

Chapter: 5

Results and Discussions

5.1 Physico-chemical characteristics of Ramna MSW leachate

Leachate samples were collected from Ramna and Karsara MSW dumping site and analysed to assess their physicochemical characteristics and its pollution potential.

Ramna leachate samples were analysed for eighteen physicochemical parameters and ten heavy metals under various perspective. MSW composition, temperature, moisture, time, and dissolved oxygen influence the leachate characteristic. Average value of physicochemical parameters of leachate samples (L_1 and L_2) collected in the year 2014 are shown in table 5.1.

The observed temperature ranged from 24.9 °C - 27 °C, is favorable for microbial activity in the process of leachate formation and other chemical and biological reactions [114]. pH value of leachate samples was found in the range of 8.3 - 9.3, which indicates the alkaline nature of leachate. The alkaline nature of leachate specifies the old stage of the landfill site [10]. EC (5.65 mS/cm), TDS (2632 mg/l), Chloride (1420 mg/l), NO_3^- (72 mg/l) and Mg (275 mg/l), values were found to be the maximum in L_2 leachate sample as compared to L_1 leachate sample. High conductivity value in the leachate greatly affects the leachate percolation inside the soil strata which facilitate the leakage of pollutants to groundwater [115]. Hardness (800 mg/l), alkalinity (2200 mg/l), BOD (1344 mg/l), COD (8350 mg/l), Ca (360 mg/l), Na (875 mg/l) K (1337 mg/l) and PO_4^{3-} (42.3 mg/l) content were found maximum in L_1 Sample. High BOD and COD value indicates a strong organic and inorganic characteristic of leachate. These values are observed within the range of MSW leachate characteristic according to leachate indicator parameters [116]. It is obvious from table 5.1 that 1.30 mg/l of Cr, 0.24 mg/l of Cu and 3.70 mg/l of Fe were detected in L_2 leachate sample while 1.42 mg/l, 0.34 mg/l, and 5.5 mg/l were detected in L_1 leachate sample respectively. Cr content in leachate indicates the presence of wood preservatives and paint products in the dumped

solid waste [8]. High concentration of Fe (5.5 mg/L) in the leachate indicates the presence of iron and steel constituents in municipal solid waste [117].

Table 5.1 Results of physico-chemical analysis of leachate samples of Ramna dumping site, 2014

S. No	Parameters	Average Value (Oct 2014) (L ₁)	Average Value (Nov 2014) (L ₂)	Mean	Leachate Disposal Standard for Inland surface water (MSW Management and Handling Rules, 2000)	Leachate characteristics, generated from MSW in Developing countries (UNEP, 2005)
1	Temperature	27.0	24.9	25.9	NM	NM
2	pH	8.3	9.3	8.8	5.5-9.0	4.5-9
3	EC	3.46	5.65	4.55	NM	NM
4	TDS	2024	2632	2338	2100	0-42,300
5	DO	7.6	7.8	7.7	NM	NM
6	Chloride	1202	1420	1311	1000	100-5,000
7	Hardness	800	780	790	NM	0-22,800
8	NO ₃ ⁻	60	72	66	50	0-25
9	Total alkalinity	2200	1815	2007	NM	300-11,500
10	BOD ₅	1344	1327	1335	30	20-40,000
11	COD	8350	8319	8332	250	500-60,000
12	BOD ₅ /COD	0.16	0.15	0.16	NM	NM
13	Ca	360	340	350	NM	10-250
14	Mg	127	275	201	NM	40-11,50
15	Na	875	616	745	NM	50-4,000
16	K	1337	1155	1246	NM	10-2,500
17	Fluoride	2.1	0.2	1.7	2	NM
18	Cr	1.42	1.30	1.36	2.0	NM
19	Zn	ND	ND	ND	5.0	0.03-120
18	Cu	0.34	0.24	0.29	3.0	4-1,400
19	Cd	ND	ND	ND	2	NM
20	Pb	ND	ND	ND	0.1	8-1020
21	Fe	5.5	3.7	4.6	NM	3-2100
23	Ni	ND	ND	ND	3.0	NM
24	Mn	ND	ND	ND	NM	0.03-65
25	As	ND	ND	ND	0.2	NM
26	PO ₄ ³⁻	42.3	18.5	30.4	NM	0.1-30

All value in mg/l except Temp (°C), EC (mS/cm) and pH

*ND- Not detectable, *NM- Not Mention

Reduction of these heavy metals is more common into more soluble species. Therefore the concentration of these heavy metals increases under favorable circumstances near to a dumping site and may lead to a serious toxicity to surrounding subsurface aquifer. Zn, Cd, Pb, Ni and Mn were not detected in any leachate sample of Ramna dumping site.

High concentration of phosphate (42.3 mg/l) was observed in L₁ sample which values is much higher than the disposal standard value (30 mg/l) as suggested by MSW Management and Handling Rules, 2000. Phosphate may be transported from surrounding agriculture field through surface water during post-monsoon period. Phosphate is mainly responsible for the eutrophication of the surface water body and act as limiting factor [26].

5.2 Physico-chemical characteristics of Karsara MSW leachate

Physico-chemical analysis of inorganic, organic and heavy metal constituents of Karsara MSW leachate are presented in table 5.2.

The mean value of temperature of Karsara (26.6°C) is very much favorable for leachate formation from the municipal solid waste. The pH of the leachate of Karsara MSW (pH 9.4) was found high, indicating alkaline nature. The mean of electrical conductivity was found 11.58 mS/cm. The TDS mean value was observed to be 8129.5 mg/l. TDS value was found much higher than leachate disposal standard (2100 mg/l). The BOD₅ value was found 3190.5 mg/l. BOD₅ concentration was observed greater than the inland leachate disposal standard (30 mg/l). The Higher value of BOD₅ observed in Karsara MSW leachate indicates higher loading of organic pollutants. The amount of the organic waste in the landfill leachate is inversely proportional to the age of landfill [118]. BOD₅ value treated as a suitable indicator of functional stability since it indicates stability of organic matter in MSW leachate.

Table 5.2 Results of Physico-chemical analysis of Karsara MSW leachate sample in 2014

S. No.	Leachate quality Parameters	Average Value (Oct 2014) (L3)	Average Value (Nov 2014) (L4)	Mean	Leachate Disposal Standard for Inland surface water (MSW Management and Handling Rules, 2000)	Characteristics of leachate generated from MSW in Developing countries (UNEP, 2005)
1	Temperature	28.9	24.3	26.6	NM	NM
2	pH	9.1	9.6	9.4	5.5-9.0	4.5-9.0
3	EC	12.57	10.6	11.58	NM	NM
4	TDS	8430	7829	8129.5	2100	0-42,300
5	DO	7.3	7.6	7.45	NM	NM
6	Chloride	765	815	790	1000	100-5,000
7	Hardness	720	756	738	NM	0-22,800
8	Nitrate	75	91	83	50	0-25
9	Total alkalinity	907	824	865.5	NM	300-11,500
10	BOD5	3120	3261	3190.5	30	20-40,000
11	COD	11980	12675	12327.5	250	500-60,000
12	BOD5/COD	0.26	0.25	0.25	NM	NM
13	Ca	230	310	270	NM	10-250
14	Mg	293	252	272.5	NM	40-11,50
15	Na	1260	1123	1191.5	NM	50-4,000
16	K	1420	1547	1483.5	NM	10-2,500
17	Fluoride	0.35	0.61	0.48	2	NM
18	Cr	ND	ND	ND	2	NM
19	Zn	ND	ND	ND	5	0.03-120
20	Cu	0.31	0.21	0.26	3	4-1,400
21	Cd	ND	ND	ND	2	NM
22	Pb	ND	ND	ND	0.1	8-1020
23	Fe	1.5	1.67	1.58	NM	Mar-00
	Ni	ND	ND	ND	-	NM
24	Mn	ND	ND	ND	NM	0.03-65
25	As	ND	ND	ND	0.2	NM
26	PO ₄ ³⁻	42.3	36.1	39.2	NM	0.1-30

All value in mg/l except Temp (°C), EC (mS/cm) and pH

*ND- Not detectable, *NM- Not Mention

The mean value of dissolved oxygen (DO), hardness, total alkalinity, Na, Mg, Ca, K and fluoride content were found to be 7.45 mg/l, 738 mg/l, 865.5 mg/l, 1191.5 mg/l, 272.5 mg/l, 270 mg/l, 1483.5 mg/l and 0.48 mg/l respectively leachate sample. The COD value was found 12327.5 mg/l which is much than the leachate disposal limit value (250 mg/l). Higher nitrate concentration was observed to be 83 mg/l. The BOD₅/COD ratio of Karsara was found to be 0.25.

The mean value of phosphate was found with a value of 39.2 mg/l which are much higher than the leachate characteristic range (1-30 mg/l) of MSW. This may be due to runoff of fertilizer used in the agricultural fields, around Karsara dumping sites. Heavy metal in the leachate was observed in a significant amount of Cu (0.26 mg/l) and Fe (1.58 mg/l), while Cr, Zn, Ni, As, and Mn were not detected in leachate sample. Thus Karsara MSW leachate shows the high substances of organic and inorganic constituents with the toxic heavy metals concentrations. A Physico-chemical characteristic result shows that the leachate is of higher strength in their pollutant concentration.

5.3 Comparative discussion of physico-chemical analysis of Ramna and Karsara MSW leachate

The mean value of physico-chemical analysis parameters of both the MSW leachate are presented in Table 5.3. The temperature of Karsara (26.60 °C) and Ramna (25.9 °C) is very much favorable for leachate formation from the municipal solid waste. pH of the leachate of Karsara MSW (pH 9.4) sample is more basic than that of the Ramna MSW sample (pH 8.8). Alkaline nature of leachate indicates the old age of the landfill [119], [120], [10]. Manning and Robinson (1999) [121] stated that as the pH of leachate increases, the dissolution of chloride compounds increases and thus the chloride concentration in leachate also rises. The mean value of electrical conductivity was higher (11.58 mS/cm) in Karsara leachate sample than the Ramna leachate sample (4.55 mS/cm). **High conductivity value indicates high dissolved salt in leachate which**

hinder the biological and chemical treatment process of the leachate [122]. The higher value of conductivity in leachate samples of Karsara MSW leachate signify for the higher content of dissolved inorganics such as chloride, nitrate, and phosphate as anions and sodium, magnesium, calcium and iron as cations[123], [124]. The TDS mean value of leachate samples of Karsara and Ramna MSW were found to be, 8129.5 mg/l and 2338 mg/l respectively. TDS value was found much higher than leachate disposal standard (2100 mg/l) at both the dumping sites, which is considered as an important parameter for permitting discharge of landfill leachate in most of the countries [125]. The chloride value was higher in Ramna leachate sample (1311 mg/l) than the Karsara leachate sample (790 mg/l). Chlorides content in the leachate are not weakened by soil strata and are transportable under all circumstances, therefore, it acts as a tracer ionic species to reach the groundwater aquifers [26]. Chloride also is a conservative pollutant which is not altered by the biochemical process so its infiltration into groundwater is not hindered [123]. Therefore, the chloride causes a serious impact on groundwater of the dumping area [126]. BOD₅ mean value was observed higher (3190.5 mg/l) in Karsara leachate than Ramna leachate sample (1335 mg/l). BOD concentration was observed greater than the inland leachate disposal standard (30 mg/l) in both the dumping sites. The Higher value of BOD₅ observed in Karsara leachate indicates higher loading of organic pollutants. The amount of the organic waste in the landfill leachate is inversely proportional to the age of landfill [118]. However, Kulikowska and Klimiuk 2008[127] reported the leachate characteristics do not show any specific tendency with age. BOD may be treated as a suitable indicator of functional stability since it indicates stability of organic matter in MSW leachate. The mean value of dissolved oxygen (DO), hardness, total alkalinity, Na, Mg, Ca, K and fluoride content were found to be 7.45 mg/l, 738 mg/l, 865.5 mg/l, 1191.5 mg/l, 270 mg/l, 272.5 mg/l, 1483.5 mg/l and 0.48 mg/l

respectively in Karsara leachate sample and for Ramna MSW sample these values were 7.7 mg/l, 790 mg/l, 2007, 745 mg/l, 201 mg/l, 350 mg/l, 1246 mg/l and 1.7 mg/l respectively. The COD value was observed high in Karsara MSW leachate (12327.5 mg/l) as compared to the Ramna MSW leachate (8332 mg/l). COD concentration was found much higher than the leachate disposal limit (250 mg/l). Rafizul and Alamgir (2012)[84] concluded that hardness, total alkalinity, chloride and COD seems to be proportional to one another in a scattered way. However, it is very difficult to simplify the variation of concentration of a particular leachate parameter in a specific time, and in most of the cases, concentration increases during a relatively short period of time [128]. Mean value of nitrate of Karsara MSW leachate (83 mg/l) is much higher than the Ramna MSW leachate (66 mg/l). Higher nitrate concentration in the leachate sample has an inhibitory effect on methanogenesis process of solid waste [129]. COD is higher during the vigorous initial stage of decompositions of leachate and slowly decreases with time due to stabilization of leachate [25], [130]. The mean value of BOD₅/COD ratio of Karsara and Ramna leachates were found to be 0.25 and 0.16 respectively. A very low ratio indicates the methanogenic and degradable conditions of dissolved organic matter of both dumping sites [131], [132], [133]. A High BOD₅/COD ratio (0.69) is an indicator of high biodegradability through an anaerobic phase of a landfill [90]. Phosphate mean values for leachate sample of Karsara and Ramna MSW were found, 39.20 mg/l and 30.40 mg/l respectively which are much higher than leachate characteristic range (1-30 mg/l) of MSW given by UNEP (2005) [116]. Higher concentration of phosphate and nitrate in leachate may be due to runoff of fertilizer used in the agricultural fields, around both the dumping sites. As far as the occurrence of heavy metals in the studied sample is concerned, a significant amount of Cu (1.58 mg/l)

and Fe (.26 mg/l) were observed in Karsara leachate sample while Cr, Zn, Ni, As, and Mn were not detected in leachate sample.

Table 5.3 Results of Physico-chemical analysis of Karsara and Ramna MSW leachate samples

S. No.	Leachate quality Parameters	Ramna Leachate Sample (mean value)	Karsara Leachate Sample (mean value)	Leachate Disposal Standard (MSW Management and Handling Rules, 2000)	Characteristics of leachate generated from MSW in Developing countries (UNEP, 2005)
1	Temperature	25.9	26.6	NM	NM
2	pH	8.8	9.4	5.5-9.0	4.5-9.0
3	EC	4.55	11.58	NM	NM
4	TDS	2338	8129.5	2100	0-42,300
5	DO	7.7	7.45	NM	NM
6	Chloride	1311	790	NM	100-5,000
7	Hardness	790	738	NM	0-22,800
8	Nitrate	66	83	NM	0-25
9	Total alkalinity	2007	865.5	NM	300-11,500
10	BOD ₅	1335	3190.5	30	20-40,000
11	COD	8332	12327.5	250	500-60,000
12	BOD ₅ /COD	0.16	0.25	NM	NM
13	Ca	350	270	NM	10-250
14	Mg	201	272.5	NM	40-11,50
15	Na	745	1191.5	NM	50-4,000
16	K	1246	1483.5	NM	10-2,500
17	Fluoride	1.7	0.48	NM	NM
18	Cr	1.36	ND	2.0	NM
19	Zn	ND	ND	5.0	0.03-120
20	Cu	0.29	0.26	3.0	4-1,400
21	Cd	ND	ND	Nm	NM
22	Pb	ND	ND	0.1	8-1020
23	Fe	4.6	1.58	NM	3-2100
24	Ni	ND	ND	NM	NM
25	Mn	ND	ND	NM	0.03-65
26	As	ND	ND	0.2	NM
27	Phosphate	30.4	39.2	NM	0.1-30

All value in mg/l except Temp (°C), EC (mS/cm) and pH

*ND- Not detectable, *NM- Not Mention

Cr (1.36 mg/l), Cu (0.29 mg/l), and Fe (4.6 mg/l) were detected in Ramna leachate sample while Zn, Cd, Ni and Mn were not detected. These heavy metals are non-biodegradable thus causes a long-term impact on the environment. Alkaline nature of leachate causes an inhibitory impact on metal solubility with the landfill ages [127]. Fauziah et al. (2013) [134] concluded the toxic nature of the leachate from both active and non-active landfills site are due to high concentration of heavy metals.

Thus leachate was characterized by high substances of organic and inorganic chemicals as well as the toxic nature arising from heavy metals concentrations. Higher values of these pollutants in the leachate samples indicate that the weakening capacity of this landfill is close to exhaustion [135]. Overall physico-chemical analysis results show that the leachate of Karsara dumping site is of higher strength than leachate of Ramna dumping. Heavy metals (Cr, Cu, & Fe) and nitrate show a significant role in leachate characteristic and toxicity due to its reducing and everlasting persistence nature in the environment [136].

5.4 Calculation of leachate pollution index (LPI) of Ramna and Karsara MSW dumping Leachate

In order to assess the leachate pollutant potential of Ramna and Karsara dumping sites leachate pollution index (LPI) value was calculated by using the following equation which is given by D. Kumar and B.J. Alappat[52].

$$LPI = \frac{\sum_{i=1}^n w_i p_i}{\sum w_i} \quad (12)$$

Leachate pollution index (LPI) of the dumping site was estimated with the help of weight factor (w_i), pollution concentration and sub-index value (p_i) of eleven important parameters as shown in Table 5.4. LPI of Ramna dumping site was observed high i.e. 15.62. This high LPI value indicated a unstabilised, young, and are still undergoing decomposed landfill and thus have high risks to cross-contaminate the groundwater of

surrounding areas [92]. Heavy metals and inorganic constituents (COD) persist a long time in leachate so its low concentration in leachate directly alters the cumulative pollution rating($w_i p_i$). It may be one of the reasons for the high value of LPI in open dumping sites. The high value of LPI represents the overall leachate contamination potential of MSW and hazardous MSW landfill sites. Thus high LPI value indicated to this dumping site is more prone to pollute surrounding groundwater.

Table 5.4 Leachate pollution Index (LPI) of the leachate of Ramnadumping site, 2014

S No.	Parameters	Weight Factor (Wi)	Mean Pollutant conc.	Sub index value (pi)	Cumulative pollution rating($w_i p_i$)
1	COD (mg/l)	0.062	8332.00	70	4.320
2	BOD ₅ (mg/l)	0.061	1335.00	40	2.440
3	pH	0.055	8.82	5	0.275
4	TDS (mg/l)	0.050	2338.00	5	0.275
5	Chloride (mg/l)	0.049	1311.00	10.6	0.519
6	Chromium (mg/l)	0.064	1.36	5	0.320
7	Lead (mg/l)	0.063	0.00	5	0.315
8	Zinc (mg/l)	0.056	0.00	5	0.280
9	Nickel (mg/l)	0.052	0.00	5	0.260
10	Copper (mg/l)	0.050	0.29	5	0.250
11	Iron (mg/l)	0.045	4.60	5	0.225
$\sum w_i = 0.607$				$\sum_{i=1}^n w_i p_i = 9.479$	

$$LPI = \sum_{i=1}^n w_i p_i$$

$$LPI = \frac{\sum_{i=1}^n w_i p_i}{\sum w_i}$$

$$LPI = 9.479/0.607$$

$$= 15.62$$

Table 5.5 Leachate pollution index (LPI) of the leachate of Karsaradumping site, 2014

S. No.	Parameters	Weight factor (w_i)	Pollutant concentration (Average value.)	Sub-index value (p_i)	Cumulative pollution rating($w_i p_i$)
1	COD (mg/l)	0.062	11980.00	73	4.526
2	BOD ₅ (mg/l)	0.061	3120.00	40	2.440
3	pH	0.055	9.10	6	0.330
4	TDS (mg/l)	0.050	8430.00	12.5	0.625
5	Chloride (mg/l)	0.049	765.00	5.5	0.3283
6	Chromium (mg/l)	0.064	0.00	5	0.32
7	Lead (mg/l)	0.063	0.00	5	0.315
8	Zinc (mg/l)	0.056	0.00	5	0.28
9	Nickel (mg/l)	0.052	0.00	5	0.26
10	Copper (mg/l)	0.050	0.31	5	0.25
11	Iron (mg/l)	0.045	1.50	5	0.225
12	As (mg/l)	0.061	0.002	5	0.305
		$\sum w_i = 0.668$		$\sum_{i=1}^n w_i p_i = 12.3945$	

$$LPI = \frac{\sum_{i=1}^m w_i p_i}{\sum w_i}$$

$$LPI = 12.3945/0.668$$

$$LPI = 18.55$$

Leachate pollution index (LPI) of Karsara dumping site was estimated with the help of weight factor, pollution concentration and sub-index value of twelve important leachate pollution index parameter as shown in Table 5.5. LPI of Karsara dumping site was found high that is 18.55. The higher value of LPI indicates a hazardous and non-stabilized generated and a poor environmental condition of the dumping site. Thus dumping will have a chance to pollute the surrounding groundwater.

5.5 Comparative discussion of LPI of Ramna and Karsara MSW leachate

The high value of LPI of both the MSW leachate indicates that the contaminants observed in the leachate are high in concentration with a poor environmental condition. Higher concentrations of BOD, COD and TDS value of both the leachate samples accountable for higher individual and cumulative pollution rating. It is one of the reasons for the high value of LPI of both dumping sites. Thus both the dumping sites are hazardous in nature at a particular time. A value of LPI higher than 7.50 specifies a polluting leachate for health and the surrounding environment [58]. High LPI for this MSW dumping sites represents a hazard and that can be responsible for some level of risk to the water, air and land environment. So a risk assessment has been useful to MSW landfills, for the leachate releases and groundwater pollution with respect to landfill aftercare [136]. So to avoid any pollution problem the prioritization of landfill sites treatment can be done by LPI value. The pollution potential evaluations of landfills is useful in evaluating the level of care required post-closure and use as an integrated approach for risk assessment and to make forecasts on the long-term impacts of a landfill on human health and environment. Kumar and Aalpat in 2005 [51] has also mentioned in their research that closed landfills have equal or more contamination potential in comparison with active landfills so the remediation activities and post-closure monitoring should be very essential at the closed landfills. As long as a landfill signifies a hazard, there is a receptor-like human health or environmental media such as groundwater that can be harmful at the same level of risk that is linked with the age of the landfill. To estimate the risk of a closed landfill, potential adverse impacts on human health & environment and the probability of their happening must be assessed. An aftercare action of leachate emissions is very useful to be maintained at the site for a

long period of time. [92]. Leachate pre-treatment combined with shortening the post-closer care periods are beneficial to achieve both sustainable and economical friendly landfill management [137].

LPI can be used as a tool to detect a landfill's pollution potential relative to other landfills and therefore also to rank remediation investments [138]. Thus, the assessment of leachate quality by evaluating LPI at any early stage may be assumed to (a) to detect whether the solid waste leachate are hazardous, (b) to recognize a suitable landfill design, (c) to develop a sustainable leachate treatment method and d) to forecast the effects of leachate on groundwater by accepting various monitoring and investigation approaches. Leachate pollution potential of these dumping site can also use as a combined approach for risk assessment and to make estimates on the long-term impacts of a dumping MSW on human health and environment. A tolerable level of risk is delineated for the dumping sites at the end of aftercare. So, to evaluate the risk of a closed dumping sites on human health and environment and the probability of their existence need to be assessed [139]. This can be evaluated in concern of leachate quality gas composition, liner design, site geology, side-slope, hydrogeology, production cover, climate, ecosystems human exposure, potential receiving bodies, and other factors considered relevant on a site-specific basis [140]. Some of the hazardous chemicals such as heavy metals and salts will not decay in a dry old landfill. To minimize the lasting impact of these chemicals on the environment, landfill should be functional stable which is based on an assessment of the long-term emissions from landfill with the time.

5.6 Physico-chemical characteristics of groundwater samples around the Ramna dumping site in pre- and post-monsoon period of the year 2015

The explanatory statistics of the analysed water quality parameters during pre- and post-monsoon are shown in Table 5.6. The temperature of the seventeen

groundwater samples was found in the range of 27-33.9 °C with a mean value of 31.16 °C in pre-monsoon, while 21.1-23.6 °C with an average value of 22.2 °C in post monsoon. This range of temperature impacts on the reaction of most inorganic constituents and chemical contaminants that may affect the quality of the water.

Table 5.6 Descriptive statistics of water quality parameters in pre- and post-monsoon period, 2015

Parameters	Pre-monsoon Period			Post-Monsoon Period				
	Min	Max	Mean	Min	Max	Mean	WHO Guideline for drinking water -2011	Drinking water acceptable limit (BIS-10500:2012)
Temperature	27	33.9	31.1	21.1	23.6	22.2	NM	NM
pH	6.43	7.31	6.94	6.4	8.15	7.67	6.5-9.2	6.5-8.5
EC	0.41	2.01	1.32	0.6	2.84	1.49	0.3	NM
TDS	230	1505	723	313	1704	1006	500	500
DO	4	12.5	7.4	4.3	9	6.3	NM	NM
Chloride	30	232	130	18	294	156	250	250
Hardness	46.2	208	76.39	190	815	416.35	300	200
NO ₃ ⁻	9.2	142.6	55.77	17	110	68.29	50	45
Alkalinity	233	715	441	66	126	86.71	500	200
BOD	0	6.3	3.11	0	3	1.57	NM	NM
COD	17	181	67.88	19	188	93.52	NM	NM
Ca	6	88	24	14	107	57	150	75
Mg	17.44	96.35	26.74	0.05	7.05	2.33	200	30
Na	55	230	137	50	270	137	200	NM
K	3	142	19.94	1	90	13.82	NM	NM
PO ₄ ³⁻	1.21	2.8	2.09	2	21.5	11.14	NM	5
Fe	0	1.17	0.2	0	5.11	1.06	0.3	0.3

All value in mg/l except Temp (°C), EC (mS/cm) and pH, *NM- Not Mention

Three times pre and post monsoon data is summarize in above table.

The pH of the groundwater samples in the study area was fluctuated from 6.43 to 7.31 with an average value of 6.94 in pre-monsoon, from 6.40 to 8.15 with an average of

7.67 in post- monsoon. EC was varied from 0.41 to 2.01 mS/cm with mean value of 1.32 mS/cm in pre-monsoon, from 0.6 to 2.84 mS/cm with mean value of 1.49 mS/cm in post monsoon. The higher mean value of EC in post-monsoon is possibly due to the presence of high ionic species from anthropogenic source (Kale et al., 2010). The TDS was ranged from 230 to 1505 mg/l with a mean value of 723 mg/l in pre-monsoon, from 313 to 1704 mg/l with a mean value of 1006 in post monsoon. Mean value of TDS was found much more than WHO and BIS acceptable standard (500 mg/l) in both pre- and post-monsoon. Its value increases in the post-monsoon period, that indicating anthropogenic input in groundwater during this period. The NO_3^- value was observed 9.20 to 142.6 mg/l with a mean value of 55.77 mg/l in pre-monsoon and 17 to 110 mg/l with an average value of 68.29 in post-monsoon. High NO_3^- content in groundwater interconnected with different sources, such as leaching of organic and inorganic fertilizers from the agricultural area, by permeation and leaching of irrigation water, animal waste and seepage from sewers [141], [142]. The alkalinity was ranged from 233-715 with an average value of 441 in pre-monsoon, from 66-126 mg/l with an average of 86.71mg/l in post monsoon. Mg, Ca and K ions were observed within the acceptable limit of drinking water standard in both pre- and post-monsoon. The average value of hardness (416.35mg/l) was found above the WHO and BIS standard in post-monsoon. Average value of chloride was found 130 mg/l in pre-monsoon and 156.92 mg/l in post monsoon which is within the range of WHO and BIS acceptable value (250 mg/l).

The COD concentration varied from minimum 17 mg/l to maximum 181 mg/l with a mean value of 67.88 mg/l in pre-monsoon, while minimum 14 mg/l to maximum 107 mg/l with a mean value of 57 mg/l in post-monsoon. The mean value of BOD was found considerable amount in both pre- (3.11 mg/l) and post-monsoon (1.57 mg/l) period as

shown in the table 5.6. The observed average value of iron was found above the acceptable limit (0.3mg/l) in both pre- (0.20 mg/l) and post-monsoon (1.06 mg/l) of the samples it may be due to the presence of iron-containing solid waste like an electronic waste at dumping sites. The presence of iron above the permissible limit (1.0 mg/l) in groundwater is responsible for its taste and appearance which makes the water aesthetically unpleasant and not safe for drinking purpose [143]. Average concentration of PO_4^{3-} was observed below the permissible limit (5 mg/l) in all the seventeen water samples in pre-monsoon but significantly increased value was observed in post-monsoon, which may be degradation of food, garden waste, fertilizer from the surrounding field and another form of waste liberate nutrients wastes such as PO_4^{3-} from dumping site which might contaminate the groundwater

5.7 Spatial distribution of observed contaminants in groundwater around the Ramna dumping site

Zonation map of high values observed pollutants (EC, TDS, NO_3^- , Fe and PO_4^{3-}) were prepared by setting the value below and above the acceptable limit of groundwater quality [144]. Inverse Distance Weighted (IDW) technique was used for curve fitting, which is a method of assigning values to unidentified points by using values from identified points. IDW technique is used for spatial distribution of observed water quality pollutant for pre- and post-monsoon in Arc GIS. The zonation maps of the spatial distribution of EC, TDS, phosphate and Fe are showing in figure 5.1, 5.2, 5.3 and 5.4 respectively, which indicate the potential groundwater pollution by these pollutants. The spatial distribution map of EC and TDS are showing the most of the area around the dumping site is contaminated during the post-monsoon period. NO_3^- concentration was observed above the acceptable limit in the almost the whole studied area around the dumping site during post-monsoon. It may be due to landfill waste dissociate with

rainwater and produces a large quantity of polluted water in the form of leachate that transported to the groundwater. Vertical profile of soil is more vulnerable for NO_3^- saturation which results to leaching from the dumping area to the groundwater [145]. Most of the village area comes under the above the acceptable limit of iron drinking water standard. Redox reactions and ion-exchange process responsible for the iron contamination from the solid waste into the groundwater. In pre-monsoon period the PO_4^{3-} value observed below the acceptable limit in almost whole village area but in post-monsoon all area come under above the acceptable limit of drinking water standard (5 mg/l) that indicate the large anthropogenic impact of PO_4^{3-} generating sources like agricultural practices, organic waste from municipal solid waste. It was clearly observed that the TDS, NO_3^- , PO_4^{3-} and iron concentration rapidly increase during the post-monsoon as compared to the pre-monsoon near the dumping site. **Due to the presence of iron minerals in the weathered materials, may responsible for reduction of ferric iron into ferrous iron in post monsoon.** Spatial distribution of pollutants shown in the map clearly marked that most of the above acceptable limit water sample very near to the dumping site and therefore dumping site may be one of the reasons of groundwater pollution. This significant spatial variation in TDS, NO_3^- , Fe and PO_4^{3-} during pre- and post-monsoon indicate anthropogenic impacts [146].

5.8 Statistical analysis of results of groundwater quality

Multivariate statistical analysis with cluster analysis, principal component analysis and factor analysis were applied for the interpretation of a large complex groundwater quality data of the Ramna studied area.

5.8.1 Total Variance Explanation of Pre- and post-monsoon data, 2015

The table 5.7 represents the percent of the variance, initial eigenvalue and cumulative percent of the total variance of groundwater data obtained in pre- and post-monsoon.

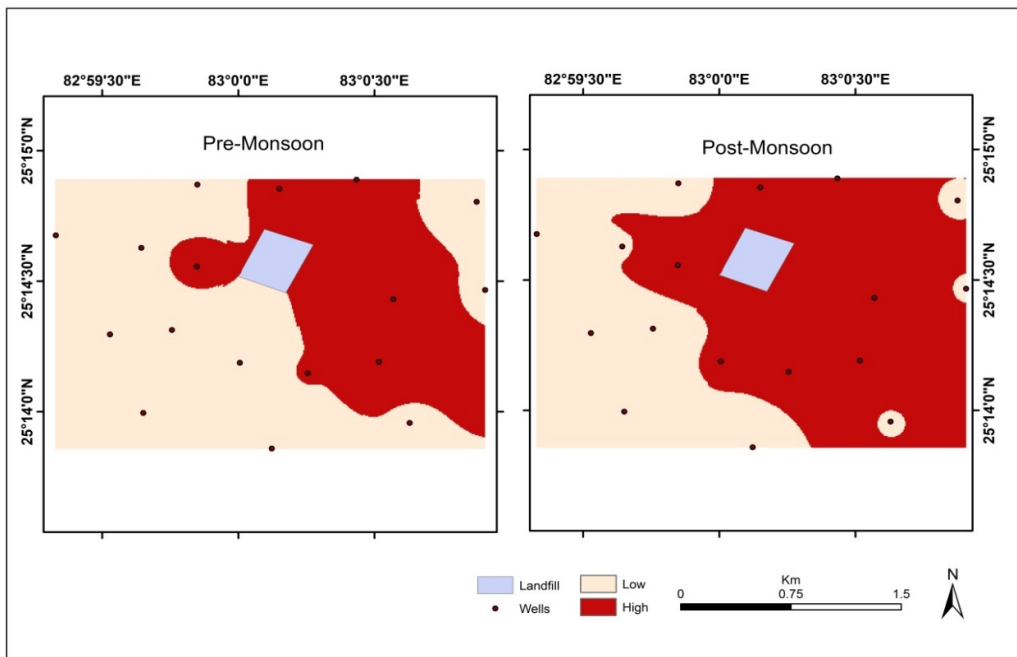


Figure 5.1 ECzonation map showing groundwater pollution around Ramna dumping site, 2015

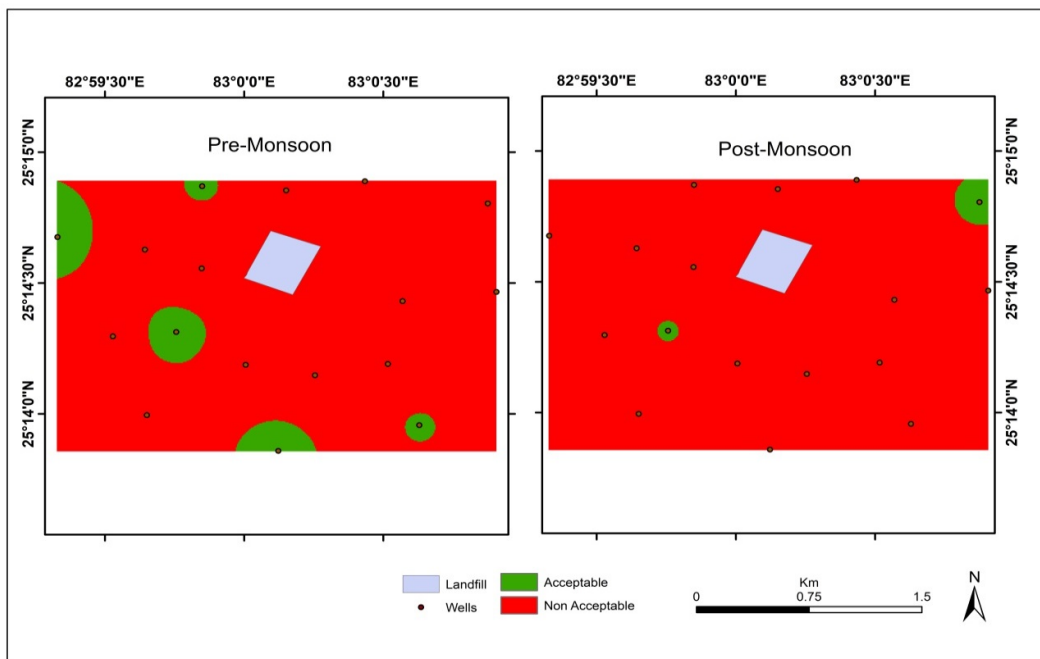


Figure 5.2 TDSzonation map showing groundwater pollution around Ramna dumping site, 2015.

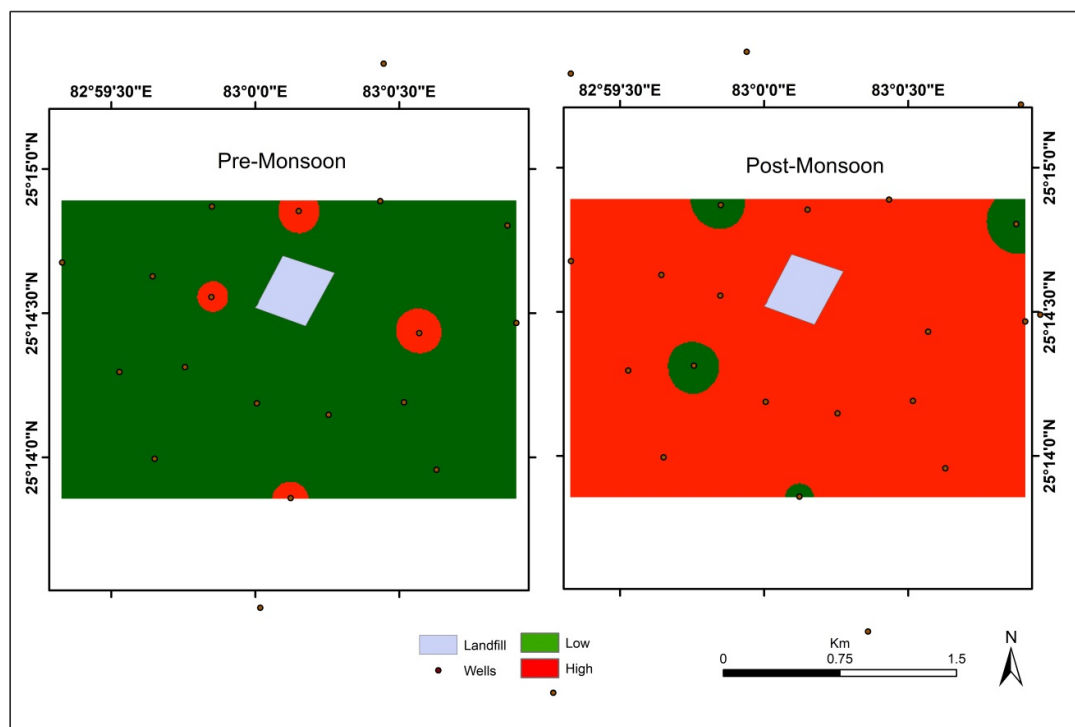


Figure 5.3 Phosphate zonation map showing groundwater pollution around Ramna dumping site, 2015.

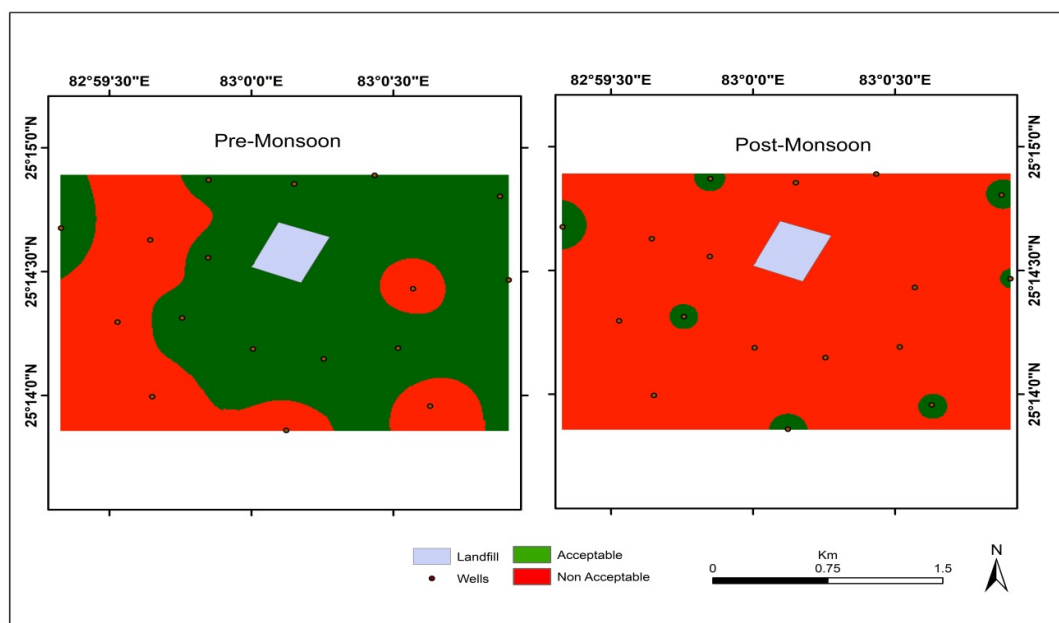


Figure 5.4 Fe zonation map showing groundwater pollution around Ramna dumping site, 2015.

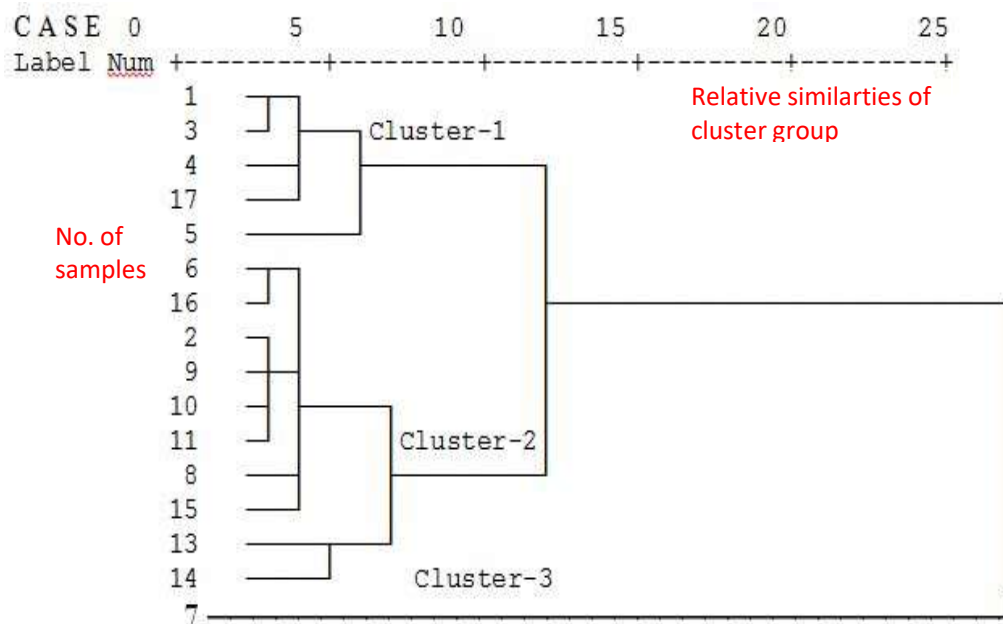
The table 5.8 shows the rotated component matrixes of pre- and post-monsoon period data that showing the first component characterized by the strong loading of EC, TDS, chloride, hardness, and Na in post-monsoon period. The great loading factor of conductivity is due to the active contribution of dissolved ions in the groundwater quality. Strong loading between these components also indicates leaching of solid waste effluent from the open dumping site [51]. The second component explains 18.666 % in pre-monsoon and 18.341% in post-monsoon characterized by strong loading of Ca and Na. The third component is 12.998% in pre-monsoon and 12.511% in post-monsoon of the total variance. It shows strong loading of Fe, phosphate and DO. The fourth component exhibits 8.296% in pre-monsoon and 9.251% in post-monsoon of the total variance, showing strong loading of nitrate ion. The fifth component explains 7.691% in pre-monsoon and 7.873 % in post-monsoon. The sixth component explains 7.544% in pre-monsoon and 6.915 % in post-monsoon.

Table 5.7 Total variance explained data of pre- and post-monsoon period, 2015

Pre-monsoon Data, 2015							Post-monsoon Data, 2015					
Component	Initial Eigen values			Rotation Sums of Squared Loadings			Initial Eigen values			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.928	28.989	28.989	3.046	17.918	17.918	5.043	29.668	29.668	4.598	27.048	27.048
2	3.173	18.666	47.656	3.035	17.851	35.768	3.118	18.341	48.009	3.067	18.041	45.089
3	2.21	12.998	60.653	2.877	16.922	52.69	2.127	12.511	60.52	2.037	11.98	57.069
4	1.41	8.296	68.95	2.396	14.097	66.786	1.573	9.251	69.771	1.74	10.237	67.306
5	1.307	7.691	76.641	1.522	8.955	75.741	1.338	7.873	77.645	1.539	9.053	76.359
6	1.282	7.544	84.185	1.435	8.444	84.185	1.176	6.915	84.56	1.394	8.201	84.56
7	0.814	4.788	88.973				0.82	4.823	89.383			
8	0.638	3.755	92.728				0.652	3.838	93.221			
9	0.53	3.119	95.847				0.45	2.65	95.871			
10	0.374	2.197	98.044				0.284	1.671	97.542			
11	0.149	0.874	98.918				0.162	0.955	98.496			
12	0.091	0.534	99.452				0.118	0.691	99.188			
13	0.049	0.285	99.737				0.107	0.631	99.819			
14	0.023	0.138	99.876				0.021	0.122	99.941			
15	0.016	0.093	99.968				0.007	0.042	99.983			
16	0.005	0.032	100				0.003	0.017	100			
17	-7	-4.123	100				3.65E-17	2.15E-16	100			

Table 5.8 Rotated component matrixes of pre- and post-monsoon data, 2015

Parameters	Component number for pre-monsoon						Component number for post-monsoon					
	1	2	3	4	5	6	1	2	3	4	5	6
Temp	0.08	0.497	0.684	0.097	0.029	0.4	0.011	0.701	0.372	0.295	0.324	0.285
pH	0.397	0.729	0.325	0.017	0.069	0.292	0.255	0.722	0.167	0.083	0.128	0.089
EC	0.896	0.152	0.032	0.165	0.149	0.114	0.826	0.007	0.013	0.072	0.009	0.047
TDS	0.929	0.075	0.009	0.009	0.089	0.036	0.941	0.164	0.04	0.097	0.015	0.215
DO	0.166	0.076	0.894	0.042	0.025	0.126	0.014	0.141	0.951	0.104	0.171	0.058
Chloride	0.171	0.122	0.027	0.932	0.093	0.098	0.889	0.169	0.009	-0.05	0.093	0.246
Hardness	0.027	0.906	0.083	0.208	0.126	0.067	0.522	0.465	0.435	0.142	0.441	0.054
NO ₃ ⁻	0.008	0.339	0.719	0.291	0.314	0.194	0.093	0.033	0.096	0.883	0.02	0.03
Alkalinity	0.528	0.289	-0.03	0.426	0.237	0.173	0.902	0.021	0.121	0.105	0.148	0.167
BOD	0.43	0.309	0.705	0.218	0.067	-0.07	0.254	0.854	0.197	0.278	0.026	0.033
COD	0.158	0.392	0.281	0.391	0.584	0.129	0.084	0.831	0.112	0.104	0.127	0.053
Ca	0.135	0.147	0.271	0.182	0.833	0.116	-0.3	0.485	0.659	0.282	0.033	0.171
Mg	0.642	0.031	0.076	0.13	0.446	0.013	0.033	0.049	0.032	0.073	0.087	0.951
Na	0.05	0.207	0.108	0.919	0.172	0.033	0.853	0.235	0.373	0.083	0.052	0.072
K	0.052	0.099	0.098	0.092	0.066	0.933	0.365	-0.1	0.285	0.478	0.591	0.062
PO ₄ ³⁻	0.468	0.097	0.533	0.148	0.052	0.412	0.177	0.108	0.201	0.622	0.023	0.447
Fe	0.132	0.924	0.131	0.234	0.179	0.028	0.156	0.169	0.054	-0.11	0.886	0.119

**Figure 5.5** Dendrogram of observed data in pre-monsoon

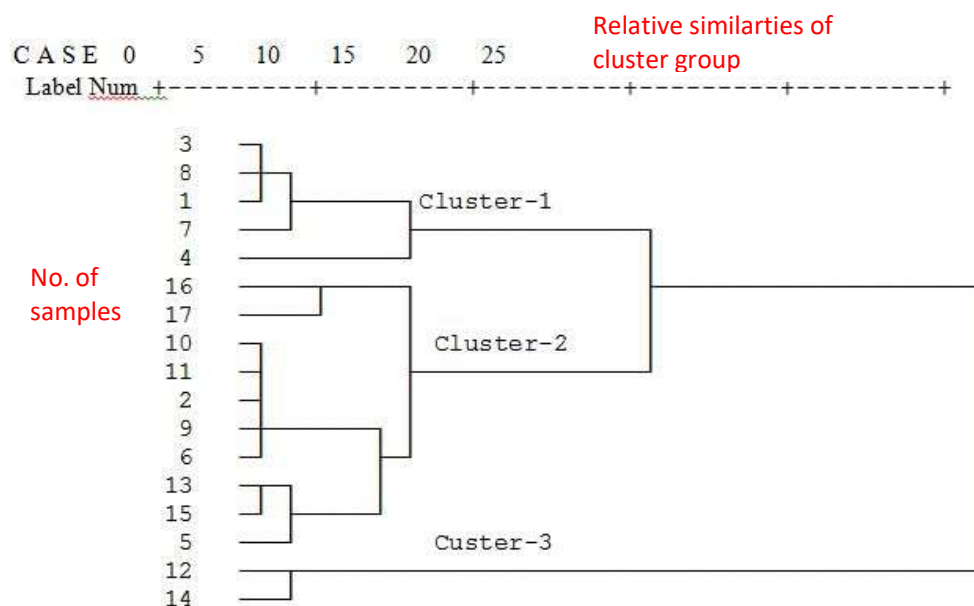


Figure 5.6 Dendrogram of observed data in post-monsoon

5.8.2 Hierarchical cluster analysis

Cluster analysis is a useful statistical analysis for the analysis of groundwater quality data with an outlook to group the similar pollution sources [147]. Cluster analysis used to classify observation into a finite and a small number of groups based on distance (proximity). Hierarchical cluster analysis is applied Euclidean distance as distances determine and Ward's method as a connection rule to produce the most characteristic groups [148]. Clustering of sampling points is to be done on the basis of the concentration of constituent parameter. The output result of cluster analysis has shown as a dendrogram (figure 5.5 and 5.6). The horizontal axis given at the top indicates the relative similarity of different cluster groups, lesser distance corresponds to a greater similarity between samples [149]. Each group indicates the water characteristic of a distinct quality. There was three distinct cluster of the sample as shown in figure 5.5 and 5.6 obtained for both pre- and post-monsoon data.

Cluster 3 represents the samples that are highly contaminated under the influence of MSW open dumping site, which are situated very near to the dumping site as compare

to other samples. Cluster 2 represents the samples having moderate pollution level and cluster 1 represents low pollution level with no influence of MSW open dumping site. The degree of association is strong between the samples within all the three clusters while it is showing a weak relationship between cluster 1, cluster 2, and cluster 3.

5.8. 3 Correlation analysis

The correlation coefficient (r) measures the degree of relationship between two variables out of which one is considered as dependent variable. Table 5.9 and Table 5.10 represent the correlation matrices for the seventeen water quality parameters for both pre- and post-monsoon seasons. During pre-monsoon, highly positive correlation was observed between pH-BOD, EC-TDS, EC-chloride, EC-alkalinity, EC-Na, TDS-chloride, TDS-alkalinity, TDS-Na, Chloride-alkalinity, Hardness-K, BOD-COD, BOD-pH and negative correlation was observed between Temperature-BOD, Na-Ca. During post-monsoon highly positive correlation coefficient was observed between EC-TDS, DO- NO_3^- , Hardness-iron, Na-chloride and negative correlation was observed between pH-Fe, DO-BOD. There is a good correlation between conductivity and alkalinity during pre- and post-monsoon and not affected by dilution process during the rainy season [150]. Highly positive correlations between the variable parameters were observed during post-monsoon might be the effect of contaminants passing through rainwater effluent, generated from the open dumping site.

Table 5.9 Pearson's correlation matrix of pre-monsoon (2015) groundwater quality parameters (**Correlation is significant at the 0.01 level, *Correlation is significant at the 0.05 level, 2 tailed).

Parameter	Temp	pH	EC	TDS	DO	Chloride	Hardness	NO ₃ ⁻	Alkalinity	BOD	COD	Ca	Mg	Na	K	PO ₄ ³⁻	Fe
Temp.	1																
pH	0.333	1															
EC	0.043	0.218	1														
TDS	-0.08	0.376	.740**	1													
DO	0.433	0.018	0.076	0.018	1												
Chloride	0.058	0.29	.634**	.939**	0.056	1											
Hardness	0.253	-0.25	.536*	0.367	0.397	0.334	1										
NO ₃ ⁻	0.198	-0.18	0.172	0.192	0.026	-0.136	-0.084	1									
Alkalinity	0.124	0.174	.633**	.815**	0.121	.753**	.491*	-0.17	1								
BOD	591*	.614**	0.283	0.314	0.232	0.338	-0.2	0.222	0.171	1							
COD	0.441	0.476	0.104	0.07	0.034	0.055	-0.322	-0.06	-0.053	.620**	1						
Ca	0.278	-0.37	0.295	0.341	.538*	-0.299	0.264	0.232	-0.247	0.319	.493*	1					
Mg	0.252	0.081	0.025	0.224	0.091	-0.223	0.034	0.09	0.092	0.031	0.02	0.138	1				
Na	0.098	0.425	.624**	.867**	0.292	.826**	0.178	-0.16	.734**	0.267	0.176	.654**	0.036	1			
K	0.038	-0.01	0.203	0.345	0.409	0.403	.680**	-0.39	0.362	0.082	0.015	0.036	-0.1	0.288	1		
PO ₄ ³⁻	0.109	-0.27	0.283	0.305	0.166	0.273	0.293	-0.37	0.124	0.129	0.055	0.046	-0.35	0.045	0.287	1	
Fe	0.091	-0.18	0.065	0.155	0.225	0.021	-0.204	-0.14	0.301	0.118	0.142	0.038	-0.25	0.074	-0.28	0.052	1

Table 5.10 Pearson's correlation matrix of post-monsoon (2015) groundwater quality parameters.

Parameter	Temp	pH	EC	TDS	DO	Chloride	Hardness	NO ₃ ⁻	Alkalinity	BOD	COD	Ca	Mg	Na	K	PO ₄ ³⁻	Fe
Temp	1																
pH	0.027	1															
EC	0.005	0.456	1														
TDS	0.012	0.419	.925**	1													
DO	0.456	0.352	0.114	0.172	1												
Chloride	0.049	0.21	0.306	0.183	0.175	1											
Hardness	0.473	.592*	-0.21	0.073	-0.03	-0.348	1										
NO ₃ ⁻	0.358	0.416	0.099	0.021	.648**	0.225	-0.212	1									
Alkalinity	0.108	0.365	.488*	0.476	0.158	.514*	-0.289	0.247	1								
BOD	.497*	0.143	0.473	0.35	.615**	0.222	-0.366	-0.22	.511*	1							
COD	0.013	0.419	0.168	0.167	0.211	0.419	-0.429	0.305	0.399	0.179	1						
Ca	0.317	0.07	0.184	0.136	0.174	0.068	0.178	0.461	-0.186	-0.16	0.282	1					
Mg	0.161	0.202	0.458	0.425	0.174	0.279	-0.194	-0.085	0.273	0.26	0.391	-0.07	1				
Na	0.027	0.268	0.261	0.104	0.186	.898**	-0.349	0.414	0.348	0.126	0.381	0.295	0.097	1			
K	0.268	0.268	0.236	0.135	-0.21	0.166	-0.189	-0.168	0.016	0.121	-0.02	-0.21	-0.01	0.075	1		
PO ₄ ³⁻	0.232	0.272	0.343	0.364	-0.36	0.031	-0.103	-0.459	0.133	0.48	0.229	-0.12	0.318	0.073	0.32	1	
Fe	.519*	.645**	-0.25	0.154	0.01	-0.365	.948**	-0.243	-0.478	.498*	.521*	0.225	-0.23	0.356	0.12	-0.177	1

5.9 Spatial Analysis of Groundwater Quality around Ramna MSW dumping site by using WQI and LPI in 2016

To find out overall groundwater status around Ramna MSW dumping site, spatial distribution of contaminants was analysed by evaluating WQI.

5.9.1 Evaluation of Leachate pollution index (LPI)

Leachate pollution index (LPI) of the MSW of leachate was estimated with the help of weight factor, pollution concentration and sub-index value of twelve important leachate pollution index parameters as shown in table 5.11.

Table 5.11 Leachate pollution index (LPI) of Ramna MSW dumping site, 2016.

S.No.	Parameters	Weight factor (w_i)	Pollutant conc. (All values are in mg/l except pH)	Sub-index value (p_i)	Cumulative pollution rating ($w_i p_i$)
1	COD	0.062	8279.00	70	4.320
2	BOD ₅	0.061	27.80	5	0.305
3	pH	0.055	8.82	5	0.275
4	TDS	0.050	2322.50	5	0.275
5	Chloride	0.049	1221.00	7.5	0.367
6	Cr	0.064	1.77	5.5	0.352
7	Pb	0.063	0.0002	5	0.315
8	Zn	0.056	0.0003	5	0.280
9	Ni	0.052	0.18	5	0.260
10	Cu	0.050	0.33	5	0.250
11	Fe	0.045	5.40	5	0.225
12	As	0.061	0.001	5	0.305
		$\sum w_i = 0.607$		$\sum_{i=1}^m w_i p_i = 7.529$	

$$LPI = \frac{\sum_{i=1}^m w_i p_i}{\sum w_i}$$

$$LPI = 7.529/0.607$$

$$= 12.40$$

LPI of Ramna dumping site was found high that is 12.40. The LPI of Ramna leachate was decreases with calculated value of 12.40 in year 2016 than the value of 15.62 in year 2014. It may be due to biodegradation of organic constituents in MSW by microorganism with the passage of time that results into lower pollutants concentration in MSW leachate. Most of the biodegradable material of MSW waste transformed within 25 to 57 days at temperature between 34 to 38 °C [151]. But this value is still too much high for leachate pollution and indicates the contaminants observed in the leachate are high in concentration with poor environmental conditions. LPI value higher than 7.50 specifies that leachate is the main source of pollution and have an adverse effect on the surrounding environment [58]. High LPI for this dumping site represents a hazardous nature and it can be responsible to some level to the water, air and land pollution. Therefore, a suitable treatment methodology and continuous monitoring are required to control the LPI for this dumping site.

5.9.2 Statistical analysis of the physicochemical characteristic of groundwater quality around the Ramna dumping site in 2016

Statistical measures of physical and chemical parameters including minimum concentration, maximum concentration, mean concentration and standard deviation of pre- and post-monsoon data are given in table 5.12. The temperature of the water samples (n=16) of the studied area was found to varied from 30.1 °C to 32.5 °C with an average value of 31.6 °C in pre-monsoon and from 20.4 °C to 22.9 °C with an average value of 21.6 °C in post-monsoon. However, pH of the groundwater samples was fluctuated from 5.6 to 7.4 with an average value of 6.5 in pre-monsoon and from 7.0 to 7.7 with an average reading of 7.3 in post-monsoon, which may be due to the dissolved carbonates are mainly in the HCO_3^- form [152]. The sorption and co-precipitation reaction of contaminants on the solid surface is influence by pH, So it can act as

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aninhibitor parameter in waste transformation process [38]. The dissolved oxygen was varied from 3.5 to 7.8 in pre-monsoon and from 4.3 to 7.9 in post-monsoon. The total dissolved solids (TDS) were ranged from 331 to 1140 (mg/l) with a mean value of 652 mg/l in pre-monsoon, from 358 to 1245 (mg/l) with a mean value of 651 in post-monsoon. Mean value of TDS was found higher than WHO guideline and BIS acceptable limit (500 mg/l) of water quality in both pre- and post-monsoon period. High EC and TDS may be due to leaching of ions into the groundwater released from the waste of the sampling sites. Total hardness of water sample was found to vary from 230 to 604 (mg/l) in pre-monsoon and from 236-470 (mg/l) in post-monsoon, the mean value of hardness was found above the drinking water acceptable limit (300 mg/l). The maximum concentration of hardness may be due to carbonate weathering in the study area. Alkalinity was ranged from 230 to 630 (mg/l) in pre-monsoon and 265 to 410 (mg/l) in post-monsoon. The mean value of alkalinity was observed below the WHO guideline (500 mg/l) while above the Indian acceptable limit in both pre- and post-monsoon. Chloride was ranged between 39 - 205 (mg/l) in pre-monsoon and from 35.50 - 144 mg/l in post-monsoon which was found below the limit of WHO guideline and acceptable limit of BIS. Na^+ Ca^{2+} and K^+ were ranged from 6 to 37 mg/l, 10.60 to 70.40 mg/l, and 0.30 to 41.60 mg/l respectively in pre-monsoon while they were varied from 8 to 171 mg/l, 34.00 to 63.40 mg/l and 3.0 to 20 mg/l respectively in post-monsoon. Nitrate value was observed 16 to 142.6 mg/l with the mean value of 68.81 mg/l in pre-monsoon and 10 to 171 mg/l with the average value of 52.48 in post-monsoon. It may be due to the domestic sewage, or agriculture runoff near to the sampling location. Fluoride was varied from 0.1 to 1.1 mg/l in pre-monsoon and from 0.1 to 0.7 mg/l in post-monsoon. Low concentration of fluoride indicates controlled the lithogenic impact of fluoride ion in groundwater samples. The COD content were varied

from minimum 21 mg/l to maximum 350 mg/l with the mean value of 96.50 mg/l in pre-monsoon, while minimum 15 mg/l to maximum 275 mg/l with the mean value of 94.5 mg/l in post-monsoon. The observed mean value of iron was found above the acceptable limit (0.3mg/l) of BIS in both pre- (0.93 mg/l) and post-monsoon (0.97 mg/l) of the samples. Higher consumption of these ions containing water may lead to a liver disease known as Haemosiderosis[20]. Arsenic was not detected in any water sample in pre- and post-monsoon. TDS, hardness and nitrate concentration were found much higher than the WHO guideline and Indian acceptable limit of groundwater quality for drinking purpose. Anthropogenic activities like the direct discharge of domestic effluent, agricultural impact, landfill leaching are a major cause of such type of seasonal variation in groundwater quality in the studied area.

5.9.3 Assessment of groundwater quality around the Ramna MSW dumping site by using WQI

The results of all 16 groundwater samples were used for WQI evaluation. Further, the World Health standards (WHO, 2008) and Bureau of Indian standards (2012) were utilized for WQI calculations as shown in table 5.13. WQI of groundwater was calculated for all the samples in both pre- and post-monsoon and given in table 5.14. The calculated WQI values range from 89.42 to 99.37 in the pre-monsoon and between 88.25 to 99.62 in the post-monsoon. During pre-monsoon eight water samples (W₁, W₃, W₄, W₆, H₁, H₇, H₈ and H₉) are classified as excellent water and seven samples (W₅, W₇, H₂, H₃, H₄, H₅ and H₆) are classified as good water while only one sample (W₂) comes under fair water quality.

Table 5.12 Descriptivestatistics of physico-chemical analysis of groundwater samples (16) in pre- and post-monsoon period, 2016.

Parameters	Pre-monsoon (2016)			Post-monsoon (2016)				Drinking water guideline WHO, 2011	Drinking water acceptable limit (BIS-2012)
	Min.	Max.	Mean	Min.	Max.	Mean	Undesirable effect		
Temp	30.1	32.5	31.5	20.4	22.9	21.5		NM	NM
pH	5.6	7.4	6.5	7	7.7	7.3	Taste	6.5-9.2	6.5-8.5
DO	3.5	7.8	6.33	4.3	7.9	6.75		NM	NM
EC	0.56	1.67	0.96	0.54	1.87	0.97		0.3	NM
TDS	331	1140	652	358	1245	651	Gastro intestinal irritation	500	500
Hardness	230	604	381	236	470	353	Scale formation	300	200
Alkalinity	230	630	377	265	410	343		500	200
Chloride	39	205	91.19	35.5	144	79.67	Salty taste	250	250
Na ⁺	6	137	113.56	8	171	171.6	Salinity	200	NM
Ca ²⁺	10.6	77.4	30.55	34	63.4	50.16	Scale formation	150	75
K ⁺	0.3	41.6	4.7	3	20	10.3		NM	NM
Nitrate	16	252	67.81	10	171	52.48	Blue baby syndrome	50	45
Fluoride	0.1	1.1	0.51	0.1	0.7	0.24	Fluorosis	1.5	1
Fe	0.01	3.66	0.93	0.08	2.31	0.97	Bad taste	0.3	0.3
COD	21	360	96	15	271	94.5		NM	NM
As	ND	ND	ND	ND	ND	ND	Skin lesions, black foot	0.01	0.05
Cr	ND	ND	ND	ND	ND	ND	Carcinogenic, Mutagenic	0.005	0.05
Zn	ND	ND	ND	ND	ND	ND	Astringent taste to water.	NM	5
Cu	ND	ND	ND	ND	ND	ND	Gastrointestinal distress	NM	0.05
Cd	ND	ND	ND	ND	ND	ND	Hepatotoxicity, Kidney damage.	0.003	0.003
Ni	ND	ND	ND	ND	ND	ND	Allergic sensitization, eye and skin irritation	NM	0.02
Pb	ND	ND	ND	ND	ND	ND	Kidney and brain damage	0.001	0.05

All value in mg/l except Temp (°C), EC (mS/cm and pH); ND- Not detectable;

NM- Not Mention, **Three times pre and post monsoon data is summarize in above table.**

Table 5.13 Relative weights of water quality parameters.

Water quality parameters	WHO Standards (20011) (mg/l)	BIS Standards (2012) (mg/l)	Weight (w)	Relative Weight ($W_i = w_i / \sum w_i$)
pH	6.5–8.5	7.5	0.0260	0.040
EC	NM	1.5	0.287	0.040
Total hardness	300	200	0.0260	0.036
Total alkalinity	NM	200	0.0260	0.036
Chloride	250	250	0.0289	0.040
Na ⁺	200	0	0.0289	0.040
Ca ²⁺	300	75	0.0260	0.036
Nitrate	50	45	0.0578	0.080
Fluoride	1.5	1	0.052	0.072
Fe	0.3	0.3	0.347	0.048
Cr	0.05	0.05	0.751	0.104
Zn	3	5	0.052	0.072
Cu	2	0.05	0.052	0.072
Cd	0.003	0.003	0.0751	0.104
Pb	0.01	0.01	0.0751	0.104
Ni	0.02	0.02	0.520	0.072
			$\sum w_i = 0.7192$	$\sum W_i = 1$

All values are in mg/l except pH; *NM- Not Mention

Table 5.14 Types of the water in pre- and post-monsoon in the studied area.

Samples	Pre-monsoon		Post-monsoon	
	WQI = $\sum_{i=1}^n SI_i \times W_i$	Water type	WQI = $\sum_{i=1}^n SI_i \times W_i$	Water type
W ₁	99.37	Excellent	97.79	Excellent
W ₂	89.42	Fair	96.90	Good
W ₃	97.78	Excellent	90.07	Fair
W ₄	97.81	Excellent	93.14	Excellent
W ₅	95.01	Good	97.63	Excellent
W ₆	97.73	Excellent	95.48	Good
W ₇	95.93	Good	99.62	Excellent
H ₁	98.05	Excellent	98.35	Excellent
H ₂	96.77	Good	99.40	Excellent
H ₃	95.96	Good	89.25	Fair
H ₄	96.74	Good	88.96	Fair
H ₅	94.84	Good	96.11	Good
H ₆	97.09	Good	95.52	Good
H ₇	98.44	Excellent	90.55	Fair
H ₈	99.33	Excellent	91.63	Fair
H ₉	97.99	Excellent	90.98	Fair

W-Well, H-Hand pump

In post-monsoon five water samples (W_1, W_4, W_7, H_1, H_2) comes under excellent water quality, four samples (W_2, W_6, H_5 and H_6) are showing good water quality and six samples (W_3, H_3, H_4, H_7, H_8 and H_9) are showing fair water quality. Results of WQI showed that in pre-monsoon 50% of groundwater samples are excellent that encountered desirable level, 43.75% are good and 6.25 % are fair water quality for drinking purpose. During post monsoon the quality of water is significantly changed that is 37.5 % are excellent, 25% are good and 37.5 % are fair. It may be due to rise in groundwater table during post-monsoon therefore; **water may be contaminated by percolation and surface runoff easily in comparison to the deep groundwater table of pre-monsoon.**

5.9.4 Spatial mapping of WQI by using Arc GIS around Ramna MSW dumping site.

WQI map (Fig 20) delineates two classes of water quality in the pre-monsoon period and three classes in the post-monsoon period of the year 2016.

The WQI map shows that most of the studied area around the dumping site comes under the good water quality in pre-monsoon and it changes in fair water quality in the post-monsoon period which is very close to the dumping site. The significant change in water quality around the dumping site in post-monsoon may be due to increase in water level of wells that easily fascinate the leachate pollutants to contaminate the groundwater. In the map a significant change from good to fair water quality is observed near to the dumping site. Isolated patches of excellent water quality in the map are observed around the dumping site in pre-monsoon but in post monsoon, it was observed in the north-west of the study area and east region of the study area. WQI Map clearly shows that as the depth and distance of the wells increases from the dumping site simultaneously groundwater quality also improves [153].

The wells and hand pumps sample which are very close to dumping site showing highest concentration of TDS, hardness, alkalinity, nitrate, COD, iron and chromium in post monsoon. These parameter also observed with high value in MSW leachate samples. It may be possibilities that MSW leachate percolate during monsoon periods and contaminates the nearest observation wells. In the table 5.15 as the distance from the dumping site increases the concentration of some observed parameter likes TDS, hardness, nitrate, alkalinity and COD decreases.

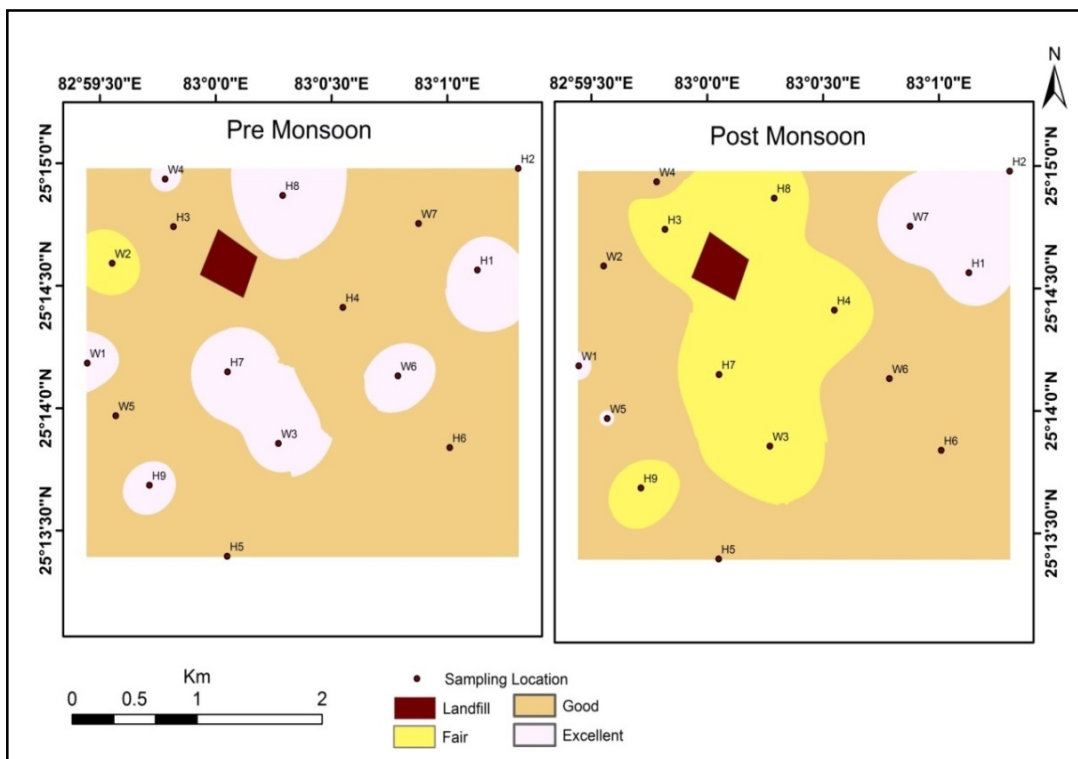


Figure 5.7 Map of WQI showing water quality statuses in Ramna village.

Table 5.15 The concentration of pollutants near the dumping site in groundwater

Sample	Distance from dumping sites (m)	TDS (mg/l)	Hardness mg/l	Nitrate (mg/l)	Alkalinity (mg/l)	COD (mg/l)
H1	512	371	260	25.5	230	178
H2	415	575	300	33.3	268	32
H3	367	503	252	49.7	284	62
H4	470	505	360	23.3	308	95
H5	773	390	240	17.9	314	37
H6	724	465	270	16.5	300	26
H7	253	1112	230	52.3	436	78
H8	350	770	260	42.3	298	59
W1	536	596	364	78.9	260	68
W2	321	857	564	142	390	21
W3	380	590	604	47.7	466	77
W4	567	532	422	74.4	402	64
W5	260	925	582	60.4	590	123
W6	509	517	560	33.6	484	180
W7	284	1140	567	64.5	380	84

5.10 Analysis of groundwater quality using WQI and GIS near the Karsara MSW dumping site, 2016.

Statistical measures of physical and chemical parameters including minimum concentration, maximum concentration, and mean concentration of pre- and post-monsoon data are given in table 5.16. Statistical measures of physical and chemical parameters including minimum concentration, maximum concentration, mean concentration and standard deviation of pre and post-monsoon data are given in Table 23. The pH of the groundwater samples in the study area was fluctuated from 6.5 to 7.8 with an average value of 7.0 in pre-monsoon, from 6.8 to 7.7 with an average reading of 7.2 in post monsoon, which may be due to the dissolved carbonates are mainly in the HCO_3^- form[152]. DO was varied from 5.1 to 9.7 in pre-monsoon and from 5.7 to 9.1 in post monsoon. The total dissolved solids (TDS) were ranged from 372 to 1321 (mg/l)

with a mean value of 872.6 mg/l in pre-monsoon, from 372 to 1321 (mg/l) with a mean value of 881 in post monsoon.

Mean value of TDS was found higher than WHO [154] and BIS standard of water quality (500 mg/l) in both pre and post monsoon.

Table 5.16 Descriptive statistics of physico-chemical analysis of groundwater samples in the pre- and post-monsoon period, 2016.

Parameters	Pre-monsoon (2016)			Post-monsoon (2016)				
	Min.	Max.	Mean	Min.	Max.	Mean	Drinking water guideline WHO, 2011	Drinking water acceptable limit (BIS-10500:2012)
pH	6.5	7.8	7	6.8	7.7	7.2	6.5-9.2	6.5-8.5
DO	5.1	9.7	7.5	5.7	9.1	7.1	NM	NM
TDS	372	1321	872	372	1320	882	500	500
EC	0.56	2.01	1.21	0.56	1.98	1.08	0.3	NM
Hardness	104	432	221	102	562	231	300	200
Total alkalinity	300	690	464	255	676	469	500	200
Chloride	23.64	204.1	114	24.85	193.5	119	250	250
COD	11	167	86.1	187	271	89.5	NM	NM
Na	36	356	153	56	231	143	200	NM
Ca	10.6	110	40.74	2	28	8.85	150	75
K	0.4	3	1.63	3	40	9.3	NM	NM
Nitrate	18	135	45.61	10	110	60.45	50	45
Fluoride	0.01	0.7	0.2	0	0.1	0.042	1.5	1
Fe	0.13	0.89	0.35	0.03	0.82	0.4	0.3	0.3
Cr	ND	ND	ND	ND	ND	ND	0.05	0.05

All value in mg/l except Temp (°C), EC (mS/cm) and pH, *NM- Not Mention

EC was fluctuated between 0.56 to 2.01mS/cm with mean value 1.21 mS/cm in pre-monsoon and between 0.56 to 1.98 mS/cm with 1.08 1.21 mS/cm in post monsoon.

High EC and TDS may be due leaching of ions into the groundwater released from MSW near to the sampling sites. Hardness was varied from 104 to 432 (mg/l) in pre-monsoon and from 102 to 562 (mg/l) in post-monsoon, the mean value of hardness was

found above the drinking water standard limit (300 mg/l). The maximum concentration of hardness may be due to carbonate weathering in the study area [155]. Alkalinity was ranged from 300 to 690 (mg/l) in pre-monsoon and 255 to 676 (mg/l) in post monsoon.

While mean value was observed below the WHO guideline and above the Indian acceptable limit in both pre and post monsoon as shown in the table 5.16.

Chloride was ranged from minimum 23.64 to 204.10 (mg/l) in pre-monsoon and from minimum 24.85 mg/l to maximum 193.50 mg/l in post monsoon. Chloride content was found below the limit of WHO guideline and acceptable limit of BIS. The COD level in the sixteen groundwater samples varied from minimum 11 mg/l to maximum 167 mg/l with the mean value of 86.10 mg/l in pre-monsoon, while minimum 187 mg/l to maximum 271 mg/l with the mean value of 89.50 mg/l in post-monsoon. Na, Ca and K were varied from 36 to 356 (mg/l), 10.60 to 110.00(mg/l), and 0.40 to 3.00 respectively in pre-monsoon while they were varied from 56 to 231 (mg/l), 2 to 28 (mg/l) and 3 to 40 mg/l respectively in post monsoon. Nitrate value was observed 18 to 135 (mg/l) with the mean value of 45.61 mg/l in pre-monsoon and 10 to 110 mg/l with the average value of 60.45 in post-monsoon. It may be due to due to the domestic sewage, or lack of proper management of dumping sits near to the sampling location. Methamoglobinemia (blue baby syndrome) is a disease caused by the potential toxic effects of nitrate on young infants. Fluoride was varied from 0.1 to 0.70 (mg/l) in pre-monsoon and from 0.0 to 0.1 (mg/l) in post monsoon. Low concentration of fluoride indicates controlled the lithogenic impact of fluoride ion in groundwater samples. The observed mean value of iron was found above the acceptable limit (0.3mg/l) in both pre (0.35 mg/l) and post (0.40 mg/l) monsoon of the samples. Higher consumption of these iron containing water may lead to a liver disease known as Haemosiderosis[20]. Cr was not detected in any water sample in pre while in post monsoon only it ranged from 0.0 to 0.13 mg/l with

mean value 0.01 mg/l. TDS, hardness and nitrate concentration were found much higher than the WHO guideline and Indian acceptable limit of groundwater quality for drinking purpose. Anthropogenic activities like the direct discharge of domestic effluent, agricultural impact, landfill leaching are a major cause of such type of seasonal variation in groundwater quality in the study area.

5.10.1 Spatial distribution of observed contaminants in groundwater around the Karsara dumping site

Some parameters like EC, TDS, alkalinity, nitrate and iron were observed much more than their acceptable limit in groundwater samples around Karsara dumping site. Zonation map of these pollutants was made in GIS environment using Inverse Distance Weighted (IDW) technique. Maps revealed that higher value was observed in those water samples which are very close to the dumping site.

EC zonation map (figure 5.8) shows that most of the area the value of EC is low in pre-monsoon but in post-monsoon its value is high around the dumping site. TDS zonation map (figure 5.9) shows that study area is severely contaminated by TDS during post-monsoon period. Most of the area covers by above the acceptable limit of drinking water quality in both pre- and post-monsoon period. Study area also demarcated with higher value of alkalinity very close to dumping site. Alkalinity zonation map (figure 5.10) shows the area for from the dumping site having value below the acceptable limit. Spatial map of Nitrate (figure 5.11) and iron (figure 5.12) clearly shows that nitrate and iron concentration very closed to the dumping site in both pre and post monsoon period. These all pollutants also observed in leachate sample in significant amount that may be leach out during post monsoon contaminants the nearest wells in the study area. Some property like toxicity, mobility and capability to travel over large distances, need continuous monitoring of the concentration of these pollutants around the dumping site.

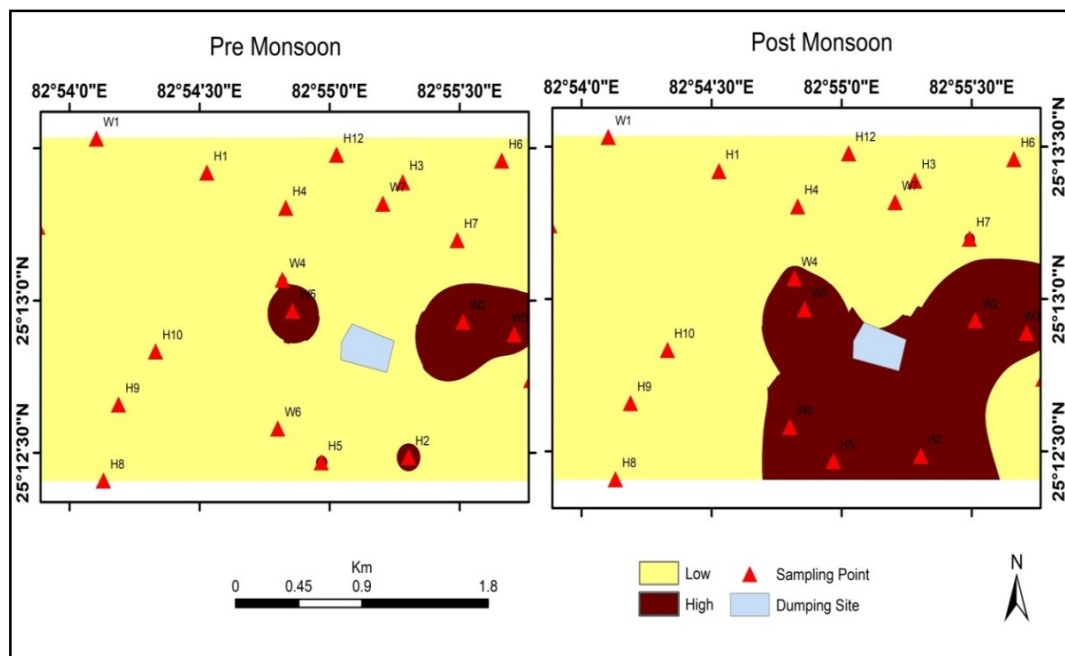


Figure 5.8 EC zonation map showing groundwater pollution around Karsara dumping site.

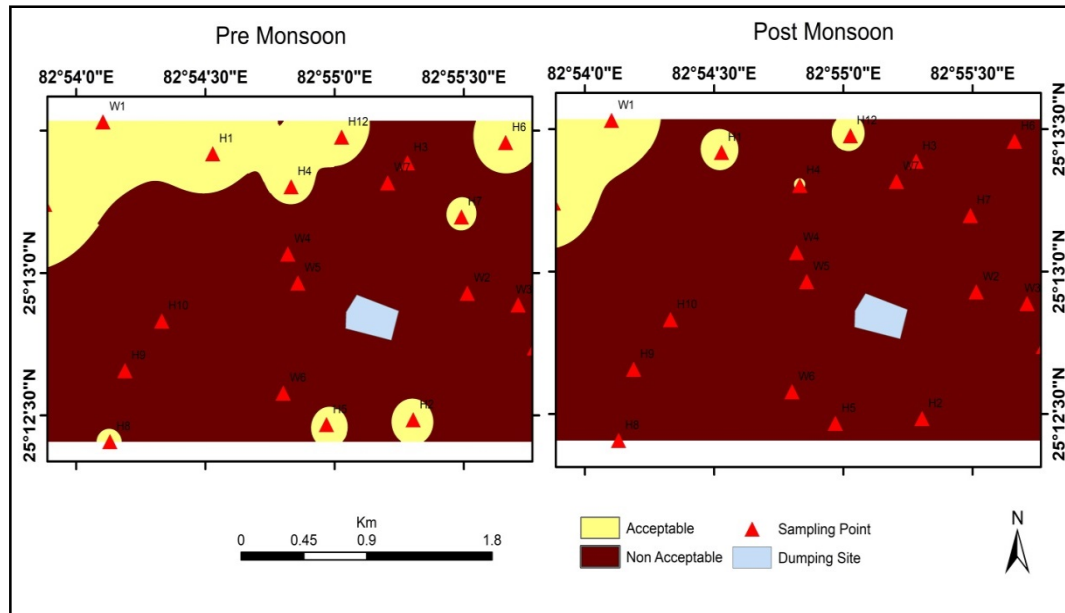


Figure 5.9 TDS zonation map showing groundwater pollution around Karsara dumping site

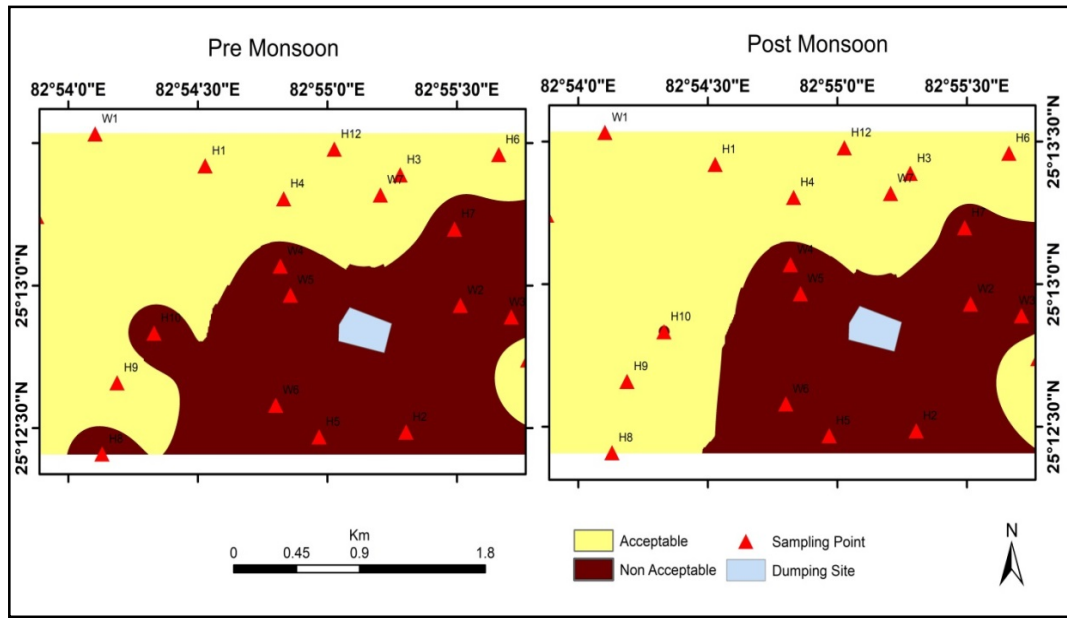


Figure 5.10 Alkalinity zonation map showing groundwater pollution around Karsara dumping site.

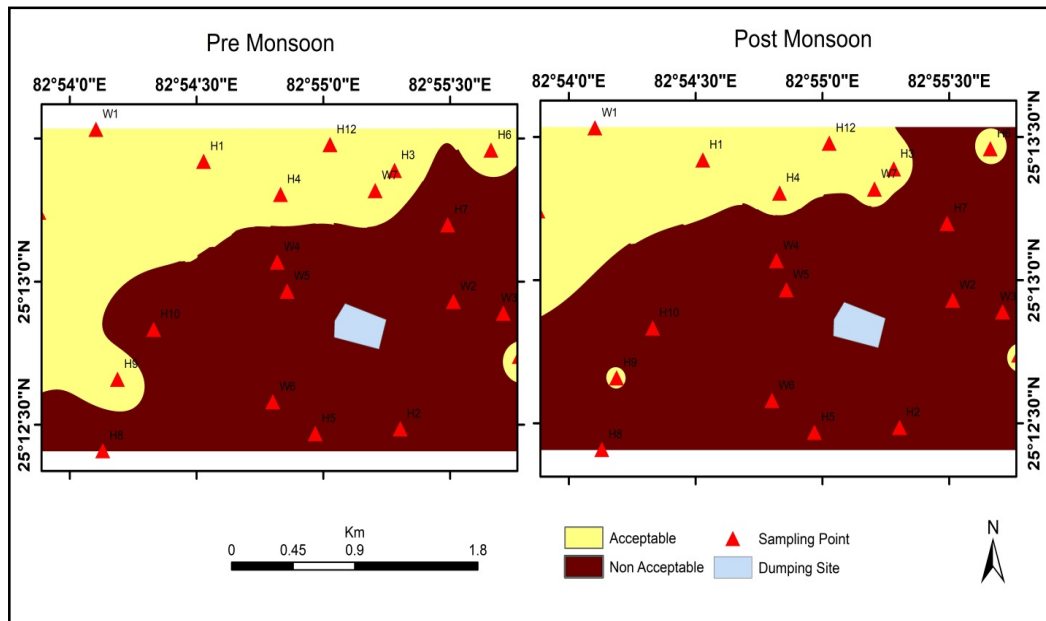


Figure 5.11 Nitrate zonation map showing groundwater pollution around Karsara dumping site.

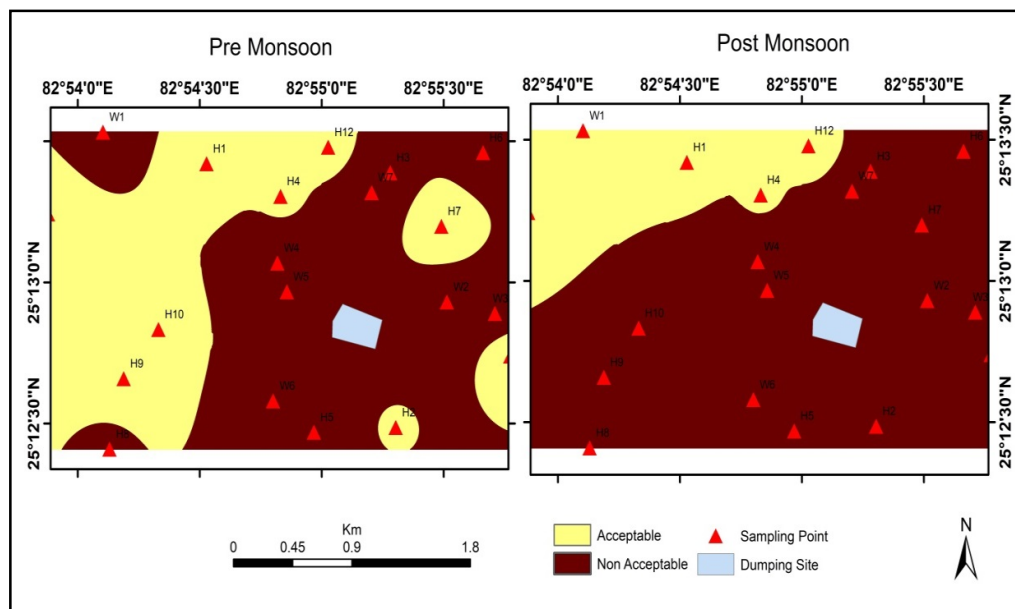


Figure 5.12 Fe zonation map showing groundwater pollution around Karsara dumping site.

Table 5.17 shows that the concentrations of some pollutants like TDS and Alkalinity are mostly decreases as the distance between sampling points and dumping site increases, but this relationship not too strong in nitrate and Fe contaminants, it may be due to other confined anthropogenic sources i.e. application of fertilizers and pesticides in nearby agriculture field, domestic sewage etc[10]. The oxide and sulfide iron species are usually the major sources of iron in the groundwater [100]. A concentration of iron above the certain limit (0.3 mg/l) in groundwater is dangerous for health. Oxide and sulfide iron compound main source of groundwater contamination [100]. Usually, heavy metal concentrations in wells decrease with distance but after one year the concentration of the contamination increases close to dumping site [39].

Table 5.17 The pollutants showing maximum concentration in groundwater near the Karsara dumping site during post monsoon

Water Sample	Distance from dumping sites (m)	TDS (mg/l)	Nitrate (mg/l)	Alkalinity (mg/l)	Fe (mg/l)
W2	468	386	10	255	0.034
W6	565	1340	110	690	0.821
H5	567	1320	96	625	0.745
W5	618	1043	76	550	0.491
H2	725	1199	87	600	0.691
H7	733	1056	63	528	0.456
W3	776	819	70	439	0.281
W4	835	567	32	331	0.194
H3	869	940	83	570	0.671
W7	890	768	46	408	0.271
H11	902	690	38	341	0.218
H10	927	950	81	561	0.566
H4	972	873	53	471	0.341
H12	1000	733	70	531	0.476
H6	1050	942	52	510	0.417
H9	1080	900	57	481	0.402
H1	1100	987	60	520	0.432
H8	1170	745	45	390	0.243
W1	1500	532	31	300	0.165
H13	1822	400	21	295	0.139

5.10.2 Evaluation of Water Quality Index at Karsara MSW dumping site.

WQI of groundwater around the karsara dumping site was calculated for all the samples (20) in both pre- and post-monsoon and given in table 5.18.

The calculated WQI values are ranges from 80.93 to 99.50 in the pre-monsoon and from 76.33 to 99.91 in the post-monsoon. In pre-monsoon four water samples (W₁ H₇ H₈ and H₁₀) are classified as excellent water quality, Seven water samples (W₂ W₃ W₄ W₆ H₁₂ H₉ and H₁₃) are classified as marginal water quality, Six samples (W₇, H₁, H₂, H₃,

H₄ and H₆) comes under good water quality and only two sample (H₅ and H₁₁) showing fair water quality.

Table 5.18 Relative weight of water quality parameters

Water quality parameters	WHO Standards (2011) (mg/l)	BIS Standard (2012) (mg/l)	Weight (w)	Relative Weight ($W_i = \frac{w_i}{\sum w_i}$)
pH	6.5–8.5	7.5	0.0289	0.069
EC	NM	1.5	0.0287	0.057
Hardness	300	200	0.026	0.063
Total alkalinity	NM	200	0.026	0.063
Chloride	250	250	0.0289	0.07
Na	200	200	0.0289	0.07
Ca	300	75	0.026	0.063
Nitrate	45	45	0.0578	0.07
Fluoride	1.3	1	0.052	0.126
Fe	0.3	0.3	0.0347	0.084
Cr	0.05	0.05	0.0751	0.182

All values are in mg/l except pH, *NM- Not Mention

While in post-monsoon fourteen water samples (W₁, W₂, W₃, W₄, W₅, W₆, H₃, H₄, H₅, H₆, H₁₁ and H₁₂) are classified as marginal water quality, Two samples (i.e. W₇ and H₁₀) comes under fair water quality and only one sample (H₂) is observed as fair water quality. Results of WQI revealed that 35% groundwater samples are good, 35% are marginal, 20% is excellent and 10% is fair in pre-monsoon while in post monsoon it showed 70% are marginal, 15% is excellent, 10% is fair and 5% is good

Table 5.19 Types of the water in pre- and post-monsoon in the study area

	Pre-monsoon		Post-monsoon	
Samples	WQI= $\sum_{i=1}^n SI_i \times W_i$	Water type	WQI = $\sum_{i=1}^n SI_i \times W_i$	Water type
W1	99.16	Excellent	83.3	Marginal
W2	82.08	Marginal	80.85	Marginal
W3	83.3	Marginal	83.36	Marginal
W4	80.93	Marginal	83.43	Marginal
W5	92.77	Good	76.33	Marginal
W6	82.46	Marginal	77.01	Marginal
W7	93.95	Good	91.29	Fair
H1	96.08	Good	99.91	Excellent
H2	95.46	Good	94.69	Good
H3	93.4	Good	81.6	Marginal
H4	95.48	Good	80.16	Marginal
H5	92.37	Fair	81.33	Marginal
H6	96.29	Good	84.77	Marginal
H7	97.86	excellent	99.55	Excellent
H8	99.5	excellent	98.94	Excellent
H9	83.74	Marginal	81.47	Marginal
H10	97.9	Excellent	92.32	Fair
H11	88.98	Fair	80.47	Marginal
H12	84.31	Marginal	79.51	Marginal
H13	82.36	Marginal	83.61	Marginal

*W-Well, *H-Hand pump

5.10.3 Spatial mapping of WQI around the Karsara dumping site using Arc GIS,

WQI map of the study area was prepared (Figure 5.13) by Geographic Information System (GIS) using inverse distance weightage (IDW) method to predict the water quality status in the study area. WQI map delineates four classes of water quality i. e. marginal, fair, good and marginal water in the study area during pre and post-monsoon. Map exposes that most of the study area around the dumping site comes under the fair water quality in pre-monsoon while in a post-monsoon period area close i. e. 300m.

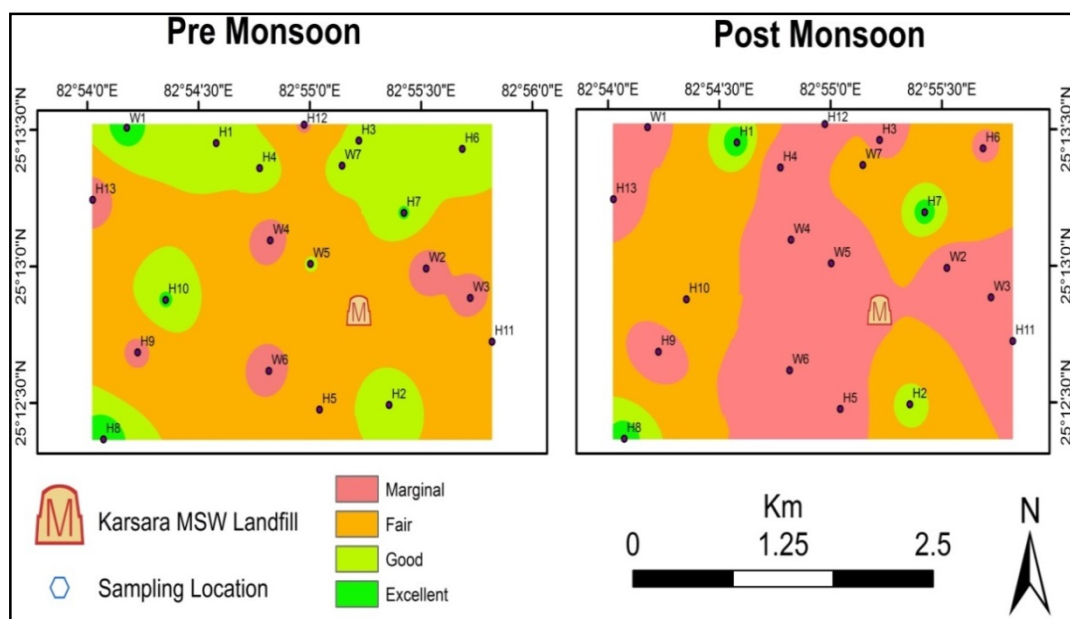


Figure 5.13 Thematic map of WQI, showing water quality status in Karsara study area.

The dumping site exposed as a threatened water quality. It means water quality deteriorates in post-monsoon because of the leaching of a pollutant from the dumping site. Only two sampling location were (W_5 and W_6) showing significant changes of water quality i.e. good to poor water quality near to the dumping site. Generally, groundwater contamination appeared within 1000 m of a landfill site while in most of the severe groundwater contamination occurred within 200 m which very near to landfill site [156].

5.11 Groundwater modelling at Ramna study area

Ramna MSW dumping site was preferred for groundwater flow and contaminants transport modeling as some parameters were observed very high in this leachate sample such as TDS, Chloride, COD, Cr, Cu and Fe. LPI value of leachate also found too much high i. e. 15.62 and 12.40 in the year 2014 and 2016. These parameter also were observed higher than the acceptable limit of drinking water quality. Groundwater quality near the dumping sites was significantly changed from good water quality to fair water quality. Therefore to measure the impact of leachate contaminants

on surrounding groundwater quality, groundwater flow and transport model was performed by visual mudflow software.

5.11.1 Groundwater flow modelling

Groundwater flow modelling is significant for conceptualizing the hydrogeological processes and forecasting the leachate pollutants. To predict the leachate flow and its fate of composition for any landfill site to remains active groundwater modelling is very important. This is also helpful for the leachate treatment or for the discharge of leachate to the surrounding environment [157].

Therefore Simulation of the model is done for one year by giving input value to the flow setting and transport setting database of the software to know the groundwater velocity and flow direction in the study area. To develop model there are several step that explain briefly in the following headings.

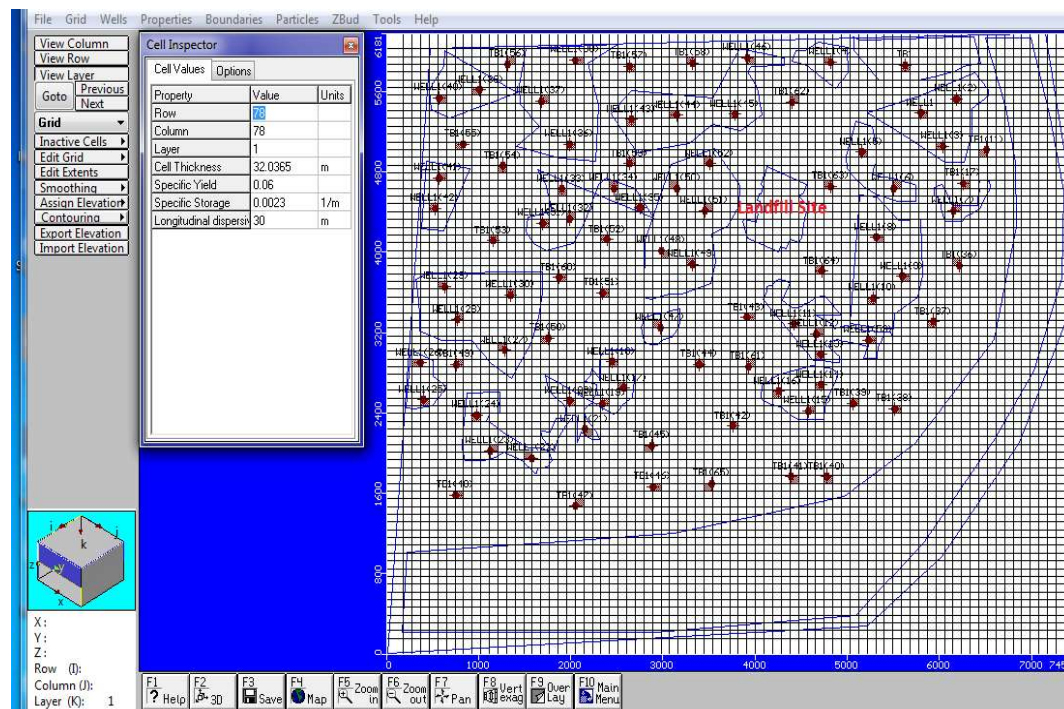


Figure 5.14 Snap shot of Model grid of model showing study area.

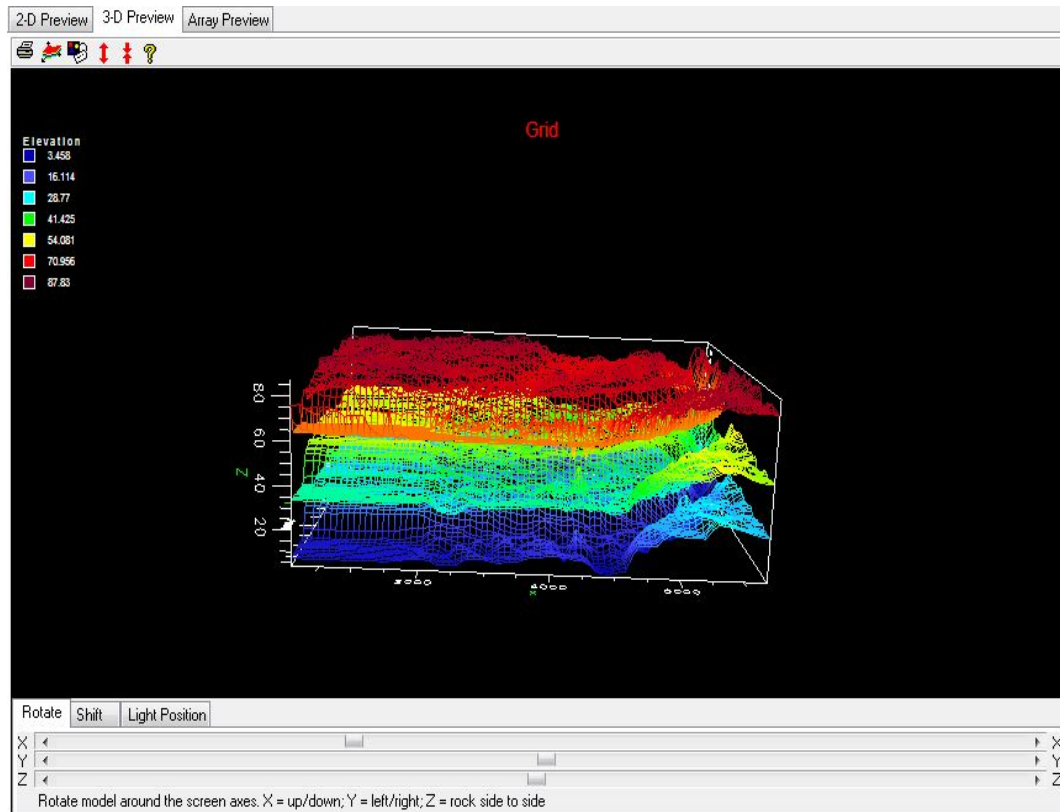


Figure 5.15 Snap shot 3D view of the model grid

5.11.1.1 Grid design of flow model

Grid module helps to explain and discretize the modelling domain. The geographic boundaries of the model grid are covering about 40 km² of the study area. The base map of the model grid was discretized into 78 rows and 78 columns and vertically the grid distinct in two layers of the aquifer system. Each small cell of the grid is equivalent to 8 m² of the study area.

The surface layer is used to make model layer for that the data is being imported. The model layers that is ground surface (top of layer 1), second layers and a third layer made by incorporating .DEM file downloaded from USGS site.

5.11.1.2 Assign of pumping well data

Pumping rates value for specified time periods was assigned for the each tube wells and open wells in pumping schedule database as shown in figure 5.16 and 5.17.

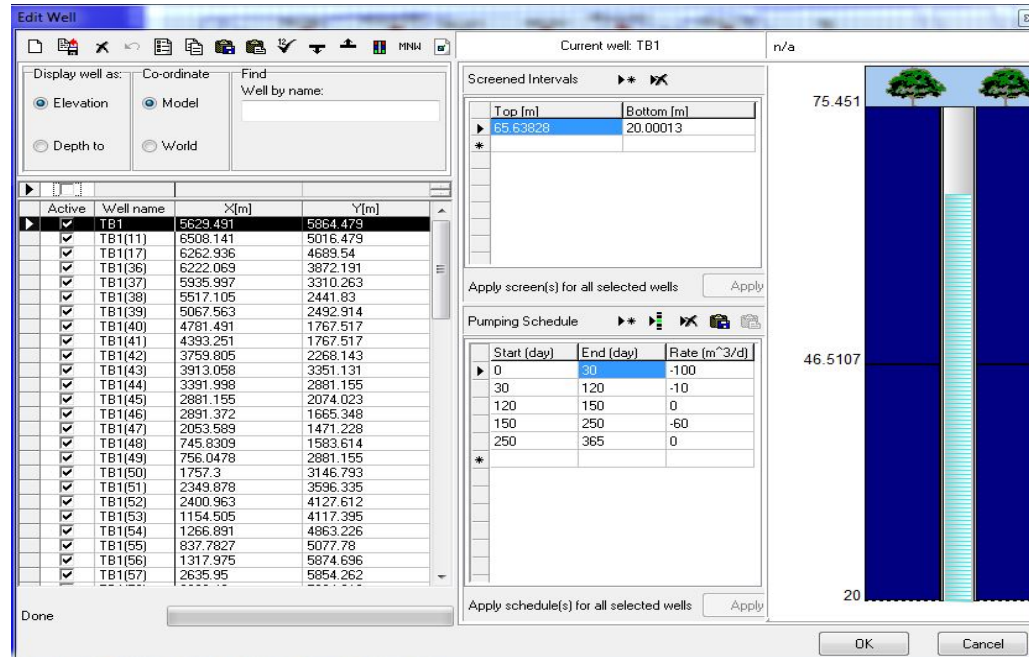


Figure 5.16 Snap shot of Pumping schedule database for rice and wheat crop in Ramna study area

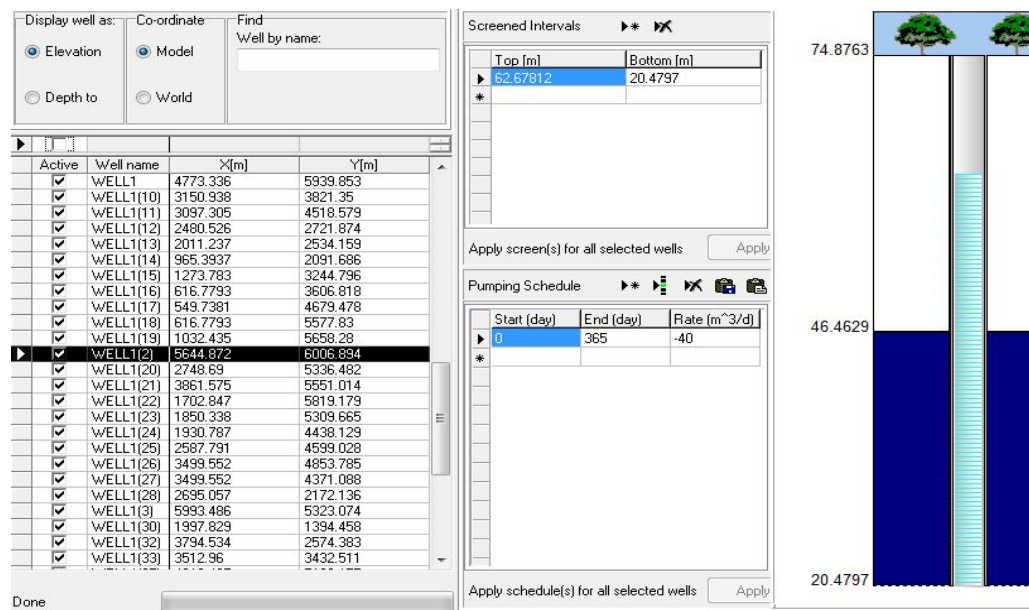


Figure 5.17 Snap shot of Pumping schedule database for open wells in Ramna study area

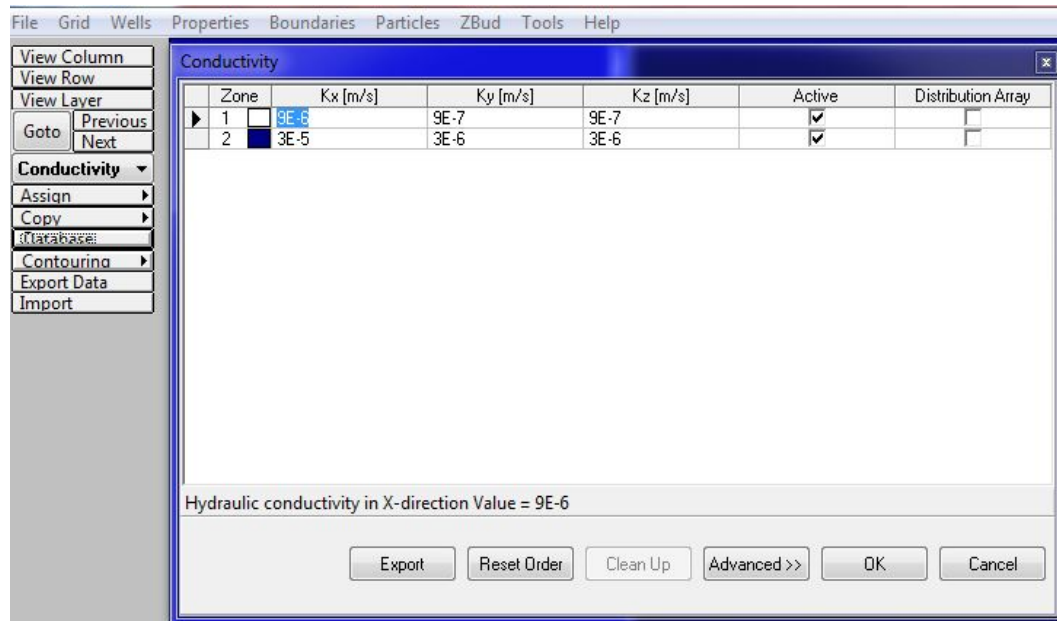


Figure 5.18 Snap shot of Soil Conductivity data assigned to zone 1(layer 1) and zone 2 (layer 2)

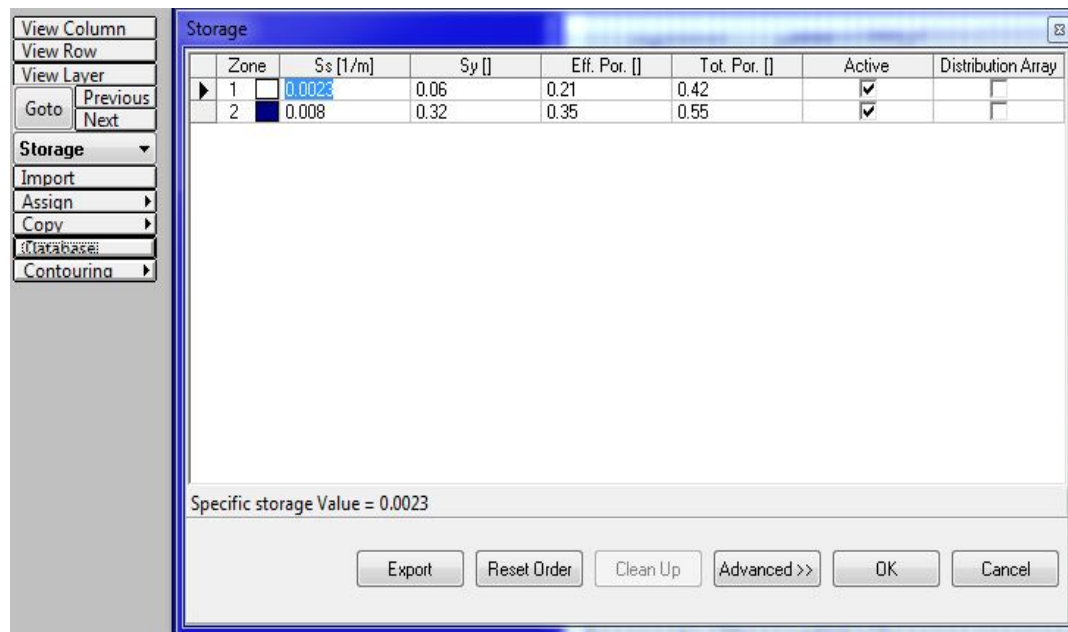


Figure 5.19 Snap shot of storage data assigned for zone 1(layer 1) and zone 2 (layer 2)

5.11.1.3 Assigning of head observation data

56 head observation data of pre- and post-monsoon period were assigned in head observation database of the software for calibration and simulation. Wells location and their head value incorporated through xls file. To simulate the hydrogeological and hydrogeochemical process flow properties such as conductivity (K_x , K_y , K_z), storage (S_s , S_y , P_{eff} , P_{tot}) and initial head were assigned with their respective value for layer one and layer two. These soil properties and their related parameters are assigned in the input screen of the each parameter.

5.11.1.4 Assigning Boundary Conditions

The relationship between the system and the surrounding environment is signifying by boundary conditions. It defines the exchange of flow between the model and the external system the boundary condition assigned in the boundaries database of the input section of the software. Eastern and southern parts of the study area have the river so it was considered as hydrological flow boundary for the model. This River boundary simulated the influence of the Ganga river on the groundwater flow.

River Stage (river surface elevation) Riverbed Bottom (river seepage layer elevation) River Conductance (the resistance to cause by riverbed) was assigned as shown in figure 5.21. Western and northern boundaries have been modeled as a constant head boundary as shown in the figure 5.20. The constant head was assigned as no flow boundary for groundwater flow modeling. The constant head boundary condition fixed the observed head value in designated grid cells as a ceaseless source of water entering the system. Therefore, constant head boundary conditions have a significant impact on the output result of the simulation.

Start time head and stop time head value assigned from pre-monsoon, monsoon and post-monsoon observation data of the year.

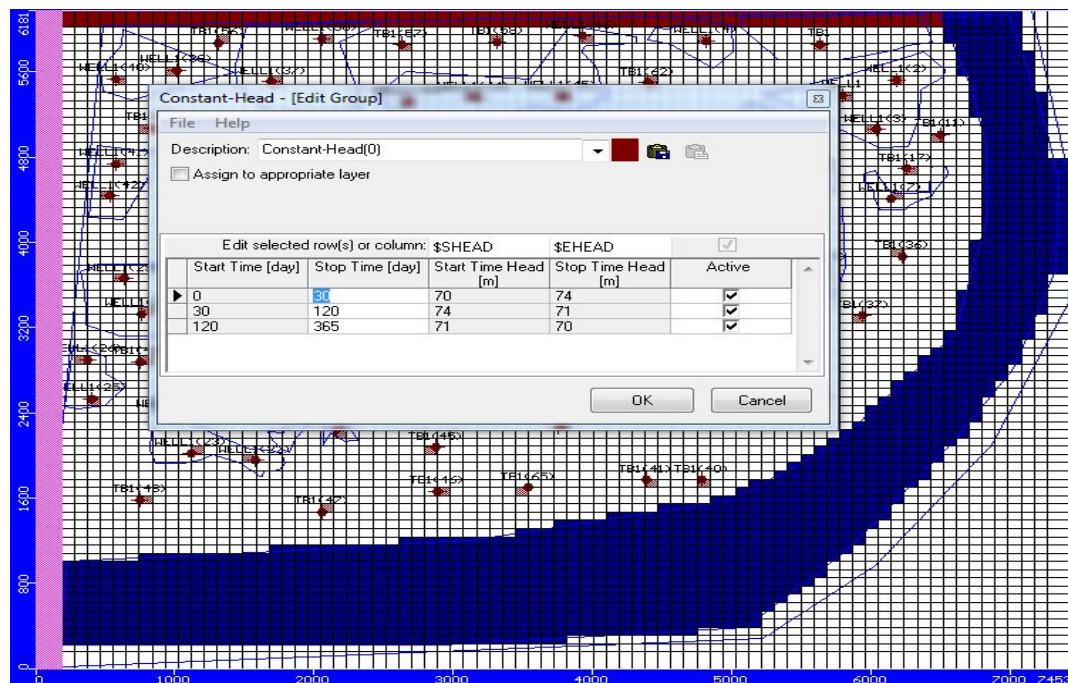


Figure 5.20 Snap shot of Constant head assigned as a boundary condition

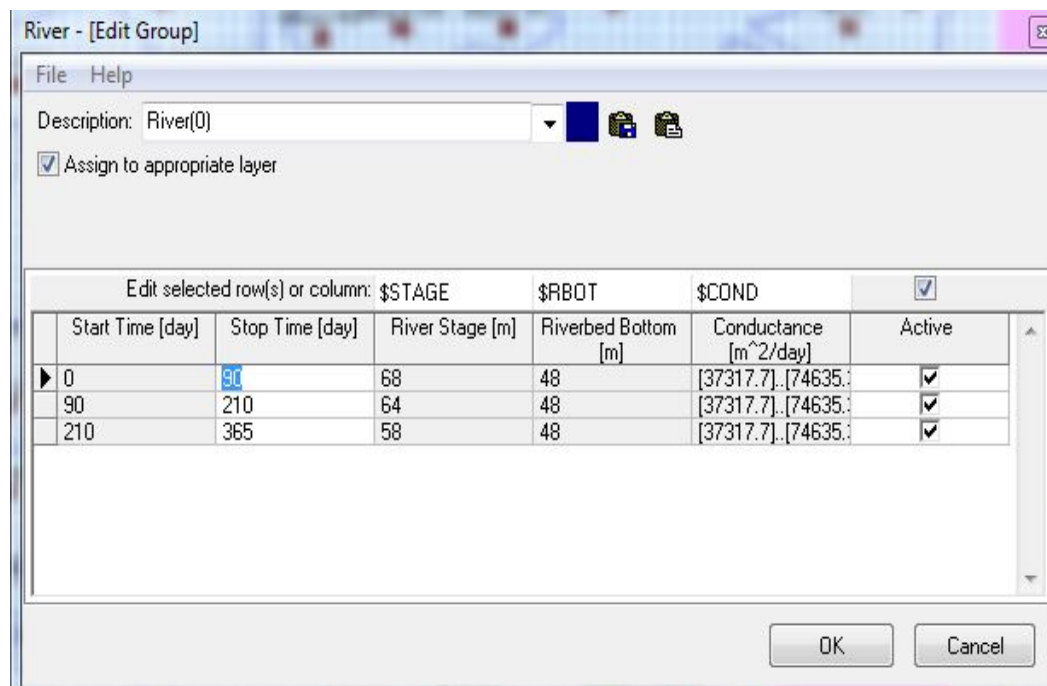


Figure 5.21 Snap shot of River assigned as a boundary condition

5.11.1.5 Assigning Recharge data

Recharge data used to simulate the recharging through the ground surface to the groundwater system in the study area. Mostly recharge occurs due to precipitation percolating into the groundwater. Precipitation occurs in the rainy season so for this period the recharge rate value is assigned as shown in figure 5.22 and rest of the period assigned with no recharge value.

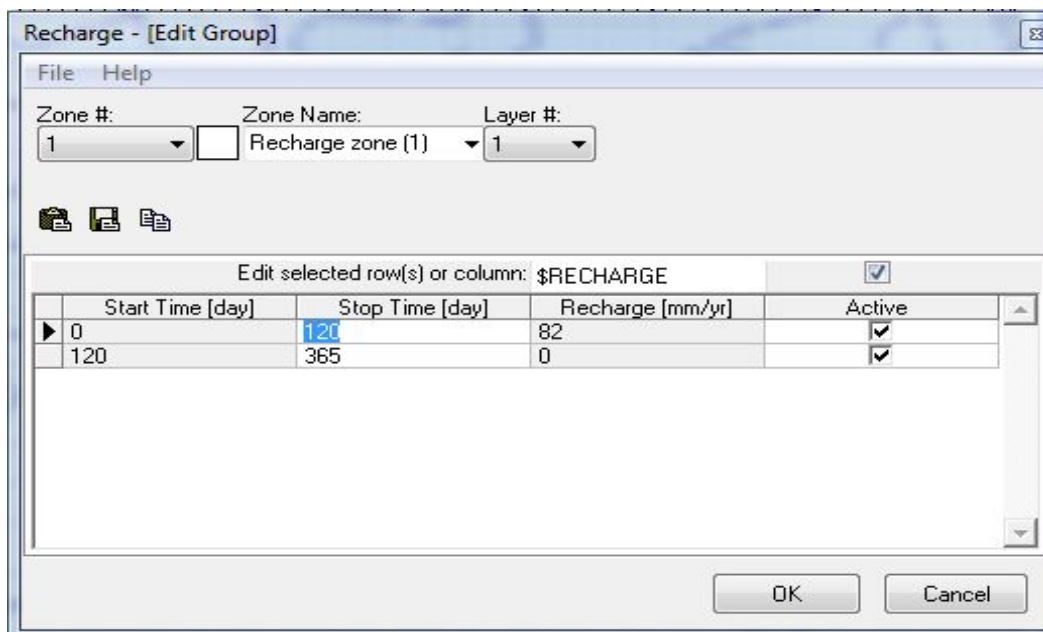


Figure 5.22 Snapshot of Recharge data assigned in the input database

5.11.1.2 Run model

To run the flow model transient flow option is selected in run type and USGS MODFLOW 2005 in engine type. The model was run with different inputs for one year. During model running process MODFLOW automatically combined all of the various time period data assigned for each pumping well and boundary condition into the stress period setup. The output result gives a time-dependent groundwater flow simulation.

5.11.1.3 Output of the run model

The outputs from the model simulation are the hydraulic heads and groundwater flow heads, which are in equilibrium with the hydro-geologic condition like topographical characteristic, hydrologic boundaries, initial and transient conditions. Generally pumping the water from the wells creates influences in the water table and changes the groundwater flow direction.

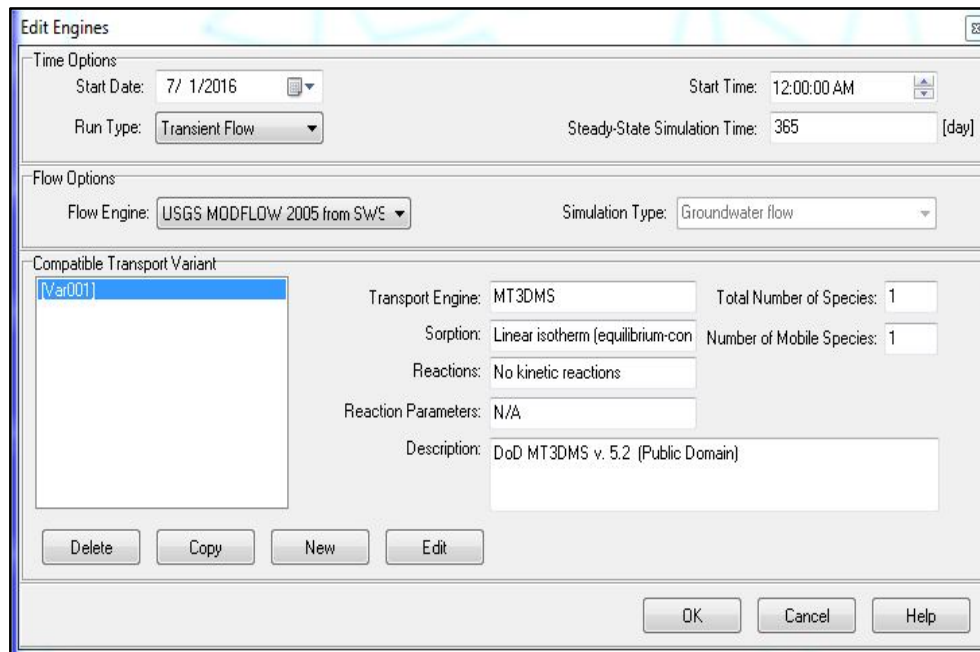


Figure 5.23 Snapshot of Run engine database

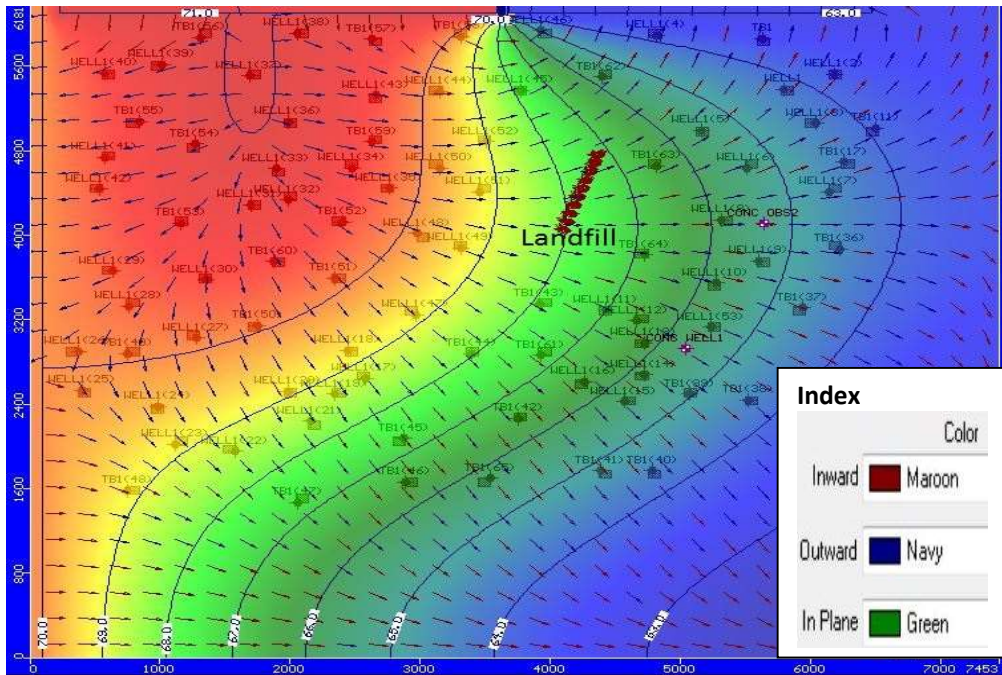


Figure 5.24 Snapshot of model showing groundwater flow direction in the study area.

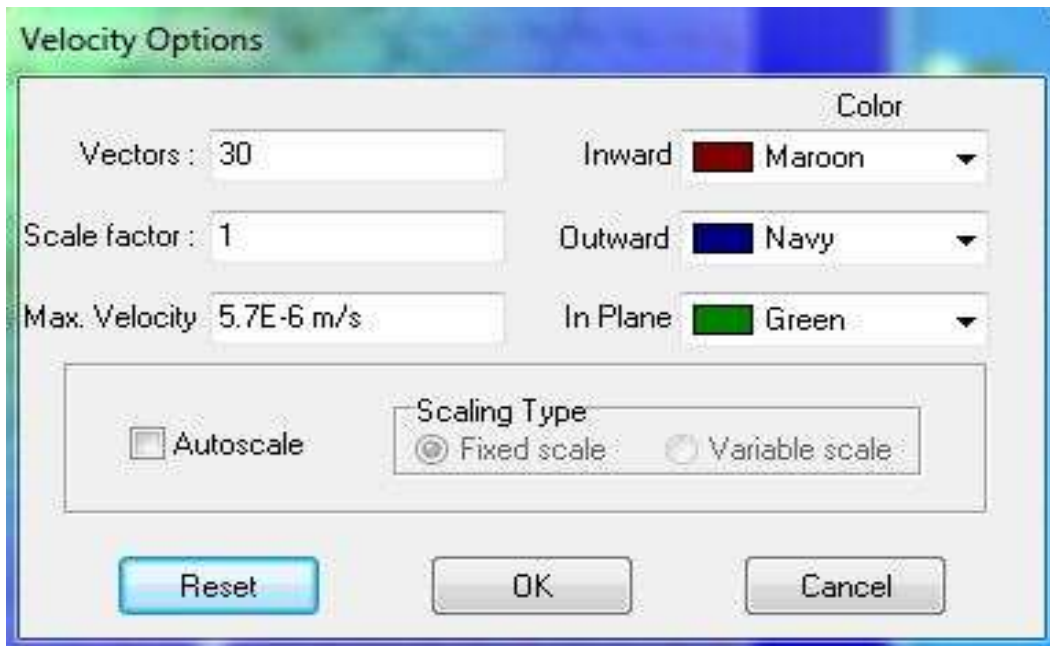


Figure 5.25 Snap shot of pore water velocity

The direction of the groundwater flow of the simulated model shown in figure 5.24, which indicates that the groundwater is flowing from higher heads (water table) to lower heads (towards Ganga river) in the study area.

The maximum velocity of groundwater flow is calculated to be $5.7\text{E-}06$ m/s (5.7×10^{-7} m/s). The studied area having distinct flow patterns, from west plain to east riverside following the topographical elevation mainly changes in hydraulic gradient responsible for such flow pattern. Therefore, increase in the hydraulic head during the monsoon period may be responsible for the downward and outward flow of groundwater. It may be the cause of groundwater contamination towards riverside. The result of the spatial mapping of WQI reveals that most of the study area is fair in post-monsoon and groundwater flow modeling of the study also shows the direction of groundwater flow towards the fair water quality. Therefore, this finding may play an important role in protecting the fair water quality to become threatened water.

Simulated groundwater table was shown in the figure 5.26, which was ranged from minimum 58 meters to maximum 74.93 meters. This result validated with the field monitoring data of water table which was also observed between 61.96 m to 78.85 m. The hydraulic heads value changes with pre- and post-monsoon period as change in recharge and precipitation value during these period [158].

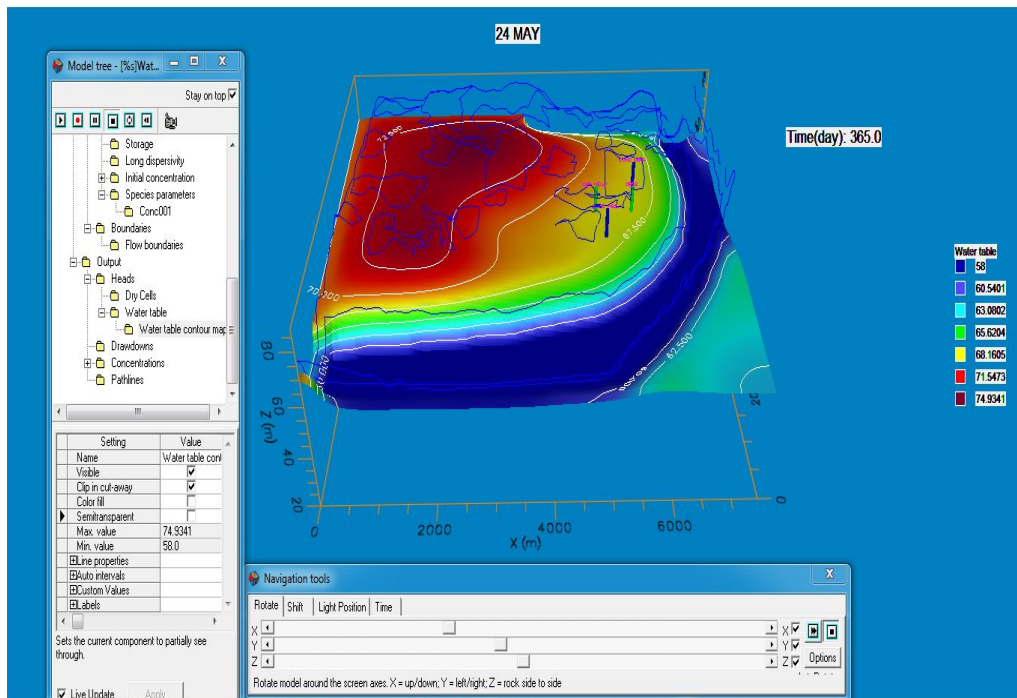


Figure 5.26 Snap shot of 3D view of the simulated groundwater table

5.11.1.4 Calibration graph

Model calibration is the very important process in preparing the groundwater flow model because the excellence of the calibration certainly determines the reliability of any decisions made by the simulation results. Most of the observed point comes under 95% interval. The 95% interval is the interval where 95% of the total numbers of data points are estimated to occur. A 95% confidence interval allows the user to visualize a range of calculated values for each observed value with 95% confidence [159]. It means the simulated result will be acceptable for this observed value. Groundwater head varied with the changes in aquifer water levels. According to sensitivity analysis, it was observed that model results were influenced by hydraulic conductivity, specific storage, and specific yield of layers. Correlation coefficient (r^2) was equal to 0.714 for the

calculated and observed head. This represented a good agreement between measured and simulated values.

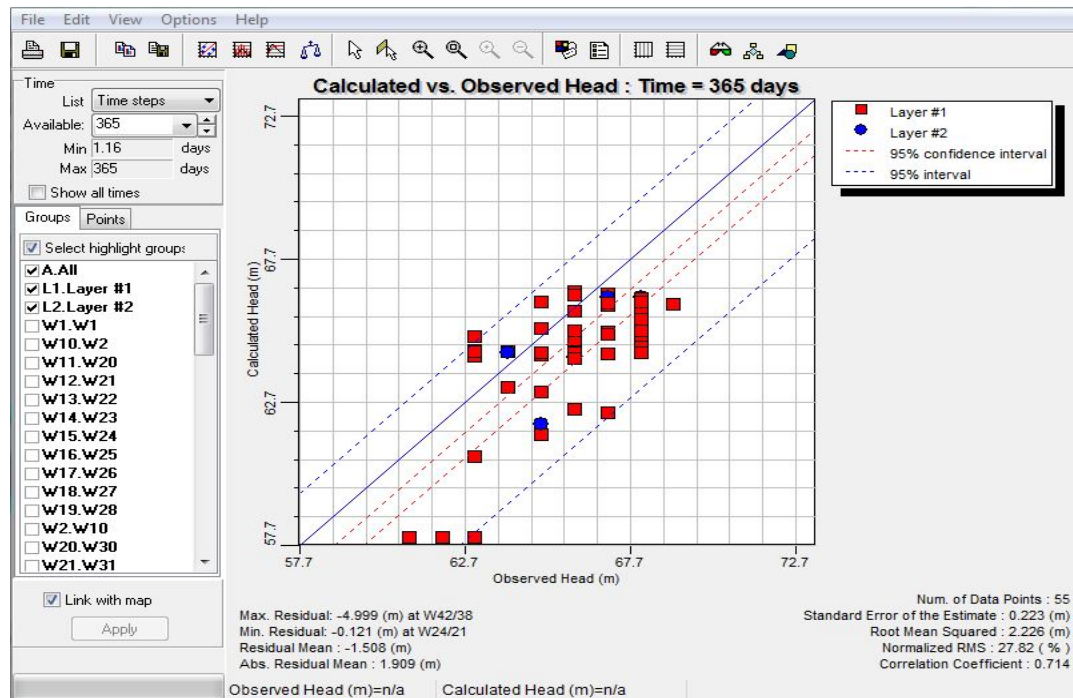


Figure 5.27 Snap shot of calibration graph between observation well and the calculated value

5.11.2 Pollutant transport modelling

By the analysis of the leachate sample and groundwater sample, it was observed that TDS and Nitrate are high in concentration in both the sample at Ramna and Karsara MSW study area. Therefore, these pollutants are selected for the transport modeling analysis for Ramna study area.

5.11.2.1 TDS transport modelling

The transport engine for the running model is MODPATH and MT3DMS. Linear isotherm (equilibrium controlled) with no kinetic reactions are assumed for contaminants transport modeling. The dispersion coefficient 10.15×10^{10} m²/sec is assumed and dispersivity data is taken from USGS site as 0.00033m for TDS

transport modelling. TDS concentrations, model boundary, particles tracking algorithm and advection parameters were adjusted to run the model for one 5 year started from 1st July 2016 by using methods of transport modelling.

Simulation results of TDS transport model indicate the movement of TDS pollutant toward the groundwater flow direction. TDS Path lines in figure 5.29 showing that where the groundwater is flowing, and how much distant it would take to reach nearest observation wells. This model was run for one year so that contaminants pathline may cover less distance , within this time period but in future there will be chance to cover more distance and contamiante more open wells nearby the MSW dumping site. Hydraulic gradient inferring the advection process that is one of the main factors that spreading of TDS pollutants. Generally, TDS are measured as a secondary water pollutant [160] and it have been related to poor health conditions and no current data on health effects linked with the assimilation of TDS in drinking-water however early studies inverse relationships were reported between TDS concentrations in drinking water with cancer and heart disease[161].

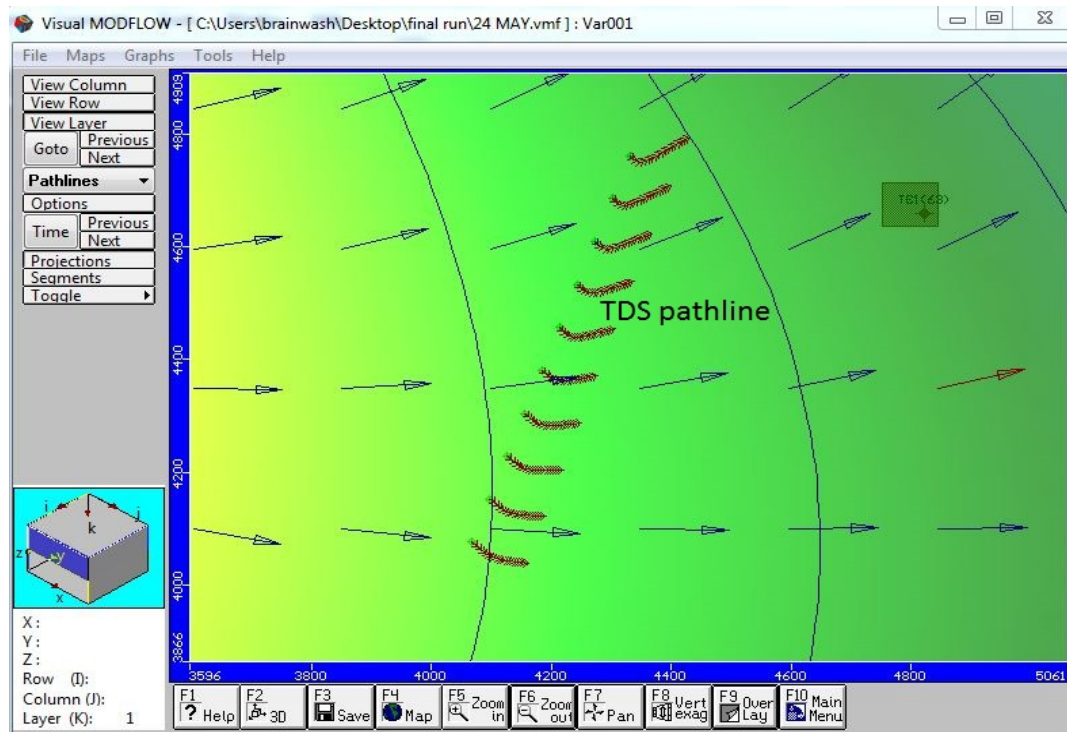


Figure 5.28 Snap shot of TDS path line showing contamination towards groundwater flow direction

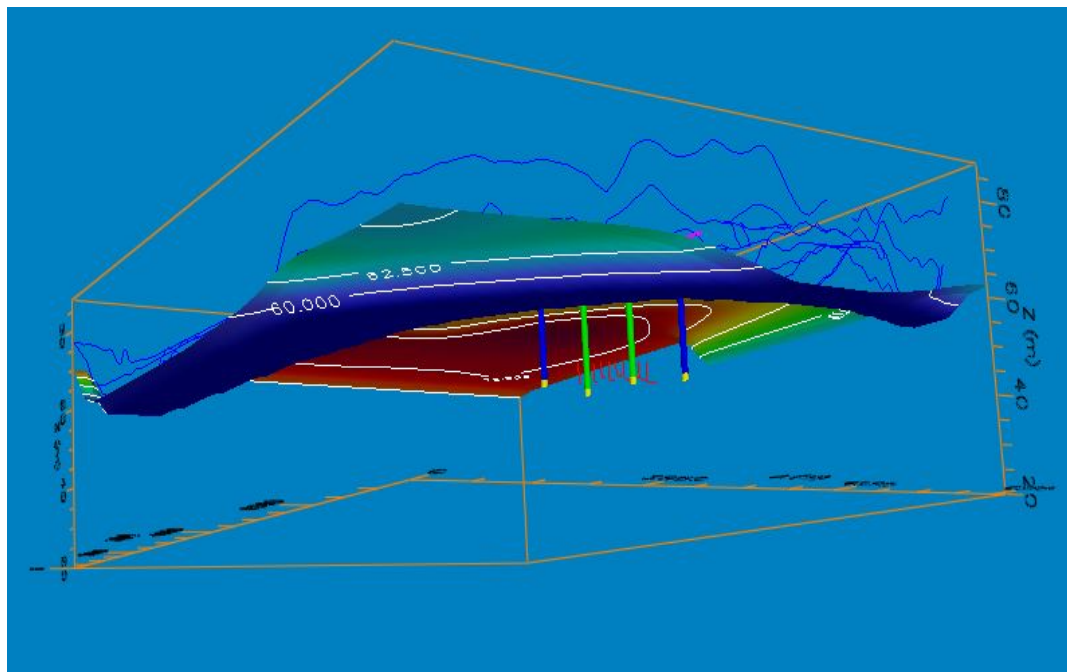


Figure 5.29 Snap shot of 3D View of TDS path line

5.11.2.2 Nitrate transport modelling

Data for Nitrate modeling

- Molecular diffusion coefficient = $0.00005 \text{ m}^2/\text{day}$
- longitudinal dispersivity = 18.288 m
- The ratio of horizontal and longitudinal dispersivity = 0.1
- The ratio of vertical and longitudinal dispersivity = 9.95188×10^{-4}
- The model is run for 5 years started from 1 July 2016

The output result was showing the path line of nitrate contamination started from the dumping site to nearest open wells as shown in figure 5.31. Groundwater table in study area fluctuated from lowest 61 m to highest 78 m in study area. This output result validated with the field monitoring data of water table which was also observed between 61.96 m to 78.85 m. Sandy soil of the study area can facilitate the nitrogen transport; therefore low concentration of the nitrate may reach the deep water table of the aquifers. However mechanism of NO_3 percolation in aquifers is very complex. Depth sampling, hydrogeological condition, isotopic tracers, and microbiological activity are the factors that affect the nitrate transportation [162].

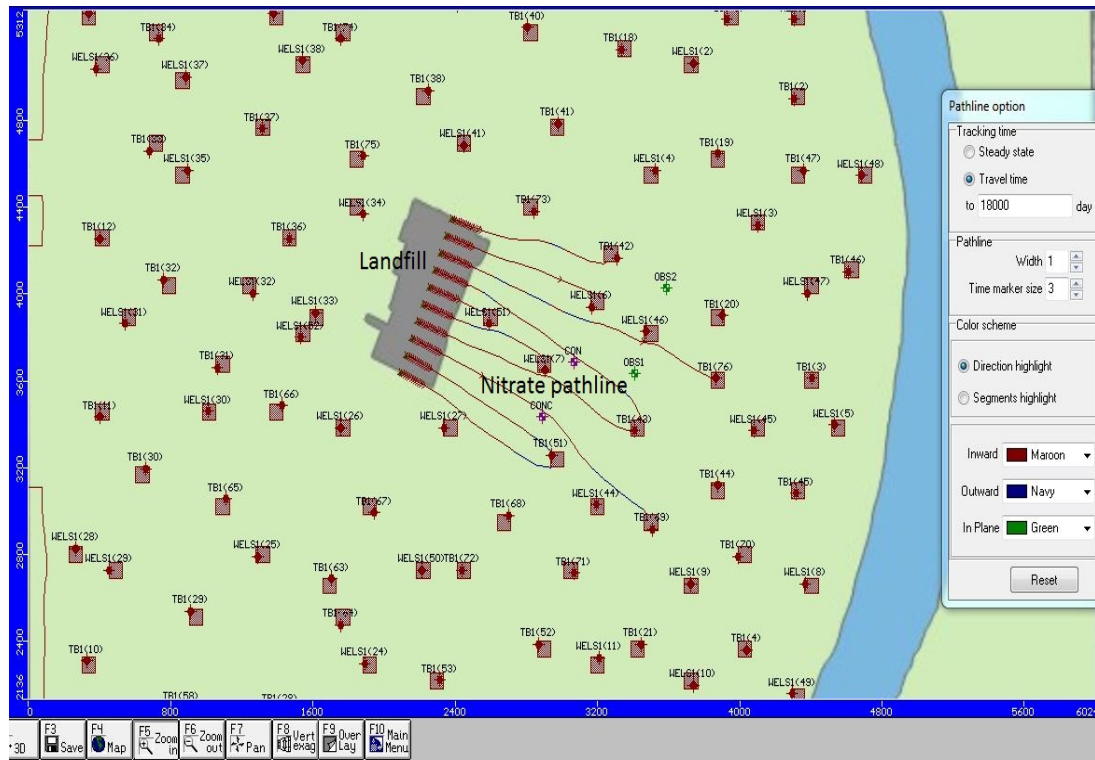


Figure 5.30 Snap shot of Nitrate path line showing contamination of nearest observation wells

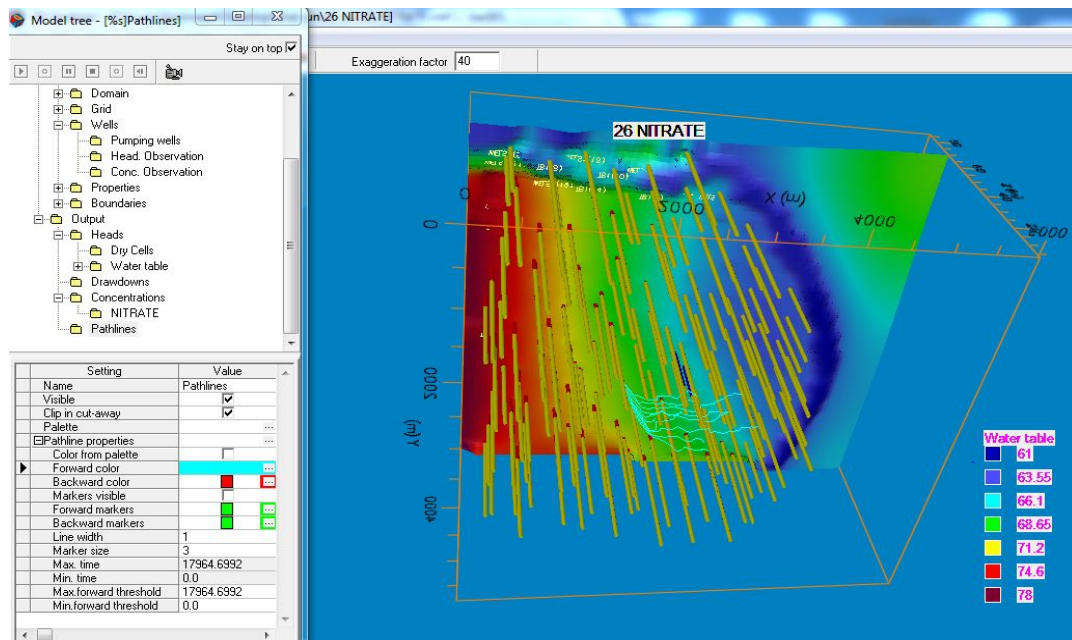


Figure 5.31 Snap shot of 3D View of nitrate path line

Thus from the result of the TDS and nitrate transport modelling it can be interpreted that other pollutants from the dumping site may be percolate and contaminate the nearest observational wells. Percolation of these contaminants are mainly due to the result of hydrogeological factors such as soil sorption capacity, reaction rate of the contaminant with solid phase, pollutant concentration and water movement rate [117].

Results of WQI evaluation showing the threatened groundwater quality near the Karsara dumping site which has high LPI (18.55) value while fair water quality near the Ramna dumping site having comparatively low LPI (12.40) value. By this finding it can be interpreted that the higher LPI value of leachate favours the lowering of the WQI, means water quality deteriorated from good to threatened water quality. So an inverse relationship is observed between LPI of MSW leachate and WQI.

Result of spatial mapping of WQI also revealed that as the depth in and distance of the wells decrease from the dumping site simultaneously groundwater quality also degraded especially in post- monsoon period. It may be due to increase in the rate of leachate infiltration from precipitation during post monsoon period. Groundwater quality analysis shows TDS, nitrate, alkalinity, Hardness, COD, and iron concentration were found above the acceptable limit of drinking water quality, mostly within 500 meter of the both the dumping site. The leachate generation over the time at the both the dumping site were represented a major threat to the groundwater quality.