Chapter-IV

Water Quality Index

4.1 Introduction:

Water is the most valuable resource on the earth and currently is of global concern (Villeneuve et al., 1990; Isa et al., 2012). It plays a major role in water supply, ecosystem functioning and human well-being (Sheikhy Narany et al., 2014), and at the same time is one of the essential natural resources which has extensive uses. This resource is sometimes inadequate, sometimes plenteous and is always very unevenly distributed, both in space and time. It is utilized for domestic, industrial and agricultural purposes. In recent times, its usage has increased and the trend will continue. The physical and chemical composition of surface and sub-surface water varies over space and time. It depends on many factors such as atmospheric precipitation, in-land surface water, geological formation and anthropogenic activities (Ramesh & Elango, 2006; Vasanthavigar et al., 2010). All these factors jointly affect water quality which changes spatially and temporally. Globally, surface and sub-surface water is being exploited due to the rapid increase of industries, agriculture, irrigation and drinking purposes (Boyacioglu & Boyacieoglu, 2010). The over-exploitation of the resource might be a greater threat to water quality. In addition, excessive pumping, industrial and domestic waste disposal, inappropriate land use, air pollution and wastewater discharge contribute to contaminating the water which adversely affects the quality of surface as well as sub-surface water. Thus, surface and sub-surface water quality is an important issue that needs to be monitored and evaluated for the sustainability of water and human health. Water Quality Index (WQI) is one of the most efficient methods for the detection and monitoring the surface and sub-surface water quality. In addition, the WQI method has been widely used to indicate water quality for drinking and also for irrigation (Asadi et al., 2007). The present work assesses surface and sub-surface water quality assessment in the Surat-Bharuch Industrial region. This region has many industries (small and large scale), therefore, it is presumed industrial wastewater contains a significant amount of soluble inorganic and organic chemicals and their by-products.

4.2 Literature Review for Water Quality:

Dong et al., (2007), has made an attempt on, "Environmental Characteristics of Groundwater: An Application of PCA to Water Chemistry Analysis in Yulin". This study tested 76 typical water samples and applied Principal Component Analysis techniques. Seven PCA were extracted which respectively accounted for 37.4%, 13.0%, 8.1%, 7.2%, 6.3%, 5.9% and 4.6% of the total variation. The results showed that the groundwater environment of this region was largely controlled by natural and anthropogenic factors.

Gupta et al., (2008), analyzed a study on, "Geochemistry of Groundwater, Burdwan District, West Bengal, India". This study examined its suitability for drinking as well as for irrigation. 49 groundwater samples were collected from various sources like bore wells, handpumps etc. and water parameters like Ca^2+, Mg^2+, Na+, K+, $CO3^{2-}$, HCO^{3-}, Cl^-, $SO4^{2-}$ and NO^{3-}were analysed. The outcome of study stated that most of the samples were suitable for drinking.

Ayenew, (2008), focused on the "The Distribution and Hydrogeological Controls of Fluoride in the Groundwater of Central Ethiopian Rift and Adjacent Highlands." In this study, the distribution of fluoride in groundwater was investigated and the outcome indicated extreme spatial variations in the element and its effect on human health.

Kannan & Joseph, (2009), focused on the "Quality of Groundwater in the Shallow Aquifers of a Paddy dominated Agricultural River Basin, Kerala, India". In this study, water samples were collected in three seasons (Monsoon, Post monsoon and Pre monsoon). Spatio-temporal variations were observed in the study area and different hydrochemical parameters were identified.

Kumar et al., (2009), has analyzed a study on, "Assessment of Groundwater Quality and Hydrogeochemistry of Manimuktha River Basin, Tamil Nadu, India". The study assessed the groundwater quality with the help of twenty six bore well water samples. They concluded that groundwater quality changed due to man-made activities like agriculture and natural influences such as weathering.

P & K, (2010), in "Assessment and Spatial Distribution of Quality of Groundwater in Zone - II and III, Greater Visakhapatnam, India Using Water Quality Index (WQI) and GIS" demarcated the zone of groundwater quality with the help of geospatial technology, applying

Inverse Distance Weighted (IDW) Raster Interpolation technique in ArcGIS platform. The results concluded that due to the influence of sewage, saltwater intrusion, industrial and high urban concentration, the groundwater quality was not suitable for drinking.

Reza & Singh, (2010), have examined the "Assessment of Ground Water Quality Status by Using Water Quality Index Method in Orissa, India." Twentyfour groundwater samples were collected from different sources viz. open and tube wells during summer and post-monsoon seasons. WQI was mainly affected by the concentration of dissolved ions (F^-, NO_3 , Ca^2+ and Mg^2+) in ground water. In the post monsoon higher concentration of dissolved solids was observed which exhibited poor quality of water as compared to summer.

Bu et al., (2010), analysed a study on, "Water Quality Assessment of the Jinshui River (China) Using Multivariate Statistical Techniques." This study examined that water quality and evaluated aquatic ecosystem health of the Jinshui River using Multivariate Statistical techniques viz. cluster and factor analysis.

Garizi et al., (2011), made a study on, "Assessment of Seasonal Variations of Chemical Characteristics in Surface Water using Multivariate Statistical Methods". This study evaluated the seasonal changes in water quality of surface water. For the study, multivariate statistical techniques were used including variance, discriminant analysis, principal component analysis and factor analysis. 12 parameters were recorded and evaluated for the years 1995 and 2008. The results showed that surface water quality has significantly changed with the season.

Dar et al., (2011), proposed a study on, "Investigation of Groundwater Quality in Hardrock Terrain using Geoinformation System". The present study, was intended to determine geochemistry of the groundwater and to evaluate the overall physico-chemical characteristics. The results showed that most of the area was contaminated by higher concentration of EC, TDS, K^+ and NO^{-3}. This water can be utilized for irrigation purposes.

Pius et al., (2012), made a study on, "Evaluation of Groundwater Quality in and around Peenya Industrial Area of Bangalore, South India Using GIS Techniques." In this study, for WQI ten physico-chemicals parameters were taken and GIS environment was used for monitoring the groundwater quality in the study area. The WQI varied from 49 to 502 which was observed over entire the region. High index value indicated high level of contamination.

Nirmal Kumar et al., (2012), made an analysis of "Assessment of Water Physico-Chemical Characteristics and Statistical Evaluation of Narmada Estuarine Region, Gujarat, India". The paper investigated the physico-chemical parameters of Narmada estuary such as temperature, pH, salinity, dissolved oxygen during July 2008 to June 2009. The results from the factor analysis, indicated two major factors controlled the hydro-chemistry of this region.

Soni & Thomas, (2013), worked on the "Assessment of Surface Water Quality in Relation to Water Quality Index of Tropical Lentic Environment, Central Gujarat, India". The main objective of the study was to assess the various water quality parameters and calculate the Water Quality Index for the tropical aquatic body. pH, Dissolved Oxygen (DO), Total Dissolved Solids (TDS), Calcium Hardness (Ca), Sodium and Potassium, were analyzed for Water Quality Index (WQI). Surface water quality which was unfit for human consumption, and requires measures for the improvement were the prominent findings of the study.

Taheri Tizro et al., (2014), carried out a study on, "Spatial Variation of Groundwater Quality Parameters: A Case Study from a Semiarid Region of Iran." This paper analyzed the spatial variation of groundwater quality that was collected from an unconfined aquifer and interpreted some of the chemical parameters such as EC, SAR, etc. The IDW method was applied in this study for the better-visualized Kriging,.

Upadhyaya et al., (2014), worked on the, "Occurrence and Distribution of Selected Heavy Metals and Boron in Groundwater of the Gulf of Khambhat region, Gujarat, India." The study focused on the Gulf of Khambhat and employed factor analysis for the identification of heavy metals in groundwater.

Pandey & Kumar, (2015), examined the "Spatio-Temporal Variability of Surface Water Quality of Freshwater Resources in Ranchi Urban Agglomeration, India using Geospatial Techniques". This analysis focused on the surface water quality of major rivers and reservoirs during pre-and post-monsoon periods. The outcome of the research indicated an increase in chemical contaminants and reduction in the biological contaminants in monsoon period.

P. Kumar et al., (2017), have made an attempt on, "Evaluation of Aqueous Geochemistry of Fluoride Enriched Groundwater: A Case Study of the Patan district, Gujarat, Western India". This study examined that high fluoride in groundwater leads to deformation of bones and bilateral lameness. For the identification of occurrence of fluoride in groundwater factor analysis was applied.

Mostafa et al., (2017), had carried out a study on, "Assessment of Hydro-geochemistry and Groundwater Quality of Rajshahi City in Bangladesh". This study highlighted the hydro-geochemistry and groundwater quality in the Rajshahi City of Bangladesh during pre-monsoon, monsoon and post-monsoon seasons. The study found that the rock–water interaction was the major geochemical process controlling the chemistry of groundwater in the region.

Lkr et al., (2020), made a study on, "Assessment of Water Quality Status of Doyang River, Nagaland, India, using Water Quality Index". This study assessed the water quality in the pre-monsoon and post-monsoon seasons. Physico-chemical parameters such as pH, DO and BOD played an important role in affecting the water quality. The maximum percentage of water was of good quality which can be used for different human uses.

Jha et al., (2020), worked on **"**Assessing Groundwater Quality for Drinking Water Supply Using Hybrid Fuzzy-GIS-Based Water Quality Index**."** The concentrations of Ca^2, Mg^2 and SO^4 in groundwater were observed with respect to the desirable limits set by WHO for drinking water, during pre-monsoon and post-monsoon seasons. The concentrations of seven parameters (TDS, $NO_{3,}$ N^+, Cl, K^+, F^- and Hardness) exceeded the permissible limits.

4.3 Chemistry of Water:

The chemistry of surface water is commonly used to assess trace element pollution in aquatic environment (B. Kumar et al., 2010). The surface water chemistry differs with the seasons. It also varies over time.The surface water characteristics depends on rainfall, runoff, weathering of crustal materials, etc. and also on anthropogenic influences (agricultural activities, industrial effluents, urban waste disposal).The quality of surface water in an inland water body has a tremendous effect on the sub-surface water table and sub-surface water quality of surrounding aquifers (Ravikumar et al., 2013).

The chemical composition of sub-surface water depends on several factors, such as geological formation, chemical weathering of rocks, quality of recharge rate, frequency of rainfall, presence of organic matter etc. (Paul et al., 2019). Complex sub-surface water quality is responsible for such factors and their interactions which varies over space and time. The concentrations of the chemical constituents in the sub-surface water are comparatively higher than the rainwater which denotes that the dissolution of salts and other mechanisms change the rainwater chemical composition during infiltration into the sub-surface water (Adams et al., 2001).

4.4 Water Quality Index (WQI):

Water Quality Index (WQI) is defined as an aggregate indices rating which reflects the composite influence of different water quality parameters (Horton, 1965; Şener et al., 2017; Sahu & Sikdar, 2008). In other words, this method is a mathematical equation which is primarily used for data reduction of a large number of water parameters into a single number to evaluate the overall water quality at a specific location (Zhang et al., 2019). WQI is a highly effective and efficient tool for measuring water quality (Srivastava et al., 2011). It provides information that is simple and understandable for decision-makers about overallwater quality (Reza & Singh, 2010). It generates a score (zero to hundred) and this score illustrates the water quality status. The index allows the comparison of different sampling sites.The Bureau of Indian Standards (BIS) standards for drinking purposes were considered for the interpretation of WQI.

4.4.1 WQI Calculation:

Finally, Water Quality Index was computed using the 5 measured parameters at each site. For the calculation of WQI the average value of two same seasons viz., pre-monsoon (2016 and 2017), monsoon (2016 and 2017) and post-monsoon (2015 and 2016) was considered.

Weighted Arithmetic Index method developed by Horton's (1965) and Brown et al. (1970) was applied using the following equation;

$$\text{WQI} = \frac{\sum q_n . w_n}{\sum w_n}$$

Where, q_n = Quality rating of nth water quality parameter, W_n = Unit weight of nth water quality parameter (Table 4.1).

Table 4.1 Water Quality Parameters, Weight and Standards of Each Parameter Used in WQI Determination

S.No	Name of Parameters	Recommended Agency	Standards (Sn)	Weightage (Wn)
1	pH	BIS	8.5	0.103
2	TDS (mg/l)	BIS	500	0.002
3	Calcium (mg/l)	BIS	75	0.012
4	Sodium (mg/l)	WHO	200	0.004
5	Fluoride (mg/l)	BIS	1	0.879

Source- Bureau of Indian Standards (BIS, 1991), World Health Organization (2011)

Quality Rating (q_n)

The quality rating **(q_n)** is calculated using this equation

$$q_n = [(V_n - V_{id})/(S_n - V_{id})] \times 100$$

Where,

V_n = Estimated value of nth water quality parameter at a given sample location.

V_{id} = Ideal value for nth parameter in pure water. (V_{id} for pH = 7 and 0 for all other parameters)

S_n = Standard permissible value of nth water quality parameter.

Unit weight

The unit weight (W_n) is calculated using the expression given in the following equation.

$$W_n = k / S_n$$

Where,

S_n = Standard permissible value of nth water quality parameter.

k = Constant of proportionality and it is calculated by using the expression given in Equation.

$$k = [1/ (\sum 1/ S_{n=1,2,..n})]$$

On the basis of above calculations the water quality was rated as excellent, good, poor, very poor and unfit for human consumption (Table 4.2).

Table 4.2 Water Quality Index (WQI) and Status of Water Quality

Water Quality Index Level	Water Quality Status	Probable Usage
0-25	Excellent water quality	Drinking, irrigation and industrial purpose
26-50	Good water quality	Drinking, irrigation and industrial purpose
51-75	Poor water quality	Irrigation and industrial purpose
76-100	Very Poor water quality	For irrigation purpose
Above 100	Unfit for drinking	Proper treatment required for any kind of usage

Source- Chatterji and Raziuddin 2002

4.5 Water Quality Parameters:

4.5.1 pH:

pH is the measure of the number hydrogen ion concentration in an aqueous solution and indicates whether the water is acidic or alkaline. It is also defined as the negative logarithm of the hydrogen ion concentration expressed in moles/liter in water. Water is taken into account as ‘acidic’ when the pH is below 7 and ‘basic’ when it is more than 7. Water with a pH value of 7 is termed as ‘neutral’. It has no direct adverse impact on health. The pH of the water is influenced by the various dissolved constituents. When acidic waters interact with certain chemicals and metals, they make them more poisonous than neutral. The pH level has an extreme effect on all body organisms, health and disease (Avvannavar & Shrihari, 2008).

4.5.2 Total Dissolved Solids (TDS):

Total Dissolved Solids are the total amount of the cations and anions in water. Calcium, magnesium, fluoride, carbonate, bicarbonate, chloride, phosphate, nitrate, sulfate, sodium and potassium are the compounds of Ions which usually constitute TDS. In water, a higher amount of TDS concentration reduces the water transparency and minimizes the rate of photosynthesis. To determine the suitability of water for any use, it is necessary to distinguish the water by its Physico-chemical properties based on TDS values (Freeze and Cherry, 1979). A high concentration of TDS in the water depends on the originating source. It may pass through soils that contain high soluble salts or minerals that have higher TDS levels. High concentrations of TDS also come from natural sources agricultural runoff, industrial wastewater and urban sewage and industrial wastewater.

4.5.3 Calcium (Ca):

Calcium (Ca) is found naturally in water bodies and its concentration is mostly determined by the carbonate balance (Potasznik & Szymczyk, 2015). It is also the reason for water hardness. It has no adverse biological effects on the human system, however, some researches state that it plays a role in heart disease (Kumaresan, 2006; Mohammed, 2013). Food is the principal source of calcium and it is also a vital element for the health particularly for the functioning of nerves and muscle tissue. Dairy products are good sources of calcium and contribute over 50% of the total calcium.

4.5.4 Sodium (Na):

Sodium is a highly soluble chemical element that is naturally found in water (Sayyed & Arjun, 2011). In general, all sub-surface water contains little amount of sodium, however, the most common sources are naturally occurring brackish water of some aquifers, saltwater intrusion into wells in coastal areas, road salt storage and application, agricultural runoff and precipitation leaching through soils, water pollution by sewage effluent, landfill and industrial sites. High intake of sodium may cause many health problems including high blood pressure, hypertension and heart disease or kidney problems.

4.5.5 Fluoride (F):

In general, fluoride (F) occurs as a natural constituent. High concentration of fluoride in water determines that bedrock containing fluoride minerals, temperature, pH, depth, porosity, the capacity of ion exchange in aquifer materials and the concentration of carbonates and bicarbonates in the water (Selvam et al., 2013; Sajil Kumar & James, 2013; Pradesh, 2016). Other originating sources of fluoride in water are runoff and infiltration of chemical fertilizers from agricultural areas, liquid waste from the industrial sector and septic and sewage treatment system. The desirable range of fluoride in drinking purposes is 0.6–l mg/l, with permissible up to 1.5 mg/l (BIS 1992). According to the Ministry of Water Resource data, 18 of Gujarat's 26 districts have crossed the permissible limit set in subsurface water by BIS of fluoride concentration. Among the 19 states Gujarat ranks 5th with high fluoride content in sub-surface water (Pradesh, 2016).

Fluoride is a widespread natural element that enters in body through several ways like water, food, industrial exposure, cosmetics and drugs etc. (Ghaderpoori et al., 2019). Subsequently, a very small quantity of fluoride in the diet is important to the growth of strong bones and teeth but excessive fluoride has a pernicious effect on human health such asdental fluorosis, skeletal fluorosis, deformation of ligaments and bending of the spinal column (Sajil Kumar & James, 2013).

4.6 WQI Results and Evaluation of Surface Water:

4.6.1 Pre-monsoon:

In this study, WQI values ranged from 11.11 to 162. WQI between 0-25 was noted in 5.59% of samples and it spread over 2.01% area. During pre-monsoon season, this range was found in small pockets in the north-western part of the study area. 26-50 WQI range was noted in 17.48% samples and they were spread over 14.48% of the area. This range was observed in the north-eastern and southern parts of the study region. 25.18% of samples were under the range of 51-75 and they covered 30.75% of the area. This range of water is considered as a “Poor Water Quality”. This range was largely observed in the north-eastern, central and southern parts of the region. As per the BIS, this type of water quality can be used for industrial and irrigation purposes. The WQI range of 76-100 was observed in 23.78% of samples and was spread over 24.92% area. It was seen in the north-western and central parts. This range of water quality is “Very poor”. 27.97% of samples were in the range of >100 depicting water quality as “Unfit for Drinking”. It was spread over 24.82% of the area (Table 4.2). WQI based spatial variation

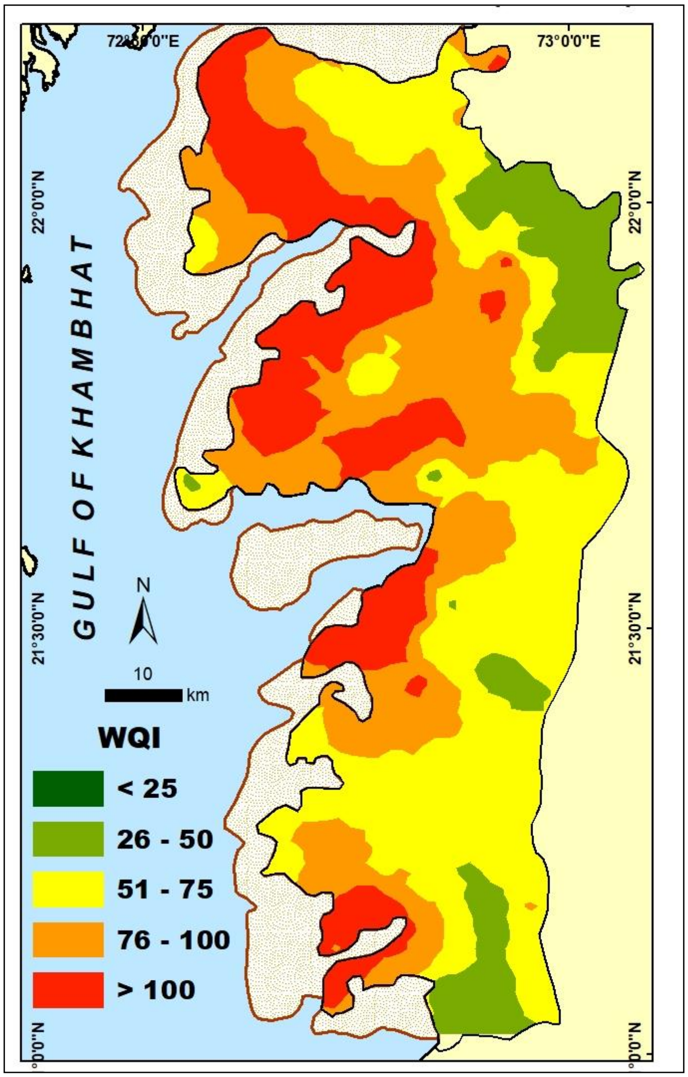

Fig. 4.1 WQI of Pre-monsoon Season (Surface Water)

map (Fig.4.1 and Fig. 4.2) represented, that the range was largely found in the extreme western and southern parts.

Table 4.3 WQI of Pre-monsoon Season (Surface Water)

WQI range	Explanations	Sample (%)	Area in (%)
0-25	Excellent Water Quality	5.59	2.01
26-50	Good Water Quality	17.48	14.48
51-75	Poor Water Quality	25.18	30.75
76-100	Very Poor Water Quality	23.78	24.94
Above 100	Unfit For Drinking	27.97	27.82
Source- Computed		100	100

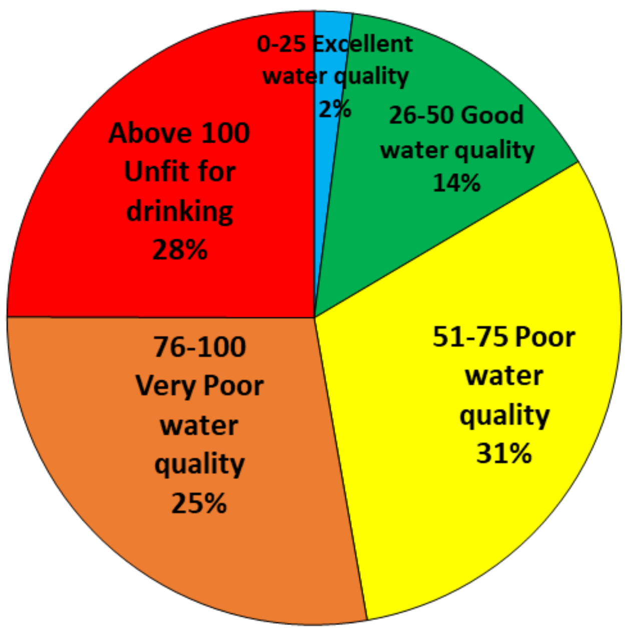

Fig.4.2: WQI Category Wise Percentage of Distribution for Pre-monsoon Season (Surface Water).

4.6.2 Monsoon:

In this study, WQI values ranged from 13.33 to 114.22. WQI between 0-25 was noted in 6.29% samples and it was spread over 1.98% area (Table 4.3). This range occupied a very small area. 26-50 WQI range was noted in 29.37% samples and they were spread over 28.96% of the area. This category was found in north-eastern, central and southern parts of the region. The WQI range of 51-75 was noted in 37.76% samples which were spread over 48.12% of area. This range was observed in the entire region. The WQI range of 76-100 was observed in 20.98% samples and was spread over 17.45% area. It was seen in the northern, central and southern parts. 5.59% of samples were in the range of >100 representing water quality as "Unfit for Drinking". It was spread over 3.50% of area (Fig 4.3 and Fig. 4.4).

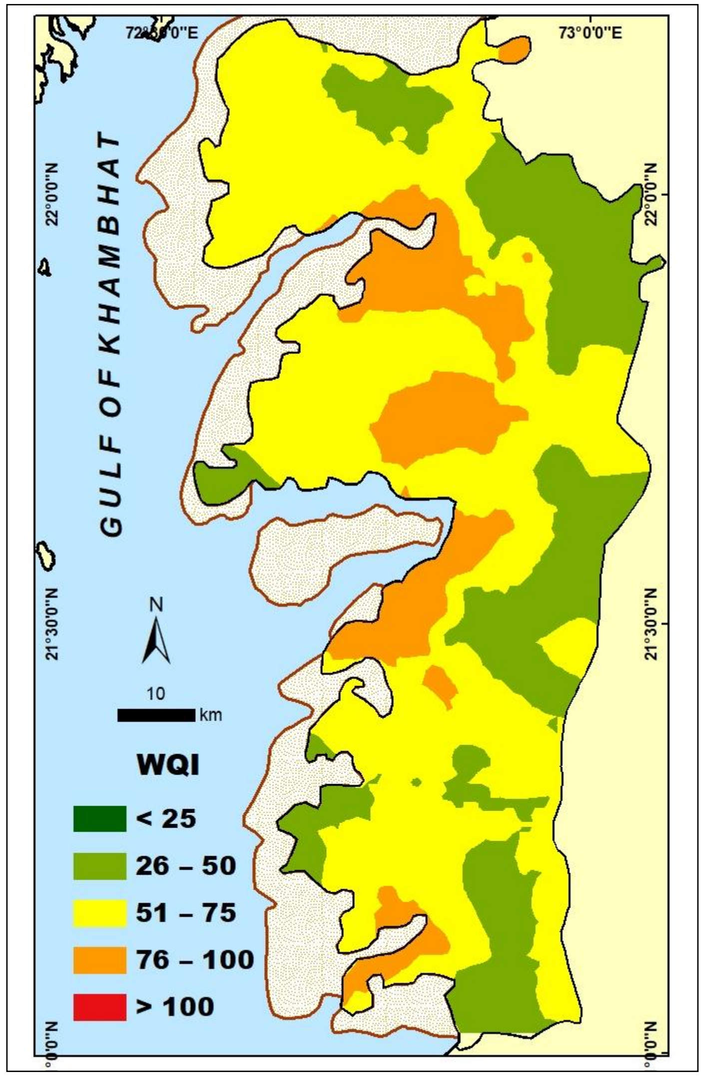

Fig. 4.3 WQI of Monsoon Season (Surface Water)

Table 4.4 WQI of Monsoon Season (Surface Water)

WQI range	Explanations	Sample (%)	Area in (%)
0-25	Excellent water quality	6.29	1.98
26-50	Good water quality	29.37	28.96
51-75	Poor water quality	37.76	48.12
76-100	Very Poor water quality	20.98	17.45
Above 100	Unfit for drinking	5.59	3.5
Source- Computed		100	100

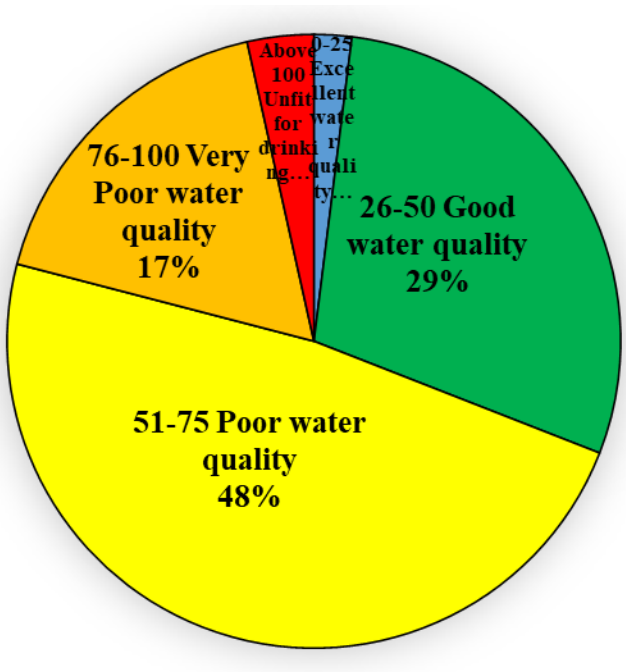

Fig. 4.4: WQI Category Wise Percentage of Distribution for Monsoon Season (Surface Water).

Kadodara, Surat District

4.6.3 Post-monsoon:

In this study, WQI values ranged from 11.90 to 152.22. WQI between 0-25 was noted in 6.99% samples and it spread over 1.06% area (Table 4.4). This range was found in small pockets at Mangrol, Intola, Muler Shamba, Malpore villages which is located in north-eastern part Hansot, Sayan, Rohid, Rayma villages as well as in central parts of the region. 26-50 WQI range was noted in 24.48% samples and they were spread over 25.55% of the area. This category was largely observed in the north-eastern, central and southern parts of the study area. 31.47% samples had the range of (51-75) and can be considered as "Poor Water Quality". They covered 38.63% of the area. This range was found in the entire region as continuous patches. The WQI range of 76-100 was observed in 25.18% samples and was spread over a 28.19% area. It was largely observed in the north-western, central and southern parts where major industries are located. This range of water quality is "Very Poor". In this season, 11.89% samples were in the range of >100 representing water quality as "Unfit for Drinking". It was spread over 6.57% of the area (Fig. 4.5 and Fig. 4.6).

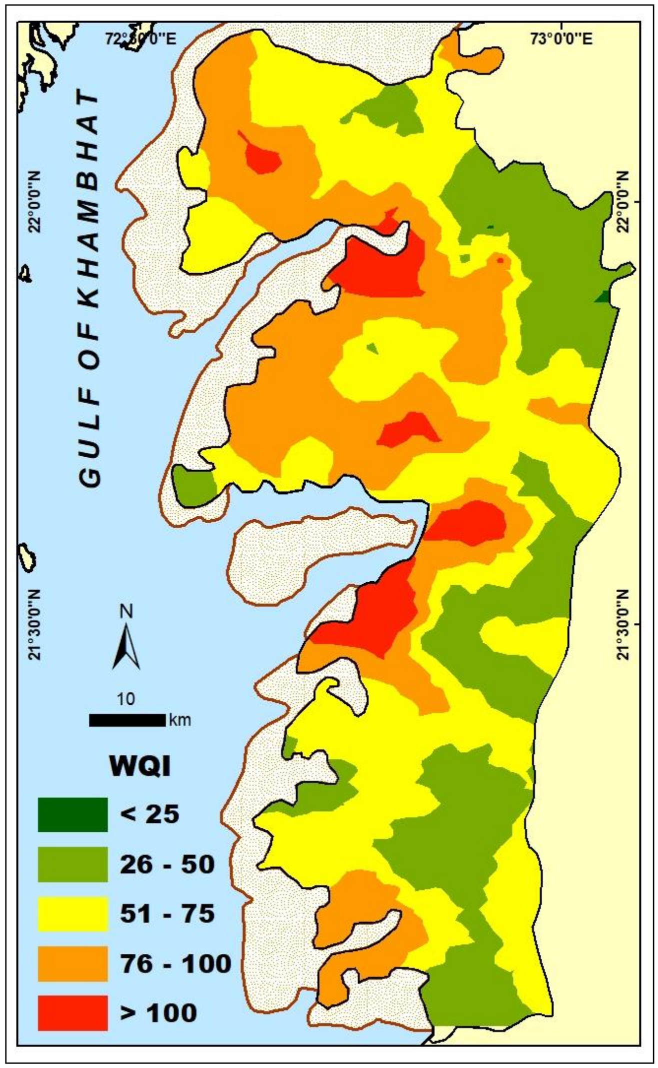

Fig. 4.5 WQI of Post-monsoon Season (Surface Water)

WQI range	Explanations	Sample (%)	Area in (%)
0-25	Excellent water quality	6.99	1.06
26-50	Good water quality	24.48	25.55
51-75	Poor water quality	31.47	38.63
76-100	Very Poor water quality	25.18	28.19
Above 100	Unfit for drinking	11.89	6.57
Source- Computed		100	100

Table 4.5 WQI of Post-monsoon Season (Surface Water)

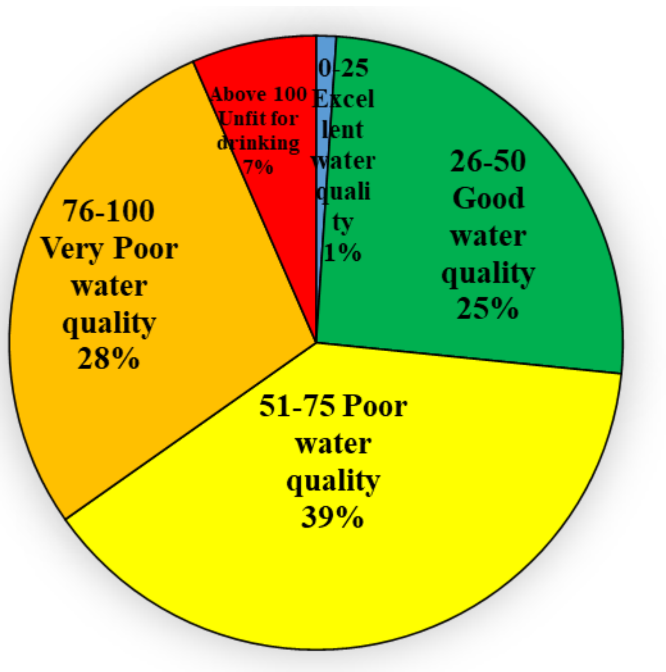

Fig. 4.6: WQI Category Wise Percentage of Distribution for Post-monsoon Season (Surface Water).

4.7 Comparison of WQI (Surface Water):

4.7.1 Pre-monsoon to Post-monsoon:

Area-wise variation was observed between pre-monsoon and post-monsoon seasons. In post-monsoon season, 0-25 WQI range was noted in 1.06% area which was 2.01% in pre-monsoon. WQI of 0-25 in post-monsoon was located in north-eastern part whereas, in pre-monsoon season, these smaller patches were found in north-western part. This category of water is used for industries, domestic and agricultural purposes. The area of the WQI category of 26-50 was higher in post-monsoon season as compared to the pre-monsoon. The area was 25.55% in post-monsoon but in pre-monsoon it occupied 14.48% of the area. These changes were largely observed in the central and south-eastern parts of the study area. The next category with 51-75 WQI was observed in 30.75% area in pre-monsoon and 38.63% in post-monsoon which illustrated a decrease of 7.88% area in the pre-monsoon season. In post-monsoon, this category was mostly found in north-eastern, central and southern parts whereas during pre-monsoon this category was more conspicuous from central to southern parts. In another category of WQI (76-100), which is the 'very poor quality' can be utilized only for agricultural uses. However, the variation of the area in both the seasons was low. In the pre-monsoon season it was noted in 24.94% area and in the post-monsoon in 28.19%. WQI (>100) was noted in 27.82% area in pre-monsoon which reduced to 6.57% in the post-monsoon. In comparison to the pre-monsoon, 21.25% area declined in post-monsoon. The changes are mainly observed in western portion, during pre-monsoon season. Table 4.5 presented the comparison of WQI between pre-monsoon and post-monsoon Season (Fig. 4.1 and 4.5).

Table 4.6 Comparison of WQI between Pre-monsoon and Post-monsoon Season

WQI range	**Explanations**	**Pre-monsoon**	**Post-monsoon**
		Area (%)	**Area (%)**
0-25	Excellent water quality	2.01	1.06
26-50	Good water quality	14.48	25.55
51-75	Poor water quality	30.75	38.63
76-100	Very Poor water quality	24.94	28.19
Above 100	Unfit for drinking	27.82	6.57
Source- Computed		100	100

4.7.2 Post-monsoon to Monsoon:

The WQI range of 0-25 was observed at 1.98% area during monsoon which decreased to 1.06% in post-monsoon. Approximately 0.92% of the area was less than the monsoon season. The area of the WQI category 26-50 reduced in the post-monsoon as compared with the monsoon season. The area was 28.96% in the latter and 25.55% in the former. Between the two seasons, 3.41% of the area decreased. These changes were observed in the north-eastern and southern parts of the region in post-monsoon season. In the next category (51-75

WQI) 48.12% area was noted in monsoon and 38.63% in post-monsoon which indicated a decrease of 9.49% area in the post-monsoon season. During both seasons, this category was spread over the entire study area. In the post-monsoon period, the area of the WQI 76-100 was more than that in the monsoon season. The area was 17.45% in the monsoon and 28.19% in the post-monsoon, with a variation of 10.74% between both the seasons. This category was largely seen in the north-western part of the study area in post-monsoon season. In the next category, WQI of >100 was noted in 3.50% area in monsoon and 6.57% in the post-monsoon season. Therefore, a variation of 3.07% was observed between both the seasons. These changes were observed in isolated patches in the north-western and central portions in the post-monsoon season (Table 4.6). Seawater intrusion or geological factors could be the reason for these phenomena (Fig. 4.3 and 4.5).

Table 4.7 Comparison of WQI between Post-monsoon and Monsoon Season

WQI range	Explanations	Post-monsoon	Monsoon
		Area (%)	Area (%)
0-25	Excellent water quality	1.06	1.98
26-50	Good water quality	25.55	28.96
51-75	Poor water quality	38.63	48.12
76-100	Very Poor water quality	28.19	17.45
Above 100	Unfit for drinking	6.57	3.5
Source- Computed		100	100

4.7.3 Monsoon to Pre-monsoon:

Between monsoon and pre-monsoon, the quality of water fluctuated due to the rainfall. WQI category of 0-25 accounted for 1.98% area in the monsoon season and 2.01% in the pre-monsoon. 0.03% of the area reduced in the monsoon season. During the monsoon period, the WQI category of 26-50 was noted in the north-eastern and eastern parts whereas in pre-monsoon, the water quality was spread over in the southern portion and in few isolated patches in the northern part. The area was 28.96% in the monsoon and 14.48% in the pre-monsoon season with a decline of 14.48% of area. 51-75 WQI was observed in 48.12% area in monsoon and 30.75% in pre-monsoon, denoting a variation of 17.37% area between both the seasons. During pre-monsoon, this category was observed in the northern and southern parts whereas in monsoon period this category of water was noted in the entire study region.

WQI of 76-100 was noted in 24.94% area in the pre-monsoon and 17.45% in the monsoon season. Approximately 8% area was higher in the pre-monsoon season. During this time, this category of water was observed towards north to central parts and few isolated patches in the south-western part of the study area. In the next WQI category, (>100) 3.50% area was noted in monsoon which increased to 27.82% in the pre-monsoon. Thus, 24.32% variation was observed between both the seasons (Fig. 4.1 and 4.3). These changes were largely observed in the north-western and south western portions in the pre-monsoon season (Table 4.7).

Table 4.8 Comparison of WQI between Monsoon and Pre-monsoon Season

WQI range	**Explanations**	**Monsoon Area (%)**	**Pre-monsoon Area (%)**
0-25	Excellent water quality	1.98	2.01
26-50	Good water quality	28.96	14.48
51-75	Poor water quality	48.12	30.75
76-100	Very Poor water quality	17.45	24.94
Above 100	Unfit for drinking	3.5	27.82
Source- Computed		100	100

Narmada River, Bharuch District

4.8 WQI Results and Evaluation of Sub-surface Water:

4.8.1 Pre-monsoon:

During the pre-monsoon season, WQI values ranged from 5.51 to 255.22. WQI between 0-25 was noted in 7.97% samples and it spread over 3.37% area. This range was found in small pockets in the north-eastern and central parts of the study area. 26-50 WQI range was noted in 16.67% samples and they were spread over 13.26% of the area. This range was observed in the form of patches in the north-eastern part. 14.49% samples were under the range of 51-75 and can be considered as "Poor Water Quality". They covered 16.98% of the area and was largely observed in the north and central parts of the region. As per the BIS, this type of water quality can be used for industrial and irrigation purposes. The WQI range of 76-100 was observed in 15.94% samples and spread over 20.44% area. It was noted in the north-eastern part. 44.93% samples were in the range of >100 representing water quality as "Unfit for Drinking" (Table 4.8). It was spread over 45.95% of the area. WQI based spatial variation map represented, that the range was largely found in the southern and north-western parts. Another small pocket was seen in the eastern segment (Fig. 4.7). The high value of WQI at these locations was observed due to higher values of sodium, calcium, nitrate, fluoride and total dissolved solids in the sub-surface water. It might be the reason for the leaching of ions, water-rock interaction and anthropogenic activities such as excessive

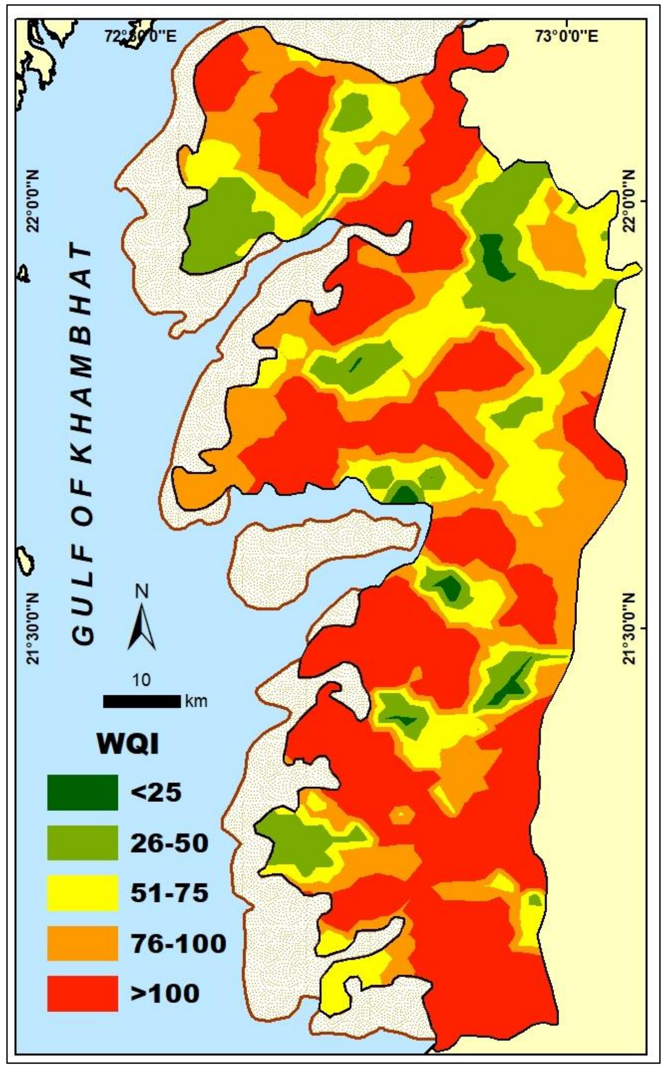

Fig. 4.7 WQI of Pre-monsoon Season (Sub-surface Water)

pumping, industrial effluents, irrigation, and domestic uses (Reza & Singh, 2010; Şener et al., 2017).

Table 4.9 WQI of Pre-monsoon Season (Sub-surface Water)

WQI range	Explanations	Sample (%)	Area in (%)
0-25	Excellent water quality	7.97	3.37
26-50	Good water quality	16.67	13.26
51-75	Poor water quality	14.49	16.98
76-100	Very Poor water quality	15.94	20.44
Above 100	Unfit for drinking	44.93	45.95
Source- Computed		100	100

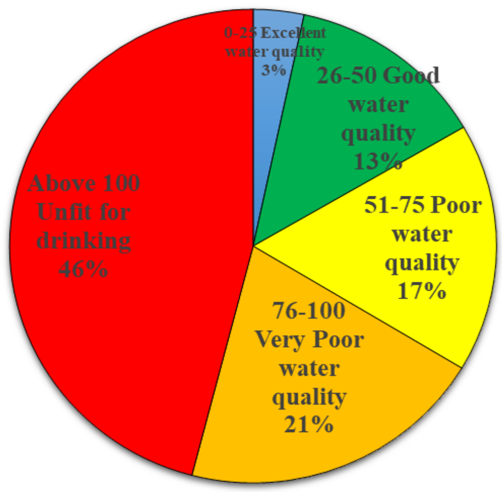

Fig. 4.8: WQI Category Wise Percentage of Distribution for Pre-monsoon Season (Sub-surface Water).

Hansot Taluka, Bharuch District

4.8.2 Monsoon:

During the rains, WQI values ranged from 6.99 to 224.94. WQI between 0-25 was noted in 11.36% samples and it covered 6.13% area. This range was found in small pockets in the north-eastern, north-western, central and south-western parts. They were mostly associated with the rivers Vishwamitri, Narmada and Tapi. 26-50 WQI range was noted in 21.97% samples and they were spread over 25.16% of the area. This category was largely observed at north-eastern and central parts and few patches were also seen over the entire region. 18.94% of samples had the range of 51-75 and can be considered as “Poor Water Quality”. They covered 24.50% of the area. This range was largely observed in the northern and central parts of the region. As per the BIS, this type of water quality can be used for industrial and irrigational purposes. The WQI range of 76-100 was observed in 15.15% samples and spread over 18.74% area. It was seen in the northern, central and southern parts. 32.58% of samples were in the range of >100 representing water quality as “Unfit for Drinking” (Table 4.9). It was spread over 25.48% of the area. WQI based spatial variation map represented (Fig. 4.9), that the range was largely found in the southern part where many major and minor industries are located at Olpad, Surat, Sachin and Kathodara. These categories of water are also found in Dahej-Jambusar industrial belt. Another small pocket was seen in the eastern part.Therefore,

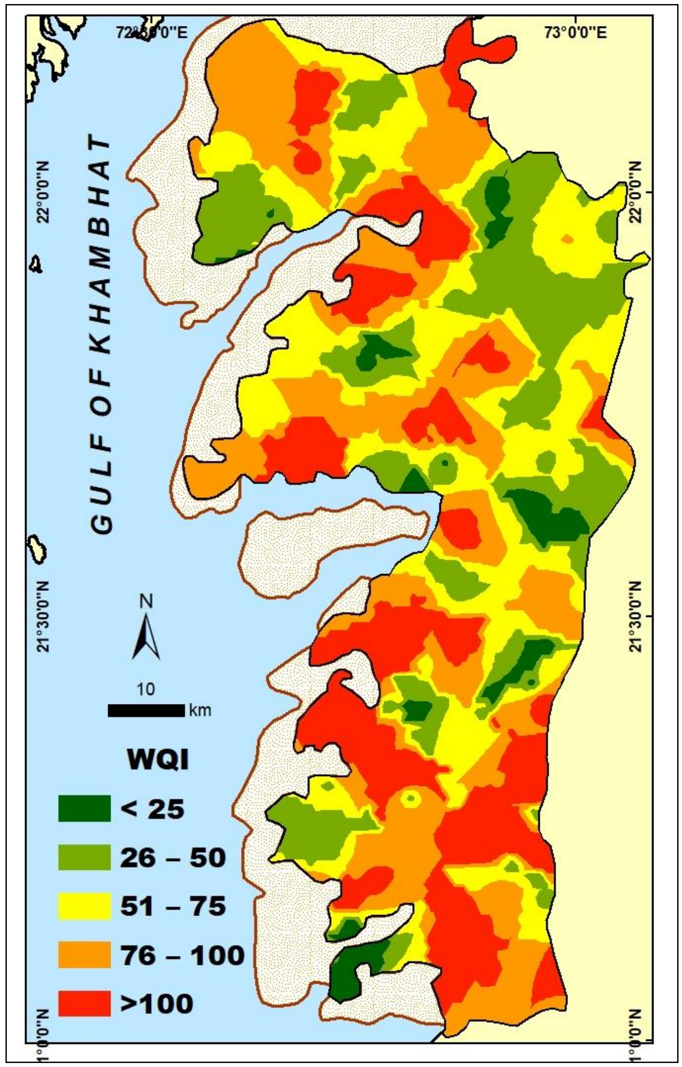

Fig. 4.9 WQI of Monsoon Season (Sub-surface Water)

the presence of industries and geological formations might be the reason for the water being "Unfit for Drinking" (Reza & Singh, 2010; Şener et al., 2017).

Table 4.10 WQI of Monsoon Season (Sub-surface Water)

WQI range	Explanations	Sample (%)	Area in (%)
0-25	Excellent Water Quality	11.36	6.13
26-50	Good Water Quality	21.97	25.16
51-75	Poor Water Quality	18.94	24.5
76-100	Very Poor Water Quality	15.15	18.74
Above 100	Unfit for Drinking	32.58	25.48
Source- Computed		100	100

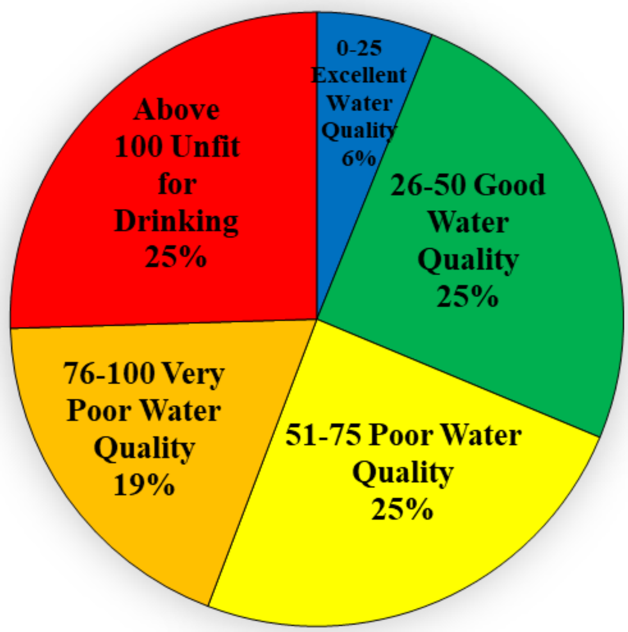

Fig. 4.10: WQI Category Wise Percentage of Distribution for Monsoon Season (Sub-surface Water).

Tapi River, Surat District

4.8.3 Post-monsoon:

In this season, WQI values ranged from 6.19 to 245.94. WQI between 0-25 was noted in 10.61% samples and it was spread over 4.29% area. This range was found in small pockets at Asnera and Nahier villages which are located in the north-eastern part, Pipalia, Kalam and Limdi in north-western; Kasva, Bhadbhut and Haripura in central and Rohid and Kosamba in the southern parts. 26-50 WQI range was noted in 18.18% samples and they were spread over 18.97% of the area. This category was largely observed in the north-eastern to the central part, in the form of patches on both sides of Narmada River. 15.15% samples had the range of 51-75. They covered 21.53% of the area. This range was largely observed in the entire region as continuous patches. As per the BIS, this type of water quality can be used for industrial and irrigation purposes. The WQI range of 76-100 was observed in 16.67% samples and was spread over a 20.37% area (Table 4.10). It was found in the northern and north-western part where Dahej industrial belt is located. These were also observed in the central part in small patches. In this season, 37.88% samples were in the range of >100. It spread over 34.87% of the area. WQI based spatial variation map illustrated that the range was largely confined in the southern segment and few patches in the north-western and central parts (Fig. 4.11 and Fig. 4.12).

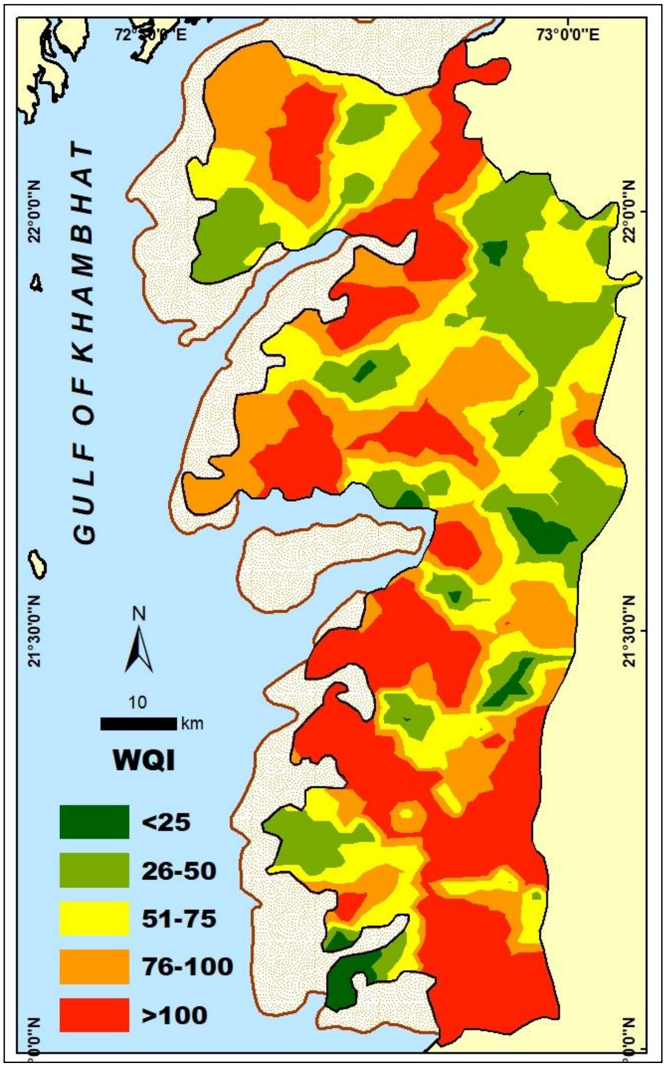

Fig. 4.11 WQI of Post-monsoon Season (Sub-surface Water)

Table 4.11 WQI of Post-monsoon WQI (Sub-surface Water)

WQI range	Explanations	Sample (%)	Area in (%)
0-25	Excellent Water Quality	10.61	4.29
26-50	Good Water Quality	18.18	18.97
51-75	Poor Water Quality	15.15	21.53
76-100	Very Poor Water Quality	16.67	20.37
Above 100	Unfit for Drinking	37.88	34.83
Source- Computed		100	100

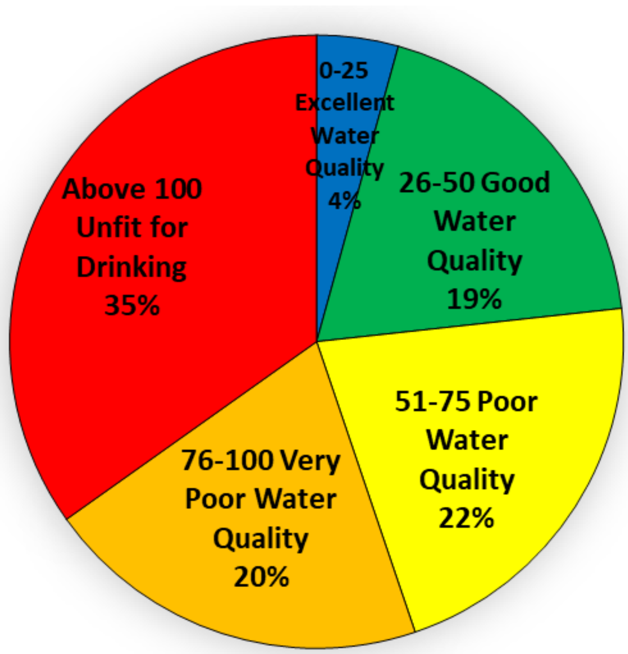

Fig. 4.12 WQI Category Wise Percentage of Distribution for Post-monsoon Season (Sub-surface Water).

Jambusar Taluka, Bharuch District

4.9 Comparison of WQI (Sub-surface Water):

4.9.1 Pre-monsoon to Post-monsoon:

Area wise variation of WQI was noted between pre-monsoon and post-monsoon seasons. In post-monsoon season, WQI range of 0-25 was noted in 4.29% area but in pre-monsoon season it decreased to 0.92%. Smaller patches of 0-25 range were located at central and southern parts whereas, in pre-monsoon, these smaller patches merged with another category. This category of water is 'excellent' for all purposes viz. drinking, industries, domestic and agricultural uses. The area of the WQI category of 26-50 reduced in the pre-monsoon season. The area was 18.97% in post-monsoon but in pre-monsoon it decreased by 5.71% and became 13.26%. These changes were largely observed in the north-western and north-eastern parts. In the pre-monsoon season, this category consolidated in one big pocket at the north-western part. The next category with 51-75 WQI was observed in 16.98% area in pre-monsoon and in 21.53% in the post-monsoon which illustrated a decrease of 4.55% area from the pre-monsoon season. In post-monsoon, this category was mostly distributed over the entire region whereas during pre-monsoon it was largely confined to the northern and north-western parts. In another category of WQI (76-100), which is of very poor quality and not suitable for drinking and agricultural uses was noted with low variation in area in both the seasons. In the pre-monsoon season, 20.44% area was under this category whereas, in the post-monsoon season, the percentage of area was 20.37. WQI (>100) was noted in 45.95% area in pre-monsoon which reduced to 34.83% in the post-monsoon. In comparison to the pre-monsoon, 11.12% area declined after the rains (Table 4.11).

Table 4.12 Comparison of WQI between Pre-monsoon and Post-monsoon Season

WQI range	**Explanations**	**Pre-monsoon Area (%)**	**Post-monsoon Area (%)**
0-25	Excellent water quality	3.37	4.29
26-50	Good water quality	13.26	18.97
51-75	Poor water quality	16.98	21.53
76-100	Very Poor water quality	20.44	20.37
Above 100	Unfit for drinking	45.95	34.83
Source- Computed		100	100

4.9.2 Post-monsoon to Monsoon:

The Water Quality Index (WQI) range of 0-25 was observed in 6.13% area during monsoon which decreased to 4.29% in post-monsoon, an approximate decline of 1.84%. WQI in post-monsoon depicted that excellent water quality belts were noted at villages of Asnera (Jambusar taluka), Pipalia (Vagra taluka), Haripura (Ankleshwar taluka) and Kadarma (Hansot taluka) of Bharuch district. The area with 26-50 WQI also decreased in the post-monsoon season. The area was 25.16% in the monsoon and 18.97% in the pre-monsoon, with a decrease of 6.19%. These changes were observed in the north-western part and in few pockets of the central part of the region. The next category with 51-75 WQI, was observed in 24.50% area in monsoon and 21.53% in post-monsoon, indicating a decrease of 2.97% in area. During post-monsoon, this category was found scattered over entire the study area. In the monsoon period, the area of 76-100 WQI, was lesser than the post-monsoon season. It was 18.74% in the monsoon and 20.37 % in the post-monsoon season, with a variation of 1.63% between both the seasons. WQI of >100 was observed in 25.48% area in monsoon season which expanded to 34.83% in the post-monsoon. 9.35% variation was observed between both the seasons. These changes were largely noted in the northern and southern portions (Table 4.12 and Fig. 4.9 and 4.11).

Table 4.13 Comparison of WQI between Post-monsoon and Monsoon Season

WQI range	**Explanations**	**Post-monsoon**	**Monsoon**
		Area (%)	**Area (%)**
0-25	Excellent water quality	4.29	6.13
26-50	Good water quality	18.97	25.16
51-75	Poor water quality	21.53	24.5
76-100	Very Poor water quality	20.37	18.74
Above 100	Unfit for drinking	34.83	25.48
Source- Computed		100	100

4.9.3 Monsoon to Pre-monsoon:

The fluctuations in the quality of water were observed between the monsoon and pre-monsoon seasons. WQI category of 0-25 was witnessed in 6.13% area during monsoon which decreased to 3.37% in the pre-monsoon viz a decrease of 2.76% in area. During monsoon season, few patches were observed in the central, northern and southern parts whereas in the pre-monsoon these patches were confined to the southern part only. During the monsoon period, the WQI category of 26-50 was mostly confined in the north-western and central parts but in pre-monsoon, these patches were conspicuous in the north-western part. The area was 25.16% in the monsoon and 13.26% in the pre-monsoon, a reduction of 11.90%. In the next category (51-75 WQI) 24.50% area was observed in monsoon and 16.98% in pre-monsoon, indicating a variation of 7.52% area between both the seasons. During monsoon, this category was noted in the southern and north-eastern parts whereas in the pre-monsoon it was largely observed in the north and in the central parts. Area under WQI of 76-100 was 18.74% in the monsoon and 20.44% in the pre-monsoon, with variation of 1.70%. WQI of >100 was noted in 25.48% area in monsoon season which expanded to 45.95% in the pre-monsoon, with 9.35% variation between both the seasons (Fig. 4.7 and 4.9). These changes were largely observed in the southern segment and in the north-eastern part (Table 4.13).

Table 4.14 Comparison of WQI between Monsoon and Pre-monsoon Season

WQI range	**Explanations**	**Monsoon**	**Pre-monsoon**
		Area (%)	**Area (%)**
0-25	Excellent water quality	6.13	3.37
26-50	Good water quality	25.16	13.26
51-75	Poor water quality	24.5	16.98
76-100	Very Poor water quality	18.74	20.44
Above 100	Unfit for drinking	25.48	45.95
Source- Computed		100	100

Resume:

This chapter evaluated water quality status of surface and sub-surface water using Water Quality Index (WQI) in Surat-Bharuch Industrial region. It was observed that, poor quality of surface water was more pronounced in south-eastern part but in monsoon season it spread out in the north-western part. In the post-monsoon season “Poor Water Quality” and “Very Poor Water Quality” both were found scattered over the entire region. WQI of sub-surface water depicted that percentage of “Unfit for Drinking” water quality in pre-monsoon, monsoon and post-monsoon seasons were higher than other categories of water. This range was seen in the southern part of the region. The next chapter will focus upon the spatio-temporal analysis of land use and land cover pattern of the study area.

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