

# **CHAPTER 7 SUITABLE METHOD FOR REDUCTION OF CONTAMINANT TO MINIMIZE HEALTH RISK**

## **7.1 General**

After conducting a comprehensive assessment of groundwater vulnerability utilizing a validated modified DRASTIC model and establishing a strong correlation with relevant water quality parameters, it has been conclusively determined that the concentration of Nitrate in the groundwater is considerably high. This high Nitrate level indicates a significant risk to human health, necessitating urgent measures for effective reduction. The study area is having various hydrogeological conditions, including diverse aquifer materials and varying groundwater table levels.

Within this complex and varied context, the identification and implementation of appropriate Nitrate reduction methods are paramount. By employing the Analytical Hierarchy Process (AHP), a powerful Multi-Criteria Decision Making (MCDM) technique derives a scientifically grounded recommendation for the most suitable Nitrate reduction method. As a result, a specific method at each well location will be helpful to reduce the Nitrate concentration which will ultimately minimize human health risk.

## **7.2 Flow chart to suggest suitable method to reduce Nitrate in groundwater**

The initial step involves identifying and characterizing the dominant contaminant in the groundwater, (in this case: Nitrate ( $\text{NO}_3$ )), within the study area. Understanding the extent of high Nitrate concentrations is essential. Following established USEPA guidelines it is calculated the Hazard Quotient (HQ) for both adults and children to evaluate associated health risks. This assessment is further refined by incorporating a screening process based on land use, land cover mapping, water use scenarios and population distribution. An argument for screening exists, for example, if Nitrate concentration is very high and HQ is also more than 1 at same point location but the population is not at all using the groundwater then this point location will not be located in critical area having health risk.

For critical area of identification, the layer of higher health risk index among children and adults needs to be considered along with layer of highly and severely vulnerable classes of vulnerability index and merged using GIS tool. During GTS, groundwater samples have been

collected and with area specific characteristics information have been noted this is used to suggest appropriate Nitrate reduction method.

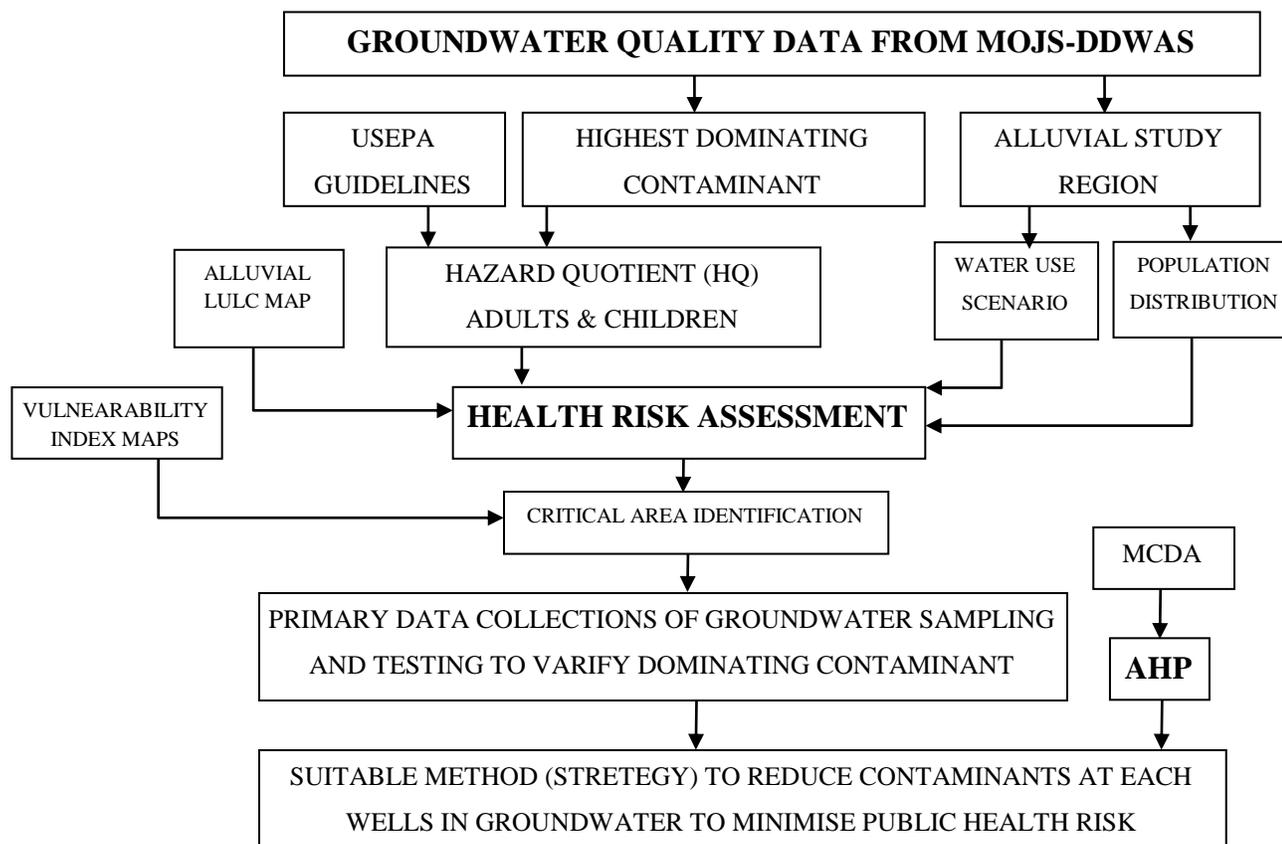


Fig 7.1 Flow chart to suggest suitable method to reduce contaminants in groundwater

Subsequent to identifying critical zones, an investigation was initiated to validate the heightened Nitrate concentrations and gather data. This primary dataset formed the basis for formulating targeted remedial approaches for individual well sites within these critical zones.

### 7.3 Health Risk Assessment

High Nitrate levels in groundwater pose a significant health risk to human populations. Nitrates repeatedly infiltrate groundwater from agricultural runoff, fertilizers, septic systems and industrial waste. When contaminated groundwater is consumed or used in drinking water sources, Nitrates can convert to nitrites within the body, particularly in infants, which can disrupt the blood's ability to carry oxygen, leading to a potentially life-threatening condition called methemoglobinemia or "blue baby syndrome." Additionally, high Nitrate exposure has been linked to increased risks of certain cancers, thyroid disorders and adverse effects on the

cardiovascular system. It is crucial to monitor and regulate Nitrate levels in groundwater and implement proper water treatment methods to mitigate health risks and ensure safe drinking water for communities. Public education and awareness campaigns are also essential to encourage prudent water usage and reduce Nitrate contamination at its source.

### 7.3.1 Hazard Quotient

Human health risks due to high Nitrates in groundwater have been assessed as per USEPA proposed HRA method. As the groundwater is the primary source of drinking water, oral ingestion is considered as the leading human exposure indicator (Adimalla and Li 2018, Ahada and Suthar 2018). The Health Risk Assessment is based on following governing equations. The ingestion of Nitrate ions with drinking water in human body is calculated by following equation,

$$\text{Chronic Daily Intake (CDI)} = ((C * IR * EF * ED) / (BW * AT)) \quad (11)$$

Chronic Daily Intake (CDI) is the ingestion dose from drinking water in (mg/kg/day). In the above equation, C is the concentration of Nitrate ions evaluated in groundwater samples, in mg/l. IR is the average daily Ingestion Rate of drinking water, in L/day, the values of IR are 2 L/day for adults and 1 L/day for children. EF is the exposure frequency, in 365 days/year. ED is the exposure duration. BW is the body weight, 70 kg for adults and 15 kg for children. AT is the average exposure time, 10950 days and 5380 days for adults and children respectively (Ahada & Suthar 2018). The Hazard quotient ( $HQ_{\text{Nitrate}}$ ) is used to estimate the Non-carcinogenic health risk, by following equation,

$$HQ_{\text{nitrate}} = \text{CDI}/\text{RfD} \quad (12)$$

Where, RfD is the reference dose, in 1.6 mg/kg/day for non-carcinogenic health risk. ( $HQ_{\text{Nitrate}} < 1$ ) is an acceptable level of non-carcinogenic risk and ( $HQ_{\text{Nitrate}} > 1$ ) potentially known to cause health risks in individuals due to ingestion of Nitrate contaminated groundwater.

The groundwater Nitrate concentration above 45 mg/L proves to be harmful for human consumption (IS: 10500-2012). Groundwater Nitrate concentrations obtained from MOJS-DDWAS data (50 samples of 2018) was used to develop spatial distribution maps for both pre and post monsoon seasons in GIS environment (IDW-Interpolation) to visualize areas with high contamination. From these maps (Figures: 7.2, 7.3), only the blue zone indicates area where Nitrate contamination is below Indian standards, everywhere else they are above the Indian standards. The highest Nitrate contamination is found in certain pockets of Northern, central and Western regions. The lowest observed Nitrate concentrations are in the range of 1 mg/L in

Karjan block for both pre and post monsoon seasons whereas highest concentrations are in the range of 294 mg/L in Jambusar block and 308 mg/L in Padra block for pre and post monsoon seasons respectively. Both Padra and Jambusar blocks are highly dominated by industrial and agricultural activities. These maps were further utilized in assessing the health risk for children and adults for both pre and post monsoon seasons. The figures 7.4 and 7.5 represent health risk to children and adults respectively for pre monsoon season. The figures 7.6 and 7.7 represent health risk to children and adults respectively for post monsoon season.

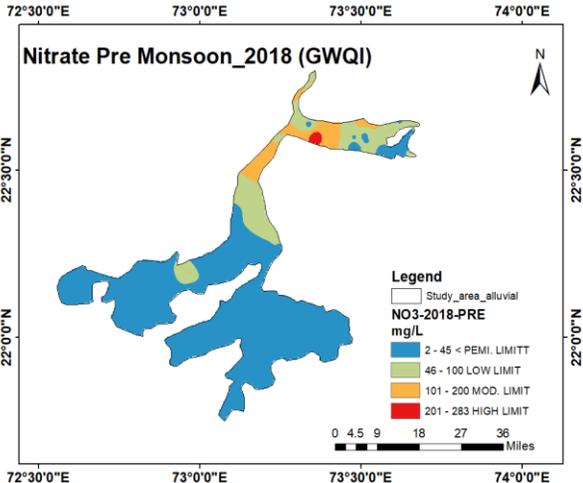


Fig 7.2 GW Nitrate 2018 – Pre Monsoon

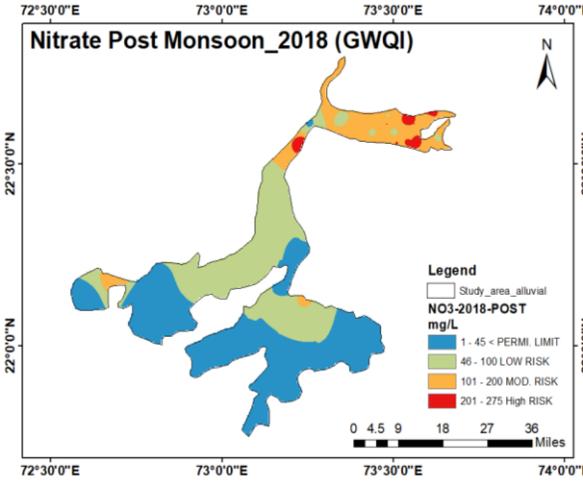


Fig 7.3 GW Nitrate 2018 – Post Monsoon

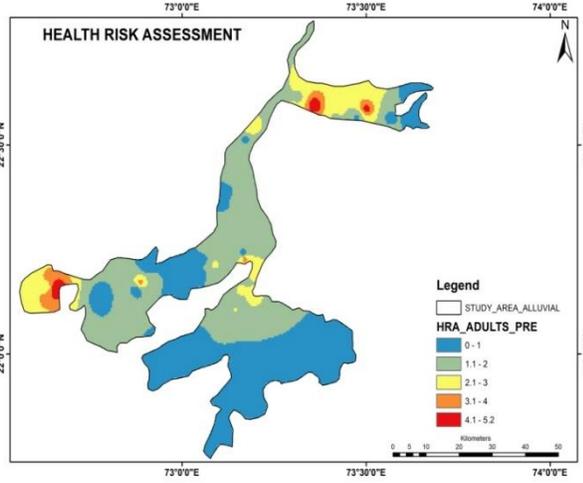


Fig 7.4 Health Risk to Adults – 2018-Pre Monsoon

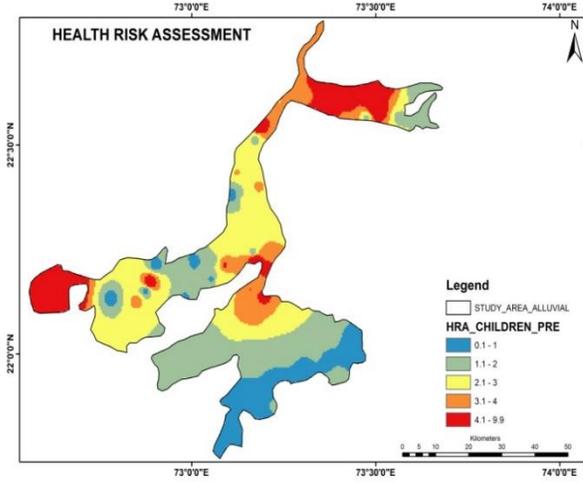
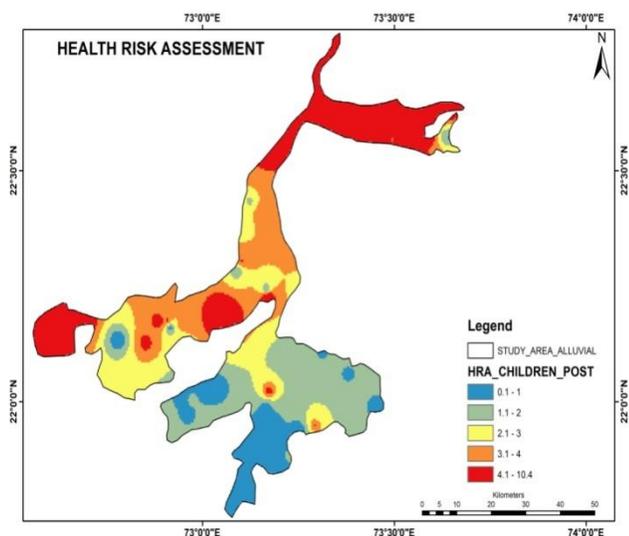
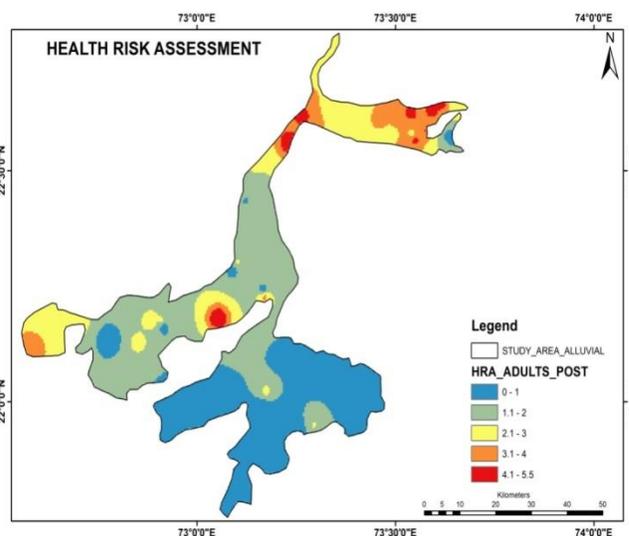


Fig 7.5 Health Risk to Children – 2018-Pre Monsoon



**Fig 7.6 Health Risk to Children – 2018-Post Monsoon**



**Fig 7.7 Health Risk to Adults – 2018-Post Monsoon**

The health risk indices of children and adults both were reclassified into 5 classes in which class-1 represents index (0-1) as a no health risk and as we go to higher classes, the health risk becomes higher. The area distribution of assessed health risk is described in table 7.1 for children and adults respectively for both the seasons. From this table it is clear that more than 70% and almost 30% of the study area indicates health risks to children and adults respectively. Present study considers classes 2 and 3 to be moderately critical whereas 4 and 5 to be the most critical which is almost 20% and 30% for the children and almost 2% and 5% for the adults in pre and post monsoon season respectively. Such critical area needs to be prioritized with groundwater management strategies that minimize the health risk on public due to groundwater Nitrate contamination.

**Table 7.1 Area Distribution of HRA for Children and Adults**

Class	HRA-Children				HRA-Adults			
	Pre-Monsoon, 2018		Post-Monsoon, 2018		Pre-Monsoon, 2018		Post-Monsoon, 2018	
	Area (km <sup>2</sup> )	% Area						
1	698	25.16	791	28.50	1998	72.00	1475	53.13
2	1027	37.02	517	18.63	535	19.26	766	27.62
3	508	18.32	669	24.09	193	6.94	397	14.32
4	271	9.78	216	7.77	39	1.42	122	4.41
5	270	9.73	583	21.01	10	0.37	14	0.52
<b>Total</b>	<b>2775</b>	<b>100</b>	<b>2775</b>	<b>100</b>	<b>2775</b>	<b>100</b>	<b>2775</b>	<b>100</b>

### 7.3.2 LULC map, Water Use Scenario and Population Distribution for HRA

Standard method suggested by USEPA guideline to evaluate health risk assessment is required to be upgraded. In the modification part of HRA, three new layers are introduced such as Land Use-Land Cover map (LULC), Water use scenario (WUS) and Population density (PD). The LULC map highlighting agriculture and non-agricultural land, major urban settlements and water bodies was derived from supervised classification of Landsat-8 images obtained from USGS (United States Geological Survey) Earth Explorer.

In addition to this, population distribution map and water use scenario map were also obtained from MOJS-DDWAS are shown in figures 7.9 and 7.10 respectively. The water use scenario showed the distribution of the use of filter points, surface water sources, deep tubewells, shallow tubewells and openwells in the study area. These three groundwater sources are given ratings of 3, 4 and 5 respectively which indicate the probability of openwells getting contaminated is higher than shallow and deep tubewells respectively. This data give significant knowledge about various water sources (groundwater, surface water or combined) currently used by the population residing in the study region and their water dependency.

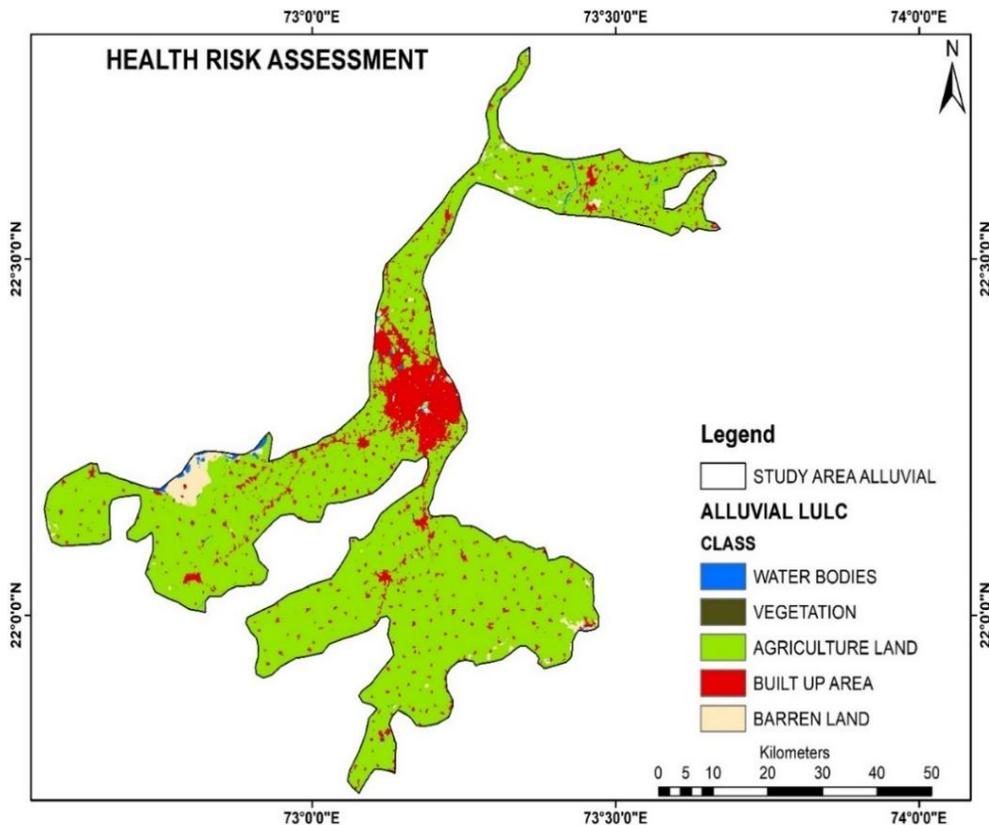
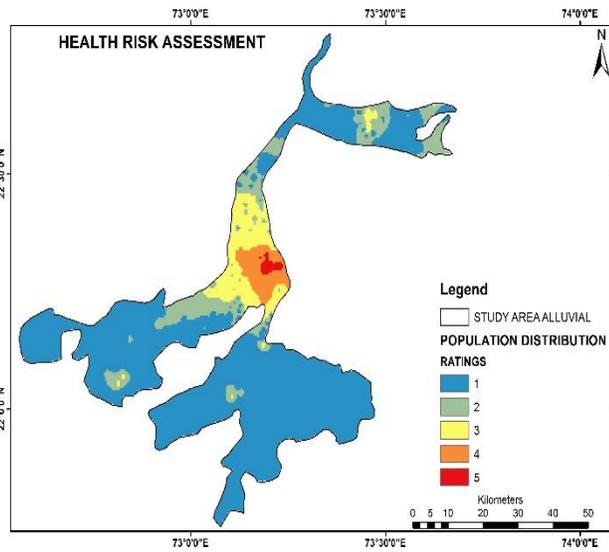
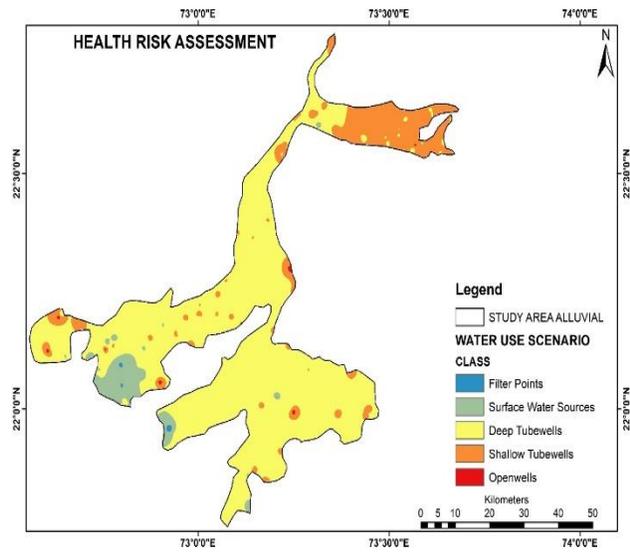


Fig 7.8 Land Use Land Cover Map 2018 (LULC)



**Fig 7.9 Population Distribution Map**



**Fig 7.10 Water Use Scenario Map**

**Table 7.2 Rating for HRA**

<b>Land Use Land Cover Classification</b>	<b>Population Distribution Classification</b>	<b>Water Use Scenario Classification</b>	<b>Ratings</b>
Surface Water	< 585	Filter Points	1
Built-up Area	586 – 1837	River/Ponds	2
Barren Land	1838 – 4595	Deep Tubewells	3
Vegetation Land	4596 – 10223	Shallow Tubewells	4
Agriculture Land	> 10223	Openwells	5

The risk ratings for land use categories, specifically agriculture land and vegetation, have been high to 5 and 4, respectively. This adjustment is a result of their significant contribution to high groundwater Nitrate levels, particularly within the alluvial region. These two categories are considered primary sources of high Nitrate contamination. In contrast, surface water sources have been assigned a relatively low rating of 1, reflecting their lower susceptibility to contamination. Built-up areas have received a rating of 2, signifying a moderate level of risk, while barren land falls in the middle with a rating of 3.

Furthermore, the population density rating has been established to align with the above-mentioned table. This rating system underscores the direct correlation between higher population densities and an increased in groundwater contamination. Thus, areas with denser populations have been attributed higher risk ratings, emphasizing the importance of managing potential contamination risks in these regions.

### 7.3.3 HRA Index

Apart from the conventional way of looking at Health risk assessment, present study adopted various other key parameters and prepared an inclusive outcome in the form of a map representing Health Risk Assessment (figures: 7.11, 7.12) with the help of overlay analysis in GIS environment. All the maps figure 7.4 to 7.10 were reclassified into (1-5) classes, and overlaid on each other giving health risk (HRA) for both pre and post monsoon seasons. Table 7.3 shows the area distribution of HRA in which it is observed that for the post monsoon season, the risk prone area (sum of class 4 and 5) almost doubles from 10.7% to 21.3% indicating the importance of seasonal analysis.

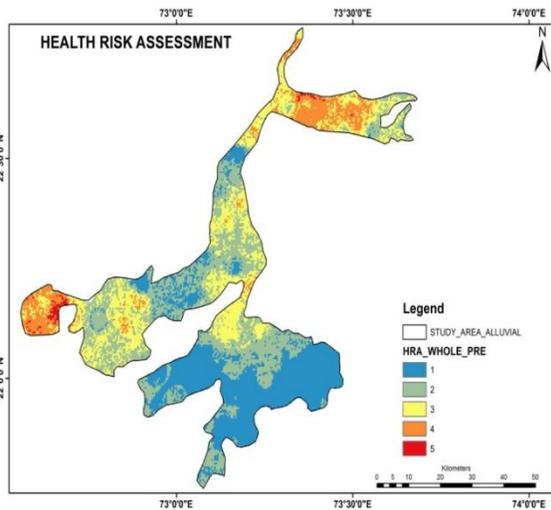


Fig 7.11 HRA – 2018-Pre Monsoon

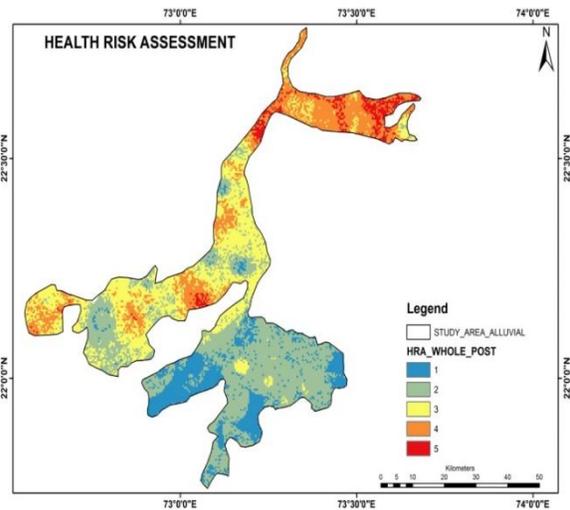


Fig 7.12 HRA – 2018-Post Monsoon

Table 7.3 Area Distribution of HRA-Whole

Class	Pre Monsoon 2018		Post Monsoon 2018	
	Area (km <sup>2</sup> )	% Area	Area (km <sup>2</sup> )	% Area
1	877	31.62	399	14.37
2	944	34.02	1034	37.25
3	657	23.66	753	27.13
4	274	9.89	488	17.57
5	23	0.81	102	3.69
<b>Total</b>	<b>2775</b>	<b>100</b>	<b>2775</b>	<b>100</b>

## 7.4 Identification of Critical Area

The primary aim of this research is to propose effective remedial measures aimed at mitigating potential public health risks. In pursuit of this objective, various key parameters were examined, including the development of modified groundwater vulnerability figures (7.13 to 7.16). These figures provide insights into the hydro-geological and physical characteristics of the study area. In order to pinpoint critical areas requiring immediate attention, upgraded DRASTIC maps and health risk assessment maps for the entire region is used.

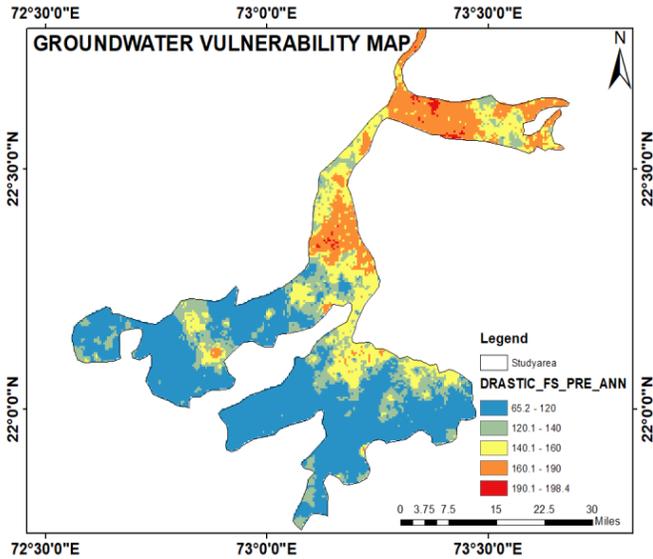


Fig 7.13 DRASTIC-FS Vulnerability map pre monsoon

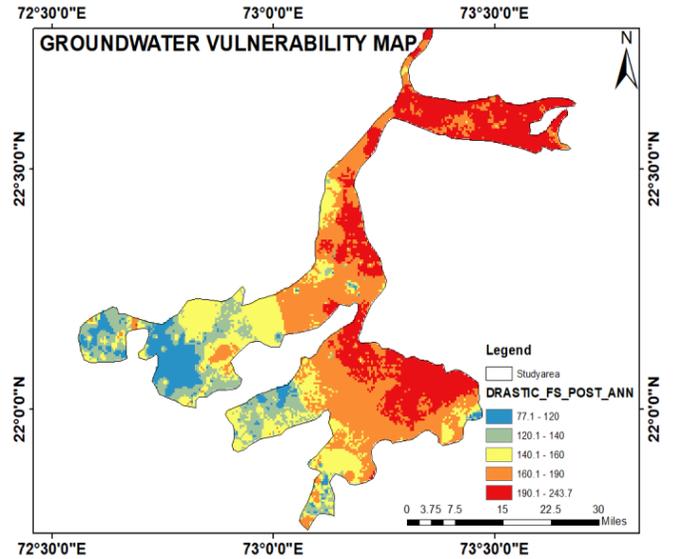


Fig 7.14 DRASTIC-FS Vulnerability map post monsoon

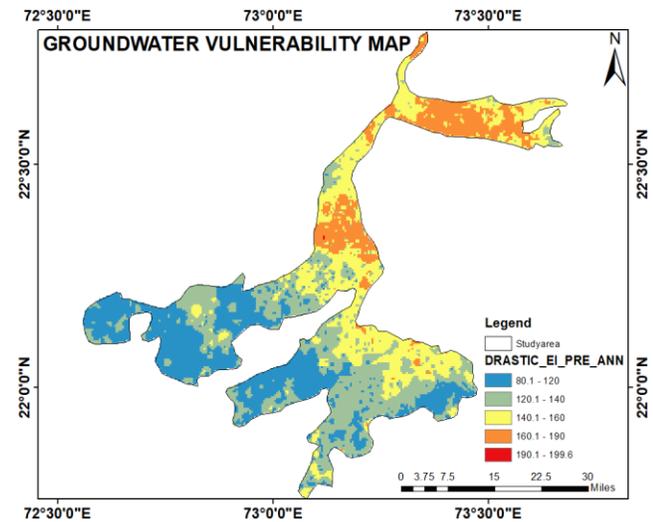


Fig 7.15 DRASTIC-EI Vulnerability map pre monsoon

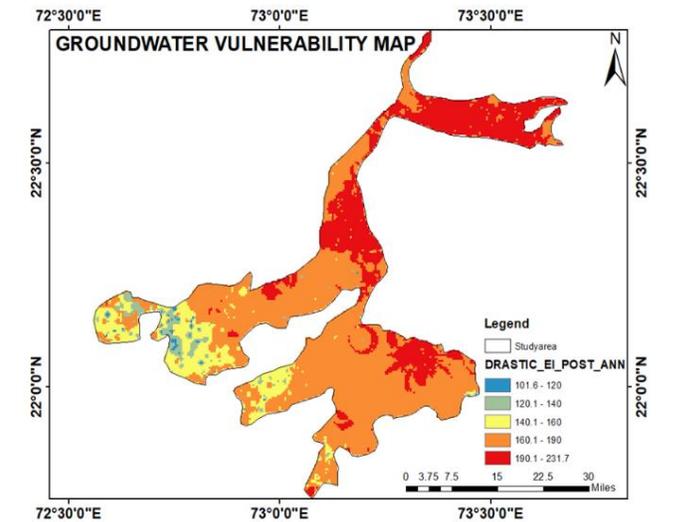
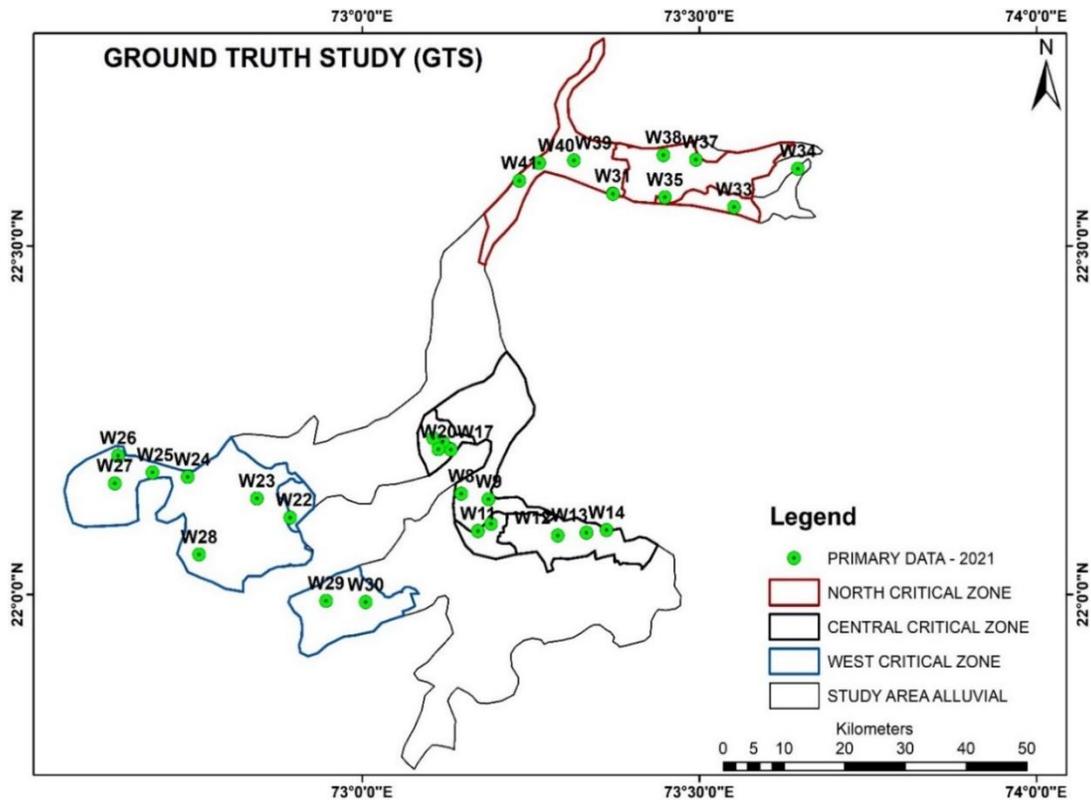


Fig 7.16 DRASTIC-EI Vulnerability map post monsoon



**Fig 7.17 Identify the critical zones and sample collection in study area**

Analysis of groundwater vulnerability, both pre and post monsoon season using the DRASTIC method, revealed highly and severely vulnerable zones, particularly in the Northern, Central and Western region. The Health Risk Assessment (HRA) maps, encompassing the entire study area, indicate that health risks in the Northern and Western regions fall within the categories 4 and 5.

Subsequently, by integrating the necessary raster files using the overlay tool in ARC-GIS, fig 7.17 is generated, which serves as a visual representation of the critical areas within the study region. Each highlighted polygon on this map signifies a critical area deserving special attention and targeted remedial actions.

#### **7.4.1 Ground Truth Study (GTS)**

Groundwater Treatment System (GTS) constitutes a pivotal initial phase in groundwater remediation efforts. These crucial stages involve site exploration, primary data collection, systematic sampling procedures and precise laboratory testing of a wide array of physico-chemical groundwater parameters. These activities are undertaken with the overarching objective of establishing a thorough understanding of the groundwater quality dynamics, thus laying the foundation for the selection of an appropriate and effective remediation strategy.

Upon the identification of areas with critical contamination zone, a process typically driven by health risk assessments and modified DRASTIC maps, it becomes imperative to verify these findings through primary data collection efforts. The primary data involves the direct examination of the current status of contaminants within the groundwater, providing a real-time and comprehensive perspective on the extent and nature of the pollution issues.

In this specific study, a total of 41 well samples were collected within the critical zones, as showed in the illustrative figures provided in Figure 7.17. These strategic sampling locations were chosen to ensure that they are representative of the identified areas of concern. The subsequent analysis of these samples yields invaluable insights into the nature and distribution of contaminants in the groundwater, thus serving as a critical baseline for informed decision-making and the subsequent design and implementation of effective groundwater remediation measures.

### **Delineation of Nitrate in Groundwater**

The delineation of Nitrate in groundwater, as per the American Public Health Association (APHA) guidelines, is a comprehensive process aimed at assessing the concentration of Nitrate contamination in groundwater sources. Nitrate contamination in groundwater can originate from various sources such as agricultural runoff, septic systems and industrial activities, posing potential health risks, particularly for vulnerable groups like infants and pregnant women.

The process involves careful site selection, followed by the collection of groundwater samples from monitoring wells or domestic wells in the critical areas. Proper sample preservation and handling techniques are crucial to prevent contamination during transportation to accredited laboratories where Nitrate concentration analysis is performed using approved methods. The resulting data is evaluated and spatial mapping is used to visualize the distribution of Nitrate concentrations, helping to understand the contamination extent.

The UV spectro-photometric (fig. 7.18) screening method is used to determine Nitrate from the screening samples. The sample preparation is the key phenomenon in any kind of experiment. Here 10 ml screened sample is taken and by adding distilled water a 50 ml solution is made, then 1 ml HCL is added before taking the absorption of samples. Then, Nitrate calibration curve (fig. 7.19) is prepared as per APHA (1998). The absorption values of each sample is taken with reference to stock Nitrate solution in photo-spectrometer, for the range of 220 nm and 275 nm from this respective values of Nitrate concentration have been obtained.

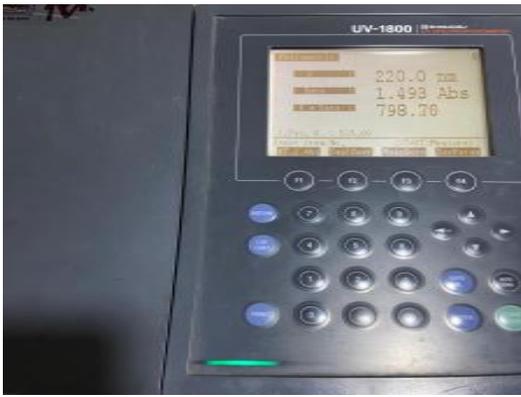


Fig 7.18 Ultraviolet spectro-photometric

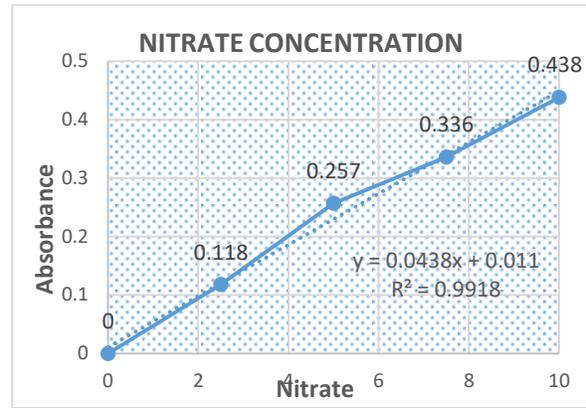


Fig 7.19 Nitrate Calibration Curve

## 7.5 Suitable method to reduce Nitrate in groundwater with AHP

### Analytical Hierarchy Process (AHP)

The AHP first explained by Saaty (1980) is one of the most widely used MCDA methods that incorporates qualitative and quantitative data to reveal the choice orders of decision-makers (DMs). The starting step is to decompose the decision making problem in a hierarchical manner to develop the pairwise comparison matrix based on choice order of the alternatives (ranks) and criteria (weights) considering inputs of DMs. A scale rating of nine orders in which 1 denotes equivalent and 9 indicates highest importance with 2 to 8 even numbers as intermediate ratings are assigned to each criteria and alternatives to compute weightage by following equation:

$$Pq = \lambda_{\max} * q \quad (13)$$

Where, P is the comparison matrix of n dimension,  $\lambda_{\max}$  is the highest eigenvalue of P and q is eigenvector corresponding to  $\lambda_{\max}$ . The consistency of the comparison matrix has to be checked as the inputs from DMs might contradict their own preferences. The inclusion of consistency ratio (CR) in any MCDA method is a common practice to evaluate any inconsistencies in the comparison matrix.

$$CI = (\lambda_{\max} - n) / (n - 1) \quad (14)$$

$$CR = CI / RCI \quad (15)$$

Where CR is the consistency ratio, CI is the consistency index, RCI is the average random consistency index with the same dimension of the comparison matrix, n is the number of criteria/alternatives. If the CR is greater than 10%, the matrix is said to be inconsistent and DMs are advised to revise the matrix until CR comes below 10%.

The present research has emphasized evaluating eight fundamental criteria, consisting of four non-technical aspects: Initial Cost (IC), Operation and Maintenance Cost (OMC), Remedial Time (RT), and Removal Rate (RR) and four technical considerations: Ground Water Table (GWT), Aquifer Material (AM), Location Specific Characteristic (LSC), and Contamination Level (CL). These criteria were employed to assess the performance of 5 distinct groundwater remediation alternatives, namely phytoremediation (PHYTO), pump and treat (PAT), pump and fertilize (PAF), permeable reactive barrier (PRB) and chemical reduction (CHEM).

From the results of AHP, highest eigenvalue ( $\lambda_{max}$ ) of the criteria comparison matrix (Table 7.4) is 8.97, the consistency index (CI) is 0.14, the average random consistency index (RCI) of eight criteria is 1.41 given in table 7.5 and submitting above values in equation of AHP, the consistency ratio (CR) is found to be 9.87% which is less than 10% making the comparison matrix to be consistent. The same AHP method was applied to evaluate alternatives for each criteria mentioned in table 7.6, to 7.13 representing remediation alternatives comparison matrix for Initial Cost (IC), Operation and Maintenance Cost (OMC), Remediation Time (RT), Removal Rate (RR), Ground Water Table (GWT), Aquifer Material (AM), Location Specific Characteristic (LSC) and Contaminant Loading (CL) respectively. The weights obtained for each criterion and each remedial alternative per criteria have been termed as local weights mentioned in table 7.14. The product of local weights of respective criteria and alternatives have been termed as global weights which helped in determining the choice order of remedial measures based on sorting values from high to low highlighting the preferential sequence: (1) CHEM (2) PAT (3) PHYTO (4) PRB (5) PAF. Such choice order was then applied at each primary well location falling in the critical area with Nitrate concentration above permissible limit and described in table 7.15. A single well data has been calculated at a time using this method, for example, Well No. 1 (Bauchawad, Panigate, Vadodara) calculation presented.

To form pairwise comparison metric, experts such as professors with expertise in water resources and environmental engineering, and Ph.D. research scholars have been selected for their perceptions regarding the remedial methods. In accordance with the requirements of the AHP method, a preference sheet was created to assign ratings based on multiple criteria for selection of a nitrate reduction method. The pairwise comparison metric has been formulated

based on the preferences obtained from the experts and pairwise comparison matrices were developed. Final output of the preference sheet has been attached in the Annexure III.

**Table 7.4 Criteria comparison matrix**

	<b>IC</b>	<b>OMC</b>	<b>RT</b>	<b>RR</b>	<b>GWT</b>	<b>AM</b>	<b>LSC</b>	<b>CL</b>	$\lambda_{max}$	8.97
<b>IC</b>	1.00	3.00	2.00	0.33	0.25	0.25	0.33	0.50	<b>CI</b>	0.14
<b>OMC</b>	0.33	1.00	0.33	0.25	0.20	0.25	0.33	0.50	<b>RCI</b>	1.41
<b>RT</b>	0.50	3.00	1.00	0.50	0.33	0.50	0.50	0.50	<b>CR</b>	9.87
<b>RR</b>	3.00	4.00	2.00	1.00	0.50	0.50	0.50	0.50		
<b>GWT</b>	4.00	4.00	3.00	2.00	1.00	0.33	2.00	0.50		
<b>AM</b>	4.00	4.00	2.00	2.00	3.00	1.00	0.50	0.50		
<b>LSC</b>	3.00	3.00	2.00	2.00	0.50	2.00	1.00	2.00		
<b>CL</b>	2.00	2.00	2.00	2.00	2.00	2.00	0.50	1.00		

**Table 7.5 Average random consistency index RCI**

<b>n</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
<b>RCI</b>	0	0	0.58	0.9	1.12
<b>n</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>
<b>RCI</b>	1.24	1.32	1.41	1.45	1.49

**Table 7.6 Remedial alternatives comparison matrix for initial cost (IC)**

<b>IC</b>	<b>PHYTO</b>	<b>PAT</b>	<b>PAF</b>	<b>PRB</b>	<b>CHEM</b>	$\lambda_{max}$	5.20
<b>PHYTO</b>	1.00	4.00	3.00	4.00	2.00	<b>CI</b>	0.05
<b>PAT</b>	0.25	1.00	0.33	0.50	0.25	<b>RCI</b>	1.12
<b>PAF</b>	0.33	3.00	1.00	2.00	0.33	<b>CR</b>	4.55
<b>PRB</b>	0.25	2.00	0.50	1.00	0.33		
<b>CHEM</b>	0.50	4.00	3.00	3.00	1.00		

**Table 7.7 Remedial alternatives comparison matrix for operation and maintenance cost (OMC)**

<b>OMC</b>	<b>PHYTO</b>	<b>PAT</b>	<b>PAF</b>	<b>PRB</b>	<b>CHEM</b>	$\lambda_{max}$	5.42
<b>PHYTO</b>	1.00	2.00	2.00	0.33	0.25	<b>CI</b>	0.11
<b>PAT</b>	0.50	1.00	0.50	0.50	0.50	<b>RCI</b>	1.12
<b>PAF</b>	0.50	2.00	1.00	0.33	0.33	<b>CR</b>	9.47
<b>PRB</b>	3.00	2.00	3.00	1.00	0.50		
<b>CHEM</b>	4.00	2.00	3.00	2.00	1.00		

**Table 7.8 Remedial alternatives comparison matrix for remediation time (RT)**

<b>RT</b>	<b>PHYTO</b>	<b>PAT</b>	<b>PAF</b>	<b>PRB</b>	<b>CHEM</b>	$\lambda_{max}$	5.35
<b>PHYTO</b>	1.00	0.25	0.33	0.33	0.25	<b>CI</b>	0.09
<b>PAT</b>	4.00	1.00	4.00	3.00	2.00	<b>RCI</b>	1.12
<b>PAF</b>	3.00	0.25	1.00	0.50	0.33	<b>CR</b>	7.74
<b>PRB</b>	3.00	0.33	2.00	1.00	2.00		
<b>CHEM</b>	4.00	0.50	3.00	0.50	1.00		

**Table 7.9 Remedial alternatives comparison matrix for Removal Rate (RR)**

<b>RR</b>	<b>PHYTO</b>	<b>PAT</b>	<b>PAF</b>	<b>PRB</b>	<b>CHEM</b>	$\lambda_{max}$	5.21
<b>PHYTO</b>	1.00	0.20	0.33	0.25	0.25	<b>CI</b>	0.05
<b>PAT</b>	5.00	1.00	4.00	2.00	2.00	<b>RCI</b>	1.12
<b>PAF</b>	3.00	0.25	1.00	0.33	0.33	<b>CR</b>	4.75
<b>PRB</b>	4.00	0.50	3.00	1.00	0.50		
<b>CHEM</b>	4.00	0.50	3.00	2.00	1.00		

**Table 7.10 Remedial alternatives comparison matrix for groundwater table (GWT)**

<b>GWT_5-20 (ft)</b>							
<b>GWT</b>	<b>PHYTO</b>	<b>PAT</b>	<b>PAF</b>	<b>PRB</b>	<b>CHEM</b>	$\lambda_{max}$	5.42
<b>PHYTO</b>	1.00	5.00	2.00	3.00	4.00	<b>CI</b>	0.11
<b>PAT</b>	0.20	1.00	0.50	0.50	3.00	<b>RCI</b>	1.12
<b>PAF</b>	0.50	2.00	1.00	4.00	3.00	<b>CR</b>	9.45
<b>PRB</b>	0.33	2.00	0.25	1.00	3.00		
<b>CHEM</b>	0.25	0.33	0.33	0.33	1.00		

**Table 7.11 Remedial alternatives comparison matrix for Aquifer Material (AM)**

<b>Aquifer Material_Clay</b>							
<b>AM</b>	<b>PHYTO</b>	<b>PAT</b>	<b>PAF</b>	<b>PRB</b>	<b>CHEM</b>	$\lambda_{max}$	5.45
<b>PHYTO</b>	1.00	4.00	3.00	3.00	3.00	<b>CI</b>	0.11
<b>PAT</b>	0.25	1.00	0.50	0.50	3.00	<b>RCI</b>	1.12
<b>PAF</b>	0.33	2.00	1.00	3.00	2.00	<b>CR</b>	9.94
<b>PRB</b>	0.33	2.00	0.33	1.00	2.00		
<b>CHEM</b>	0.33	0.33	0.50	0.50	1.00		

**Table 7.12 Remedial alternatives comparison matrix for Location Specific Characteristic (LSC)**

<b>LSC_Urban highly population area, improper sewerage</b>							
<b>LSC</b>	<b>PHYTO</b>	<b>PAT</b>	<b>PAF</b>	<b>PRB</b>	<b>CHEM</b>	$\lambda_{max}$	5.35
<b>PHYTO</b>	1.00	0.25	0.50	0.20	0.20	<b>CI</b>	0.09
<b>PAT</b>	4.00	1.00	3.00	2.00	2.00	<b>RCI</b>	1.12
<b>PAF</b>	2.00	0.33	1.00	0.33	0.33	<b>CR</b>	7.77
<b>PRB</b>	5.00	0.50	3.00	1.00	0.33		
<b>CHEM</b>	5.00	0.50	3.00	3.00	1.00		

**Table 7.13 Remedial alternatives comparison matrix for Contamination Level (CL)**

CL_70-110 (mg/l)							
<b>CL</b>	<b>PHYTO</b>	<b>PAT</b>	<b>PAF</b>	<b>PRB</b>	<b>CHEM</b>	$\lambda_{max}$	5.27
<b>PHYTO</b>	1.00	0.33	0.50	0.33	0.25	<b>CI</b>	0.07
<b>PAT</b>	3.00	1.00	2.00	0.50	0.33	<b>RCI</b>	1.12
<b>PAF</b>	2.00	0.50	1.00	0.50	0.50	<b>CR</b>	6.05
<b>PRB</b>	3.00	2.00	2.00	1.00	0.33		
<b>CHEM</b>	4.00	3.00	2.00	3.00	1.00		

**Table 7.14 Weights of criteria and alternatives from AHP**

CRITERIA	WT.	PHYTO	PAT	PAF	PRB	CHEM	PHYTO	PAT	PAF	PRB	CHEM
<b>IC</b>	0.07	0.40	0.07	0.15	0.10	0.28	0.028	0.005	0.011	0.007	0.020
<b>OMC</b>	0.04	0.14	0.11	0.12	0.26	0.37	0.006	0.004	0.005	0.010	0.014
<b>RT</b>	0.07	0.06	0.40	0.11	0.22	0.21	0.004	0.028	0.008	0.015	0.015
<b>RR</b>	0.11	0.06	0.38	0.10	0.20	0.26	0.006	0.042	0.011	0.022	0.029
<b>GWT</b>	0.18	0.41	0.12	0.26	0.15	0.07	0.072	0.020	0.047	0.026	0.012
<b>AM</b>	0.18	0.42	0.13	0.22	0.15	0.09	0.075	0.023	0.040	0.026	0.015
<b>LSC</b>	0.19	0.06	0.35	0.10	0.20	0.30	0.011	0.065	0.018	0.038	0.056
<b>CL</b>	0.17	0.07	0.18	0.13	0.22	0.40	0.012	0.029	0.022	0.037	0.067
<b>TOTAL</b>	1.00	1.61	1.72	1.20	1.50	1.97	<b>0.213</b>	<b>0.217</b>	<b>0.161</b>	<b>0.182</b>	<b>0.228</b>
<b>Preference Rank</b>							<b>3</b>	<b>2</b>	<b>5</b>	<b>4</b>	<b>1</b>

## 7.6 Outcome of AHP analysis

In proposing specific Nitrate reduction method for addressing high Nitrate concentrations at specific well sites, there have taken into account a range of hydrogeological criteria, including Location-Specific Characteristics, Aquifer Material, Contamination Level and Groundwater Table. Additionally, four non-technical criteria such as Initial Cost, Operation and Maintenance Cost, Removal Rate, and Remediation Time have been included in the approach of Analytical Hierarchy Process of MCDM. To minimize the public health risk due to high Nitrate concentration specific Nitrate reduction method for 24 wells have been determined using the AHP method, and the results are presented in Table 7.15. For well no 1 of urban region the values of global weight obtained on which the preference of remedial method is recommend as CHEM = 0.228, PAT = 0.217, PHYTO = 0.213, PRB = 0.182, PAF = 0.161. Similarly, for all remaining wells individual AHP matrix has been computed based on which these below table 7.15 has been prepared.

**Table 7.15 Groundwater Nitrate from primary data collection and sample location specific characteristics**

(fbgl = Feet Below Ground Level)

Sr.	Zone	Block	Village	Location	NO <sub>3</sub>	Ground Water Level (fbgl)	Aquifer Material	Suitable Remedial Strategy
W1	Central	Vadodara	Panigate	Bauchawad, Yakutpura, Panigate	73.76	05 – 20	Aggregated Clay	CHEM
W3	Central	Vadodara	Kevdabaug	Batuk Mandir, Kevdabaug	140.83	05 – 20	Sandy Loam	PAT
W7	Central	Vadodara	Tarsali-2	Bhathiji Mandir, Tarsali	93.01	05 – 20	Loam	CHEM
W9	Central	Vadodara	Por	Icici Bank Building, Por Village	124.13	> 50	Sandy Loam	PAT
W10	Central	Karjan	Bamangam	Bhathiji Maharaj Temple	108.35	35 – 50	Sand	PAT
W11	Central	Karjan	Manglage	Varahi Mata Temple	112.11	35 – 50	Sandy Loam	PAT
W12	Central	Dabhoi	Parikha	Ramdev Mandir, Opp. Gram Panchayat	55.23	35 – 50	Aggregated Clay	PAF
W13	Central	Dabhoi	Mandala	Near RangaiKaansh, Mandala	68.53	35 – 50	Clay	PAF
W16	Central	Padra	Chansad-1	Opp. Baps Shree Swaminarayan Mandir	155.96	20 – 35	Sand	PAT
W17	Central	Padra	Chansad-2	Opp. Panchayat Karyalay, Chansad	140.83	20 – 35	Sand	CHEM
W19	Central	Padra	Darapura	Farm near entrance of Darapura Village	122.66	> 50	Sandy Loam	PAT
W22	Central	Padra	Kanzat	Near Amba Mata Temple and Pond	62.94	35 – 50	Aggregated Clay	PAF
W25	West	Jambusar	Nahar	Near Bhathiji Temple and Pond	95.5	5 – 20	Clay Loam	PHYTO
W27	West	Jambusar	Hamdpor	Village Vasahat, near large Pond	69.36	35 – 50	Clay Loam	PAF
W30	West	Amod	Suthodara	Village Vasahat near Pond	46.97	35 – 50	Clay Loam	PAF
W31	North	Savli	Tulsipura	Near Pond and VillaeVasahat	167.61	5 – 20	Sand	PAT
W31a	North	Savli	Tulsipura	Near Pond and VillaeVasahat	204.22	20 – 35	Sand	PAT
W32	North	Halol	Dharampuri	Masonry Well in Farm, Village Vasahat	129.91	20 – 35	Sand	CHEM
W33	North	Halol	Muladhari	Rameswar Temple, Panigate	78.72	5 – 20	Clay Loam	PHYTO
W34	North	Ghoghamba	Raveri	Near Karad Canal, Ghoghamba Village	48.62	5 – 20	Gravel	CHEM
W35	North	Kalol	Madhvas	Muvla area Opp. Mahvir Park	67.61	35 – 50	Clay Loam	CHEM
W36	North	Kalol	Kalol City	Private Farm of Virendra Patel in Kalol	102.94	20 – 35	Sand	CHEM
W37	North	Kalol	Delol	Near Panchvati Lemon farm, Delol	116.7	> 50	Gravel	CHEM
W39	North	Savli	Mevli	Farm near Mevli Village Vasahat	133.49	> 50	Peat	PRB