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Integrated Weighted Overlay Model Using Inverse Distance Weightage for Assessing Groundwater Quality

ABSTRACT

Groundwater management is a potential solution to the global water crisis. This study assessed the groundwater quality at Mettupalayam, Tamil Nadu, India in order to determine its suitability for drinking. Groundwater samples were collected and their physicochemical parameters such as pH, electrical conductivity (EC), total hardness (TH), total dissolved solids (TDS), Ca^{2+}, Mg^{2+}, SO_4^{2-} and Cl^- were determined and benchmarked with standard drinking water requirements. The variations of these parameters were presented spatially. The groundwater is generally brackish and hard; and of low alkalinity and high salinity. Consequently, the groundwater in most parts of the study area is unsuitable for drinking without treatment. It is recommended that point and nonpoint sources of groundwater pollution at Mettupalayam should be identified, monitored and managed in order to protect the groundwater resource.

G. Shyamala[1*]
J. Jeyanthi[2]

[1] Department of Civil Engineering, Sree Sakthi Engineering College
[2] Department of Civil Engineering, Government College of Engineering

corresponding author:
civilshyamala@gmail.com

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INTRODUCTION

Development of nation is associated with sustainable development and stress on water in recent days is increasing the threat on human existence (*Kanungo and Gupta 2011; Currell 2014*). Our nation is progressing towards paucity of water, due to improper management of water resource (*Renganayaki and Elango 2014*). Water pollution has been an issue for the past decades and the recent problems like management of industrial waste and radioactive waste, disposal of sewage and population explosion also contributed to the exacerbation (*Gurarslan and Karahan 2015*). Drinking water source should be protected by suppressing commercial, residential and recreational activity in the vicinity of rivers and dams. Recently the exhaustive research towards the hydrogeology is increasing due to deterioration of ground water quality. The ground water quality is deteriorating due to geogenic and anthropogenic activities (*Tanvir et al. 2014*). Most of the industries' untreated or partially treated effluents discharging into the sewers, drain and spread on land surfaces and create numerous environmental problems in and around the industries (*Singh et al. 2015; Salifu et al. 2015; Ben, Salwa, and Thouraya 2014*).

As groundwater flows through soil layers and rock formations, the minerals contained in such elements are disolved. Harmful contaminants get associated with the groundwater through the process of seepage from the surface water and biological activities. (*Ghazavi, Vali, and Eslamian 2012*); (*Brindha et al. 2014*). The chemical composition of groundwater is controlled by several factors including the composition of the rainfall, geological structure of the area and mineralogy of the watersheds, aquifers and geological processes within the aquifer along with impact of external pollution contribution like discharges from agricultural return flow, industrial and domestic activities. Quality of groundwater is alike important to its quantity owing to the suitability of water for numerous purposes (*Saleem, Dandigi, and Kumar 2012);(Javad, Milad, and Aminiyan 2015*).

Geographic information systems (GIS) incorporate procurement of information, storage, analysis and managing tool that solve problems associated to geospatial information. GIS is a dynamic tool for groundwater quality mapping and vital for monitoring the environmental changes (*Engay 2015; Guzman et al. 2010*). Water quality index (WQI) has been formulated based on the comparison between and among water quality parameters and standards. Large water quality data is concluded in a single number and in a simple term using water quality index (*Sahoo, Patra, and Khatua 2015*) The objectives of the research were to predict the physiochemical characteristics of groundwater and to determine the water quality index to identify pollution sensitive area using weighted overlay analysis mapping.

MATERIALS AND METHODS

Study Area and Sampling

Mettupalayam is located in the foothills of Nilgiris, India. The Bhavani River located in the foothills of Nilgiris is one of the perennial rivers in India. In recent years, many industries have been established at the aquifer boundary of Bhavani River, which is one of the sources of water to the people in the taluk. Other sources include borehole and hand-dug wells, and pipe-borne water. Mettupalayam is an important trading hub and transit centre for hill products. *Mukherjee and Nelliyat* (*2006*) reported that the groundwater quality at Thekkampatty, Jadayampalayam and Irumborai, which are villages in Mettupalayam, have been affected by industrial pollution.This study was undertaken by randomly collecting 40 groundwater samples (**Figure 1**) from open wells within Mettupalayam, Taluk.

Methods

The representative groundwater samples were collected and analysed in accordance with standard methods recommended by *APHA* (*1998*). The pH, total dissolved solids (TDS) and electrical conductivity (EC) were analysed on site using digital meters. Other parameters were determined in the laboratory. Calcium (Ca^{2+}) and total hardness (TH) were determined using versenate titration method. The concentration of Mg^{2+} was then determined by calculating the difference between TH and Ca^{2+} concentration. Chloride (Cl^-) and sulphate (SO_4^{2-}) were determined by titration method and turbidimetric method, respectively (**Table 1**).

Spatial interpolation technique functions was used in the study to delineate the distribution of water pollutants (*Mohammad 2014*). Inverse Distance Weighted (IDW) analysis, which is a deterministic interpolation method that assigns values to locations based on the surrounding measured values and on specified mathematical formulas that determine the smoothness of the resulting surface, is best suited for a set of points that is dense enough to capture local surface variation. IDW method can be used efficiently with spatial data that have a normal distribution. The groundwater contaminations at unknown locations are determined based on the distance and direction of the observation wells using spatial interpolation method (*Adhikary et al. 2012*). The geostatistical analyst extension with IDW algorithm in ArcGIS was used to interpolate the points and create the spatial distribution map. Spatial variation maps of major water quality parameters like pH, EC, TH, TDS, Ca^{2+}, Mg^{2+}, SO_4^{2-} and Cl^- were produced. Water Quality Index map was created by assigning weightages and ranks to each parameter characterized for the assessment and management of ground water. For each of the map, the study area was classified into three categories, namely good, moderate and poor quality.

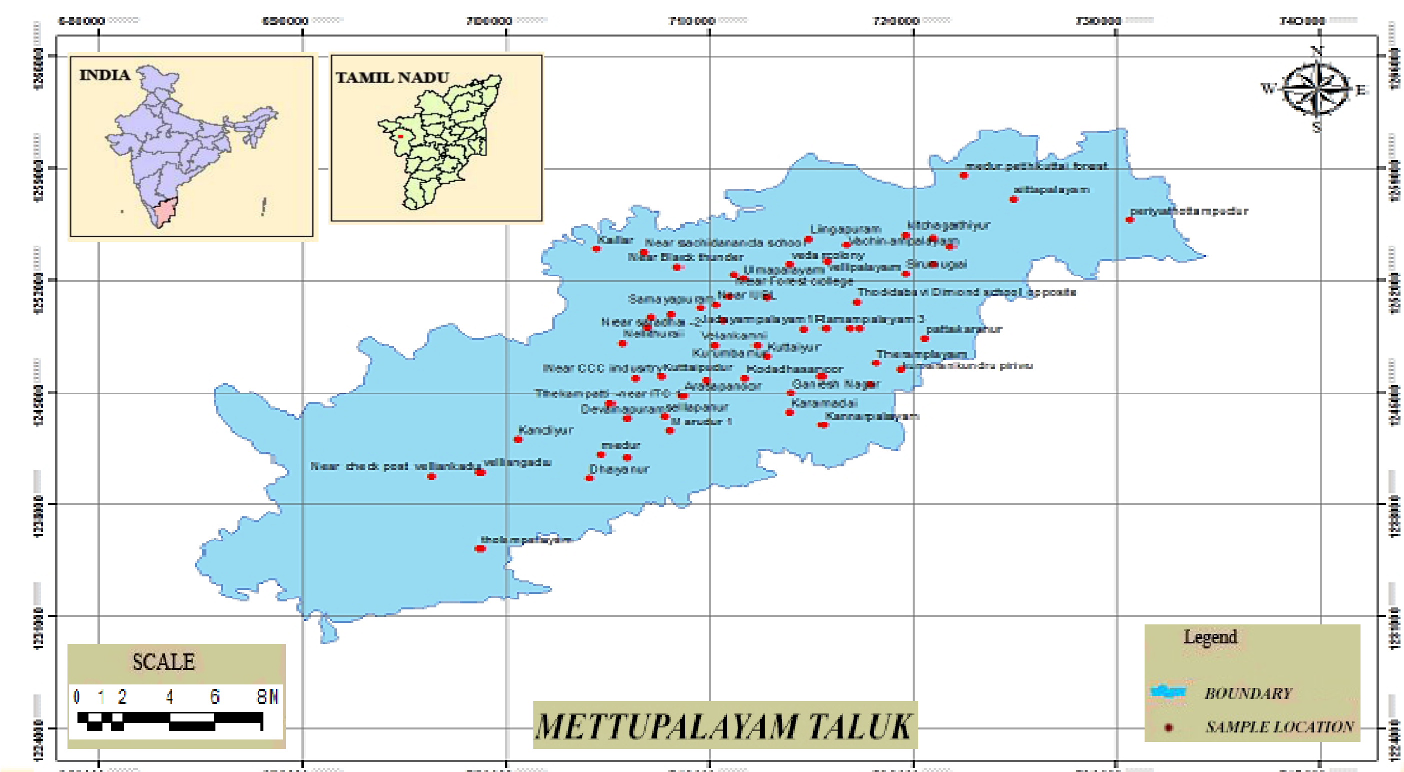

Figure 1. Map showing administrative boundary of the study area and sample collection points.

Table 1. Hydrochemistry of groundwater in the study area.

S. No.	Sample Location	pH	EC dS m^{-1}	TH mg L^{-1}	TDS mg L^{-1}	Ca mg L^{-1}	Mg mg L^{-1}	Cl mg L^{-1}	So_4 mg L^{-1}
1	Thodathasanur	7.2	4.75	800	2670	237	148	745	235
2	Thekampatti	8.6	6.51	650	4600	325	162	1033	246
3	Near CCC industry	8.2	5.90	860	4720	356	161	987	296
4	Kuttaipudur	8.2	3.62	500	1950	139	105	318	281
5	Nellithurai	7.9	2.65	560	1420	151	113	406	281
6	Velspuram	9.2	3.58	720	2050	245	123	586	196
7	Samayapuram	8.1	3.18	650	1900	140	120	568	287
8	Sankarnagar	8.2	3.12	800	1880	268	131	596	285
9	Odanthurai	8.1	1.96	340	1250	146	110	325	316
10	Kallar	7	2.52	470	1520	182	148	470	258
11	Vachinampalayam	7.7	2.15	420	1390	139	116	405	320
12	Sirumugai	7.6	3.68	700	2350	326	156	889	210
13	Rayon nagar	8.9	4.12	510	2480	265	165	685	211
14	Kuthamandi Pirivu	7.4	3.23	540	1950	198	116	411	326
15	Amman pudur	7.2	3.75	440	2250	141	119	476	241
16	Ramampalayam	8.1	5.07	830	4060	342	151	1085	255
17	Jadayampalayam	8.9	4.25	860	2550	271	148	913	499
18	Dimond school	8.6	5.17	780	4160	341	126	821	641
19	Alangombu	8.6	5.53	790	4430	348	139	913	367
20	Kitchagathiyur	8.3	2.85	360	1710	171	125	362	317
21	Kumarankundru pirivu	7.9	1.85	365	1110	108	85	368	181
22	Kittampalayam	7.9	2.12	360	1270	156	100	398	228
23	Marudur	8.2	2.45	420	1470	169	121	385	266
24	Arasapanoor	7.9	2.74	510	1640	161	131	394	267
25	Velliangadu	7.8	2.10	380	1360	144	121	458	215
26	Check post velliankadu	7.9	2.15	368	1360	143	135	443	276
27	Bujanganur	7.9	1.70	430	1120	113	90	368	182
28	Ganesh Nagar	8.1	2.10	380	1210	111	121	312	198
29	Medur	7.8	1.85	440	1280	123	96	316	319
30	Kandiyur	7.9	1.95	560	1260	142	112	378	313
31	Pungampalayam	8.5	2.85	480	1710	132	115	398	142
32	Sellapanur	8.4	2.15	550	1380	159	111	412	330
33	Kuttaiyur	7.9	1.85	480	1450	131	110	352	218
34	velanganni	8.2	2.12	410	1340	141	121	312	314
35	Karamadai	7.8	2.95	420	1770	121	85	375	209
36	Pattakaranur	8.2	2.21	550	1490	141	114	462	256
37	Kannarpalayam	8.3	2.15	430	1290	130	115	378	270
38	Gandhi nagar	7.9	2.98	380	1350	158	114	348	267
39	Tholampalayam	7.8	1.57	470	1520	182	148	470	258
40	Periyathottampudur	8.4	2.13	460	1390	149	133	393	311

RESULTS AND DISCUSSION

The physicochemical characteristics of groundwater determine its suitability for purposes such as for drinking, irrigation and many others, Water Quality Index was calculated by assigning rating scales and weightages to water quality parameters like pH, EC, TH, TDS, Ca^{2+}, Mg^{2+}, SO_4^{2-} and Cl^-. The weightage of each parameter was assigned according to its relative importance in overall water quality. Based on the importance of each parameter, weightages were assigned to calculate water quality index (**Table 2**).

The water samples were characterized as acidic, neutral or alkaline based from its pH value. The pH of the groundwater samples at Mettupalayam was generally alkaline. However, the Bureau of Indian Standards (BIS) gives the permissible range of pH for drinking water to be 6.5-8.5. Consequently, pH values within this range were considered to be normal value below this range were considered to be acidic while those above were considered to be alkaline. The distribution of the pH for the groundwater samples indicates pH values are within the normal or acceptable range. While about 19.5% of the study area has its groundwater classified as being alkaline. The minimum and maximum pH are 7.0 and 9.2, respectively; with the mean pH of the distribution being 8.1.

Table 2. Weightage and Ranking for Water Quality parameters.

Criteria	Parameter Range	Ranking	Weightages
pH	7.0 to 7.5 6.0 to7.0 &7.5 to 8.5 <6 & >8.5	1 2 3	15%
Electrical conductivity ($dS\ m^{-1}$)	0 - 0.75 0.75 - 2.25 >2.25	1 2 3	15%
Total Hardness ($mg\ L^{1}$)	0 - 300 300 - 600 >600	1 2 3	15%
Total Dissolved Solids ($mg\ L^{-1}$)	0 - 500 500 - 2000 >2000	1 2 3	15%
Calcium ($mg\ L^{-1}$)	<75 75 - 100 >100	1 2 3	10 %
Magnesium ($mg\ L^{-1}$)	< 30 30 - 100 >100	1 2 3	10%
Sulphates ($mg\ L^{-1}$)	0 - 200 200 - 400 >400	1 2 3	10%
Chlorides ($mg\ L^{-1}$)	< 250 250 - 1000 >1000	1 2 3	10%

In the spatial distribution map the pH was classified in to three ranges which are normal (6.5 to 8.5), alkaline (>8.5) and acidic (<6.5). Spatial distribution map indicated that 80.5% of the area falls in the normal range and 19.5% of the area in the alkaline range. The parameter was assigned 15% weightage for calculating the WQI.

The electrical conductivity (EC) of water was analyzed by means of portable ionic water test equipment and was expressed in milliequivalents per liter. The total amount of dissolved salts present in water can be approximately estimated by measuring the EC of water. The EC was classified into three ranges: good (0.25-0.75), moderate (0.75-2.25) and poor (>2.25). Spatial distribution map plotted for EC represents that 2% of the area is categorized as good, 44 % of the area is suitable for domestic and irrigation purpose and categorised as moderate and 54% of the area represents high salinity of ground water and is categorized as poor. The electric conductivity of the study area reaches the maximum value of 7.11 $dS\ m^{-1}$. In the area where electric conductivity is higher than 1.5 $dS\ m^{-1}$ proper drainage should be ensured.

Hardness in water is influenced by carbonates, bicarbonates, chlorides and sulphates of calcium and magnesium dissolved in it (*Twaha et al. 2013*). Hardness was measured by means of the versenate method. The total hardness was assorted as good (<300 $mg\ L^{-1}$), moderate (300 -600 $mg\ L^{-1}$) and poor (>600 $mg\ L^{-1}$). In the research domain 68 % is within the permissible limit, while the remaining is within the sensitive area. For domestic use hardness up to 300 ppm is not objectionable. To derive water quality index 15% weightage is assigned for hardness.

TDS is an important parameter of drinking water quality testing which indicates the presence of various kinds of dissolved minerals (*Mokarram 2016*). The higher value of total dissolved solid is credited to the application of agricultural fertilizer (*Ketata, Gueddari and Bouhlila 2012*). The total dissolved solids ranged from 1110 $mg\ L^{-1}$ to 5680 $mg\ L^{-1}$.The TDS was classified into three ranges (0-500 $mg\ l^{-1}$, 500-2000 $mg\ L^{-1}$ and >2000 $mg\ L^{-1}$) as good, moderate and low. The spatial variation map for TDS was prepared based on these ranges. From the study 25% of the sample exceeds the permissible limits as per *BIS* (*2009*) standards.

Calcium is naturally present in water. Calcium is a determinant of water hardness because it can be found in water as Ca ion. The calcium content of groundwater samples in the study area varied from 96.42 $mg\ L^{-1}$ to 182.38 $mg\ L^{-1}$. As per the spatial variation map, 71.3 % of the samples were within the permissible limits and 28.7 % of the samples exceeded the limit. For the water quality index computation, 10% importance is provided for Ca.

Magnesium is washed from rocks and subsequently may end up in water in different ways. Chemical industries include magnesium to plastics and other materials as a fire safety measure or as filler. Most of the samples (85%) on the site crossed the permissible limit as per *BIS* (*2009*) standards.

Geological formation such as pyrite, lignite and coal contribute sulphates in the groundwater in natural form. The permissible limit for sulphate is 400 $mg\ l^{-1}$, if it exceeds it can be a source of gastrointestinal problem among water drinkers. As per *BLS* (*2009*) standards the values are assigned as good (<200), moderate (200-400) and poor (>400). Mettupalayam spatial map indicates 7 % of the sample is under good condition, 84% of sample is moderate and 9% of the sample is poor.

Chloride is an indicator of water and is due to sodium, potassium and calcium salts (*Belkhiri and Mouni 2012*)

Extreme chloride in potable water is predominantly not harmful but the criteria set for chloride assessment is based on its potentially high corrosiveness. The value of chloride is high (7%) in central part of the study area. In most of the area moderate range (93%) of chlorides is observed. Weightage of 10% was specified in deriving water quality index.

The model was validated by determining the mean absolute percentage error. From the spatial interpolation, eight latest sample locations were selected and the hydrochemistry of groundwater were predicted from the model developed (**Table 3**). The interpolated values were compared with the observed values. The statistical error between the observed value and predicted value is evaluated using Mean Absolute Percentage Error (MAPE).The better agreement between observed and predicted value is noticed when the MAPE is less than 3%.

GIS database is proven to be a very useful tool especially for groundwater studies when vital decisions are required which are going to affect the entire ecology, economic and socio-economic setup of the area. The spatial variation maps of major groundwater quality parameters were integrated and a groundwater quality map was

Table 3. Hydrochemistry of eight selected groundwatersampling locations in the study area.

Sample Location		**pH**	**EC dS m^{-1}**	**TH mg L^{-1}**	**TDS mg L^{-1}**	**Ca mg L^{-1}**	**Mg mg L^{-1}**	**Cl mg L^{-1}**	**SO_4 mg L^{-1}**
Kuttaipudur	predicted	8.1	3.7	510	1970	141	110	380	345
	observed	8.1	3.8	500	2000	140	110	380	350
Thekampatti	predicted	8.4	6.0	720	4100	355	170	875	320
	observed	8.5	5.9	710	4100	350	170	870	320
Sirumugai	predicted	7.9	3.72	755	2630	386	210	850	290
	observed	8.0	3.75	760	2650	385	200	850	290
Tholampalayam	predicted	7.9	1.60	550	1610	235	185	550	285
	observed	7.8	1.61	550	1600	235	180	550	290
Alangombu	predicted	8.1	5.65	830	4510	357	145	1050	387
	observed	8.0	5.7	820	4500	360	140	1050	390
Ramampalayam	predicted	8.3	4.57	860	4260	350	160	955	285
	observed	8.3	4.6	870	4250	350	160	950	280
Jadayampalayam	predicted	9.0	4.35	920	2410	310	155	1045	510
	observed	9.1	4.4	900	2400	310	150	1050	510
Tholampalayam	predicted	7.9	3.41	325	1560	150	135	462	345
	observed	8.0	3.45	320	1550	150	130	460	350

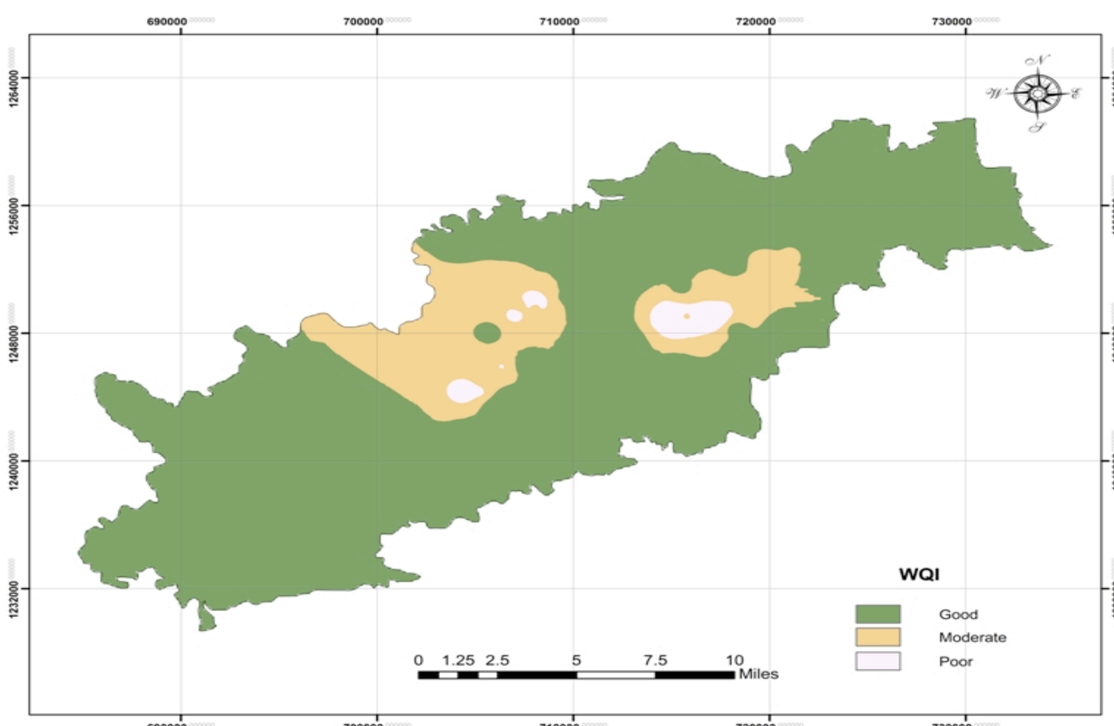

Figure 2. Weighted Overlay map Showing Pollution Potential of Study area .

prepared (**Figure 2**). The integrated map shows the details of pollution potential in the study area. The Groundwater quality map of the study area reveals that the groundwater qualities in Alangombu, Ramampalayam, Sirumugai, Jadayampalayam and Thekkampatty villages are deteriorated as per the *BIS* (*2009*) standards.

CONCLUSION

Seven out of the 40 samples were found to be with high alkalinity. The bicarbonate alkalinity of the samples may be due to the seepage of effluent and domestic sewage around the station. Electrical conductivity of the study area is elevated for about 54 % of the total study area. In the study area most of the land is used for agriculture purpose where the application of fertilizer is contributing heavily to the high values of conductivity. Hardness of the samples in 68 % of the study area is within the permissible limit. Too soft water loses its taste. From health point of view, hardness even up to 600 ppm is not of any concern but beyond that may cause a laxative effect. Throughout the study area, the total dissolved solids is moderate to high. Poor spatial distribution is seen in Ramampalyam and Thekampatti area. Based on the spatial distribution map of magnesium, it can be interpreted that moderate value of hardness is observed in central zone of Mettupalayam.

From the results, 80.2 % of the area groundwater quality is within the permissible limit, 14.6 % of area is nearly polluted as per WQI and is susceptible to pollution. Total sensitive area is 5.2% and seriously aggravated by the pollution caused by industries in the forms of effluent discharge, urbanization, solid waste dumps, sewage disposal and application of fertilizers. These have polluted the surface water bodies which if not rain fed, would not otherwise have become saline. Subsequently, through infiltration, the groundwater has also become contaminated. As the pollutants are conservative in nature, it is concluded that the pollutant will be cummulative downstream. Based on the research it is concluded that an integrated weighted overlay model has been found very useful in delineating groundwater pollution sensitive area prospective zones. Continuous monitoring of zero discharge in industries should be ensured in sensitive areas. The untreated sewage and sewerage flowing in various open drains should be avoided. As a long term measure, farmers should be educated about special agricultural practices. Considering terrain conditions and favourable zonation, suitable artificial recharge structures are recommended.

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