Evaluation of Water Quality Impact Caused by Common Hazardous Waste Landfill Facility in Gummidipoondi, Tamilnadu- India

D. Vasudevan, A.G. Murugesan

Abstract*: The aim of the study was to evaluate the water quality impact caused due to the operations of common hazardous waste landfill facility (CHWLF) in Gummidipoondi industrial estate, Tiruvallur district, Tamilnadu, India. The watershed area of the hazardous waste landfill facility was delineated using Arc-GIS tools and prediction of ground water flow direction was carried out using three-dimensional ground water flow model using VISUAL MODFLOW software. The water quality analysis was performed in the upstream and downstream directions of the project site and the results showed that all the tested parameters were within the BIS 10500:2012 drinking water limits, except pH which showed slightly acidic characteristics in certain locations. The tested water samples mostly belonged to the Ca + Mg-HCO3' type as classified using the multivariate analysis method using piper diagram. Co-relation between the water quality parameters were determined using statistical analysis of Pearson's correlation coefficient (r) values.

***Keywords*: Common Hazardous Waste Management Facility, Landfill, Water Pollution, MODFLOW, Impact Assessment, Ground Water Contamination.**

I. INTRODUCTION

One of the major concerns of industrial developments are the problems associated with hazardous wastes that are often generated as by-products during industrial manufacturing process. The wastes regardless of its volume are known for its toxicity, which when exposed to environment are known to bring harmful and irreversible damages (Burge and Rogers, 2000; Dongo *et al*., 2012; Fazzo *et al*., 2017; Misra and Pandey, 2005).

As per the Hazardous and Other Wastes (Management &Transboundary Movement) Rules, 2016, hazardous wastes are defined as those wastes 'which by reason of its characteristics, such as physical, chemical, biological, reactive, toxic, flammable, explosive or corrosive, causes danger to health, or environment'. The widely adopted approach in India for handling and disposal of hazardous wastes is disposal through a common hazardous waste management facility (Vasudevan and Murugesan, 2017). The common hazardous waste disposal facilities are known to offer an integrated approach for transportation, storage, treatment, and disposal of hazardous wastes for the industries. The disposal is carried out largely through engineered landfills and incinerators (CPCB, 2016). Though the methods provide a formalised and streamlined approach for managing hazardous wastes aiming to contain and treat the wastes in a secured manner, the approach still poses potential threat due to improper operation and maintenance, and accidental release of hazardous substances through such facilities. The limitation of hazardous waste landfills is its potential to contaminate ground water sources, whereas the operation of incinerators may cause air pollution due to improper combustion of toxic organic compounds and its release into the environment (Vrijheid, 2000, Ying Li et al, 2012, Yang et al., 2016).

Technically, the International Solid Wastes Association (Bagchi, 1994) defines landfill as "the engineered deposit of waste onto or into land in such a way that pollution or harm to the environment is prevented, and through restoration of land provided which may be used for other purpose". However, the disposal of wastes in landfill sites is a matter of concern due to possible generation of toxic leachate and the potential ground water contamination that could take place. Leachate is produced when rainwater percolates through various layers of wastes and is influenced by biological and chemical reactions within a landfill. The leachate thus comprises of complex and concentrated organic, inorganic compounds and heavy metals which have a high potential to cause adverse effects to humans and environment by contaminating ground or surface water resources (Kumar and Alappat 2005).

The generation of leachate depends on several factors including construction, operation, and maintenance of the landfill facilities. When the above steps fail to meet the required standards of performance, groundwater contamination due to leachate or mishandling of hazardous waste may take place which will also be influenced by several other parameters such as soil permeability, hydrological conditions of the site and directions of ground water flow. This is a major concern as the water pollution causes adverse health effects for populations living nearby,

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particularly in relation to those sites where hazardous waste is dumped (Kubal *et al*., 2003, Press 2016).

One important tool for assessing effective management of hazardous wastes in CHWLF and avoiding its risks of pollution is through evaluation of its environmental impacts. It helps identifying any pollution caused by the facility in early stages thereby enabling to perform pollution mitigation measures and keeping its harmful effects under check.

In recent years, geographical information system (GIS) based tools are gaining increased application for environmental impact assessments including research on groundwater assessment and management (*Singha Sudhakar et al. 2016).* GIS tools can easily access overlay and index operations and can represent real scenarios through integrated layers of constituent spatial data (Corwin, 1996). Coupling GIS technology with a process-based groundwater model facilitates conceptualization of hydro geological and hydrologic system and its characterization (Hinaman1993; Kolm1996; Gogu et al. 2001), thus enabling a proper adaptation of the groundwater flow model to the study area (Brodie1998). Chao-Shi Chen,et al.,2016 used the groundwater modelling systems software, to numerically model groundwater flow and contaminant transport for the Wang-Tien landfill site in Taiwan. The simulation results showed that the total mass of pollutants in the aquifer increased by an average of 72% for a duration of 10 years. The spatial extent of the contaminant plume was also reported that spread to 80 m in length and 20 m in depth north eastward from the landfill site. Similar application of groundwater model was demonstrated by O. Ganesh Babu *et al.*, who assessed the aquifer vulnerability of Noyyal River basin using Visual MODFLOW– MT3D. The study helped in delineating potential contamination zones as an effect of pollution caused by industrial effluents from textile industries. From the above observations and similar studies carried out by other researchers, it can be inferred that the combination of GIS and ground water models such as MODFLOW offer promising ways to predict contaminant transportation in subsurface waters, thereby flagging vulnerable areas facing high risk of pollution. Predicting and identifying vulnerable areas of pollution can help the stakeholders in preparation of suitable mitigation plans for prevention of pollution and its harmful effects.

In line with the above research works, the present study aims at evaluating the environmental impacts on ground water quality associated with the operation of a common hazardous waste landfill facility (CHWLF) in Gummidipoondi industrial estate, Tiruvallur District, Tamilnadu. The objective was to find out the impact on the groundwater quality with the help of GIS tools and carry out real time monitoring to check the presence of any pollutants in the groundwater.

II. METHODOLOGY

2.1 Study Area

The common hazardous waste landfill facility (CHWLF) extending over 9 acres, bounded by longitudes of 80˚ 06' 23" E and 80˚ 06' 27" E and latitudes 13˚ 24' 47" N and 13˚ 25' is in the State industries promotion corporation of Tamilnadu (SIPCOT) industrial complex, Gummidipoondi taluk of Thiruvallur District, Tamilnadu, India. The facility is in operation since 2007 with an engineered landfill with a handling capacity of 180 thousand tons per annum of hazardous wastes. So far around 5 lakh MT of hazardous wastes has been disposed in the landfill facility.

Area covering about 10 km radius around the landfill site with 23 monitoring location was evaluated for ground water pollution. Within the study area, the watershed of the project site was established by defining lineaments using ARC GIS techniques. The delineated watershed map encompassing the areas of natural preferred pathways of contaminants from the potential contamination zone is provided for reference in Figure 2. The details of the sampling locations are furnished in Table 1.

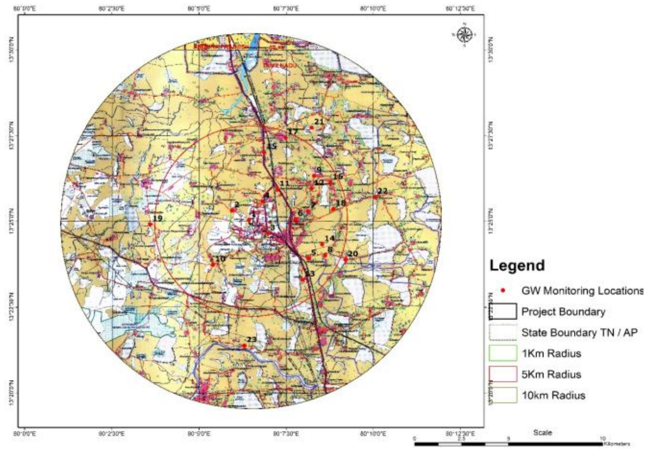

Figure 1. Map showing monitoring locations over 10 km radius from landfill site

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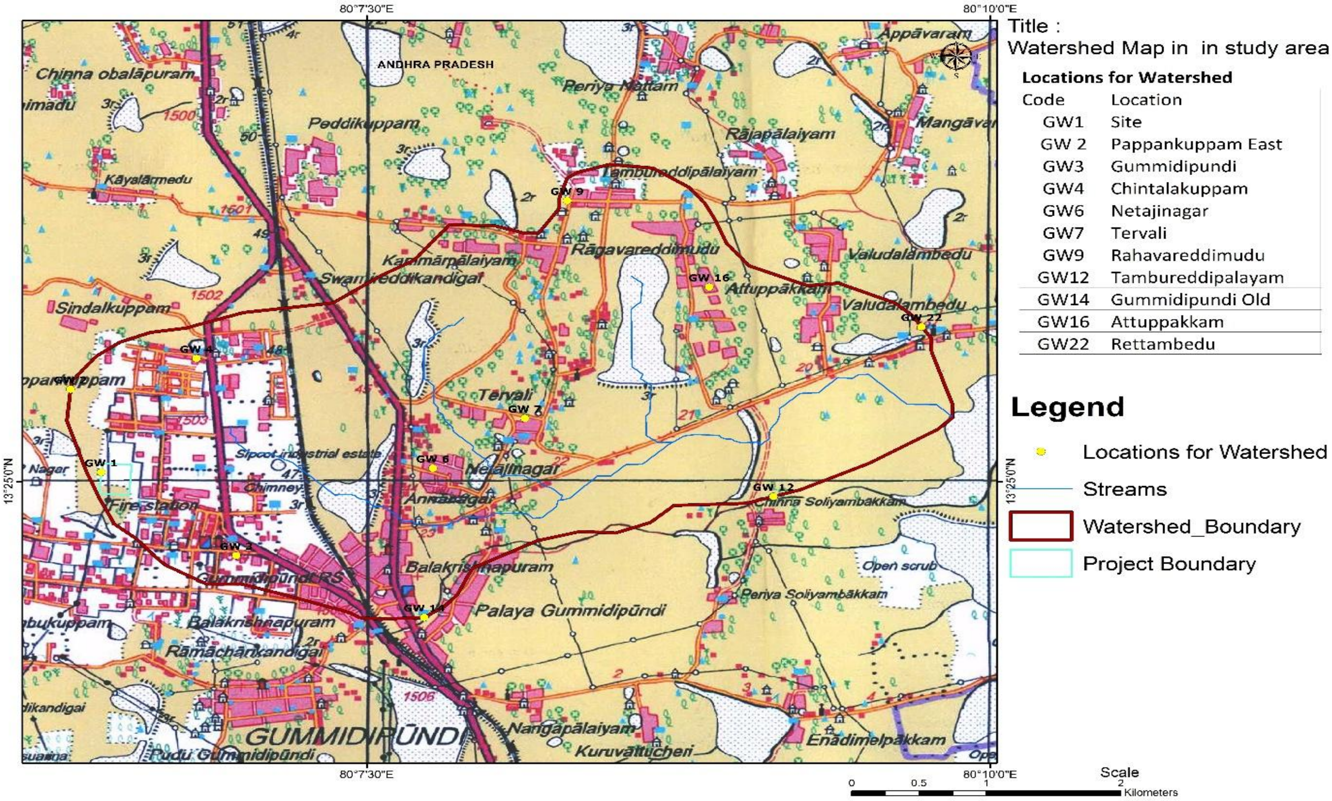


Figure 2. Delineated watershed area comprising the project site.

Table.1 Sampling locations for ground and surface water monitoring

Code	Name of the locations
GW 1	Project site
GW 2	Pappankuppan East
GW 3	Gummidipoondi new
GW 4	Chintalakuppam
GW 5	Nangopallam
GW 6	Nethaji Nagar
GW 7	Tervazhi
GW 8	Periyasoliyambakkam
GW 9	Raghavareddimedu
GW 10	Sirupuzhalpettai
GW 11	Peddikuppam
GW 12	Thambureddipalayam
GW 13	Verkadu
GW 14	Gummidipoondi Old
GW 15	Chinnaobulapuram
GW 16	Aathupakkam
GW 17	Narasinghapuram
GW 18	Valuthalambedu
GW 19	Karambedu
GW 20	Enathimelpakkam
GW 21	Natham
GW 22	Rettembedu
GW 23	Annapanaickenkuppam

2.2 Groundwater Modelling

In the field of groundwater flow modelling, numerical simulation models are employed to describe hydrologic phenomena such as groundwater movement. The main purpose of such models is to predict the direction of groundwater and solute movement, which play a significant role in understanding contaminant transportation. In the present study a hypothetical model was simulated using the finite difference model of Visual MODFLOW- 2000. The partial-differential equation of groundwater flow applied in MODFLOW (Harbaugh et al, 2000, McDonald and Harbaugh 1998) is

$$\frac{\partial}{\partial t}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t}$$

where Kxx, Kyy, and Kzz indicate aquifer conductivity along the x, y and z axes ($L\,T^{-1}$), h: flow head (m), W: sources and/or sink of water (s^{-1}), Ss: specific storage (m^{-1}), t: time (T).

Using the visual MODFLOW software, the flow direction of ground water was predicted in the watershed area. The model results helped to identify the most probable areas of contaminant transportation which were monitored by real time analysis of collected groundwater samples.

2.3 Monitoring and Analysis of Groundwater Samples

The water quality monitoring was carried out on a quarterly basis in all the 23 locations in the study area from September 2017 to August 2019. More number of ground water sampling locations were chosen based on the predicted groundwater flow direction using Visual MODFLOW.

The various water quality parameters tested in the groundwater samples and their methods of analysis are provided in the Table 2.

The results on water quality were also compared with the legacy data documented by the National Environmental Research Institute (NEERI) in 2005 prior to establishment of the landfill facility. Based on the comparisons of data obtained between 2005 and 2019, the results on impact on water quality in the study area were assessed.

Table. 2. Water Quality Parameters analyses and methodology

Parameters monitored	Methodology
pH	Electrometric Method
Electrical Conductivity (EC)	Laboratory Method
Total Dissolved Solid (TDS)	Gravimetric Method
Total Hardness (TH)	EDTA Titrimetric Method
Chloride (Cl^-)	Argentometric method
Sulphate (SO_4^{2-})	Turbidimetric Method
Phosphate (PO_4^{3-})	Colorimetric Method
Nitrate (NO_3^-)	Ion Chromatograph
Sodium (Na^+), Potassium (K^+)	Flame Photometry
Heavy Metals (Arsenic (As), Cadmium (Cd), Chromium (Cr), Mercury (Hg), Lead (Pb), Zinc (Zn), Copper (Cu))	Graphite Furnace Atomic Absorption Spectrometric Method
Biological Oxygen Demand (BOD)	Winkler's Method
Chemical Oxygen Demand (COD)	Open Reflux Method

2.4 Chemical Speciation of Groundwater Samples using Piper Trilinear Diagram:

A Piper trilinear diagram was used to classify the groundwater samples based on the presence of various ions viz, Na^+, K^+, $Ca^{2+,}$ Mg^{2+}, HCO_3^- , CO_3^{2-}, Cl^- and SO_4^{2} (Piper, A.M. 1994, Manoj *et al*., 2013).

2.5 Calculation of Pearson Correlation Coefficient

Pearson correlation coefficient was used to understand the correlation and influence of ions between each other in the ground water samples analysed.

If x and y are the two variables, $\bar{x}$ and $\bar{y}$ are the mean of x and y variables respectively, and then the Pearson correlation coefficient (PEARSON) (*r*) between the variable x and y is given by, equation (1)

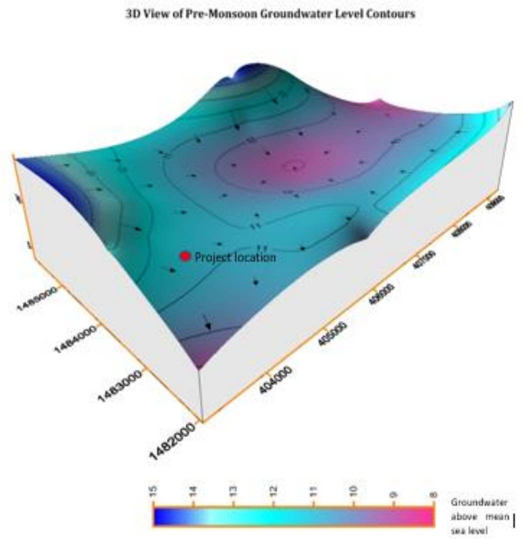
$$r = \frac{\sum(x-\bar{x})(y-\bar{y})}{\sqrt{\Sigma(x-\bar{x})^2\Sigma(y-\bar{y})^2}} \quad (1)$$

In this study r > 0.70 was considered as a significant correlation, $0.5 \leq r \geq 0.70$ as a moderate correlation, and $r < 0.5$ as a non-significant correlation (Qialin Zheng et al., 2017)

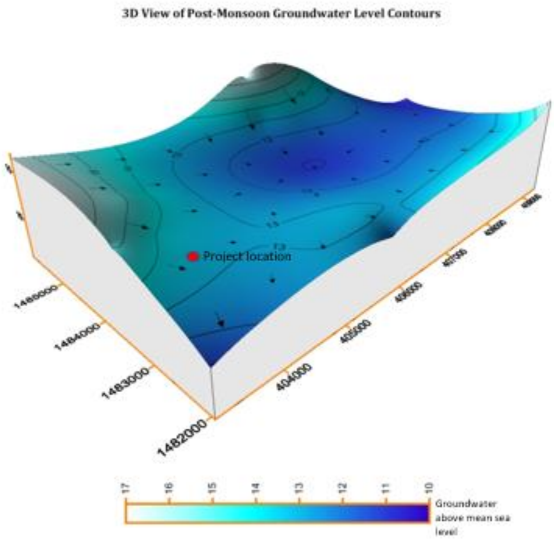
III. RESULTS AND DISCUSSION

3.1 Geology and Groundwater Flow in the Study Area

Watershed based monitoring was adopted in the current study as it helps in evaluating the condition of the ground water resource while also providing interlinked watershed information to help establish cause-and-effect relationships. Understanding the groundwater movement and its direction within the watershed is critical to identify the leachate movement in case of its inadvertent release and contamination at the landfill site. Arc-GIS tool clubbed with VISUAL MODFLOW was used perform a three-dimensional groundwater flow modelling to understand the groundwater movement from the project site (Fig. 3)



a. Pre-monsoon ground water flow directions



b. Post-monsoon ground water flow directions

Figure. 3. Groundwater flow direction in a) pre mon soon season and b) post monsoon season

The hydraulic gradient in the project site was found to be moderately low and has been observed as an average of about 1.1 m/Km in pre monsoon and 0.8 m/Km in post monsoon. A litholog of the project site (Table.3), shows presence of clay upto minimum 15 ft with a permeability co-efficient of 7.03 x 10^{-4} cm/sec. This helps us understand that the percolation of ground water at the project site may be comparatively slow due to the semipermeable nature of the soil at site.

The ground water level in the land fill site was found to be moderately deep (<15 m bgl) both in the pre- and post-monsoon periods which suggests that the infiltrating water may have least possibility to reach the ground water table. However, to validate the above understanding a real time ground water monitoring was carried out around the landfill facility.

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As suggested by earlier researchers (Brisbane, 1996), monitoring more locations in the down gradient were given more preference than in the upgradient.

Table.3. Details of litholog at project site

Sl. No	Depth (ft)	Type of soil with colour
1	5	Topsoil, Lateritic, Reddish brown in colour
2	10	Clayey Sand, Yellowish
3	15	Clayey Sand, Yellowish
4	20	Clayey Sand, Yellowish
5	25	Clayey Sand, Yellowish
6	30	Clay with little sand, Yellowish
7	35	Clay with little sand, Yellowish
8	40	Clay with little sand, Yellowish
9	45	Sand fine to medium, Quarzitic with little clay
10	50	Sand fine to medium, Quarzitic with little clay
11	55	Only sand fine to medium size

3.2 Analysis of Water Quality in the Study Area

Water quality monitoring was carried out over a period of two years year from September 2017 to August 2019 and the observations on various water quality parameters are presented below.

3.2.1 Analysis of pH

The samples were analysed for pH which is an index of the hydrogen ion concentration [H^+] in water. The [H^+] affects

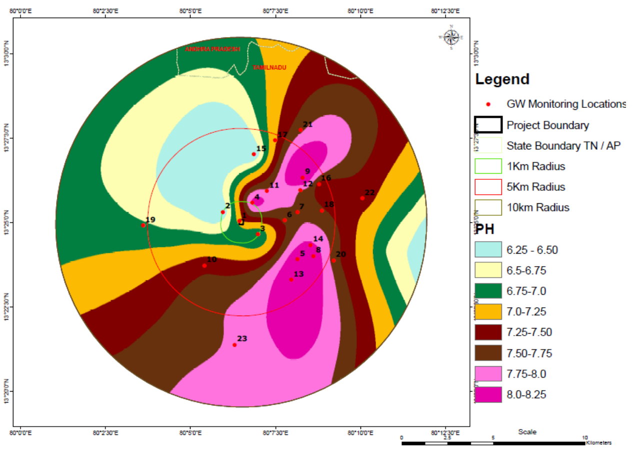

Figure. 4. The spatial distribution map of pH in the study area

most chemical and biological processes; thus, pH is an important parameter in determining the water quality (Boyd *et al.*, 2011). The Bureau of Indian standards 10500:2012 have fixed the pH criteria for drinking water ranging from 6.5 to 8. The average pH values of the study area are plotted in the spatial distribution map shown in Figure 4.

The results of the study showed the pH values of ground water ranging from 6.43 to 8.23. The minimum pH was observed inside the industrial estate in Gummidipoondi in the

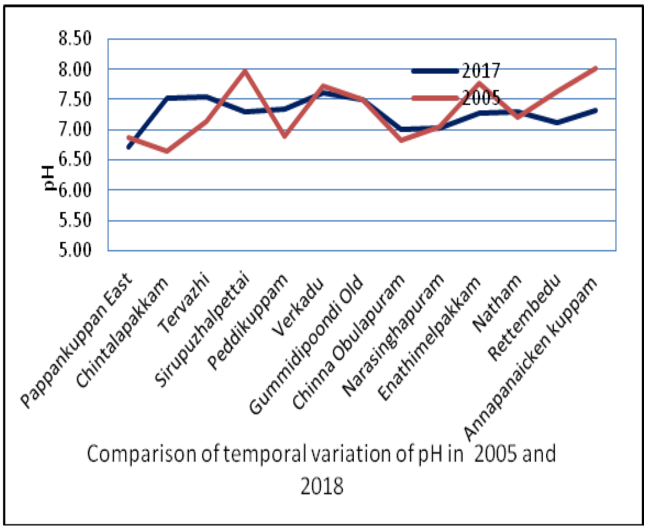

Figure. 5. Graph showing temporal variation of pH in the study area

Upstream of CHWLF site, where pH was below the prescribed limits as per BIS standards. The maximum pH was observed in Periyasoliyambakkam (GW 8) which is in the downstream and outside the industrial estate respectively.

The graph in Figure.5 illustrates the temporal variation of pH in thirteen groundwater monitoring locations for which the legacy data were sourced from NEERI report, 2005. It was noticed that the overall pH values in the study area remained almost same, where the 2005 and the current data showed values ranging from 6.65 to 8.01 and 6.71 to 7.61 respectively. Though the above pre- and post-project data does not show any significant variation in the observed pH over a decade, the slightly acidic characteristic of groundwater in certain locations raised concerns of possible groundwater contamination caused by the existing industries upstream, where outcrops and shallow levels of groundwater are observed. Similar studies on acidification of groundwater because of leaching of ferrous sulphate was reported by Kubal *et al., 2003* during their evaluation of landfill impacts at Pozdatky in Czech Republic.

However, it is noteworthy that in recent years in India, the Central and State pollution control boards have been giving more emphasis on zero liquid discharge and to recycle treated trade effluents within the industrial processes to conserve water and thereby avoid any possible contamination of groundwater.

3.2.2 Analysis of TDS

The other important water quality parameter analysed was total dissolved solids (TDS) which is a measurement of inorganic salts, organic matter and other

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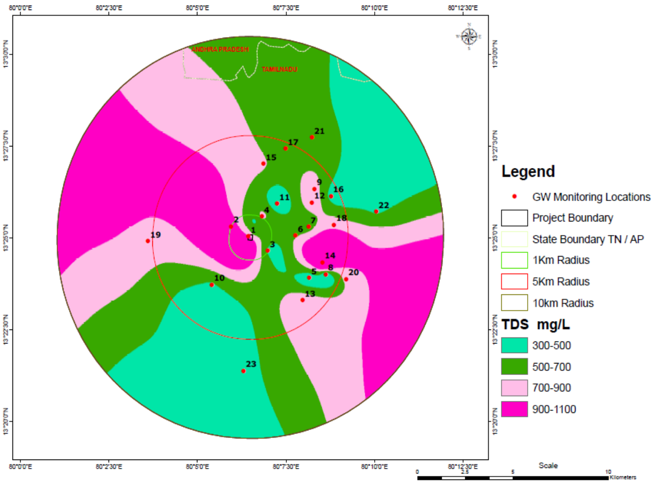

Figure.6. Spatial distribution map of TDS in the study area

dissolved materials in water (Weiner, 2000). TDS cause toxicity through increases in salinity, changes in the ionic composition of the water and toxicity of individual ions. The desired and permissible limits for TDS in drinking water are 500 mg/L and 1200 mg/L respectively.

In the research carried out by Abd El-Salam and Abu-Zuid, 2015 in Egypt on the effect of leachate contamination showed TDS in the range of 2855 to 16,276 mg/l in groundwater. Though the authors considered that improperly lined landfills may have led to increased total dissolved solids concentrations in groundwater, they have not dismissed the probable chances of contamination caused by other industrial discharges and sea water intrusion. Similar results on high TDS in groundwater were reported by other researchers, who related the results to anthropogenic effects of landfills in Delhi and Kolkata (Sunilkumar and Ramanathan, 2008 and Maiti et al., 2006).

The present analysis of total dissolved solids in the study area showed values ranging from 160 mg/L to 920 mg/L., which are within the permissible limits of BIS standards (Figure.6). Previous studies in the same landfill area reported similar results with TDS within the prescribed limits of drinking water standards and no ground water contamination was observed (N V Mariappan and Princeton, 2012). Comparison of TDS values in the study area with the 2005 data with maximum 1074 mg/L indicated that the TDS did not show any significant variation over the past decade before and after establishment of the CHWLF facility.

3.2.3 Alkalinity & Hardness

Alkalinity is referred as the buffering capacity of the water to acidity, and hardness is defined as the presence of calcium and magnesium ions related to the geological formations of the area (Boyd *et al.*, 2016). The values of alkalinity ranged from 48 to 312 mg/L and that of the hardness from 60 to 465 mg/L respectively, conforming to the permissible limits of drinking water as per IS10500:2012 standards, which is 600 mg/L for both the parameters.

It was noticed that in most of the samples, hardness values exceeded that of the alkalinity indicating predominance of non-carbonate hardness in the region. However, the results were comparable with the earlier studies conducted by NEERI in 2005 where the alkalinity and hardness values were in the ranges of 56 mg/L to 276 mg/L and 128 mg/L to 416 mg/L respectively in the monitored locations.

Alkalinity and hardness are related through common ions formed in water. They are the cations (Ca and Mg) associated with the bicarbonates. Presence of calcium showed predominance over magnesium in most of the samples analysed and were found to be in the range of 19 to 35 mg/L and 6 to 46 mg/L.

However, on observing the results it was noted that both alkalinity and hardness along with the calcium and magnesium ions conformed to the Indian water quality standards, showing no pollution or any discernible effects due to the operation of the landfill facility.

3.2.4 Chloride

The chlorides in the study area ranged from 42 mg/L to 216 mg/L. No significant variation in concentration of chloride was found when compared with the monitoring results of 2005 which ranged from 90 to 230 mg/L. The concentration of chloride was observed to be maximum at locations including Nethaji Nagar, Verkadu and Old Gummidipoondi. However, all these locations showed values below 250 mg/L thus falling within the acceptable limit for chlorides as prescribed by the Indian drinking water standards.

Chofqi et al.2004 evaluated groundwater pollution near El Jadida landfill in Morocco and found that the mean chlorides were 1620 mg/L which was very higher than the results obtained from our study. Further, in our study, no trend was observed from monitoring of upstream and downstream locations to confirm the impact of CHWTSDF on chloride contamination.

3.2.5 Sulphate

The concentrations of sulphate in the groundwater ranged from 14 to 64 mg/L, falling well below the acceptable limit of 200 mg/L of IS10500:2012 standards. Chofqi *et al*.2004 evaluated groundwater pollution in wells located near El Jadida landfill in Morocco and found that the mean sulphates values were 1000 mg/l which is very higher compared to the results of our studies. The sulphate concentration was also found to be comparable with the 2005 data which ranged from 6 mg/ L to 51 mg/L in the monitoring locations and no significant difference was observed to confirm the impact of CHWTSDH on contamination from sulphates.

3.2.6 Heavy metals

Heavy metals such as lead, cadmium, arsenic, nickel, and chromium are widely reported to be present in the landfill leachates and it becomes very important to monitor their presence in groundwater for potential contamination by landfill leachates. (Maiti et al 2006, Slack R et al., 2007, Singh et al., 2008, Ying Li, et al., 2012).

The analysis in the current study for heavy metals such as cadmium, chromium, copper, manganese, nickel, lead and zinc in the ground water samples showed that heavy metals were found below the detectable limits in the monitored locations.

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In similar studies carried out by Maiti et al., 2006 for groundwater contamination by leachate, mercury and lead were observed to present in high levels.

Levels of chromium and arsenic at the unsaturated zone/aquifer interface were found to be in exceeding levels of European Union and US-EPA drinking water standards, with presence of cadmium and mercury above minimum reporting values (MRVs) as reported by Slack R et al., 2007.

3.2.7 Nitrates and Phosphates

Nitrates and phosphates are essential nutrients required by plants and microorganisms for their physiological processes. However, they are considered harmful if their concentration exceeds prescribed limits in drinking water.

The BIS standards for drinking water prescribes nitrate concentration not exceeding 45 mg/L. Comparing to legacy data recorded by NEERI in 2005 showing higher concentrations of nitrates in certain locations in the range of 32 mg/L, 26 mg/L and 23 mg/L in Chinnaobulapuram, Annapanaikankuppam and Old Gummidipoondi respectively, the current study recorded lesser values of nitrates i.e. < 10 mg/L in all of the monitored locations. This indicates better agricultural management practices in the study area and its surroundings, where contamination due to inappropriate usage of fertilisers are reduced. Thus, all of samples tested were well within the drinking water limits for nitrate concentration indicating no nitrate pollution in the study area. Similar observations were made by Kumari et al.,2018 who reported that nitrate levels were well within the Indian drinking water standard limits. The reason was attributed to nitrates getting absorbed in nearby soil strata.

The assessment of phosphate concentration during 2005 and 2017 showed values lesser than 0.1 mg/ L in the present study, indicating no pollution due to phosphate concentrations in the groundwater.

3.2.8 Organic Pollution

The organic pollution in the ground water quality was assessed by monitoring the biological oxygen demand (BOD) and chemical oxygen demand (COD) in the ground water samples. *BOD* is the amount of oxygen required to biologically oxidize the organics, whereas *COD* is the amount of oxygen required to chemically oxidize organic matter in the water or wastewater. There is no prescribed limit given for BOD and COD in the BIS 10500:2012 for drinking water. However, concentrations of BOD and COD are expected to be zero or negligible in drinking water for safe consumption. The analysis of BOD and COD in the study area had values below detectable limits showing no organic pollution in the ground water. Also, as no legacy data on BOD or COD was available in the 2005 report, no comparison with the earlier data could be made. Results reported by Hassan and Ramadan, 2005 on impacts of sanitary landfill leachate on the groundwater also showed no organic contamination around the active cells of landfill in Egypt.

3.3 Analysis of Correlation between Physico-Chemical parameters using Pearson Co-efficient

Pearson's correlation matrices were used to find relationships between two variables of the physico-chemical parameters studied. Samples showing $r>0.7$ are strongly correlated (Qianlin Zheng *et al.*, 2017). The result of correlation analysis performed on the water quality variables are presented in Table-4. Most of the parameters tested exhibited significant correlation among each other indicating high influence on the characteristics of chemical constituents.

Table. 4. Pearson co-efficient (r) among various water quality variables

	pH	EC	TDS	Alkalinity	Hard ness	Cl-	SO_4	PO_4	NO_3	Ca	Mg	Na	K
pH	1.00												
EC	0.24	1.00											
TDS	0.24	1.00	1.00										
Alkalinity	0.54	0.00	0.26	1.00									
Hardness	0.28	0.35	0.44	0.33	1.00								
Cl-	0.12	0.82	0.86	0.11	0.44	1.00							
SO4	0.43	0.73	0.69	0.20	0.09	0.54	1.00						
Po4	0.08	0.61	0.61	0.02	0.17	-0.37	-0.01	1.00					
NO3	0.18	-0.23	0.23	0.04	-0.28	-0.46	-0.26	0.08	1.00				
Ca	0.13	0.73	0.73	0.13	0.83	0.85	0.32	-0.26	0.28	1.00			
Mg	0.12	0.66	0.66	0.14	0.75	0.64	0.42	0.03	0.22	0.87	1.00		
Na	0.42	0.82	0.82	0.26	0.21	0.81	0.57	0.11	0.32	0.78	0.73	1.00	
K	0.21	0.75	0.75	0.21	0.11	0.78	0.57	0.23	0.19	0.27	0.36	0.81	1.00

pH, electrical conductivity, and TDS showed positive correlation with all the parameters studied. Electrical conductivity was highly correlated with TDS, chlorides, sulphates, sodium, potassium, calcium, and magnesium etc. Subba Rao, 2002 reported that almost all analysed metals showed good correlation with conductivity, because conductivity increases with presence of metallic ions that aid oxidation-reduction reactions in groundwater aquifer system.

Calcium and magnesium presented a strong positive correlation (0.87), indicating a common source of origin. The correlation between Na-Ca (0.78) and Na-Mg was significant (0.73) showing strong cation exchange dependency between the ions. Chloride showed positive correlation with most anions and cations. The prevalence of hardness in the water was also evident from good correlation between calcium and chlorides (0.85) as observed in previous by Sana'a Odat, 2015.

3.4 Analysis of hydrochemical facies using Piper trilinear diagram:

Piper's plot was used to determine the ionic nature of the water samples collected from 23 locations (Figure.7).

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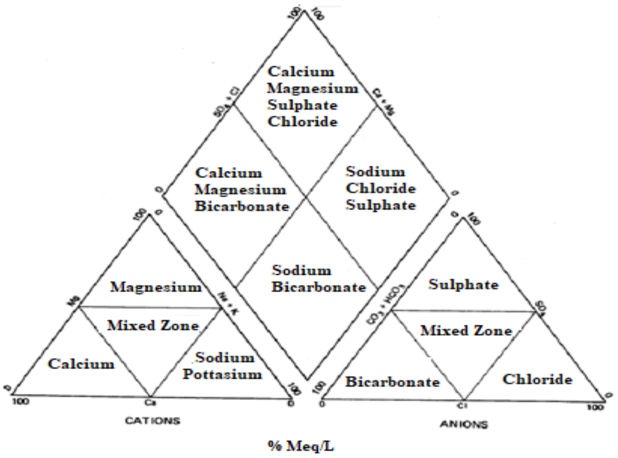
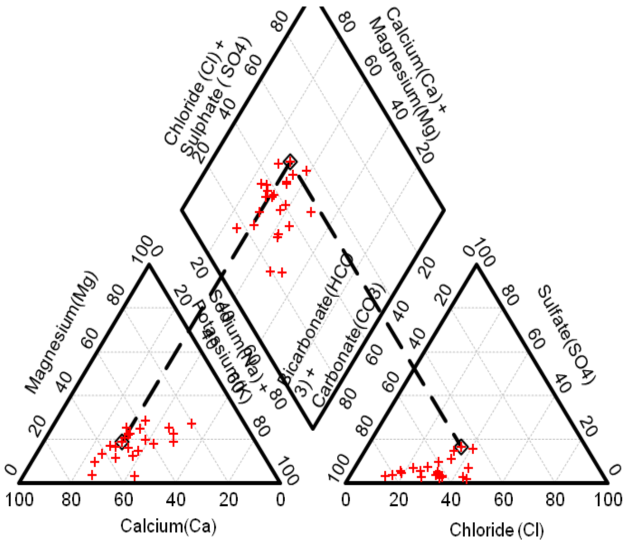
Based on the diagram a few inferences on the hydrochemical classification were made. It was evident that the bicarbonates and carbonates dominated the anions compared to chlorides and sulphates.

The plots also indicate a higher presence of Ca^{2+} in all the samples analysed. Using the classification scheme given in Figure 6. a &b, Piper's diagram classified all water samples into 'Mixed Ca^{2+} -Mg^{2+} - HCO_3^- type.

Despite the high alkalinity and buffering capacity of the groundwater in the study area, lesser pH (<7) observed in few sampling locations indicate possible leaching of anions from industrial discharges causing groundwater contamination.



a. Reference plot for ionic classification



b. Ionic classification of tested water

Figure 7. Piper plot showing hydrochemical classification

IV. CONCLUSION

A 3D ground water flow model created using VISUAL MODFLOW indicated that the water flow from the landfill site was predominantly towards the southeast direction. Based on predicted groundwater flow direction, downstream locations from the project site were monitored which showed that the water quality in the predicted vulnerable areas were not affected. However, slightly acidic pH values observed in the upstream locations raised concerns of possible groundwater contamination that would have been caused by illegal industrial discharges and aquifer contamination. The effect is observed to be nullified as the waterflows downstream and the acidity is neutralised with dilution and dispersion effects of water. The temporal analysis of pH values revealed that certain pockets of the study area were affected with low pH, even before the establishment of the landfill facility in 2007. The results thus suggests that the acidification of groundwater would have been caused by effluent discharges by the industries already present in the industrial estate and cannot be attributed the operations of common hazardous waste landfill facility. This necessitates stringent monitoring actions for treated effluent disposal and increasing emphasis on zero liquid discharges, such that any impact on groundwater quality can be avoided in future.

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