Synopsis Submitted for Doctor of Philosophy in Geography Entitled:

An Appraisal of Water Quality in the Surat - Bharuch Industrial Region, South Gujarat.

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July, 2022

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1.1 Introduction:

Water is the most important resource on the planet and it is presently a subject of worldwide 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). This resource is sometimes inadequate, sometimes abundant and is always unevenly distributed over space and time. This resource is required for different purposes like industries, agriculture, domestic, generation of electricity, irrigation, fishing, etc. It's use and usage has grown recently and the trend will continue (Pius et al. 2012). This puts an excessive pressure on water sources. Surface and subsurface water are the two types of resources and both of them are exploited in order to fulfil the expanding requirements of the people, community and region. High dependency on water resources has put a lot of pressure on them (Ghosh & Kanchan, 2014). Hence, several factors, including the discharge of industrial and domestic waste, mining sites, solid and liquid waste disposal from industries, ship breaking yards, excessive use of pesticides and fertilisers, animal manures, sewage sledge, combustion of fossils, spillage of chemicals and petrochemicals, fibres, polymers and so on, have all had an impact on water quality. Thus, surface and subsurface water quality is a significant issue that must be monitored and analysed in order for water and human health to remain sustainable. The Water Quality Index (WQI) is one of the most effective ways for detecting and monitoring the quality of surface and subsurface water.

The changing pattern of land use and land cover of the earth's surface reflects the interrelationships of physical processes and the pattern of productivity of land, ecological status and the biochemical and hydrological cycles (Turner et al. 1994). Land use is connected with human activities, as well as land management and the change of natural resources and the environment. Changes in land use and land cover have an impact on water quality (Chu et al. 2013). The changing information is important for modelling, policy making, monitoring and sustainable development (Giri et al. 2003).

Industrialisation is one of the important phenomena which ignites the mechanism of development. This phenomenon enhances work opportunities, per capita growth, literacy levels, skill and infrastructure development and so on and so forth. Subsequently, it is also responsible for excessive depletion of resources, crowding of people in a few areas, exerting pressure on existing infrastructure, ecological dis-balance, generation of industrial waste etc. Eventually, both organic as well as inorganic environment gets affected.

Industrial waste is an increasing global, regional and local concern (Nemerow, 2005). Industrial waste is defined as waste generated from industrial activity and comprises of raw materials that are made unusable during the manufacturing process, such as sludge, product residues and ashes. Petroleum hydrocarbons, chlorinated hydrocarbons, heavy metals, different acids, alkalis, dyes and other compounds are among the pollutants found in useless trash (Guerra, 2002). These waste products come in a variety of forms, depending on the individual industrial product development and processes. Industrial waste becomes an environmental problem when pollutants are discharged directly or indirectly into water bodies and also adversely affects the human health (Gagan et al. 2016).

1.2 Literature Review:

Different researchers had examined the challenges of surface and sub-surface water quality in various ways. Gupta et al. (2005) discussed the origin of high fluoride in groundwater in the North Gujarat-Cambay region and identified certain fluoride rich sub-aquifer zones and the geographical areas. Ghosh & Kanchan (2014) used geochemical and statistical approach to investigate the groundwater quality in the Bengal alluvial tract of India. Similarly, Goyal, Chaudhary, et al. (2010) worked on the groundwater quality zones for agricultural and domestic purpose of Kathial district of Haryana. Helena et al. (2008) studied the alluvial aquifer of the Pisuerga river, Spain and addressed that the groundwater quality depends not as aquifer lithology, groundwater velocity, quality of recharge waters and interactions with other types of water or aquifers but also on human activities which can alter the quality of it, either by polluting them or by modifying the hydrological cycle.

A few researchers focused on assessing the water quality of different areas. In the work of Basavaraddi et al. (2012) of Tumkur district Karnataka, Water Quality Index (WQI) was used for assessing water quality of the region. Similar study of Bhadja& Vaghela (2013) proposed Water Quality Index of reservoir water and assessed the impact of industries and human activities. The study revealed that, the pollution load is relatively high in the reservoir water during summer. Dong et al. (2007), studied 76 typical water samples and applied Principal Component Analysis techniques. Seven PCA 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. Pius et al. (2012), evaluated 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 that region was highly contaminated. Similarly, Boyacioglu and Boyacioglu et al. (2010) monitored water quality data set to investigate seasonal variations in water quality of the Tahtali reservoir (Turkey). The paper concluded with the fact that the surface water quality depends not only on natural processes but also on anthropogenic influences. The findings of the study showed, the seasonal variation of the water quality and anthropogenic impact at the reservoir. Chang (2008) extensively worked on spatial analysis of water quality trends in the Han River basin, South Korea. His work revealed that the urban land cover is positively associated with increasing water pollution. Another, investigation by Gadhia et al. (2013) at the Tapi Estuary in Hazira industrial area (Gujarat) showed that water quality of the estuary has been affected by the industrial and domestic effluents. In the study of Garaizi et al. (2011), the assessment of seasonal variation of chemical characteristics in surface water for the Chehelchay watershed (Iran), depicted significant seasonal variation in river water chemistry which was strongly affected by rock water interaction, hydrologic processes and anthropogenic activities. Some works have determined the spatio-temporal pattern of different physico- chemical parameters in soil and water (surface and sub-surface). Seasonal pattern of heavy metal concentration was studied by Mondal et al. (2010) in the Tahgaon industrial area of Dhaka, Bangladesh while Ladwani et al. (2012) worked on lignite coal mine located at Surat (Gujarat, India). Tathagata & Kanchan (2011) attempted a study on spatio-temporal pattern of arsenic concentration in groundwater in Murshidabad district, West Bengal, India. Similarly, Yang et al. (2010) analysed the spatial and temporal pattern of water pollution in the lake Dianchi (China) and concluded that the level of pollution of the lake gradually increased from south to north.

Statistical tools and techniques like Principal Component Analysis (PCA), Cluster Analysis (CA) and Discriminate Analysis (DA) were adopted by various researchers to observe the complex probable relationship between different elements and parameters. Kowalkowski et al. (2006) focused on water quality classification of the Brda River (Poland) by employing Cluster Analysis, Principal Component Analysis, Discriminant Analysis and Factor Analysis. Garizi, et al. (2011) used multivariate statistical techniques to analyse river water quality which has been carried out by ANOVA, PCA and CA for the assessment of the seasonal pattern of pollution and its effects on the quality of river water. Similarly, Upadhyaya et al. (2014) employed PCA in the occurrence and distribution of selected heavy metals and boron in groundwater of the Gulf of Khambat, Gujarat, India.

1.3 Statement of Problem:

The indiscriminate disposal of solid, liquid and gaseous wastes from industries has an impact on water. Disposal of solid waste in open pits and depressions, discharge of untreated liquid waste through open drains and emissions of poisonous gases into the environment and agricultural practices are a few common features prevalent in the industrial regions and its vicinity. This problem of contamination is more acute in industrial regions and in their fringe areas where the concentration of physio-chemical elements can be more than the desirable and permissible limits.

Surat-Bharuch industrial region is a geographically and economically favorable place with a pleasant climate and abundant natural resources. This area is rich in water sources because of being nearer to the coast and being a plain area dominated by perennial rivers. The region has efficient transportation system resulting in the coming up of many small and large-scale industries under the Gujarat Industrial Development Corporation (GIDC). Surat-Bharuch industrial region is a part of ‘Golden Corridor’ and also ‘Delhi-Mumbai Industrial Corridor’. Various industries in this region produce different types of fertilizers, chemicals and petrochemicals, textiles etc. (Brief Industrial Profile of Bharuch District, 2012-13). Essar Group of Industries, Kribcho, Larsen and Turbo, Gujarat State Petroleum Corporation Ltd, Oil and Natural Gas Company, Hazira Complex of Reliance Industries, Gujarat Alkaline Industries Ltd., National Thermal Power Corporation, Ankelshwar Gujarat Industrial Development Corporation, Jambusar Sterling Economic Zone, etc. are some of the industries located in this region. Hazira, Surat, Panoli, Ankelswar, Dahej and Bharuch industrial zones have large number of chemical industries, which discharge effluents affecting the surface water bodies, sub-surface water and the estuarine belt of Narmada and Tapi, Dhadhar, Viswamitr and Surya rivers (District Human Development Report Surat (2016) and Bharuch (2015) District).

Moreover, NH 8 traverses through the region which connects Delhi-Mumbai. Surat-Bharuch industrial region lies on the route of Express Way developed by National Highway Authority of India (NHAI). The region is a part of western railway zone and is well connected by eastern, western, northern and southern India (DIP Survey Report, Bharuch & Surat District, 2016-17).

Hence, the present study would be confined on the west of NH 8 along the Gulf of Cambay covering the districts of Surat and Bharuch which is an important industrial region of the state as well as of the country.

1.4 Objectives:

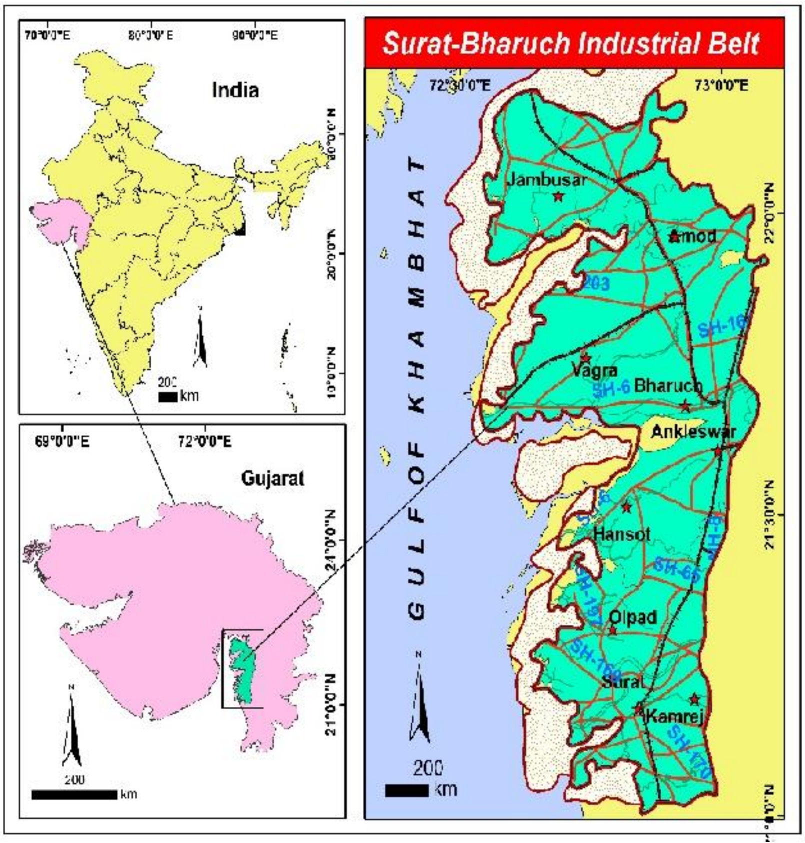
The objectives of the present study are -

1. Determine the spatio-temporal pattern of water quality.
2. Analyse the land use and land cover and identify the waste disposal sites.
3. Predict the Industrial sprawl.

2.1 Study Area:

The Gulf of Khambat is an inlet of the Arabian Sea located on India's western coast between the Saurashtra peninsula and mainland Gujarat (Upadhyaya et al. 2014). The districts of Surat and Bharuch adjoin the eastern flank of Gulf of Khambat. This region covers an area of about 4200 sq. km. and extends between 72°28'E to 73°3'E longitude and 20°59'N to 22°11'N Latitude. The two districts have many industrial zones like Jambusar, Vagra, Hansot, Bharuch and Ankelshwar in Bharuch Districts and Olpad, Surat, Katargram, Kathodara and Hazira in Surat District. Surat (54.96 Hectare) is the major industrial centre of the region. Besides it, the other important centres are Sachin (749.35), Pandesaran (218.27 Hectare), Icchapore-Bhatpore Kawas (919.84 Hectare), Hazira (428.04 Hectare), Kathodara (3.08 Hectare), Olpad (31.59 Hectare). Bharuch district too has a concentration of many small and large enterprises like – Dahej (438 Hectare), Ankelshwar (1770.97 Hectare), Panoli (879.50 Hectare), Bharuch (89.37 Hectare), Nabipur (12.84 Hectare), Pansoli (11.50 Hectare) and Jambusar (2.14 Hectare). The major industries of the region are Essar Power & Steel, Indian Oil Corporation ltd. (Bhatpur, Kribhko, Kawas, Hazira Road), Larsen and Turbo (Hazira Road), ONGC, National Thermal Power Corporation. Gail– Gas

Fig.1 Study Area



Authority of India (Amod), Glaxo India Limited, Heuback Colour Private Limited, Ankelshwar Lupin (DIP Survey Report, Bharuch & Surat District, (2016-17)). These industries produce a variety of chemicals, petrochemicals, polymers, polyesters, fibres, and other materials. The salt industry is also well developed in this region. 116 salt works are established in Bharuch–Jambusar region. Salt refinery and iodizing industry are also situated in this region (Jambusar).

This area is well connected by roads and railway line. National and State Highways and also major district roads facilities the industrial and development. Dahej, Hazira port, which is operated by Gujarat Maritime Board (GMB) is a major port through which commercial transportation is done. This region has a moderate climate (hot summer and general dryness except in the coastal region) which greater humidity. Narmada, Tapi, Dhadar, Kaveri are the major rivers which flow downward towards Gulf of Cambay. The slope is 23.5° in the north-eastern part, which gets reduced to 5° in the south and south-west. The Aliabet Island is found at the mouth of the Narmada estuary (District Census Handbook Surat and Bharuch, 2011) (Fig.1).

3. Spatio-temporal Variability of Hydrochemical and Geochemical Parameters of Surface and Sub-surface Water

3.1 Methodology:

Surface and sub-surface water samples were collected for three seasons (pre-monsoon (May-June, 2016), monsoon (September-October, 2016) and post-monsoon (October-November, 2015). The surface samples were taken from ponds, river and lakes and sub-surface from bores, wells and hand pumps. A standard procedure was followed to collect water samples (including surface and sub-surface water) (APHA, 1998). All samples were preserved to use the methodology recommended by the Integrated Coastal and Marine Area Management (ICMAM) in the 'Coastal Water Quality Measurements Protocol for the COMAPS Programme' (Document No. R 30). The entire area of 4200 sq.km was gridded in 5X5 sq.km area and one (1) surface and one (1) subsurface water sample was collected from each grid and analysed. Physical characteristics like as pH and TDS were measured on the spot with portable equipment, while chemical parameters such as calcium, sodium and fluoride were measured at the Department of Geography's laboratory. Sampling locations were marked by Hand Held GPS (Garmin GPSMAP 78S). The collected data were analyzed in Microsoft Excel 2013, SPSS V.20, and Origins 9.2. ArcGIS 10.2 software was used for mapping.

3.2 Results:

In the present study, spatio-temporal variability of hydrochemical properties and water quality of surface as well as sub-surface water were investigated.

3.2.1 Surface Water (2015-2017):

During **post-monsoon season (2015)**, pH value of surface water varied between 6.0 to 10.0, TDS concentration was found in the range of 120 to 10500 mg/l, calcium (Ca) in the study area was between 2.2 to 166 mg/l and Sodium (Na) concentration varied between 5.9 to 300 mg/l. In this period higher concentrations of physio-chemical parameters were observed in central to northern portion of the study area. In **2016**, pH value of surface water varied between 6.0 to 8.50, concentration of TDS ranged from 50 to 8490 mg/l, calcium (Ca) concentration varied between 2.6 mg/l to 312.0 mg/l and sodium (Na) absorption ranged between 2.0 to 300 mg/l.

In the **monsoon season (2016)**, pH values in the study area varied from 6.08 to 9.20, depicting a slightly acidic to alkaline nature. TDS varied from 50 to 7700 mg/l, the concentration of calcium (Ca) ranged between 9.30 to 250 mg/l. Sodium (Na) concentration ranged between 9.10 mg/1 and 300 mg/1. Fluoride (F) concentration varied was Below Detection Level (BDL) to 1.06 mg/l. In the next year **(2017),** the surface water was seen in normal to an alkaline condition. The pH value varied between 7.32 to 9.85. TDS varied between 8.80 mg/l to 6549.20 mg/l. Calcium (Ca) in the study area was between 15.80 to 120 mg/l. The concentration of sodium (Na) ranged between 8.30 to 300 mg/l. Fluoride (F) varied from Below Detection Level (BDL) to 1.65 mg/l

During **pre-monsoon season (2016)**, pH value in the study area varied between 6.11 and 8.49. The concentration of TDS ranged from 100 to 12500 mg/l. The calcium (Ca) concentration varied from 19.1 mg/l to 250 mg/l. Sodium (Na) concentration ranged was from 55 mg/l to 400 mg/l. Fluoride (F) concentration in the study area ranged from 0.2 mg/l to 1.51 mg/l. The BIS standard for fluoride (F) was 1 mg/l to 1.5 mg/l while in the year of (**2017),** pH value of surface water ranged from 7.25 to 10.49. TDS ranged from 95 mg/l to 7059.40 mg/l. Calcium (Ca) concentration varied between 3.66 mg/l and 400 mg/l. The range of sodium (Na) absorption was 0.60 mg/l to 400 mg/l. Fluoride (F) concentration was between Below Detectable Limit (BDL) to 2.81 mg/l.

3.2.2 Sub-surface Water (2015-2016):

During **post-monsoon season (2015)**, pH level in sub-surface water ranged from 6.0 to 8.50 and variations were observed in this period. TDS ranged between 50 mg/l and 8490 mg/l. Calcium (Ca) concentration varied between 9.80 mg/l and 220 mg/l. Sodium (Na) absorption ranged between 2.0 to 300 mg/l while in **(2016)** the concentration of pH varied from 6.5 to 9.5 and TDS between 100 mg/l and 12500 mg/l. The calcium (Ca) concentration varied from 19.1 mg/l to 250 mg/l. The concentration of sodium (Na) ranged from 11.3 mg/l to 300.0 mg/l.

In the **monsoon season (2016)**, the concentration of pH varied from 6.89 to 8.47, indicating a slightly acidic to an alkaline condition. A higher pH concentration was observed in the northern half of the study area. The minimum TDS value was 100 mg/l and the maximum was 8500 mg/l. The concentration of calcium (Ca) varied from 37.0 to 250.0 mg/l and sodium (Na) between 9.10 mg/1 and 300 mg/1. Fluoride (F) distribution was between Below Detectable Limit (BDL) to 1.50 mg/l. In the year **(2017),** pH values in the study area varied from 7.04 to 9.04 and depicted a normal to alkaline nature. TDS ranged between 56.50 mg/l and 7211.10 mg/l. The calcium (Ca) concentration ranged between 9.40 mg/l to 120 mg/l. In this season sodium (Na) varied between 12.5 to 305 mg/1. Fluoride (F) varied between Below Detection Level (BDL) to 2.56 mg/l.

During **pre-monsoon season (2016)**, pH value in the study area varied between 6.11 and 8.49, but in most of the samples (>80%), this value was between 7.5 and 8. TDS varied from 100 mg/l to 9555 mg/l and calcium (Ca) from 19.1 mg/l to 250 mg/l. Sodium (Na) ranged from 55 mg/l to 400 mg/l whereas the WHO standard value for it is 200 mg/l. The fluoride (F) concentration in all the sample sites was within the BIS standards. In **2017,** the level of pH varied between 6.05 to 9.45. The values of TDS ranged from a minimum of 112.50 mg/l to a maximum of 7865.40 mg/l. The concentration of calcium (Ca) ranged from 15.50 to 420 mg/l. The range of sodium (Na) in pre-monsoon season varied between 13.40 and 400 mg/l. The concentration of fluoride (F) varied between BDL to 2.86 mg/l.

4. <u>Water Quality Index (2015-2017):</u>

4.1 Methodology:

Water Quality Index was computed using the 5 measured parameters at each site. Average value of two same seasons viz., pre-monsoon (2016 and 2017), monsoon (2016 and 2017) and post-monsoon (2015 and 2016) was taken into consideration.

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

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

Where, q_n = Quality rating of n[th] water quality parameter, W_n = Unit weight of n[th] water quality parameter.

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 n[th] water quality parameter at a given sample location.

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

S_n = Standard permissible value of n[th] 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 n[th] water quality parameter.

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

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

The ranges of WQI values, on the basis of above calculation were rated as excellent, good, poor, very poor and unfit for human consumption.

4.2 Results:

In the pre-monsoon season, the majority of surface water samples were under the WQI category of "Poor Water Quality" and "Unfit for Drinking" whereas in monsoon season larger percentage of acquired area into category of "Good Water Quality" and "Poor Water Quality" while in post-monsoon season, WQI category of "Poor Quality Water" was accounted 38.63% of area in this region.

WQI of sub-surface water varied from 5.51 to 255.22 during the pre-monsoon season. In this period, 45.95% of area had "Unfit for Drinking" category and similar pattern also observed in monsoon season whereas in post-monsoon season "Excellent Water Quality" was observed in 10.61% of samples.

5. <u>Land Use Land Cover:</u>

5.1 Methodology:

Indian Remote Sensing satellite data of 1997-2017 periods were used to land use land cover classification. IRS Satellite Linear Imaging Self Scanning (LISS) III and (LISS) IV data on 1:50,000 scale was used for classification. Thereafter, land use and land cover classes were generated and topographical maps were taken from survey of India (SOI), all collected toposheets were georeferenced and digital image processing techniques were used for this analysis.

5.2 Results:

The results of LU/LC showed that the area under agriculture land was 78.14% in the year 1997 whereas 76.07% of area was found in the year of 2017. In 1997 built-up area was 6.05% but in 2017 (10.15%). Water bodies occupied 4.19 % area in 1997, but this reduced to 4.03 % in 2017. In the category of barren land showed downward rise from 9.11% in 1997 to 8.25% in 2017. 0.64% of area had 1997 and in 2017 increased the saltpans area of 0.73%. The other land classes decreased between the periods of 1997 (1.87%) to 2017 (0.82%).

6. <u>Identification of Landfill Site Selection for Solid Waste Disposal:</u>

6.1 Methodology:

Solid waste disposal sites were identified with the help of Remote Sensing & GIS and Analytic Hierarchy Process (AHP) tools. Land use/land cover, settlement, roads, railways, rivers, industrial belts and ponds map layers were prepared by visual on-screen digitization technique of the high-resolution (5.8 m) multispectral IPS6-LISS IV (2016) satellite imagery. After the analysis field

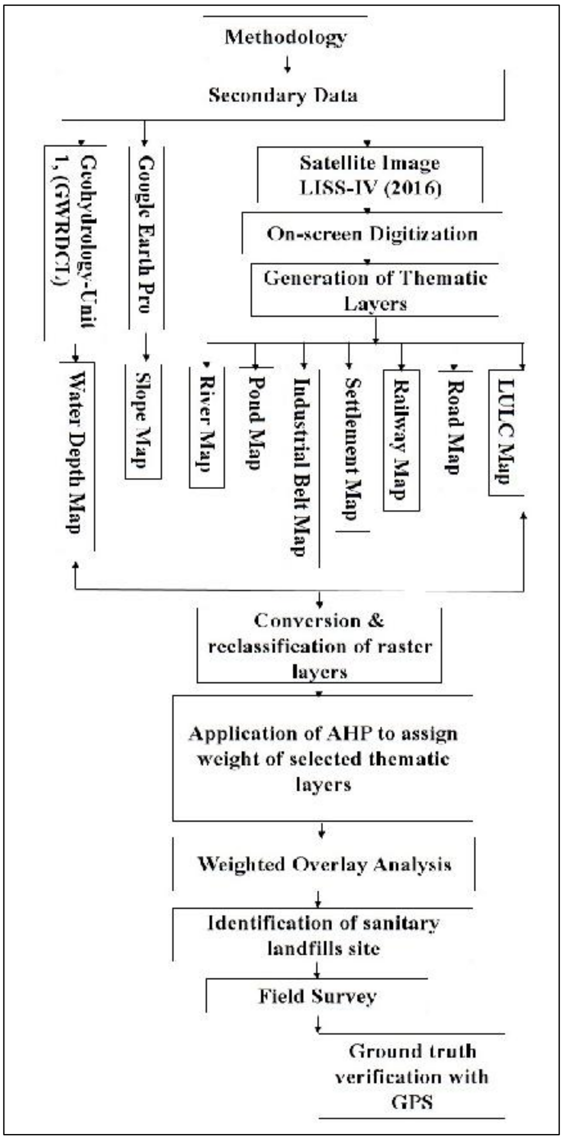


Fig: 2 Methodology Flow Chart for Solid Waste Management verification was done by Hand Held GPS (Garmin GPSMAP 78S) (Fig.2).

6.2 Results:

The present study applied Multi-criteria Decision-making Method (AHP) and Geographical Information System (GIS) for evaluating potential landfill selection in Surat-Bharuch Industrial region. AHP techniques was applied to assign weights of criteria and solve the problem of decision making. In order to study, nine (9) criteria were selected based on environmental and socio-economic factors. Spatial data were transformed into vector and raster based for the use of GIS tool (Overlay Analysis). 15 highly suitable landfill sites were identified which covered 2.75% of area and they fulfilled the minimum requirements, according to CPHEEO, 2016.

7. Discussion and Suggestion:

In the present study, various hydrochemical parameters such as pH, TDS, calcium (Ca), sodium (Na) and fluoride (F) were analysed in pre-monsoon, monsoon and post-monsoon seasons of surface and sub-surface water. The concentrations of pH, sodium (Na), TDS and calcium (Ca) was higher in the vicinity of the industrial belt and nearer to the banks of rivers Tapi and Narmada. During the monsoon season, the concentration level of all the parameters decreased significantly.

The Water Quality Index (WQI) was used to assess the water quality status of surface and sub-surface water in the Surat-Bharuch Industrial Region. It was computed separately in each of the three seasons in surface and sub-surface water. In every season, spatial interpretation was carried out by WQI range. 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” 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.

The analysis of land use land cover changes for 1997 and 2017 was done using satellite dataset. Six different types of thematic layers were generated such as agricultural land, buildup, waterbodies, saltpan, barren land and others land. The main change observed was that the area under agricultural land decreased and an increase in built-up land was noted.

Identification of landfill site selection was done using nine criteria and AHP model was generated. This technique helped to study of landfill selection and 15 highly suitable landfill sites were identified which covered 2.75% of area.

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