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Groundwater Flow and Contaminant Transport Modelling of Landfill Leachate Using Visual Modflow

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***Abstract*— The rapid growth of population accompanied by industrialization and urbanization has resulted in the increased demand for potable water. groundwater is being depleted day by day both in terms of quantity and quality. There is a need to protect the groundwater from these contaminations by industries. Industries dump the solid waste residues in a secured landfill site near the industry. A common problem of the storage of the wastes in the landfill site is the potential contamination of groundwater through leaching of hazardous waste into the groundwater by means of percolation. The quantity of leachate percolating into the landfill depends on various factors such as climatic conditions, geology and hydrogeology and amount of external water entering into the secured landfill site. The chemical quality of leachate depends upon many factors such as original nature of buried waste materials and composition of waste materials as well as conditions prevailing at the secured landfill site. The present study stresses on the need of developing a groundwater flow and contaminant transport model to understand the movement of contaminant from landfill site in groundwater. The contaminant movement will be predicted for the future years to understand the contamination state over the coming years which will help the decision makers in taking important groundwater management decisions.**

Keywords*— percolation, groundwater, landfill, contaminant.

I. INTRODUCTION

Groundwater is generally less susceptible to contamination as compared to surface water bodies. But in areas where the storage of hazardous waste in secured landfill site is not so effective then there is a chance of groundwater contamination through leaching from landfill site. Once in the landfill, chemicals can leach into the groundwater by means of precipitation and surface runoff then there is a chance for potential contamination of groundwater. Chlor-alkali industry involves the production of chlorine and caustic soda by means of Hg cathodes.

Although most of the plants have shifted from Hg cell technology to membrane cell technology but there are tonnes of Hg contaminated waste sludge accumulated at the secured landfill site nearer to the industry. Once the leachate from landfill enters into the groundwater by means of precipitation and surface runoff then the groundwater becomes very vulnerable to contamination. Hence, it was desired to carry out impact assessment and modelling studies through an integrated approach combining the monitoring of groundwater quality, in and around the Chlor-Alkali industrial area and assess the reasons for groundwater pollution in the study area and suggest suitable remedial and mitigation measures to be adopted in future .

II. DATA USED

Following data is used to decipher the groundwater quality assessment and its impact on the groundwater regime in and around the industrial area;

Physiographic Data / Maps

Survey of India Toposheet map of the study area (1:50,000 scale), Maps showing location of industries and villages, Drainage map showing river, river basin, with all branches or tributaries and surface water bodies.

Geological Data

Geological Survey of India geological map of the study area (1:50,000 scale).

Groundwater data

Water level in meter (b.g.l), geological information in the study area, Existing groundwater practices such as; withdrawal and uses.

Pumping data

Aquifer properties such as hydraulic conductivity, transmissivity, Recharge, Water level elevations.

Location and Geographical Area

The Survey of India Toposheets on 1:50,000 scale is used in the present study. Total Geographical Area: 6130.23 sq. km; Mappable area 5939.33 Sq Km- 96.88 %; Hilly/Forest 190.90 Sq Km-3.11 %

Study area has a population of 19,86,864 peoples. (2011). Population density in sq km (2011) is 326. There is marked increase in the population density per sq km in last two decade is from 227 (1991) to 326 (2011). In the last ten year (2001 to 2011) the percentage increase in population is 16.12%.

Physiography and Drainage

Topography of the area is highly rugged and undulating comprising hills, dissected plateau, valley and flats. The maximum elevation and minimum elevation observed in the area are about 468m and 494m.

The area forms part of Chambal sub basin of Yamuna River sub-basin. The major Streams are flowing in south western and central direction. The major and minor streams show dendritic and sub parallel drainage pattern. In the valley fill area, the branching of the stream is not visible. The Stream gradient is steep to moderate in the source region and it is moderate to gentle in the middle & lower reaches.

Climatic Conditions

The climate of the area varies considerably, depending on the geographical region. Monsoon plays a major role in determining the climate of the state. Summers last from March to june. In the Coastal plain, the summer temperatures are generally higher than the rest of the state, with temperature ranging between 200C and 410C. The range of winter temperature is generally 12 °C to 30 °C. The Annual Normal Rainfall in the area is 914.5 mm /yr.

Soil Type

Predominant Soil type found in the area are black cotton soils with heavy to light textures. The district faces considerable problem of soil erosion because of faulty farming practices and natural agents like wind and water.

Geology

The study area is occupied with basaltic rock formation with thick alluvium cover. It is noticed that the aquifer located directly beneath the area had yielded large quantities of low-cost water in the past is being increasingly affected by over exploitation.

Hydrogeology

Major Water bearing Formations are Alluvium Weathered, vesicular and fractured basalt. Long- term water level trend in 10 years (2003-2012) is 0.08-0.12m/yr(fall). Previous studies (CGWB 2017) indicate that discharge of 0.5-6.33lps and transmissivity of 31.8-149.6 m2/day have been obtained during exploratory drilling. The Basalt act as a good aquifer as it is porous and permeable. Piezometric wells and the bore wells/dug wells/hand pumps are the common sources of groundwater abstraction.

Figure 1 Location map of the study area

III. Methodology

General

As the present research is aimed at Development of groundwater flow and solute transport model credible primary data were generated systematically to facilitate the modelling exercise. Secondary data has been collected through interaction with apex bodies. Extensive field visits were made to understand the field conditions and accordingly conceptualize the model. The approach is to generate the maximum primary data from the area

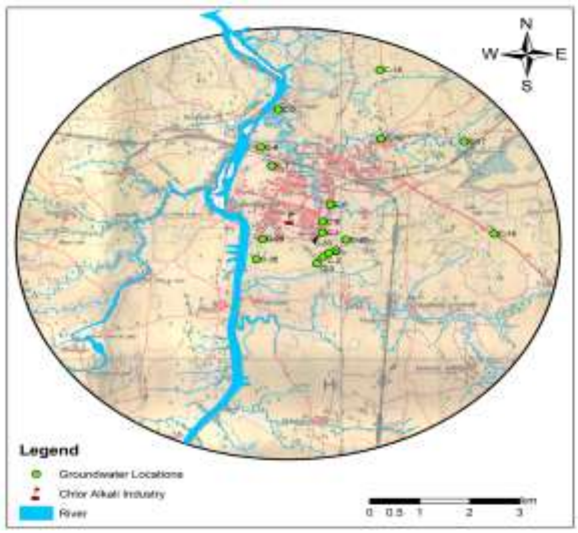

Figure 2 Drainage pattern in the study area

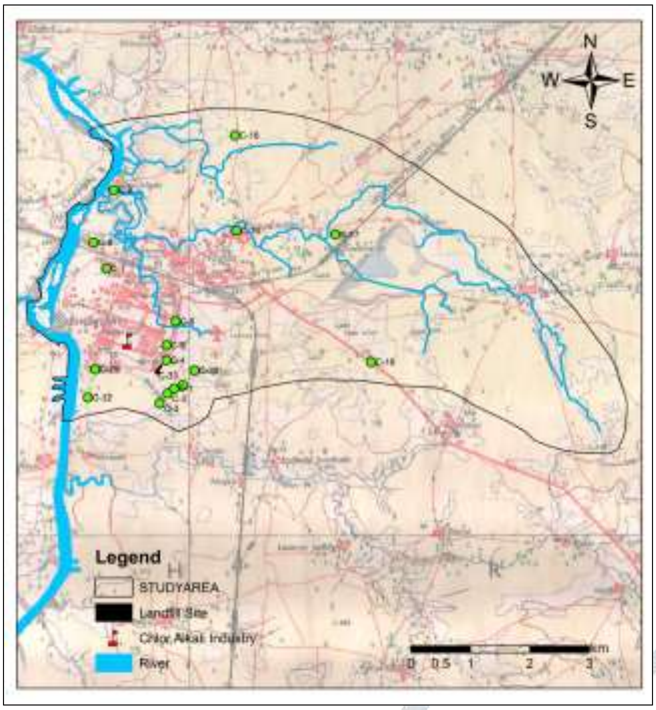

Figure 3 Delineated watershed in the study area with groundwater sampling locations

Demarcation of the study area

Based on the principle of water-shed delineation the area has been demarcated. The drainage network on the Toposheet No. 46 M/7 (Scale 1:50,000) formed the basis for demarcation of the sub-watershed. The demarcated sub-watershed area includes the industries. The important features were marked by GPS locations for transferring to the base map.

Observation well network

A network of observation wells (13nos) was set up in the study area for water level monitoring. The observation wells are the open wells and the dug wells/borewells and handpumps which are common sources of groundwater abstraction. The observation wells were well spread in the study area. The positions (latitude & longitude) of all the observation wells were obtained by hand held GPS.

Ground Water level monitoring

The water level was measured for all the observation wells in the study area. The water level was obtained using Electric Contact Gauze with a buzzer. Accordingly, the groundwater flow direction is established to draw correlation between the groundwater quality in the different wells and possible pollutant sources in the area.

Groundwater Quality Assessment

In order to assess water quality impacts ground water samples are collected from the surrounding chlor-alkali industrial area TSDF. The samples analysed for various physical and chemical parameters to know the contamination levels as per the IS Standards. Ground water quality --- IS 10500-1992

TABLE I. List of parameters for groundwater quality monitoring

Sl. No.	Parameter	Sl. No.	Parameter
1	pH	10	Sulphates
2	Turbidity	11	Chloride
3	Electrical Conductivity	12	Nitrate
4	TDS	13	Phosphate
5	Temperature	14	Sodium
6	Total Alkalinity As Caco$_3$	15	Potassium
7	Total Hardness As Caco$_3$	16	Fluoride
8	Ca Hardness As Caco$_3$	17	Nitrites
9	Mg Hardness As Caco$_3$	18	Oil And Grease

IV. MODEL DEVELOPMENT

In the most general terms, a model is a simplified representation of the appearance or operation of a real object or system. Physical models such as laboratory sand columns simulate the groundwater flow directly. Mathematical models essentially solve the governing equations which represent the groundwater system together with equations which may represent the heads, flows across the boundaries of the system (boundary conditions simplistic for the problem under consideration, a numerical model is the most appropriate tool.

TABLE II. Details of the groundwater sampling locations in the study area

S.No	Sample Code	pH	TDS (mg/l)	Conductivity (mS/cm)
Desirable		**6.5**	**500**	--
Permissible		**8.5**	**2000**	--
Groundwater Samples				
1.	C 1	6.45	552	960.48
2.	C 2	7.8	622	1082.28
3.	C 3	4.49	501	871.74
4.	C 4	7.69	371	645.54
5.	C 5	7.34	413	718.62
6.	C 6	7.7	342	595.08
7.	C 9	7.01	2550	4437
8.	C 17	7.1	790	1374.6
9.	C 18	7.5	596	1037.04
10.	C 19	7.3	1210	2105.4
11.	C 20	7.6	765	1331
12.	C 32	7.5	734	1277.16
13.	C 33	7.1	362	629.88

S.No	Sample Code	Latitude	Longitude	elevation	WL in m
1.	C – 1	23.4390951	75.4144349	478	2.45
2.	C – 2	23.4381	75.4134398	480	2.6
3.	C – 3	23.4364209	75.4120094	494	0.8
4.	C – 4	23.4430131	75.4134398	470	0.8
5.	C – 5	23.4451898	75.4131289	470	1.15
6.	C – 6	23.4491079	75.4146215	476	2.55
7.	C – 9	23.4688225	75.405355	468	7.2
8.	C – 17	23.462168	75.438876	480	2.3
9.	C – 18	23.4771561	75.423577	472	8.8
10.	C – 19	23.4429509	75.4441623	490	6.45
11.	C – 20	23.4417693	75.4176688	482	1.85
12.	C – 32	23.4374781	75.4011259	471	4.7
13.	C – 33	23.4394682	75.4153677	469	1.65

TABLE III. Groundwater Quality - Physical and Mineral Parameters

TABLE IV. Groundwater Quality - Inorganic Parameters

S. No	Sample Code	Total Alkalinity	Hardness Total	Hardness Ca	Hardness Mg	Cl	SO_4^{2-}	F-	Na	K
			(mg/l)							
Desirable		**200**	**200**	**75**	**30**	**250**	**200**	**1.0**	--	--
Permissible		**600**	**600**	**200**	**100**	**1000**	**400**	**1.5**	--	--
Groundwater Samples										
1.	C 1	120	519.2	146.08	36.96	110	22	0.2	99.3	7.8
2.	C 2	248	308	84.48	23.232	135	53	0.8	94	5.64
3.	C 3	132	158.4	49.28	8.448	150	35	0.5	54	9.68
4.	C 4	104	220	58.08	17.952	103	18	0.3	54	5.91
5.	C 5	140	206.8	47.52	21.12	123	18	0.2	48.6	5.99
6.	C 6	140	198	56.32	13.728	78	16	0.4	34.2	5.86
7.	C 9	184	1298	413.6	63.36	105	335	0.6	305	5.7
8.	C 17	188	400.4	114.4	27.456	790	109	0.5	143	4.5
9.	C 18	200	374	95.04	32.736	596	116	0.5	15	0.52
10.	C 19	212	902	202.4	95.04	1210	64	0.4	47	0.82
11.	C 20	204	519.2	156.64	30.624	765	72	0.4	99	0.48
12.	C 32	220	418	105.6	36.96	734	23	0.3	13	0.6
13.	C 33	376	365.2	93.28	31.68	362	218	0.4	183	3.7

TABLE V. Groundwater Quality – Nutrient Demand and Special Parameters

S.No.	Sample Code	Nitrate	P-PO4
		(mg/l)	
Desirable		**45**	--
Permissible		**NR**	--
Groundwater Samples			
1.	C 1	3.3	BDL
2.	C 2	1.1	0.03
3.	C 3	0.3	0.08
4.	C 4	0.3	0.01
5.	C 5	0.4	0.07
6.	C 6	1.9	0.08
7.	C 9	9.9	0.05
8.	C 17	11	0.06
9.	C 18	18.5	0.01
10.	C 19	27	0.02
11.	C 20	4	0.04
12.	C 32	0.02	0.03
13.	C 33	7.1	0.05

Groundwater models can be divided into two categories: groundwater flow models and solute transport models. The groundwater flow models solve for the distribution of head, whereas the solute transport model solves for the concentration of the solute as affected by advection, dispersion and chemical reactions.

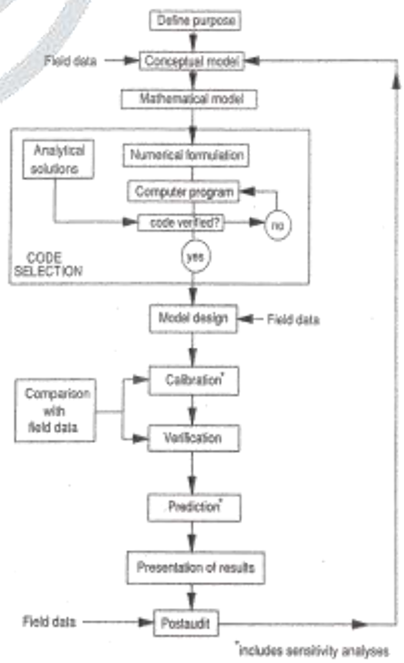

Figure 4 Modelling protocol

Flow modelling

A steady state model has been developed as long time water level data is not available using the groundwater level data of the study area. The calculated head contours were obtained after the simulation of the groundwater flow model. The model calibration results were evaluated by comparing the contour maps of targeted water levels with the simulated model water levels. The deviations in the model can be from uncertainties in the pumping rates, recharge etc. However, a correlation of 0.71 was observed between the observed head and the calculated head after the steady state calibration of the groundwater model. After the final calibration of the water levels, the model finally reveals that the simulated groundwater model is in agreement with the observed groundwater levels. This simulated and calibrated groundwater flow model serves as input to for the solute transport model. The groundwater flow simulated shows that the groundwater flow direction follows the real groundwater flow as depicted from the contour map

Mass transport Model

For any mass transport modelling in groundwater, the groundwater flow model has to be simulated according to the present field conditions and calibrated with the observed head level data. The groundwater flow model was calibrated to demonstrate that the model is capable of accurately simulating observed groundwater conditions in the study area. Calibration of the flow model was done by using a model design and input parameters and boundary conditions that produced simulated groundwater elevations that matched with the observed field head values. The contaminant travels only a distance of 0.96km in a span on 20 years.

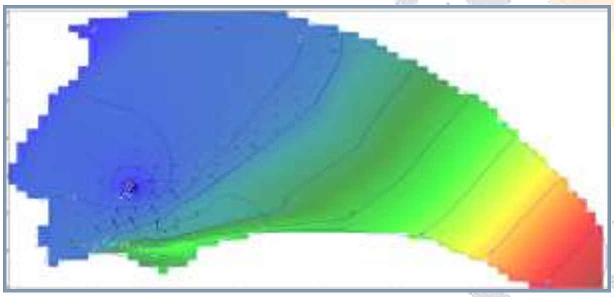

Figure 5 steady state flow model

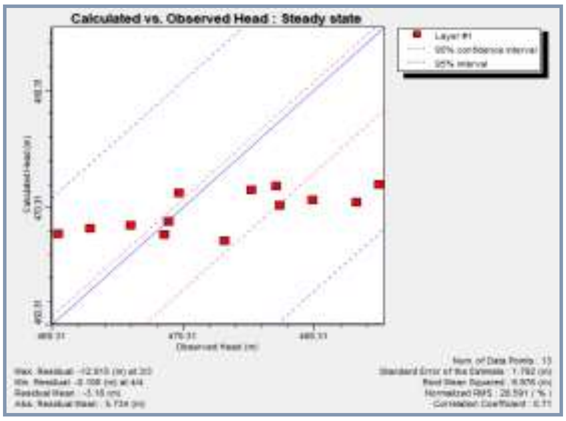

Figure 6 Calibration plot b/n calculated and Observed

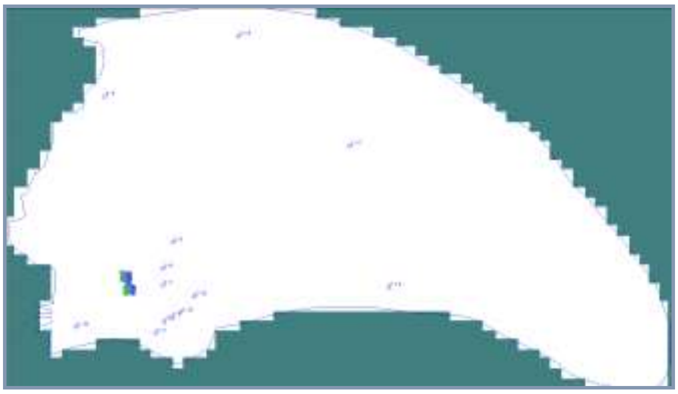

Figure 7 Migration of the contaminant over 10 yrs period

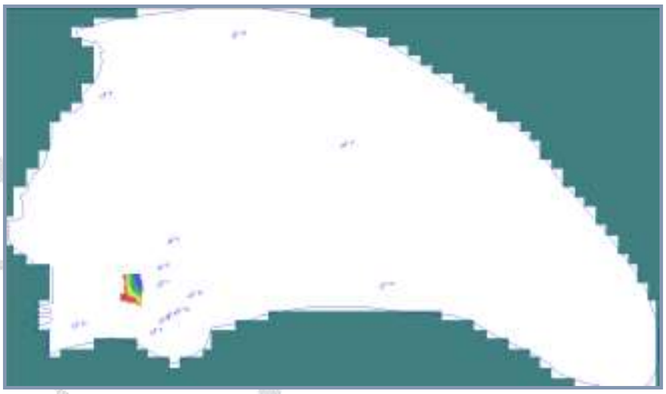

Figure 8 Migration of the contaminant over 20 yrs period

V. RESULTS AND DISCUSSION

A basemap has been established to study the flow of particles and components of the samples to visually analyse the path of various parameters such as Total dissolved solids, chlorides, sulphates, nitrates, fluorides etc..,

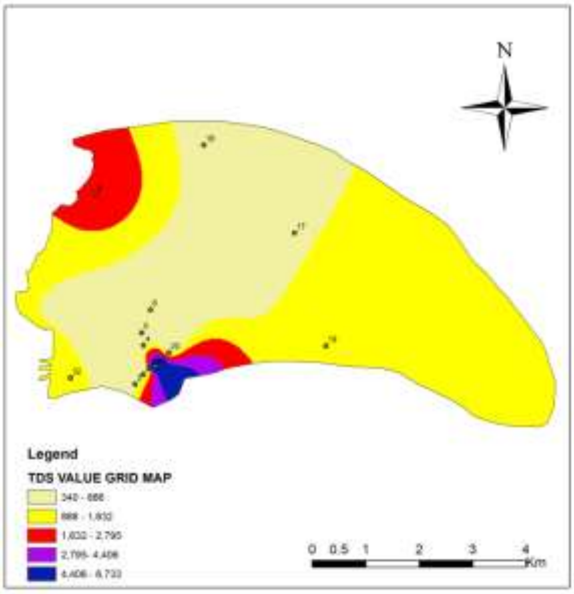

Figure 9 TDS value grid map

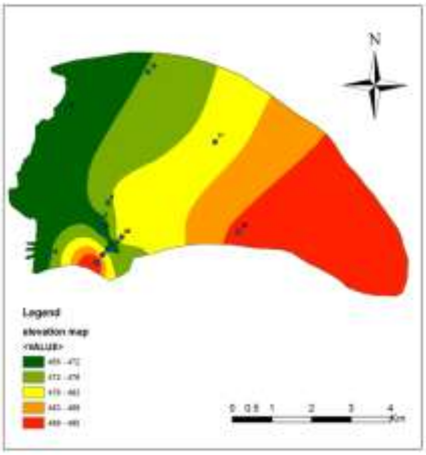

FIGURE 10 ELEVATION Map

Figure 9 & 10 Base maps detailing the elevation and the TDS level variation at the different samples collected

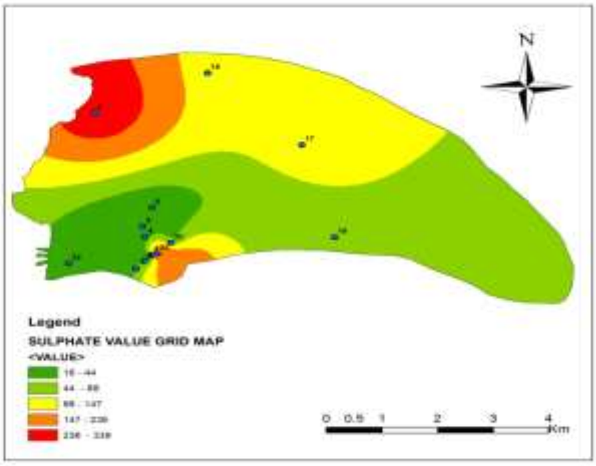

FIGURE 11 SULPHATE VALUEGRID Map

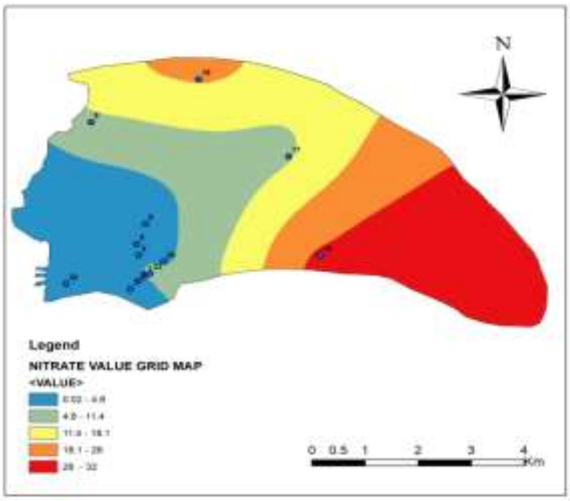

FIGURE 12 NITRATE VALUEGRID Map

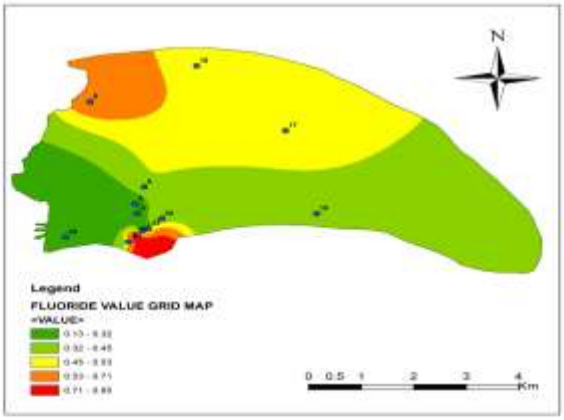

FIGURE 13 FLUORIDE VALUE GRID Map

Figure 11,12,13 Base maps detailing the sulphate, nitrate and fluoride level variation at the different samples collected respectively.

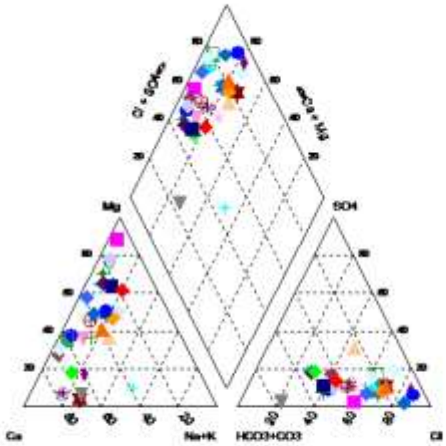

FIGURE 14 PIPER DIAGRAM

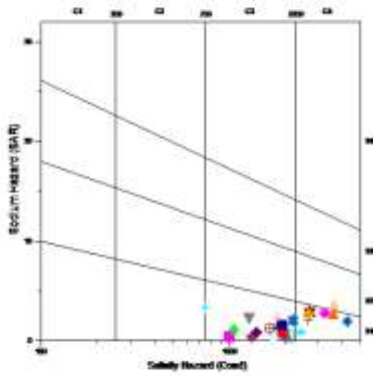

FIGURE 15 WILCOX PLOT

figure 14 &15 are groundwater quality plots are used to access for irrigation and drinking purpose.

VI. Conclusions

Based on the integrated study using the hydrogeology, geophysical studies, hydro-chemical studies, flow and mass transport modelling, the following findings can be summed up for the study area.

The groundwater quality is within the BIS limits except for few samples as far as the physicochemical parameters are concerned. The sources C-9, C-19 should not be used for drinking purpose. The study indicates that the samples in the downstream are vulnerable to contamination in future though the present study is safe enough for major cations and anions.

we can infer that in the present study area water is mixed type, temporary and permanent hardness type of water. Most of the waters are Magnesium bicarbonate type attributing to temporary hardness of water.

During the study period, in the present study area the conductivity of the ground water was found varying between 750 and 9470 mg/l. In ground water samples collected from the study area, the Sodium Adsorption Ratio (SAR) values vary from 0.308 to 4.114. The US salinity diagram shows that in the present study area the ground water is high to Very high salinity classes i.e., C3S1, C4S1, C4S2 classes C3 and C4 classes of water should not be used for Irrigation purpose.

The prediction scenario for the next 20 years by mass transport modelling indicates that the plume will migrate to approximately 0.96 Km from the source in the horizontal direction. The reaction mechanism of the solute need to be integrated in the modelling in future.

The present practice of effluent disposal needs to be changed. The disposal pond needs to have a clay liner to prevent the seepage of the leachate to the aquifer system which is very shallow. This is necessary since the water table is with in < 12 m during the post-monsoon season and < 15 m during the pre-monsoon season.

Piezometers need to be installed in the immediate downstream and upstream of each pond for monitoring of water level and water quality. A proper treatment plant has to be set up to treat the waste sludge to reduce its impact on groundwater quality.

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