includes various factors such as hydrogeology, topography, hydrology, and land use within a given area. Besides, socio-cultural and regulatory factors can play a role, as well as source water type and availability (Page *et al.* 2018), as shown in Figure 3.

Table 3 | Classification of groundwater quality based on the GWQI

GWQI value	Water quality
<50	Excellent
50–100	Good
100–200	Poor
200–300	Very poor
>300	Unfit for drinking purpose

The following are some of the advantages of MAR methods:

- Preventing saltwater intrusion in coastal aquifers,
- Providing storage without loss of valuable land surface area,
- Reducing evaporation of stored water,

  The benefits of water recycling via aquifers in urban areas may include:

- Improving coastal water quality by reducing nutrient-rich urban discharges,

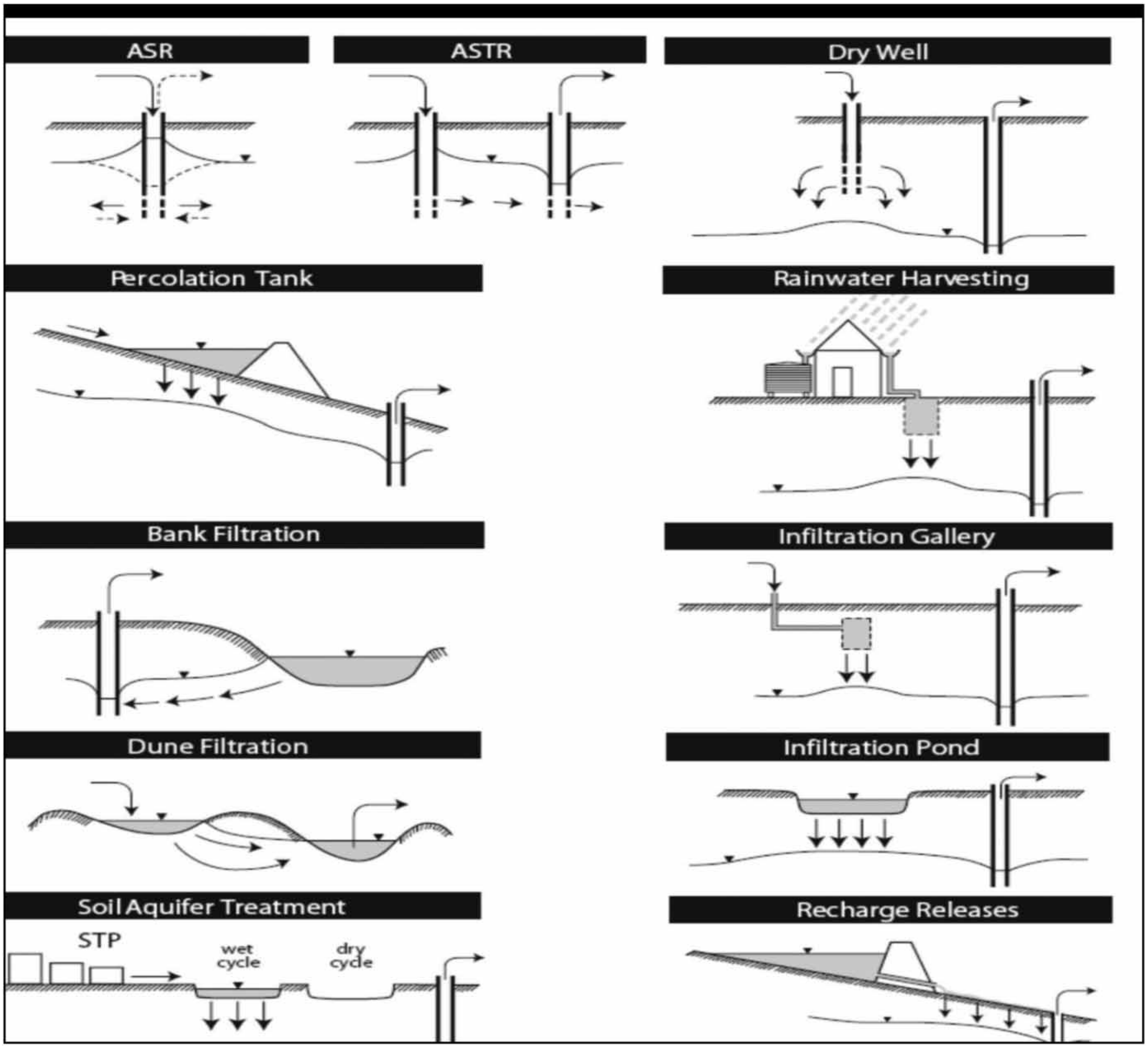

Figure 3 | Types of managed aquifer recharging (MAR) ASR – Aquifer Storage and Recovery; ASTR – Aquifer Storage Transfer Recovery; STP – Sewerage. (*Source:* Page *et al.* 2018).

- Mitigating floods and flood damage,
- Facilitating urban landscape improvements that increase land value,

E. Prediction of GWQI

$$Cr = \frac{(V1C1) + (V2C2)}{V1 + V2}$$

where,

C_r = the changed concentration of a specific groundwater quality parameter

V_1 = the amount of water accessible in the well

C_1 = the concentration of the viable parameter in the well water

V_2 = the amount of fresh water added to the well

C_2 = the concentration of the parameter under consideration for recharge

Find GWQI again with output values of Cr of each parameter using the same above steps. The last year's GWQI output values will be considered for next year's concentration values. A spreadsheet template was prepared in which all static data were entered. The groundwater quality improvement trend from 2015 to 2025 was derived by using the spreadsheet model.

RESULT AND DISCUSSION

Data were collected from the India-WRIS website from the concerned monitoring station from the year 2006 to 2015. The groundwater quality of the South-West zone of Surat city has been analyzed for a period of 10 years from 2006 to 2015. A statistical outcome of the analysis is shown in Table 5.

The above result indicates poor quality water is occurring in the study area. Study of recharge of the aquifer by the managed aquifer recharging (MAR) method was proposed. Evaluation of the GWQI including aquifer recharge and tentative improved outcomes were obtained, as shown in Table 6.

This was accomplished by identifying connections or relationships among groundwater factors of the zone. The connection grid assesses the relationship coefficients between groundwater hydro-geochemical factors. Positive and negative connections are considered for seeing how strong or weak linear relationships existed between groundwater parameters (Elubid *et al.* 2019). In Table 5 and graphically represented in Figure 4, respectively, hydro-geochemical factors have been introduced in Pearson's connection grid. The presence of an extreme connection (0.92) among electrical conductivity and Cl is credited to augmentation of dissolved constituents that points to increments in the electrical conductivity of the particles. Ca, F, Mg, NO_3, and SO_4 have solid positive connection coefficients with total dissolved and electrical conductivity showing their contribution to the development of dissolved particles in groundwater, along these lines, expanding the electrical conductivity of the ionized water. Poor correlations are additionally found among factors of significant particles (e.g. F and NO_3). Negative and poor correlation coefficients are seen among NO_3 and significant particles in the study area. (Kawo & Karuppannan 2018).

In the Managed Aquifer Recharge (MAR) method described, groundwater quality will improve with recharge into the aquifer with fresh water. Compared to GWQI values of Tables 4 and 5, observe that GWQI values decrease constantly. As in the above BIS standard, we will

Table 4 | Parameters concentration and volume of water at the existing level and recharge

Parameters	Existing elevation of water	Recharge water
Ca	44	20
Cl	135	70
EC	1140	195
F	0.35	0.2
Mg	60.84	7
NO3	32	11
SO4	54	60
Total Hardness	360	50
TDS	763.8	130

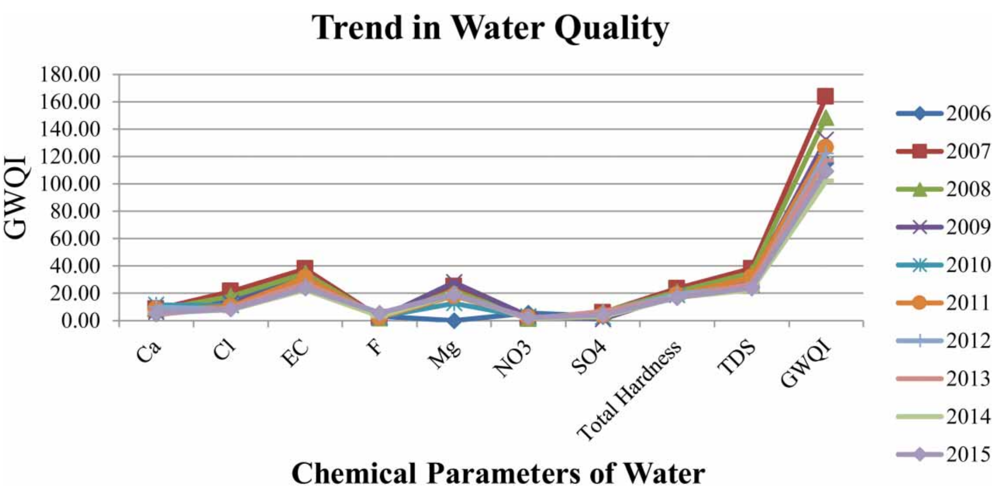

Figure 4 | Average changes in Water Quality from years 2006 to 2015.

Table 5 | GWQI for each parameter from 2006 to 2015

Year	Ca (mg/Lit)	Cl (mg/Lit)	EC (μs/cm)	F (mg/Lit)	Mg (mg/Lit)	NO_3 (mg/Lit)	SO_4 (mg/Lit)	Total Hardness (mg/Lit)	TDS (mg/Lit)	GWQI
2006	5.00	14.63	32.08	3.13	0.03	5.41	3.13	19.69	32.24	115.32
2007	8.50	21.31	37.81	2.34	25.00	1.32	5.86	23.44	38.02	163.60
2008	8.00	17.75	34.75	1.88	22.19	1.53	6.48	21.09	34.92	148.59
2009	6.50	12.88	29.69	2.19	28.13	3.19	1.09	18.75	29.84	132.25
2010	11.50	11.13	26.04	2.66	12.81	2.57	2.82	18.75	26.17	114.44
2011	8.00	10.19	31.35	2.34	18.13	2.36	3.91	18.75	31.51	126.54
2012	10.00	8.44	25.63	5.47	19.69	1.81	6.17	19.22	25.75	122.17
2013	4.50	9.50	27.16	4.68	19.68	1.18	6.71	16.41	27.30	117.14
2014	5.50	8.00	22.38	3.13	19.01	1.94	2.89	16.87	22.48	102.20
2015	5.50	8.43	23.75	5.46	19.01	2.22	4.21	16.87	23.86	109.35

Table 6 | Correlation matrix of analyzed groundwater quality parameters

	Ca	Cl	EC	F	Mg	NO_3	SO_4	Total Hardness	TDS
Ca	1								
Cl	0.15	1							
EC	0.13	0.92	1						
F	– 0.20	– 0.62	– 0.62	1					
Mg	0.12	0.11	0.09	– 0.10	1				
NO3	– 0.22	0.02	0.05	– 0.16	– 0.72	1			
SO4	0.08	0.21	0.27	0.33	0.16	– 0.62	1		
Total Hardness	0.44	0.90	0.87	– 0.53	0.12	– 0.01	0.25	1	
TDS	0.13	0.92	1	– 0.62	0.09	0.05	0.27	0.87	1

get the approximate good quality of water after 10 years with specific recharge (GWQI < 50), as shown in Table 7 and graphically represented in Figure 5, respectively.

CONCLUSION

The water quality index is helpful in the assessment and management of water quality. The present investigation represents the groundwater quality assessment for the South-West Zone of Surat City.

- It highlights the salient features of various important chemical parameters acting upon the general water quality. The baseline data generated in these investigations and their analysis and interpretation will go a long way in improving our understanding and knowledge base about the status of water quality of a socio-economically vital fluvial system.
- The study has both academic value and practical significance. Based on the observed WQI results it can be concluded that the respectably high concentrations of EC, TDS, Cl, SO_4, NO_3, and F and so on in groundwater were found close to landfill, which disintegrates its quality for drinking and other homegrown purposes.
- The result of this study indicates that ground water quality occurs in the poor' range as per BIS standards.
- Outcomes of this study recommended improving groundwater quality before additional corruption by effective treatment measures to the aquifer of the South-West zone of Surat city, water quality by defining an appropriate water quality management plan, which in turn will support any plan for sustainable recharge.

Table 7 | Anticipated trends in water quality after aquifer recharge

Year	Ca (mg/Lit)	Cl (mg/Lit)	EC (μs/cm)	F (mg/Lit)	Mg (mg/Lit)	NO_3 (mg/Lit)	SO_4 (mg/Lit)	Total Hardness (mg/Lit)	TDS (mg/Lit)	GWQI
2016	4.75	7.36	19.56	4.81	15.51	1.88	4.03	13.82	19.66	91.38
2017	4.75	7.36	19.56	4.81	15.51	1.88	4.03	13.82	19.66	91.38
2018	4.43	6.90	17.79	4.53	14.03	1.74	3.94	12.54	17.88	83.79
2019	4.14	6.49	16.21	4.28	12.71	1.61	3.87	11.38	16.29	77.00
2020	3.89	6.13	14.80	4.06	11.53	1.50	3.81	10.35	14.87	70.93
2021	3.66	5.80	13.53	3.86	10.47	1.40	3.75	9.43	13.59	65.50
2022	3.46	5.51	12.40	3.68	9.53	1.30	3.70	8.61	12.46	60.65
2023	3.28	5.25	11.39	3.52	8.68	1.22	3.65	7.87	11.44	56.30
2024	3.11	5.02	10.49	3.38	7.93	1.15	3.61	7.21	10.53	52.42
2025	2.97	4.81	9.68	3.25	7.25	1.08	3.57	6.62	9.71	48.94

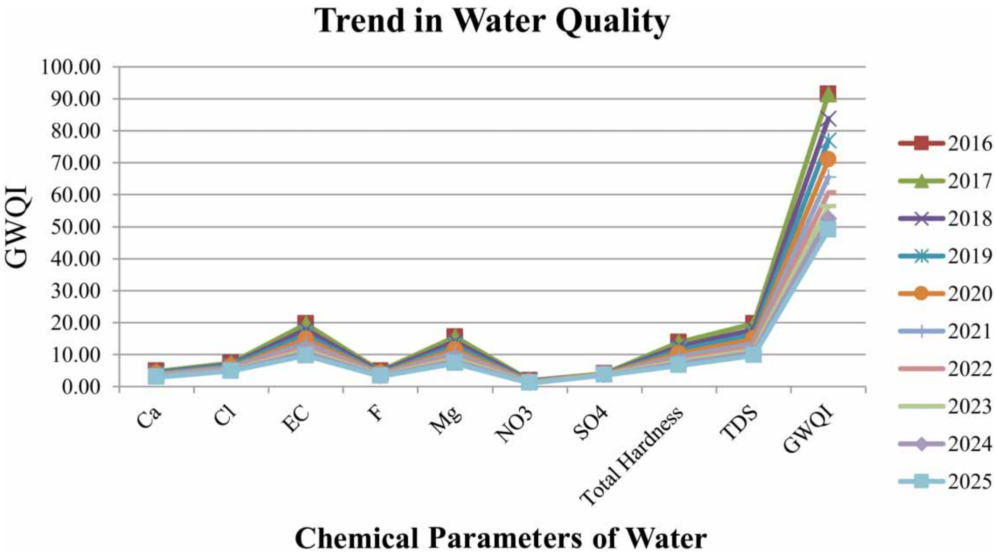

Figure 5 | Average changes in water quality from years 2016 to 2025.

- Water quality of the study area needs to be restored, as given in the planning proposal for artificial recharge or there is a need to decrease groundwater contaminants by adopting measures like restricting inflows of raw sewerage from residential/commercial establishments, limiting direct discharge from storm-water drains and preventing unabated dumping of solid waste by residing communities.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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