Chapter VI

Identification of Landfill Site Selection for Solid Waste Disposal

6.1 Introduction:

Globally, regionally as well as locally industrial waste is of growing concern (Nemerow, 2005). Rapid population growth, industrialisation, urbanization, economic development and improving living standards have increased the amount of waste generation (Parekh et al., 2015). Industrial waste refers to the waste produced by industrial activities which contains raw materials which are useless during a manufacturing process such as sludge, product residues and ashes. The useless waste material includes wide range of contaminants such as petroleum hydrocarbon, chlorinated hydrocarbons, heavy metals, various acids, alkalis, dyes and other chemicals (Guerra, 2002). These waste materials are of many types and it depends upon on individual industrial product generation and its operations. In chemical industry, the waste may include organic compounds, metals, nutrients or radioactive material (Pratyusha et al., 2012). In case of cotton textile industry, the wastewater is extremely alkaline and contains high concentration of Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Total Dissolved Solids (TDS) and alkalinity during production, process and decomposition (Sivaram et al., 2018). Whereas, in pharmaceutical industrial waste may include chemotherapy drug residues, expired drugs etc. (Pratyusha et al., 2012). With the increase of demand for different products in the production and consumption of goods, the generation of the industrial solid waste have also substantially increased. Industrial waste becomes an environmental problem when it starts affecting the soil and also adversely affects the human health. In addition, air also gets affected by the gas emissions. Hence, it is essential to manage such industrial waste in a proper way (Tadros, 2007).

For the management of solid waste, many techniques such as thermal treatment, zero landfilling, biological treatment and recycling are used. Landfill is one of the most useful techniques for waste disposal. The first step for the planning of landfill is the evaluation process through site selection for highly suitable waste disposal area (Şener et al., 2011). For the evaluation process, various factors such as local geomorphology, geology, slope, land use/land cover, water depth, water body, vegetation, soil and economic features like transportation (road and railways), settlement or built-up, industrial area, protected area etc. are to be considered for the site selection (Ghosh, 2020). Location of landfill should also maintain the government's regulations so that economic, environmental, health and social costs are minimized (Siddiqui et al., 1996). In addition, the waste disposal site must not harm the biophysical environment (Erkut & Moran, 1991).

The development of Remote Sensing (RS) and Geographical Information System (GIS) and its use has contributed in improving waste management systems. In this context, the former technique provides potential information about land features through satellite imagery that is useful for land use/land cover classification. GIS is one of the most sophisticated advance technologies to capture, store, manipulate, analyse and display spatial data (Krumm et al., 1993). It is a flexible platform which generates many layers of data or maps in a single window. Geographical Information System helps to take most effective decisions on the basis of spatial data product. GIS plays a major role in waste management applications by delivering outcome for decision support and assessment of larger projects such as site selection (landfill point) for waste disposal, generate optimal route for collecting solid waste. It is capable to provide waste management databases and maps. It also reduces time and cost of the site selection and provides asset management services for future monitoring program of the site (Chang et al., 1997). This technique provides conversion tool which helps in converting spatial data (vector data) into raster form that is useful for Weighted Overlay Analysis in GIS (Chandio et al., 2011).

Analytic Hierarchy Process (AHP) is a semi-quantitative approach and is one of the best Multi Criteria Decision Making method which is widely applied in decision making problems (Tavares et al., 2011). Integration of AHP and GIS techniques also improves the accuracy of analysis in landfill site selection (Yıldırım & Güler, 2016). Therefore, this study focuses on the application of GIS-based Multi-criteria Decision Analysis.

6.2 Literature Review:

Abba et al., 2013, analysed a study on, "Assessing Environmental Impacts of Municipal Solid Waste of Johor by Analytical Hierarchy Process". The objective of the study was the application of Analytical Hierarchy Process (AHP) technique to structure and assess the views and judgments of stakeholders on the environmental impacts of solid waste disposal. They used Super Decision software for judgements. The results of the study, stated that landfill generates less noise and vibration but are found to be responsible for more than 50% of the environmental impacts created by solid waste in this area.

Aydin & Sarptas, 2020, have done the analysis on, "Spatial Assessment of Site Suitability for Solar Desalination Plants: A Case Study of the Coastal Regions of Turkey". The study focused on model development by the use of GIS-Multi-Criteria Evaluation for the site suitability of coastal regions. Six input map layers were prepared in GIS environment. Finally, the most suitable sites for solar desalination were identified.

Chandio et al., 2011, worked on the "GIS-based Land Suitability Analysis using AHP for Public Parks Planning in Larkana City". In this study, Geographic Information System (GIS) and Analytic Hierarchy Process (AHP) as a multi-criteria evaluation approach were used to detect suitable land for public facilities and parks in the city. Expert choice 11.5 software was used to calculate the weights of the criteria and three essential suitability maps viz. a) land suitability b) land value and c) population density were produced.

Ebistu & Minale, 2013, has made a study on, "Solid Waste Dumping Site Suitability Analysis using Geographic Information System (GIS)". In this study, SPOT Satellite Imagery (Resolution 5 m) and Digital Elevation Model (DEM) with 30 m were used. Further, Ground Control Points (GCP) were collected through Ground Point Survey (GPS). Each criteria map was generated in GIS environment and overlay tool was used for the best site identification. Finally, four levels were fixed for better demarcation.

Erkut & Moran, 1991, in the paper "Locating Obnoxious Facilities in the Public Sector: An Application of the Analytic Hierarchy Process to Municipal Landfill Siting Decisions" developed modeling procedure on the basis of AHP. It also suggested that AHP approach was very beneficial where sitting decision is more complex.

Ghosh, 2020, had conducted an analysis on, "Identification of Suitable Landfill Sites in Barddhaman Development Authority, West Bengal using AHP and GIS techniques". This analysis focused on waste disposal issues in metropolises and small towns in state of West Bengal. Four criteria were considered for this analysis. AHP, Remote Sensing and GIS were used to derive best landfill sites in the study area.

Hailu, 2019, focused on the, "Municipal Solid Waste Suitable Disposal Site Selection, Case Study, Wolkite Town, Ethiopia". In this paper, three potential sites for solid waste disposal were found. GIS techniques on the basis of six major criteria was applied. This study illustrated the importance of AHP and GIS technology for solving the complex problem of site suitability for solid waste disposal.

Hasan et al., 2009, worked on the "Landfill Demand and Allocation for Municipal Solid Waste Disposal in Dhaka city — An Assessment in a GIS environment". This study examined the landfill demand for disposal of MSW of Dhaka, the capital of Bangladesh. On the basis of population projection and waste generation rate, landfill area was demarcated. Multi-criteria approach was applied for best suitable landfill sites and various maps were prepared in GIS platform. Pairwise Comparison Matrix Method was used for weightage of the criteria and ranks of the suitable sites according to size were identified.

Kumar & Hassan, 2013, worked on the "Selection of a Landfill Site for Solid Waste Management: An Application of AHP and Spatial Analyst Tool". In urban area planning the landfill site selection is complex job. In this study, distance from residential locations, transport connectivity, presence of water-bodies (drains, ponds, rivers etc.), forests, ground water table and geology were taken into consideration. Spatial Analyst Tool along with Analytic Hierarchy Process (AHP) model was applied for multi-criteria decision making. Six potential sites were identified as the suitable landfill sites.

Parekh et al., 2015, carried out a study on, "Identification and Assigning Weight of Indicator Influencing Performance of Municipal Solid Waste Management using AHP". This paper analysed the identification of loop holes in two big cities of Gujarat, using Analytical Hierarchy Process (AHP). Municipal Solid Waste management system is a simple linear model, which is largely affected by the nine indicators.

Paul et al., 2014, carried out a study on, "A Comprehensive Study on Landfill Site Selection for Kolkata City, India". This study investigated suitable sites for solid waste disposal using GIS and Remote Sensing techniques in Kolkata Municipal Corporation (KMC) area.

Sai Krishna et al., 2017, made an attempt on, "Geospatial Multicriteria Approach for Solid Waste Disposal Site Selection in Dehradun city, India". They solved the problems of best sites for the landfilling. Totally seven criteria were used in decision hierarchy for landfill sitting, which were divided in main three categories - geographical and land use, infrastructure and water resources. Pair-wise comparison methods were used to establish the relative importance of hierarchy elements. The final suitability results were divided into three classes – moderately suitable, suitable and highly suitable.

Şener et al., 2011, analysed a study on, "Solid Waste Disposal Site Selection with GIS and AHP Methodology: A Case Study in Senirkent-Uluborlu (Isparta) Basin, Turkey". This study examined the landfill site selection through Geographic Information System (GIS) with integration of Analytical Hierarchy Process (AHP). Ten different criteria were taken for landfill site selection and GIS techniques were used for criteria and suitability mapping (overlay analysis). Further, best suitable sites were determined.

Siddiqui et al., 1996, focused on the "Landfill Siting Using Geographic Information Systems: A Demonstration". Spatial-AHP was applied for potential ranks of criteria and preliminary site assessment. This paper analysed those effects of varying the relative importance of various siting criteria, landfill size and location restriction severity.

T et al., 2013, analysed a study on, "Application of Remote Sensing and GIS on Waste Disposal Site Selection and Environmental Impact Assessment around Mysore City, Karnataka, India". In this study ETM+ and TM Satellite Imagery, topographic maps and other collateral data were used to create thematic maps such as – parcels, road map, streams, village settlement, drainage and water bodies. A Multi Criteria Decision Making Method (MCDM) known as the Analytic Hierarchy Process (AHP) was used for deciding the weightage that needs to be given to the criteria. Further, the results of AHP were integrated in GIS. Finally, seven sites were finalized for the management of solid waste.

Uyan, 2014, made a study on, **"**MSW Landfill Site Selection by combining AHP with GIS for Konya, Turkey**".** In this study, suitable landfill site selections were determined by using the Geographical Information System and the Analytic Hierarchy Process. The outcome was classified into four categories as, low suitable (12.69%), moderately suitable (7.27%), suitable (13.79%) and best suitable (15.52%).

Yıldırım & Güler, 2016, examined the, "Identification of Suitable Future Municipal Solid Waste Disposal Sites for the Metropolitan Mersin (SE Turkey) using AHP and GIS techniques". In the study, Analytic Hierarchy Process (AHP) and Geographic Information System (GIS) techniques were jointly used to identify suitable MSWDSs. 12 decision criteria i.e., lithology, aquifer type, distance from lineaments, distance from landslides, land use, distance from settlements, distance from roads, distance from surface waters, distance from springs and wells, elevation, aspect and slope were used for the analysis. For the assessment of site suitability selected criteria were converted into raster-based thematic layers in GIS platform.

6.3 Materials & Methodology:

The methodology of the study was divided into two phases, i.e., data collection and preparation. The spatial database used in this study was collected from the various sources. Nine criteria were selected for the site selection, based on Central Public Health and Environmental Engineering Organization (CPHEEO, 2016) and published literature. Slope map was prepared from Digital Elevation Model (DEM) and was created from contour map google earth point data. Data of water depth was collected from Gujarat Water Resource Development Corporation Limited, Office of the Geohydrology - Unit 1. It was further converted into surfaces using IDW interpolation technique. In addition, 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 IPS 6-LISS IV (2016) satellite imagery. All data layers were georeferenced within GIS framework using the (WGS 1984, UTM Projection System (43N Zone). Thereafter, geoprocessing tasks such as buffer, clip and reclassify was performed ArcGIS version 10.2 software and Spatial Analyst tool for weighted overlay analysis. For the overlay analysis, all the thematic layers were converted into raster grid format which was represent as a decision criteria layer. Multi-Criteria Decision-Making Analysis was applied for prioritization of criteria. Later for the overlay analysis, ranks were given, providing lower rank to most unsuitable area in different criterion. Subsequently, the suitable solid waste disposal sites were identified. The field survey was carried out to verify the final suitable landfill sites. The GPS (Garmin GPSMAP 78S) was used to collect actual position of sites which cheeks the accuracy level (Fig. 6.1).

6.3.1 Central Public Health and Environmental Engineering Organization (CPHEEO, 2016), MINISTRY OF URBAN DEVELOPMENT

CPHEEO (2016), established following guidelines for the selection of Sanitary Landfill Sites and they were followed for the identification of new industrial solid waste dumping sites (Table 6.1).

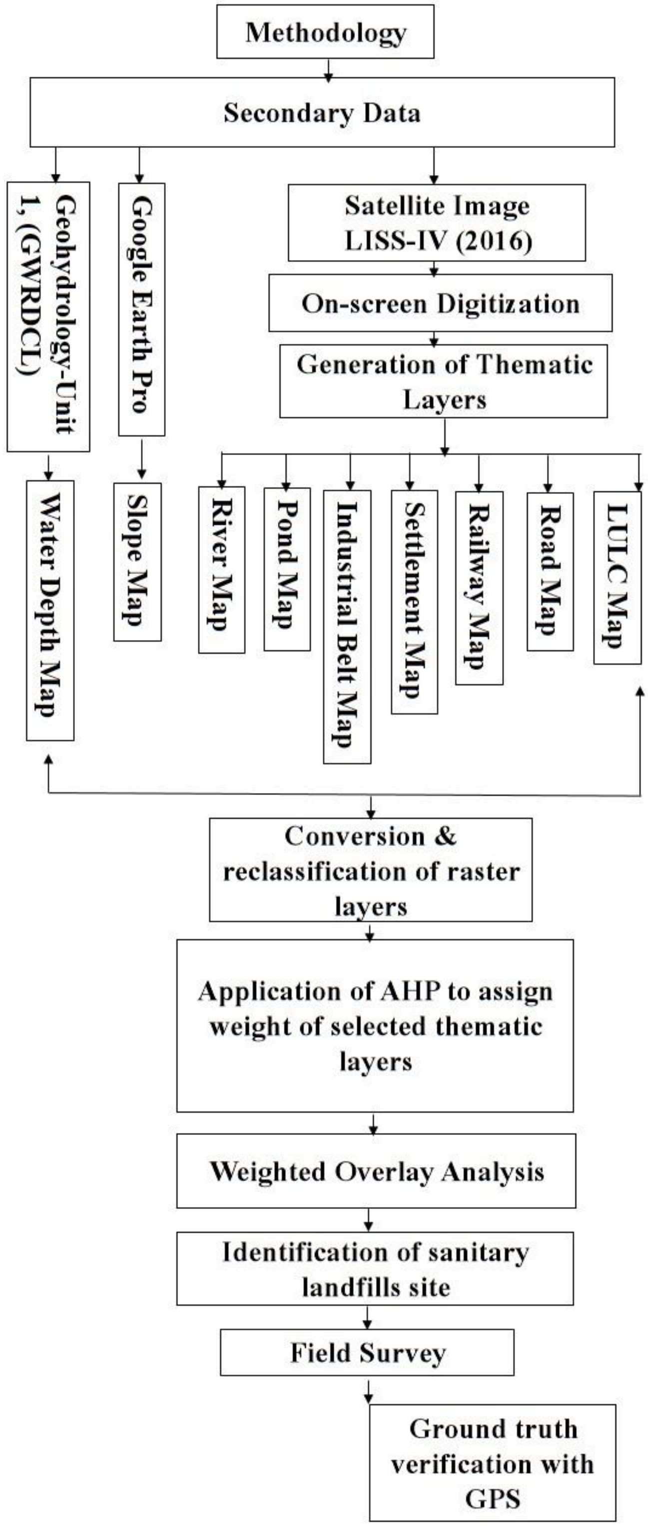

Fig: 6.1 Methodology Flow Chart

Table 6.1 Criteria for Identifying Suitable Land for Sanitary Landfill Sites

S.n	Place	Minimum Siting Distance
1	Coastal regulation, wetland, critical habitat areas, sensitive eco-fragile areas and flood plains as recorded for the last 100 years	Sanitary landfill site not permitted within these identified areas
2	Rivers	100 m away from the flood plain
3	Ponds, lakes, water bodies	200 m
4	Highway or railway line, water supply wells	500 m from centre line
5	Habitation	All landfill facilities: 500 m
6	Earthquake zone	500 m from fault line fracture
7	Flood-prone area	Sanitary landfill site not permitted
8	Water table (highest level)	The bottom liner of the landfill should be 2 m above from the highest water table
9	Airport	20 km

Source - CPHEEO, Ministry of Urban Development 2016

6.3.2 Identification of Existing Waste Disposal Sites:

In the present study, industrial waste disposal sites were identified through Google earth- Image© 2021 Maxar Technologies, Imagery Date: 10/04/2017. Subsequently, field verification was successfully done.

The waste disposal sites were more pronounced around industrial area in southern part whereas relatively lesser area was observed towards the northern.

6.4 Multi-criteria Technique: Analytic Hierarchy Process (AHP):

Multi-criteria Decision Making Analysis (MCDA) is a widely useful technique which enables the users to take appropriate choice among several criteria in a particular region.AHP belongs to MCDA and basically is a mathematical method designed by Satty in 1977 (Kurttila et al., 2000; Uyan, 2014). Many techniques such as Weighted Sum Model (WSM), Weighted Aggregated Sum Product Assessment (WASPAS), Analytic Network Process (ANP) etc. are included in MCDA. However, Analytic Hierarchy Process (AHP) is a useful method in potential landfill selection (Kharat et al., 2016; Gbanie et al., 2013; Chabuk et al., 2019). AHP deals with complex decision-making problems by breaking down the problem into a hierarchic structure and facilate by identifying and weighting of selection of criteria, evaluation of data and accelerate the decision-making process (Satty 1980). In application, the AHP is not adequate method because it is controlled by human judgments and ranking in a comparison matrix. Therefore, ranking might be biased and doubtful (Ali & Ahmad, 2020).Subsequently, a questionnaire was designed to derive expert knowledge who have expertise in this field, 10 experts were requested to fill the questionnaires as per comparison scale for weighted factors of each criteria (Pasalari et al., 2019).

In this study, landfill site selection was performed using the GIS, AHP and Remote Sensing methods. AHP was selected for the decision rules to analyze the data for landfill site selection using GIS. The techniques divide the decision problems into understandable parts; each of these parts was analyzed separately and integrated in a logical manner as suggested by Saaty (1980) and Malczewski (1997). AHP provides a proven, effective means to deal with complex decision making. It can assist with identifying and weighting of selection criteria, analyzing the collected data and expediting the decision-making process.

It observes the following steps-

(1) establishing of criteria

(2) forming pairwise comparison matrix

(3) computation of weights and assigned and

(4) weighted overlay analysis

6.4.1 Criteria Establishing:

In this study, the establishing criteria was determined and classified into two main categories. These were (1) environmental and (2) socio-economic criteria. First criteria was relevant to environmental factors (sensitive zones of an area like pond, river, biodiversity etc.), whereas the second category comprised of factors relevant to the design and the construction of the landfill of the region, respectively.

In two main categories, nine criteria such as land use/land cover, settlement, industrial belt, road, railway, pond, river, water depth and land elevation were selected for calculation processes. According to (CPHEEO, Ministry of Urban Development, 2016), these were basic criteria used in site selection of sanitary landfill.

6.4.2 Construction of Pairwise Comparison Matrix (PCM)

In terms of their relative importance, Pairwise Comparison Matrix was based on judgments between each pair of factors in a particular factor group at a time. It was used in scale range from 1 to 9 for deciding weights of criterion as: 1 for equal importance, 3 for moderate importance, 5 for strong importance, 7 for very strong importance, 9 for absolute importance and 2, 4, 6 and 8 are intermediate values (Saaty, 1997). Therefore, PCM was prepared to determine the weights of parameters according to the AHP. Ranks indicate strength and dominance of criterion. Assigned ranks (1 to 12) were used to judge the importance of criterion in PCM. Therefore, PCM were used in these studies for assigning the ranks and estimation of weights (Table 6.2).

Table 6.2 Assessment Scale of bij values

Numerical value of aij	**Degree of Preference**	**Explanation**
1	Equal importance of *i*and *j*	Two activities contribute equally to the objective
3	Moderate importance of *i*over *j*	Experience and judgment slightly to moderately favour one activity over another
5	Strong importance of *i*over *j*	Experience and judgment strongly or essentially favour one activity over another
7	Very strong importance of *i*over *j*	Activity is strongly favored over another and its dominance is shown in practice
9	Extremely importance of *i*over *j*	The evidence of favouring one activity over another is to the highest degree possible of an affirmation
2,4,6,8	Intermediate values *i*over *j*	Is used to represent compromise between the preferences in weights 1, 3, 5, 7, and 9
Reciprocals	Opposites	Is used for inverse comparison

Source: Saaty, 2000

6.4.3 Computation of Weights and Assigned

The weights of criterion were calculated in Pairwise Comparison Matrix (PCM) used Superdecision Software (Version 2.1). The calculations were processed in four steps i.e. 1) establishment of judgments 2) computation of assigned ranks 3) formulation of Normalised Pairwise Comparison Matrix and 4) calculation of weights. Compare or Judgements of ranks were prepared based on standard literature in PCM. Eigenvector values were calculated by multiplying all of the row elements and obtaining the Nth root of the result, where N was the number of row elements (Saaty, 1980). Each cell values of PCM were divided by sum of the individual column. Thereafter, obtained cell were values converted into Normalised Pairwise Comparison Matrix and averaged in row to calculate the weights of criterion (Kazemi & Akinci, 2018).

If *n* numbers of criteria to comparison, the AHP method performs following steps for to determine the weights of these criteria (Chakraborty & Banik, 2006).

a) Initially, establish ($n \times n$) pairwise matrix B for *n* objectives i.e. (1)

$$B = \begin{bmatrix} b_{11} b_{12} & & b_{1n} \\ b_{21}\, b_{22} & & b_{2n} \\ . & & . \\ . & & . \\ . & & . \\ b_{n1}\, b_{n2} & & b_{nn} \end{bmatrix} \quad (1)$$

where b_{ij}demonstrate how much more important the *i*th objective is than the *j*th objective, while making the suitable material handling equipment selection decision. For all *i* and *j*, it is necessary that b_{ij} =1 and b_{ij}=1/b_{ij}. The possible assessment values of b_{ij} in the pairwise comparison matrix, along with their corresponding interpretations, are represent in Table 6.2.

b) Then, new Q (column) matrix is construct in the AHP using the elements of B matrix. Here, element of q_i is denoting the relative degree of importance (weight) of the *i*th objective which producing the principal eigenvector.

$$Q = \begin{bmatrix} q_1 \\ q_2 \\ . \\ . \\ . \\ . \\ . \\ q_n \end{bmatrix} = \begin{bmatrix} \frac{\frac{b_{11}}{\Sigma b_{i1}}}{n} + \frac{\frac{b_{12}}{\Sigma b_{i2}}}{n} + \cdots & & & \frac{\frac{b_{in}}{\Sigma b_{in}}}{n} \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\frac{b_{n1}}{\Sigma b_{i1}}}{n} + \frac{\frac{b_{n2}}{\Sigma b_{i2}}}{n} + \cdots & & & \frac{\frac{b_{nn}}{\Sigma b_{in}}}{n} \end{bmatrix} \quad (2)$$

c) Given procedure is taken for cheek the consistency of judgments in the matrix of pairwise comparison as follows:

1) D matrix represents the results of multiplication between B and Q matrix which shows the consistency vector.

$$D = B \times Q = \begin{bmatrix} b_{11} b_{12} & & b_{1n} \\ b_{21} b_{22} & & b_{2n} \\ . & & . \\ . & & . \\ . & & . \\ b_{n1} b_{n2} & & b_{nn} \end{bmatrix} \times \begin{bmatrix} q_1 \\ q_2 \\ . \\ . \\ . \\ . \\ q_n \end{bmatrix} = \begin{bmatrix} x_1 \\ x_2 \\ . \\ . \\ . \\ . \\ x_n \end{bmatrix} \quad (3)$$

2) Calculateλ_{max}.

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \frac{xi}{qi} \quad (4)$$

where λ_{max} is the largest principle eigenvalue, *n* is the order of the pairwise comparison matrix.

3) Consistency index (CI) define as below equation.

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

The consistency of judgment should be checked in Random Index (Table 6.3) proposed by (Saaty 1980).

Table 6.3 Random Index Values

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty 1980

The preciseness of calculated weights depends on consistency of judgments and degree of preference. The Consistency Ratio (CR) evaluates logical inconsistency in judgements and helps in the identifying of errors (Cengiz and Akbulak, 2009). According to Saaty (1997), acceptable Consistency Ratio should be less than or equal to 0.10, indicating overall pairwise comparison matrix is under consistency (Salo & Hämäläinen, 1997). If CR excides the upper limit (0.10) need to improvised in judgment's (Kontos et al., 2005; Şener et al., 2011). In the present analysis, calculated CR values as represented in Table 6.4, estimated weights of selected criterion were acceptable for landfill selection. In, addition, the estimated values of weights were converted into percentage for Weighted Overlay Analysis in GIS.

Consistency Ratio (CR) define as below equation-

$$CR= \frac{CI}{RI}$$

where CR is Consistency Ratio. RI is the average of consistency index which vary upon matrix (Şener et al., 2011). This CR value is essential to calculate and check the consistency of pairwise matrix.

The pairwise comparison matrices were performed in seven criteria (Table 6.4) and also individual criterion were computed which shown in (Tables 6.5 to 6.11).

Table 6.4 Pairwise Comparison Matrix and Derived Weight of the Selected Criteria

Criteria	A	B	C	D	E	F	G	Weights
A	1	4	3	3	3	4	3	0.357
B	0.25	1	1	1	3	2	1	0.268
C	0.25	0.33	2	1	2	3	2	0.133
D	0.33	1	1	1	1	2	1	0.083
E	0.33	1	1	1	0.33	1	1	0.059
F	0.33	0.33	0.5	1	1	1	3	0.055
G	0.25	0.5	0.5	0.5	1	1	1	0.045

The letters at the decision criteria are A LULC, B Settlement and Industrial Belt, C Roads and Railways, D Pond, E River, F Water Depth and G Land Elevation
Consistency Ratio (CR) = 0.0744.

Table 6.5 Comparison Matrix & Significance Weight of Land Use/Land Cover

	A	B	C	D	AHP weight values
A	1	0.33	0.2	0.125	0.0524
B	3	1	0.5	0.17	0.121
C	5	2	1	0.33	0.2292
D	8	6	3	1	0.5974

The letters at the decision criteria are A Built-up, Water bodies and Coastal wetland, B Agriculture, C Saltpan and D Barren land and other land.
Consistency ratio: 0.0252.

Table 6.6 Comparison Matrix and Significance Weight of the Distance from Settlement and Industrial Belt

	A	B	C	D	AHP weight values
A	1	0.5	0.5	0.25	0.0942
B	2	1	0.33	0.2	0.1417
C	2	3	1	0.5	0.2143
D	4	5	2	1	0.5498

The letters at the decision criteria are A <500 m, B 500–600 m, C 600–800 m and D >800 m
Consistency ratio: 0.0486

Table 6.7 Comparison Matrix and Significance Weight of the Distance from Road and Railway

	A	B	C	D	AHP weight values
A	1	0.5	0.5	0.25	0.0979
B	2	1	0.5	0.2	0.1304
C	2	2	1	0.25	0.1923
D	4	5	4	1	0.5794

The letters at the decision criteria are A <500 m, B 500–600 m, C 600–800 m and D >800 m
Consistency Ratio: 0.0469

Table 6.8 Comparison Matrix and Significance Weight of the Distance from River

	A	B	C	D	AHP weight values
A	1	0.33	0.33	0.33	0.0939
B	3	1	0.5	0.33	0.1761
C	3	2	1	0.33	0.2472
D	3	3	3	1	0.4827

The letters at the decision criteria are A <100 m, B 100–200 m, C 200–400 m and D >400 m
Consistency Ratio: 0.0789

Table 6.9 Comparison Matrix and Significance Weight of the Distance from Pond

	A	B	C	D	AHP weight values
A	1	0.5	0.5	0.5	0.1346
B	2	1	0.5	0.33	0.1682
C	2	2	1	0.33	0.2362
D	2	3	3	1	0.4611

The letters at the decision criteria are A <200 m, B 200–300 m, C 300–500 m and D >500 m
Consistency Ratio: 0.0789

Table 6.10 Comparison Matrix and Significance Weight of Water Depth (m)

	A	B	C	AHP weight values
A	1	2	5	0.0910
B	0.5	1	3	0.2180
C	0.20	0.33	1	0.6910

The letters at the decision criteria are A <2 m, B 2–10 m and C >10 m
Consistency Ratio: 0.0560

Table 6.11 Comparison Matrix and Significance Weight of Land Elevation (m)

	A	B	C	AHP weight values
A	1	2	6	0.7324
B	0.50	1	4	0.1297
C	0.17	0.25	1	0.1378

The letters at the decision criteria are A <20 m, B 20–30 m and C >30 m
Consistency Ratio: 0.00386

Table 6.12 Total Weight of All Criteria and Subcriteria and CR

Criterions	Weight	Subcriteria	Subweight	CR	Total Weight
Land Use/ Land Cover	0.357	Built-up/ Water Bodies/ Coastal Wetland	0.0524	0.0252	0.01870
		Agriculture	0.1210		0.04318
		Saltpan	0.2292		0.08179
		Barren Land and Others	0.5974		0.21319
Distance From Settlement and Industrial Belt	0.268	<500	0.0942	0.0486	0.02527
		500-600	0.1417		0.03801
		600-800	0.2143		0.05748
		>800	0.5498		0.14747
Distance From Roads and Railway (m)	0.133	<500	0.0979	0.0469	0.01304
		500-600	0.1304		0.01737
		600-800	0.1923		0.02561
		>800	0.5794		0.07718
Distance From Pond	0.083	<200	0.1346	0.0789	0.01113
		200-300	0.1682		0.01391
		300-500	0.2362		0.01953
		>500	0.4611		0.03813
Distance From River	0.059	<100	0.0939	0.0789	0.00555
		100-200	0.1761		0.01042
		200-400	0.2472		0.01462
		>400	0.4827		0.02855
Water Depth (m)	0.055	< 2	0.0910	0.0560	0.00499
		2 - 10	0.2180		0.01196
		>10	0.6910		0.03789
Land Elevation (m)	0.045	<20	0.7324	0.00386	0.03297
		20-30	0.1297		0.00584
		>30	0.1378		0.00621

Source- Computed

6.5 Weighted Overlay Analysis (WOA)

Weighted Overlay Analysis is a useful method to solve the complex spatial problems in GIS environment. It allows overlying of several thematic raster's layer with the same measurement scale and weights based on their percentage of influence (Sk et al., 2020). This technique was used here to get a final suitability map for identifying the site for solid waste disposal.

The WOA is demarcated as

$$\text{WOA} = \sum_{i=1}^{n} Wi \times Ri$$

Where, Wi is the weight of particular decision criteria, Ci, Ri is the raster layer of the same criteria, n is the number of decision criteria.

6.6 Landfill Selection Criteria:

A suitable landfill site should be placed and designed to meet the favorable environmental and socio-economical conditions. It should maintain the safest distance from groundwater, surface water (pond, river) and pollution of the air and soil. Besides, settlement and industrial belt aspects must be considered for landfill site selection. Also, the landfill site should be located near to the existing roads to the transportation and collection costs (Aziz and Khodakarami, 2013). The analysis of selected criteria for landfill site selection was explained in the following sections.

6.6.1 Land Use and Land Cover:

Land use/land cover map is an important criteria in solid management studies (Ebistu & Minale, 2013). It gives the clear idea of spatial distribution of the land (Tadros, 2007) and it also helps to predict the possible future developments. In this study, six broad categories of the land use were identified such as agriculture (76.07 %), built-up (10.15%), water bodies (4.03 %), barren lands (8.25%), saltpan (0.73 %) and other lands (0.82 %). This vector layer was converted into a raster format for the reason of rating and providing weight values. In order, most suitable land classes were given highest

Table 6.13 Sub-Classes of Land Use/Land Cover and Area

Sub-classes	Area in (%)
Agriculture	76.07
Built-up	10.15
River/Water bodies	4.03
Barren land	8.25
Saltpan	0.73
Other lands	0.82

Source- Computed

weightage and least suitable lands were provided with low weightage. Thereafter, for the site selection, the unsuitable classes (agriculture, built-up and water bodies) were merged and were given low weightage. Rest of the suitable lands containing barren land, sparsely natural vegetated land and saltpan area were considered suitable for landfill siting. Each classes were defined and weightage was provided by AHP (Table 6.13, Fig. 6.2).

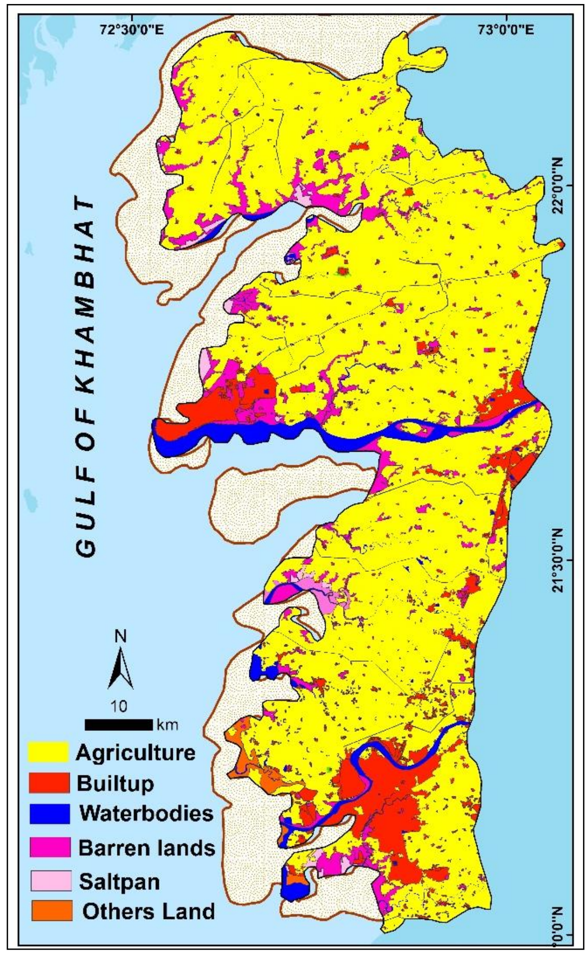

Fig. 6.2 Land Use/Land Cover Map

6.6.2 Distance from Settlement and Industrial Belt:

Disposal sites are not recommended in the vicinity of settlement areas and industrial belt because they are the major sources of toxic gas emissions, noise generation, dust etc. (Hailu, 2019; Pasalari et al., 2019). Therefore, according to the CPHEEO (2016), landfills are not be recommended within 500 meters of settlement areas. In this area, industries are located at Surat, Ankleshwar, Panoli, Bharuch, Dahej, Olpad, Pandeshara, Vagra and Jambusar. In this study, distance from settlements and industrial belts were buffered and categorized into four classes as shown in Table 6.12. Hence, ratings and weights assigned (Table 6.14) for buffer zones increased with increasing distance such as <500 m buffer zone was given scored as 1 (unsuitable) and 19.34% of area was covered, 500-600 m buffer zone was scored as 2 (marginally suitable) which covered 3.10% of area, 600-800 m buffer was scored as 3 (moderately suitable) which had 6.13% of area and >800 m was scored as 4 (highly suitable) and was spread over 71.44% of area (Fig.6.3).

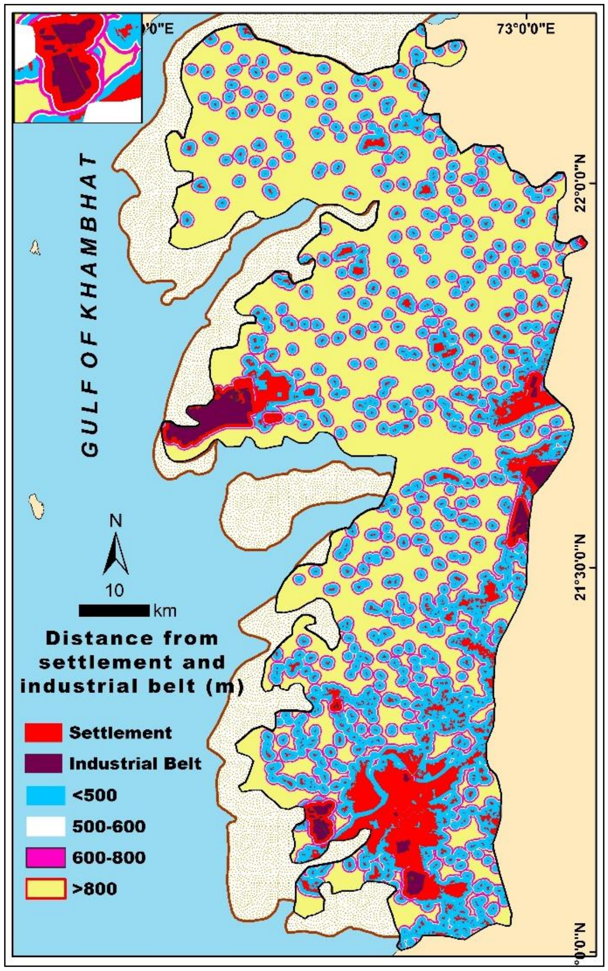

Fig. 6.3 Distance from Settlement and Industrial Belt

Table 6.14 Distance from Settlement and Industrial Belt and Area Coverage of Suitability Level

Distance (m)	Level of Suitability	Area (sq. km)	Area in %
<500	Unsuitable	809.39	19.34
500–600	Marginal suitable	129.7	3.1
600– 800	Moderate suitable	256.55	6.13
>800	highly suitable	2990.44	71.44
	Total	4188.15	100

Source: Computed

6.6.3 Distance from Roads and Railways:

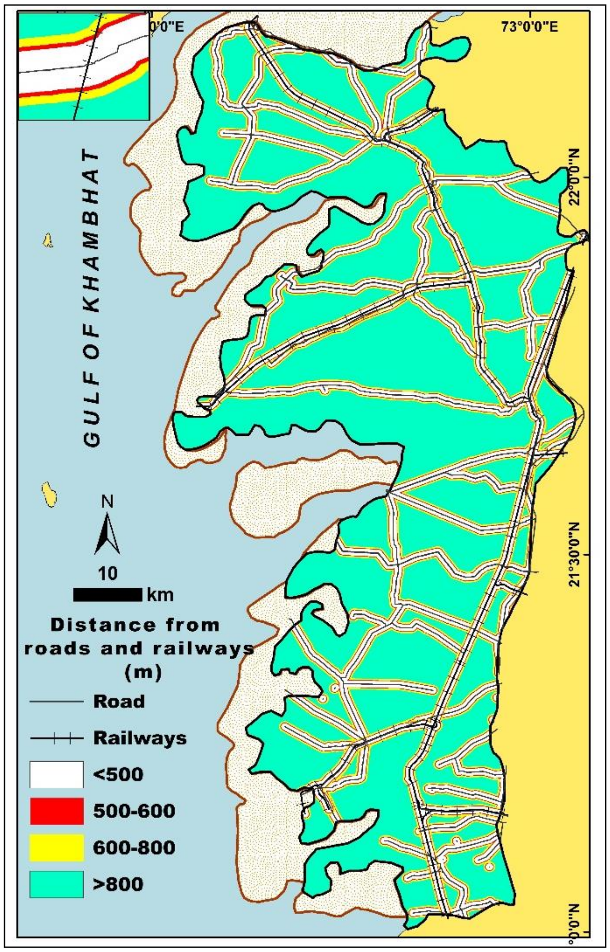

Fig. 6.4 Distance from Roads and Railways

Distance from the roads and railways are an important criterion for the waste management. According to waste management rules (CPHEEO 2016), landfill should be located at the distance of 500 m. In this study, buffered distance was measured from the existing roads and railways and were categorized into four separate classes (Table 6.16). All the buffer zones were weighted by AHP and areas that were at a distance of <500 m from roads was given score as 1 and spread over 13.14% area, 500-600 m buffer zone was scored as 2 and had 2.49% of area, 600-800 m buffer zone was scored as 3 and spread over 4.84% of area and >800 m zone was given the highest score (4) (Table 6.15). It was spread over 79.53% of area (Fig. 6.4).

Table 6.15 Distance from Roads and Railways and Area Coverage of Suitability Level

Distance (m)	Level of Suitability	Area (sq. km)	Area in %
<500	Unsuitable	550.16	13.14
500-600	Marginal suitable	104.37	2.5
600- 800	Moderate suitable	202.74	4.84
>800	highly suitable	3330.93	79.53
	Total	4188.15	100

Source: Computed

6.6.4 Distance from River:

The study area adjoins of Gulf of Khambat and two major rivers Narmada and Tapi and other minor rivers (Mahi, Dhadhar, Kim) flow through the area. According to the (CPHEEO, 2016) regulations, landfill sites should not be located near the river because fresh water and polluted the sub surface water can merge through leaching process (Pasalari et al., 2019; Aziz & Khodakarami, 2013). River water when contaminated from waste disposal contains low dissolved oxygen which is affected by animal and plants species (Townsend et al., 2015).

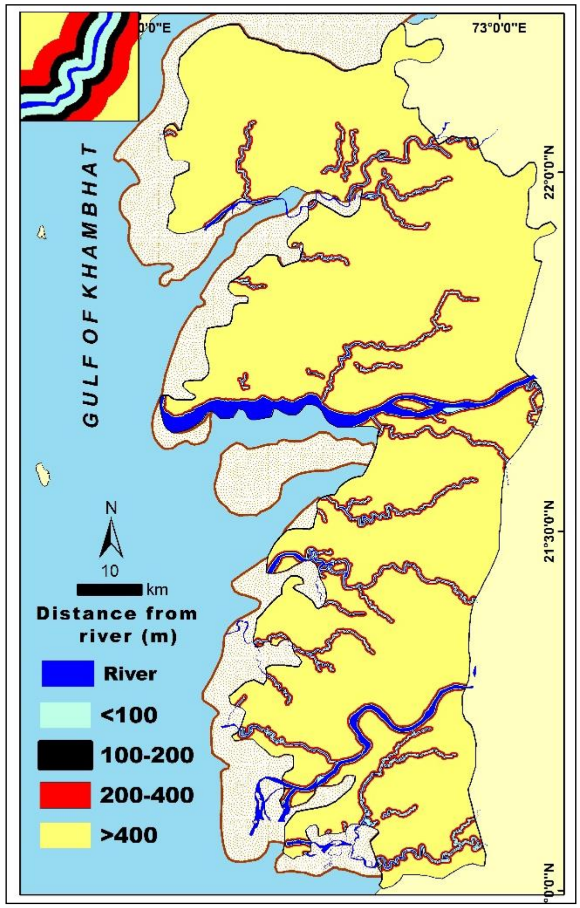

Fig. 6.5 Distance from River

Accordingly, distance from river layer was generated and four buffer zones with specified relative distance around the river was created. Each buffer zone was weighted by AHP. By considering all the rivers, >400m buffer zones were drawn for highly suitable zone and score of 4 was given and it had 80.94% of area. 200-400 m buffer zone was scored as 3 and it was spread over 6.87% area. 100-200 m buffer zone was given a score of 2 which had 3.68% of area. Lowest score (1) was assigned to a buffer of <100 m (Table 6.16 and Fig. 6.5).

Table 6.16 Distance from River and Area Coverage of Suitability Level

Distance (m)	Level of Suitability	Area (sq. km)	Area in %
<100	Unsuitable	356.75	8.52
100- 200	Marginal suitable	153.94	3.68
200- 400	Moderate suitable	287.84	6.87
>400	Highly suitable	3389.08	80.94
	Total	4188.15	100

Source: Computed

6.6.5 Distance from Pond:

Inappropriate dumping in the vicinity of pond is a greater threat to environment and human health. Thus, dumping site should not be located nearer to the pond (Babalola & Busu, 2011). According to (CPHEEO, 2016) landfill site should be >200 m. Otherwise, waste water may contaminate the soil and water by leaching process (Hailu, 2019). In the study area, lakes and ponds were scattered over the entire area and were largely located near the habitats. Therefore, in this study buffer zones were produced in 4 discrete classes such as <200 m buffer zone was scored as 1 and it was spread in 2.89% area. 200-300 m buffer was scored as 2 which covered 2.01%; 300-500 m buffer zone was scored as 3 and it had 5.27% of area. >500 m buffer zone was given highest score (4). It spread over 89.82% of area (Fig. 6.6). All the buffer zones were individually weightage by AHP in Table 6.12 and area estimation was given in Table 6.17.

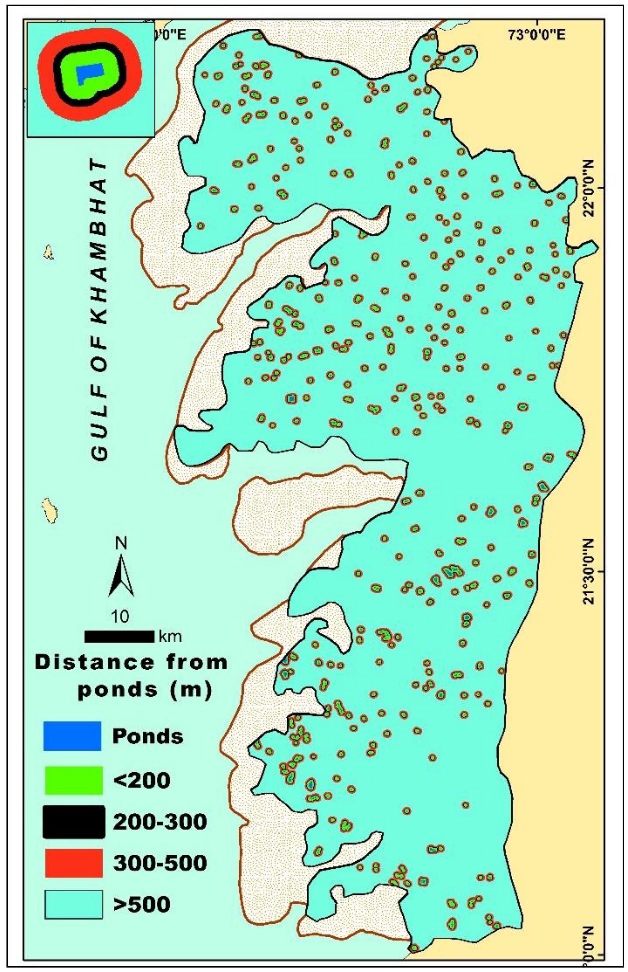

Fig. 6.6 Distance from Pond

Table 6.17 Distance from Pond and Area Coverage of Suitability Level

Distance (m)	Level of Suitability	Area (sq. km)	Area in %
<200	Unsuitable	121.06	2.89
200- 300	Marginal suitable	84.2	2.01
300- 500	Moderate suitable	220.9	5.27
>500	Highly suitable	3762.04	89.82
	Total	4188.15	100

Source: Computed

6.6.6 Water Depth:

Water depth is an important factor for landfill site selection. In general, sufficiently deep area is preferred for suitable site. Therefore, keeping in mind, that where shallower depth is present their landfill site should not be located because waste may affect the groundwater quality in leaching process (Kumar & Hassan, 2013). According to Central Public Health and Environment Engineering Organization (CPHEEO), the bottom of the landfill should be 2 m above from the highest water table. Therefore, entire area was categorized into three classes (< 2 m, 2-10 m and >10 m depth) and weighted separately by AHP in Table 6.12. Thereafter, map was generated using Inverse Distance Weightage Interpolation (IDW) method in ArcGIS software (10.2) (Fig.6.7). Sites within 2 m depth area from the surface was not considered and remaining area were given high score value (Table 6.18).

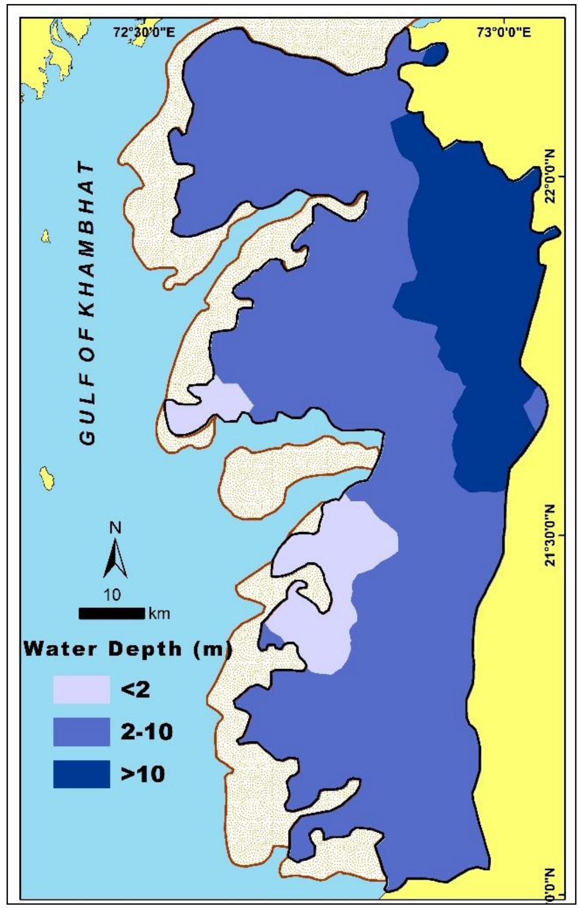

Fig. 6.7 Water Depth

Table 6.18 Water Depth and Area Coverage of Suitability Level

Distance (m)	Level of Suitability	Area (sq. km)	Area in %
<2	Unsuitable	318.98	7.62
2-10	Moderate suitable	3076.12	73.45
>10	Highly suitable	792.97	18.93
	Total	4188.15	100

Source: Computed

6.6.7 Land Elevation:

Land elevation is largely associated with landfills site selection because construction and transport operation cost is maximum at higher elevated region (Yıldırım & Güler, 2016; Şener et al., 2011; Sk et al., 2020). The highest elevation was 47 m from the mean sea level (MSL). This elevation was divided in three classes and scores were assigned (Table 6.19, Fig. 6.8) e.g.<20 m was given as 4; 20-30 m scored as 3 and >30 m was scored as 2. Each buffer zones were separately weighted by AHP (see Table 6.19).

Table 6.19 Land Elevation and Area Coverage of Suitability Level

Distance (m)	Level of Suitability	Area (sq. km)	Area in %
<20	Highly suitable	1909.92	49.60
20-30	Moderate suitable	2066.12	49.33
>300	Marginal suitable	212.11	5.06
	Total	4188.15	100

Source: Computed

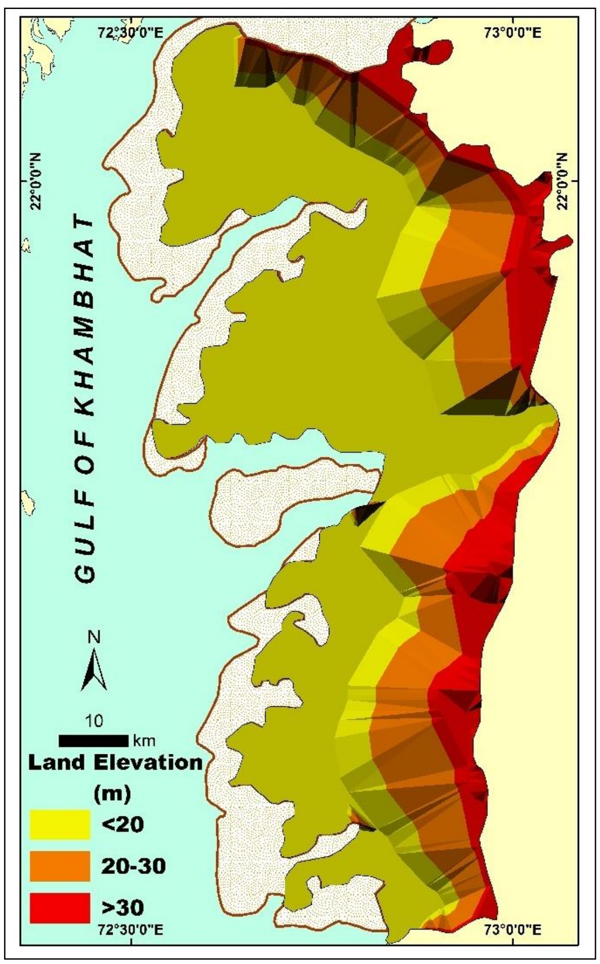

Fig. 6.8 Land Elevation

6.7. Assessment of Suitable Landfill Sites:

The single layer final suitability map depicting the distribution of potential landfill location in four (4) discrete classes was generated. According to estimated figures, highly suitable area for landfill sites was spread over 2.75%, moderately suitable class covered was 71.48%, marginally suitable occupied 5.57% area and unsuitable zone encompassed 20.21% of area (Table 6.20). In this study, seven suitable sites are chosen in the northern and seven in southern part. Landfill sites (Site-1, Site-2 and Site-3) are located in the vicinity of Jambusar City which is in northern part of the study area. They have an adequate space to serve for disposal of industrial waste. Site-4 is located around 5000 m east of Sarbhan village in the north-eastern part of the study area and at a linear distance of 7000 m from Amod town. Site-5 is located at north-eastern part. This site is nearby Nabipur village, at a linear of distance 2300 m. Site-6, is located close to Vagra town is approximately 6000 m away from the center of town. This site can be considered as a suitable place for landfill because it is currently a barren land and is away from settlement.

This site is devoid of waterbodies (pond, river) and railway but is well connected with roads. Site-7 is near Dahej industrial belt, at a distance about 6 km. The site is located in uncultivated area. There is no railway connectivity but is well connected with road network. Site-8, is located within 5000 m of highway and is also outside the buffer of >8000 m from settlement and industries. Site-9 and 10, are located at a safe distance from settlement and are accessible in terms of transport connectivity. The water depth is in these two sites is 6-10 m deep. Both the sites are far from proximity of industrial zones of Ankleshwar and Bharuch. Site-11, is located at north-western part and is closest to Kim, Popodara and New Padri. The site is well connected by road network (Mumbai and Delhi-NH-8). Site-12 is located at a distance of 3000 m from Olpad town. Site-13 is located in the south-western part and is near GIDC Surat (10 km). The site is found in barren land, with pond not existing in the vicinity of the site. Site-14 maintained a safest distance from the settlement area (>1000 m) and is located in the southern part of Surat City and outside the buffer zones of pond, river and biodiversity (Fig. 6.9). However, with the selection of new industrial waste dumping sites the pollution risk would be minimized. Hence, the technique Analytic Hierarchy Process helped in the selection of the landfill sites and the transportation cost will be minimized.

Table 6.20 Level of Suitability and Percentage of Total Area Coverage		
Level Of Suitability	**Area (sq.km)**	**Area in %**
Unsuitable	846.28	20.21
Marginal suitable	233.18	5.57
Moderate suitable	2993.73	71.48
Highly suitable	115	2.75

Source- Computed

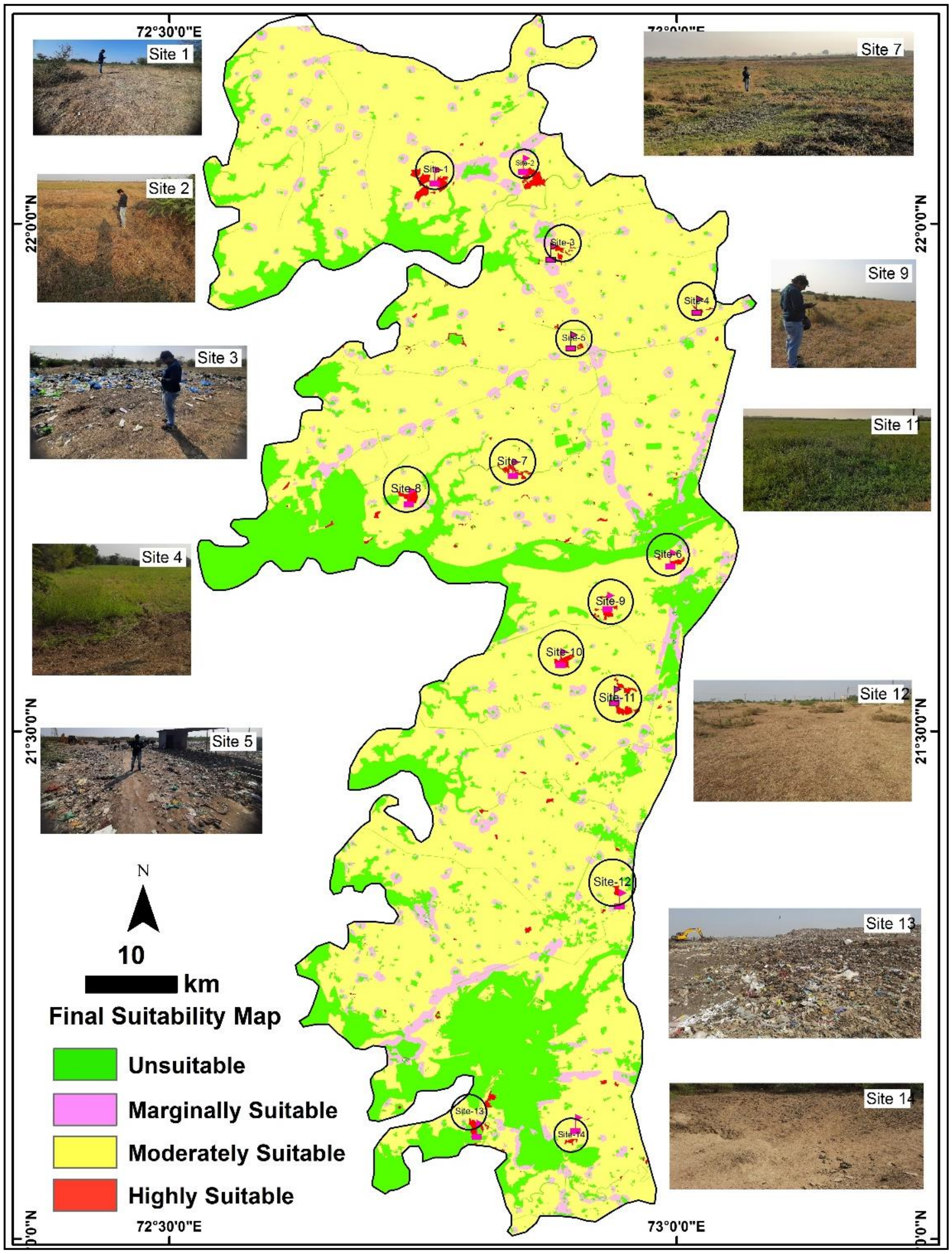

Fig.6.9 Final Suitability Map

Resume:

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. Proper location of landfill site and industrial waste management were major challenges in this study area. Therefore, 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). In this process, all the raster layers were overlaid and setup weightage that calculated by AHP. Thereafter, AHP and GIS both integrating method were used to derived final suitability map in GIS environment. 14 highly suitable landfill sites were identified which was covered 2.75% of area and fulfill the minimum requirements, according to (CPHEEO, 2016) for potential landfill sites selection. However, this study focused on selected area would be free from pollution risk and protection of environment. Therefore, this technique was help to study of landfill selection and save time and cost.

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