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Vulnerability Analysis of Ground Water in and Around MSW Disposal Site Mathuradaspura, Jaipur using Multivariate Statistical Techniques

Aruna Saini [α] & Priya Kanwar [σ]

Abstract- Dumping of municipal solid waste in an open dumping site is a big threat to the environment affecting all the natural resources. This threat reaches to groundwater through leachate which even though takes a lot of time to percolate, through the soil profile and rocks beneath, and reach the water table but once contaminated it is very difficult to clean the groundwater. This has given a motto to attempt a study on the groundwater quality analysis of the area in and around Mathuradaspura dumping site which is receiving around 500 to 600 tonnes of solid waste daily from Jaipur Municipal Corporation. The study was taken up during 2020 and about 26 water samples were collected from the dump site and its vicinity. These samples were analysed for basic quality parameters and heavy metals. The variability of water quality in the area was figured out by subjecting the parameters to multivariate statistical analysis including correlation analysis (CA), Principal component analysis (PCA) and Hierarchical Cluster Analysis (HCA). Correlation analysis and PCA helped in establishing the inter-relationship of the quality parameters and major parameters responsible for deciding the groundwater quality of the area and their possible causes, respectively. The PCA confirmed the results of CA by classifying the parameters into four principal components that area responsible for total 76% variance of hydrochemical data of the study area. The application of HCA has resulted into the formation of three clusters each of Q and R modes depending on dominant chemical composition which describes the spatial distribution of samples and the possible causes influencing the groundwater quality of the study area.

Keywords: groundwater, municipal solid waste, dumping site, water quality.

I. Introduction

Rapid urbanization, growing population and vast industrial development has affected all the natural resources that have resulted in stern environmental challenges and serious concern for the controlling and governing agencies.[1,2,3,4] These developmental processes and its related requirements are producing waste at even faster rates. The waste generated in these areas needs disposal sites which usually are open areas outside the municipal limits [5]. These sites if not designated scientifically poses threat to the air, soil, surface water and very badly to the groundwater if leachate from it percolates down [6]. The vulnerability of ground water, around an open dumping site, for getting polluted, increases many folds especially when it is an unscientific and unplanned site. [7,8]. Jaipur City is also facing similar problem of huge solid waste and also the solid waste generated in the Municipal area is being dumped in at open dump sites of Mathuradaspura and Sewapura [9]. The present study aimed at Mathuradaspura dumping site with an objective of to assess the degree of impact of the municipal solid waste on the groundwater of the area in the 2020. The groundwater samples as well as the identified chemical parameters were subjected to various statistical analysis to understand the inter-relationship among water samples as well as chemical parameters and the extent of contamination of groundwater of the area.

Multivariate statistical methods provide information from which cause-and-effect relationships can be established [10]. These methods are frequently employed to characterize the quality of groundwater as they effectively represent the data concerning groundwater pollutants and geochemistry [11]. The inter-relationship between any two quality parameters assessed through Pearson correlation analysis which is a bivariate method. A high correlation coefficient value (i.e., -1 or 1) predicts a good relation between two variables and correlation coefficient value around zero (o) predicts no relationship between them at a significant level of (p) of < 0.05[12]. Parameters showing $r > 0.7$ are considered to be strongly correlated whereas $r > 0.5$-0.7 shows moderate correlation and parameters showing $r < 0.5$ shows weak or no correlation [13,14]. Cluster and factor analysis are proficient ways of presenting the complex relationship among many samples [15,16]. To assess the chemical quality and establish the correlations between the groundwater samples collected and the chemical parameters that were analysed, well established independent and quantifiable approaches of Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA) were applied. The PCA is a very powerful tool used to reduce the dimensionality of large data set of interrelated variables into few factors called the principal components which can be interpreted to reveal fundamental data structure [17,18]. The hierarchical clustering is one of the most widely practical in Earth sciences [19], and often used in the categorization of

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hydrogeochemical data [20,21,22,23].The result of clustering is a Dendrogram representing the nested grouping of patterns and resemblance levels at which groupings change.

II. Study Area

Jaipur, capital of India's largest state Rajasthan, with a crown of "World Heritage City" also has a pride of one of the oldest planned cities of India. It was founded in 1728 A.D. by Maharaja Jai Singh was in an area of 6 sq.km has now expanded to an area of 532.7 sq.km. It has experienced vast expansion with exponential increase in population, industrial growth and other activities leading to urbanization. As per census 2011, the city has a population of more than 30 lakhs and many industrial areas have come up along with other amenities as a necessity of growing population. This noteworthy development has resulted in a major challenge of disposing the huge municipal waste. This municipal solid waste (MSW) of Jaipur City is being dumped at two sites viz. Mathuradaspura and Sewapura, located at a distance of 17 km in east and 20 km in north of the city. Another dumping site located in the north-east of Mathuradaspura was near village Langadiyawas where waste was being dumped till 2017 is now a passive site and is no longer in use [24]. This study was taken up to assess the impact of the waste being dumped at Mathuradaspura dumping site and to assess if the passive site is still contributing to the chemical quality of the area [25].

Mathuradaspura is a village located in Jamwa Ramgarh Block of Jaipur District located between East longitude 75°51'00" to 76°01'50" and North latitude 26°54'00" to 27 01'00" at distance of 19 km from Jaipur in the eastern direction (Figure 1). It has total geographical area of 3.65 sq.km and surface elevation of 370 m amsl. The total population of about 1000 persons and area is characterized mainly by agricultural crop land. It is drained by Dhund River which is ephemeral and flows from north to south.

The Mathuradaspura dumping site covers an area of about 0.44 sq.km located within the alluvial plain bounded by hillock on the eastern by forests on its western edge. The surface is gently sloping towards south-west.

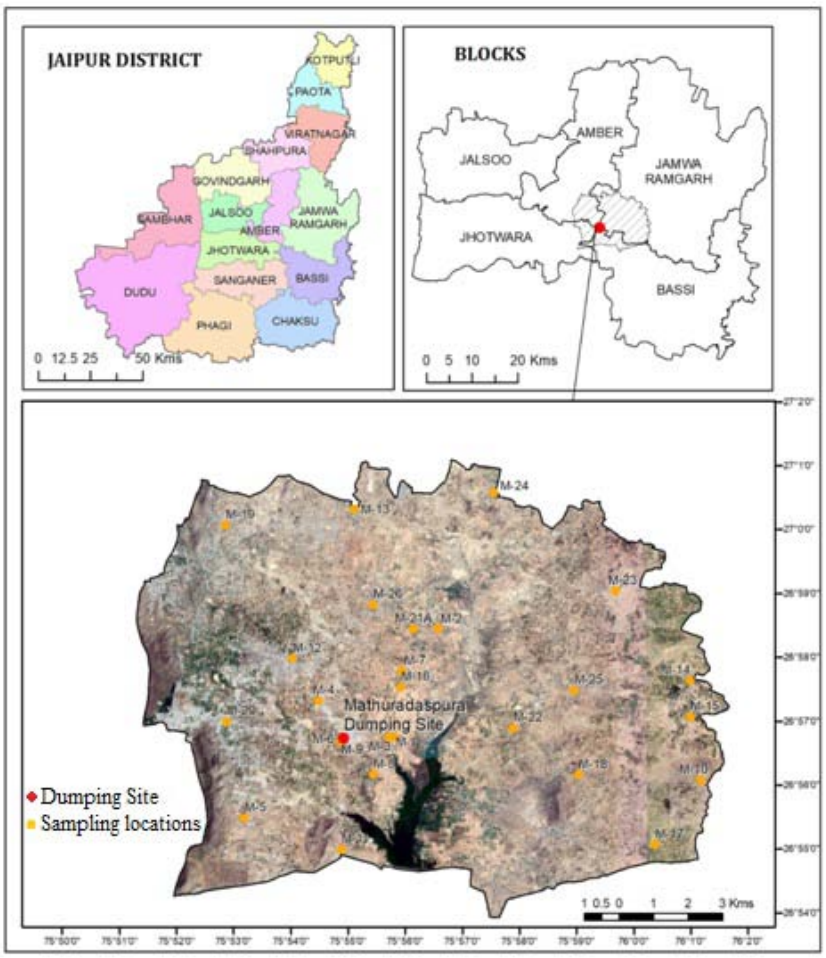


Figure 1: Study Area Map

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Almost 500 to 600 tonnes of waste are disposed at this open dumping site without any segregation or treatment as shown in figure 2. This un-segregated waste disposal at an open site imposes serious environmental issues. Liquid from wet waste and rainwater percolates through the waste and gets accumulated at the bottom of landfills from where it reaches the groundwater.

The aquifer in the study areas is mainly occupied by unconsolidated Quaternary alluvium where groundwater occurs under un-confined to semi-confined conditions in alluvial aquifers, whereas in hard rock aquifers groundwater in general, occurs under un-confined conditions. In hard rock aquifers, groundwater occurrence is controlled by thickness of weathered zone, size, continuity and interconnectivity of fractured zones and other secondary porosities. In general, the yield of wells tapping alluvial aquifers varies from 1.9 to 9.7 lps depending on the thickness of saturated granular zones and the yield of the wells tapping hard rock aquifers in ranges from 0.83 to 5.6 lps.



Figure 2: Mathuradaspura Dumping site

III. Sampling and Laboratory Analysis

To analyze the impact of uncontrolled and unscientifically dumped municipal solid waste on the groundwater quality, 26groundwater samples were collected from hand pumps and dug wells of the study area in May 2020.The samples were collected in 1L polyethylene bottles without preservation. The important in situ parameters such as temperature, electrical conductivity (EC) and pH were analyzed immediately at sampling site by using standard portable pH/EC meter (Hanna). The collected water samples were safely transferred to the National Accreditation Board for Testing and Calibration Laboratories (NABL) accredited laboratory of Central Groundwater Board, Western Region, Jaipur for analysis of various hydrochemical parameters by following the procedure specified in APHA [26]. Total Hardness (TH) and Calcium (Ca^{2+}) as $CaCO_3$ was analysed using titrimetric method with Ethylene-diamine-tetra-acetic acid (EDTA, N/50) and Mg^{2+} was estimated by calculation. Carbonate (CO_3^{2-}) and Bicarbonate (HCO_3^-) were measured by acid titration method and Chloride (Cl^-) concentration was measured by $AgNO_3$ titration method. The F^- concentration in groundwater samples analyzed by an Ion selective electrode (Model 781, Metrohm).UV-Visible spectrophotometer (Model 3200, Lab India) was used for determination of Sulphate (SO_4^{2-}) and Nitrate (NO_3^-) ions. Sodium (Na^+) and potassium (K^+) were analyzed using Flame photometer (Model-128, Systronic). Five most common heavy metals viz. Copper (Cu), Zinc (Zn), Nickel (Ni), Lead (Pb) and Iron (Fe) were analyzed by Atomic absorption spectrophotometer (PG Instruments). The ionic balance error for measured ions was within ±5%. The analytical results of physico-chemical parameters of groundwater were compared with the BIS [27] standard guideline values recommended for drinking water. The analyzed data was taken to the ARC-GIS V10.3.1environment for preparation of maps to analyze the spatial distribution and variation of various chemical parameters in the groundwater of the area. The degree of inter relationship, between the hydrochemical parameters, was identified by Pearson' correlation coefficient. The Pearson's correlation matrix was generated using SPSS 25.0 for windows. To characterize the groundwater quality in and around the dumping sites and to simplify and organize the large dataset for better understanding the interrelation of chemical variables the data was subjected to various chemometric techniques which includes statistical tools like PCA and HCA.

IV. Results and Discussions

The solid waste placed in landfills or open dumps are subjected to either groundwater underflow or infiltration from precipitation. During rainfall, the dumped solid wastes receive water and the by-products of its decomposition move into the water through infiltration. Once disposed off in landfill, solid waste undergoes various physico-chemical and biological changes. Therefore, the groundwater in the areas near Mathuradaspura dumping site, are more vulnerable to pollution. The groundwater in and around this dumping site is mainly used for domestic, agriculture and formation of bricks.

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V. Groundwater Chemistry

pH is a significant operational water quality parameter. There is an important observation, that pH values in almost all the water samples collected from the proximity of dumping yard is comparatively higher than the farther locations. It varies between 7.36 and 8.46 shows alkaline nature of groundwater of the study area. The highest pH value 8.46 was recorded at M-22 (Dangawara Khurd) in study area. The EC values of the groundwater samples ranges from 700 μS/cm in sample number M-23 to 5670 μS/cm in M-2 and the average value was 2299 μS/cm. Most of the samples had higher EC values > 1000 μS/cm and samples collected from tube-wells of the study area had higher EC values indicating the presence of more soluble salts. The TDS of groundwater ranges from 455 mg/l to 3686 mg/l with an average value of 1495 mg/l. Similar to pH and EC, 23% sampling locations in proximity of dumping sites viz. M-20, M-21, M-8, M-4, M-12 & M-2 have exceeded the permissible limit of 2000 mg/l TDS as specified by BIS for drinking water and is non-potable.

The total hardness, which results due to the presence of alkaline earths such as calcium and magnesium, varied from 50 mg/l to 1050 mg/l with an average of 308 mg/l in the study area. According to Swayer and Mc Carthy 1967 [28] classification about 65% of the groundwater samples fall under hard to very hard category. About 53% of the groundwater samples exceeds the acceptable limit of TH as prescribed by BIS viz. 200 mg/l and 11.6% of the groundwater samples exceeds the permissible limit of 600 mg/l. The concentrations of calcium(Ca^{2+}) in the groundwater samples ranges from 12 to 240 mg/l (average 51 mg/l) and magnesium (Mg^{2+}) values varies from 2.0 to 119 mg/l (average 44 mg/l). In few sampling locations lying in the vicinity of dumping yard viz. M-8, M-12 & M-20, Ca^{2+} and Mg^{2+} both exceeds the permissible limits which may be due to leachate infiltration or agricultural activities. Similarly, sodium concentration was found more than 500 mg/l viz. M-3 (590 mg/l), M-21 (690 mg/l), M-8 (700 mg/l), M-12 (770 mg/l) & M-4 (830 mg/l) in the areas lying in the close vicinity of dumping site owes to addition of Na^{+} from MSW and weathering of other silicate minerals. High concentration of sodium in drinking water may pose a health risk to persons suffering from cardiac attack, renal dysfunction and epidemics. The concentration of potassium range between 1.0 to 14.0 mg/l. Potassium is found to occur in very low concentrations in the groundwater of the study area.

Carbonate ion is not present in groundwater of study area, whereas bicarbonate ion is the most dominant anion. It varies from 281 mg/l to 988 mg/l. High chloride concentration in water is a direct indicator of water pollution in an aquifer. Chloride concentration more than 250 mg/l is generally objectionable for a municipal use. High Cl^{-} content in groundwater is likely to originate from pollution sources such as domestic effluents and fertilizers and is injurious to persons suffering from heart diseases or renal issues. The highest concentration of Cl^{-} was reported at M-12 (752 mg/l) and M-2 (1383 mg/l) which lies in close proximity to dumping site. 43% samples have exceeded the acceptable limits of Cl^{-} (>250 mg/l). Sulphate has various sources like animal sewage, by-products of industrial waste, fertilizers and natural deposits and by which it can mix with water and deteriorate its quality for various uses. Water samples from four observation wells (M-4, M-8, M-20 & M-25) exceeded the acceptable limit of 200 mg/l and two locations (M-2 & M-12) exceeded the permissible limit of 400 mg/l which may be due to drainage from farm and sewage effluents. Nitrate concentration greater than 45 mg/l is undesirable in domestic water supplies because of the potential toxic effects on young infants. The nitrate concentration ranges from 1.0 mg/l to 300 mg/l. The highest concentration of nitrate was found at the five locations (M-25, M-9, M-19, M-12 & M-20). These locations are located away from the landfill in the northeast direction. Fluoride concentration varies from 0.52 mg/l to 4.23 mg/l and 27% of the groundwater samples have fluoride concentration beyond the permissible limit of 1.5 mg/l. The median value of all the quality parameters is shown in figure 3.

Results of detailed physico-chemical analysis with statistical comparison of the groundwater samples is summarized in Table: 1

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Table 1: Descriptive statistics of measured parameters compared to BIS, 10,500 for drinking purpose

Parameter	Units	Minimum	Maximum	Mean	Standard deviation	BIS,10500 guideline		% of samples exceeding guide line	
						Accept-able Limit	Permissible Limit	Acceptable	Permissible
pH		7.36	8.46	8.02	0.26	6.5-8.5	NR	--	--
EC	μS/cm	700	5670	2299	1287.49	-	-	--	--
TDS	mg/l	455	3686	1495	836.87	500	2000	69.2	23.1
TH	mg/l	50	1050	308	200.31	200	600	57.7	11.6
Na^+	mg/l	23	970	399	248.13	--	--	--	--
K^+	mg/l	1.0	14	3.4	2.71	--	--	--	--
Ca^{2+}	mg/l	12	240	51	49.93	75	200	15.4	3.8
Mg^{2+}	mg/l	2.0	119	44	29.40	30	100	61.5	7.7
HCO_3^-	mg/l	281	988	665	200.31	--	--	--	--
Cl^-	mg/l	7.0	1383	325	317.57	250	1000	42.3	3.8
SO_4^{2-}	mg/l	2.0	458	125	138.7	200	400	15.4	7.7
NO_3^-	mg/l	0.0	300	48	71.52	45	NR	19.2	--
F^-	mg/l	0.52	4.23	1.34	0.73	1.0	1.5	42.3	26.9
Fe	mg/l	0.0	5.4	0.683	1.39	1.0	NR	23	--
Ni	mg/l	0.0	0.04	0.004	0.01	0.02	NR	11.5	--
Zn	mg/l	0.0	3.5	0.485	0.80	5.0	15.0	NIL	NIL
Cu	mg/l	0.0	0.10	0.008	0.02	0.05	1.5	4.7	NIL
Pb	μg/l	0.0	39.3	11.0	0.01	10.0	NR	42.3	NIL

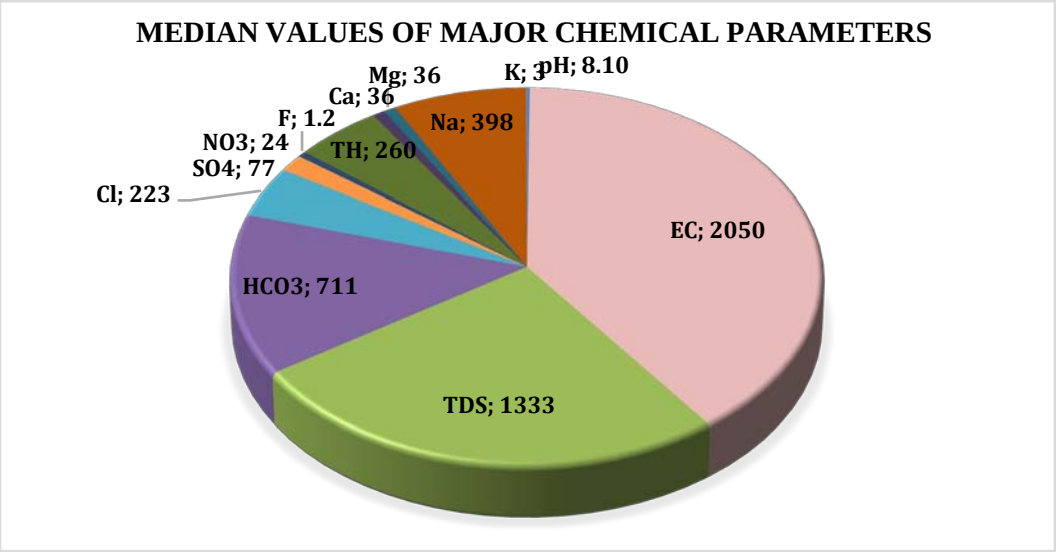


Figure 3: Pie Diagrams of Median values of cations and anions

The abundance of major cation concentration in the groundwater of the study area are in the order of $Na^+ > Mg^{2+} > Ca^{2+} > K^+$ shows that groundwater is dominated by alkali (Na) metal followed by alkaline earth (Ca & Mg). The anion chemistry of the analyzed samples shows that bicarbonate ion HCO_3^- is most dominating anion with the abundance order $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$.

Heavy metals are the key indicators of anthropogenic impact having various sources like traffic activities, road runoff, dry ash deposition from burning plants, industrial effluents and landfill leachate. Thus, the monitoring of heavy metals contamination will be important to assess the landfill impact on groundwater quality. The chemical analysis of groundwater shows that heavy metals i.e. Cu, Zn, Fe, Ni and Pb, found in

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remarkable concentration. The concentration of Ni at sampling locations MH-5, MH-7 & MH-16 has exceeded the acceptable limit (0.02 mg/l) in 11.5% of total groundwater samples.23% of total groundwater samples have Fe greater than acceptable limit 1.0 mg/l may be due to the iron and tin-based waste in landfill site. The maximum concentration of Pb is observed at MH-16 with 39.3 μg/l and in about 42.3% of total groundwater samples exceeded the acceptable limit 10.0 μg/l may be due to presence of Pb based waste like electronic waste and lead plated materials, which is significant in the study area. Concentration of Zn and Cu in the study area varies from BDL to 3.5mg/l and BDL to 0.10 mg/l respectively, which is not objectionable as per BIS standard.

VI. Statistical Analysis

a) Correlation analysis (CA)

To understand the relationship between the measured values of various parameters and to test the significance, coefficient of correlation (r) was used. The Pearson's correlation matrix presented in table 2 was generated using the dataset of 18 hydro chemical parameters (pH, EC, TDS, HCO_3^-, NO_3^-, SO_4^{2-}, Cl^-, F^-, TH, Ca^{2+}, Mg^{2+}, Na^+ K^+ Fe, Zn, Cu, Ni, and Pb).

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Table 2: Pearson's correlation matrix

	pH	*EC**	*CO3*	*HCO3*	*Cl**	*SO4*	*NO3**	*F**	*TH**	*Ca**	*Mg**	*Na**	*K**	*TDS*	*Fe*	*Ni*	*Cu*	*Zn*	*Pb*
pH	**1**																		
EC	-0.322	**1**																	
CO_3	0.347	-0.143	**1**																
HCO_3	0.277	**0.504****	0.067	**1**															
Cl	**-0.394***	**0.953****	**-0.16**	**0.272**	**1**														
SO_4	-0.442*	**0.881****	-0.18	0.229	**0.837****	**1**													
NO3	**-0.643****	0.289	-0.13	-0.079	0.233	0.471*	**1**												
F*	0.351	-0.055	0.023	0.195	-0.076	-0.172	-0.269	**1**											
TH*	**-0.728****	**0.595****	-0.23	-0.192	**0.667****	**0.753****	**0.688****	-0.28	**1**										
Ca*	**-0.646****	0.338	-0.14	-0.403*	0.475*	**0.509****	**0.621****	-0.2	**0.918****	**1**									
Mg*	**-0.687****	**0.758****	-0.28	0.06	**0.750****	**0.874****	**0.638****	-0.32	**0.912****	**0.673****									
Na*	-0.119	**0.958****	-0.06	**0.665****	**0.878****	**0.763****	0.113	0.046	0.347	0.087	**0.555****	**1**							
K*	-0.172	**0.524****	-0.08	-0.038	**0.603****	**0.523****	0.101	-0.24	**0.535****	0.488*	0.491*	0.409*	**1**						
TDS	-0.322	1	-0.14	**0.504****	**0.953****	**0.881****	0.289	-0.06	**0.595****	0.338	**0.758****	**0.958****	**0.524****	**1**					
Fe	0.064	-0.269	-0.1	-0.273	-0.206	-0.284	0.023	-0.19	-0.103	-0.039	-0.151	-0.288	-0.005	-0.27	**1**				
Ni	0.212	-0.179	-0.07	-0.093	-0.178	-0.121	-0.092	0.162	-0.17	-0.096	-0.216	-0.148	0.038	-0.18	0.134	**1**			
Cu	0.15	-0.222	-0.08	-0.247	-0.161	-0.231	-0.094	0.001	-0.051	0.015	-0.11	-0.262	0.15	-0.22	0.438*	**0.503****	**1**		
Zn	0.09	-0.19	-0.12	-0.277	-0.127	-0.131	-0.168	-0.1	-0.094	-0.095	-0.077	-0.205	-0.128	-0.19	**0.601****	0.084	0.37	**1**	
Pb	0.121	0.239	-0.17	0.181	0.237	0.16	-0.188	0.148	-0.001	-0.026	0.024	0.272	0.298	0.239	0.03	0.332	0.2	0.08	**1**

** Correlation is significant at the 0.05 level (2-tailed) ** Correlation is significant at the 0.01 level (2-tailed).*

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The correlation matrix describes the interrelationship between variables [29]. The matrix depicts that pH has low to moderate correlation with all the major and minor ions. Total dissolved solid (TDS) has very high positive 2-tailed correlation with same 0.05 significance with Na^+ (r=0.958, p <0.05), Cl^- (r=0.953, p<0.05), SO_4^{2-} (r =0.881, p <0.05) and Mg^{2+} (r=0.758, p <0.05) signifying the contribution of these major ions to the TDS of the groundwater and also their role in major geochemical processes. The total hardness by virtue of its origin has a very high positive correlation with Ca^{2+} and Mg^{2+} with same significance (r=0.918 and 0.912 with p <0.05), respectively.

Similarly, Chloride specifies high to moderate positive correlation with Na^+, SO_4^{2-}, Mg^{2+}, TH and K^+ (r =0.878, 0.837, 0.750, 0.667 and 0.603 with p <0.05) respectively signifying the role of leachate around the dumping site that has enriched the groundwater with these salts. The strong correlation of sulphate with Na^+, Mg^{2+} (r=0.763, 0.874 with p < 0.05) and moderate correlation with Ca^{2+} and K^+ (r=0.509, 0.523 with p <0.05) shows enrichment of sulphate via degradation of organic waste from topsoil and sewage infiltration in groundwater that is produced by municipal waste during and after rainfall along with fertilizer application from nearby agriculture areas [30]. Nitrate is also a good indicator of anthropogenic pollution and in the study area it shows a moderate correlation with calcium and magnesium (r=0.621, 0.638 with p <0.05).

Heavy metal distribution is closely related to organic matter and other pollutants in leachates [31]. As such there is no strong correlation within heavy metals and remaining variables in the used dataset, but matrix shows a moderate correlation with same confidence level within Fe and Zn (r=0.601, p < 0.05) and Ni with Cu (r=0.601, p < 0.05) which reveals that the sources of these metals may be same or there may be process based relationship.

b) Principal Component Analysis (PCA)

The method of principal component analysis is a special case of the more general method of Factor Analysis. The characteristic of PCA is to transform the original variables into new, uncorrelated (orthogonal) variables, called the principal components. These new variables are a linear combination of the existing variables [32]. The first four principal components (PC1, PC2, PC3 and PC4) absorb and accounts for the maximum possible proportion of the total variance in the data set. The factor loadings (value close to ±1) indicate strong relationship (positive or negative) between the variable and the factor. PCA technique extracts the eigen values and eigen vectors from the covariance matrix of original variables.

The principal component analysis (PCA) was computed using 17 variables (pH, TDS, HCO_3^-, NO_3^-, SO_4^{2-}, Cl^-, F^-, TH, Ca^{2+}, Mg^{2+}, Na^+ K^+ Fe, Zn, Cu, Ni, and Pb) for all groundwater sampling locations. After computation, 17 PCs were obtained, but only four PCs with eigen value greater than 1 are significant and considered, because higher the eigen value of a PC, the greater the contribution of that particular PC to the variability of the groundwater chemistry [33].PCA results comprising eigen values, percentage of total variance and % cumulative variance are summarized in table 3 and factor loadings in all four principal components is given in table 4.

Table 3: Eigen value, variability and cumulative % of each extracted components

Component	Eigen value	Variability (%)	Cumulative (%)
PC1	6.490	38.175	38.175
PC 2	2.999	17.640	55.815
PC 3	2.148	12.637	68.452
PC 4	1.277	7.510	75.962
PC 5	0.902	5.309	81.271
PC 6	0.800	4.704	85.975
PC 7	0.632	3.717	89.691
PC 8	0.515	3.028	92.719
PC 9	0.392	2.303	95.023
PC 10	0.336	1.976	96.999
PC 11	0.178	1.045	98.044
PC 12	0.172	1.010	99.054
PC 13	0.118	0.693	99.747
PC 14	0.042	0.250	99.997
PC 15	0.000	0.003	100.000
PC 16	7.591E-5	0.000	100.000
PC 17	-4.729E-16	-2.782E-15	100.000

Components in bold are considered to be the most significant

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The scree plot is a graphical method in which all eigen values are plotted in their decreasing order. The number of eigen values to the left of the point where the last substantial drop in the magnitude of eigen values appears suggests the number of components to retain [34]. The scree plot of the eigen values and components of the study area is presented in figure4.

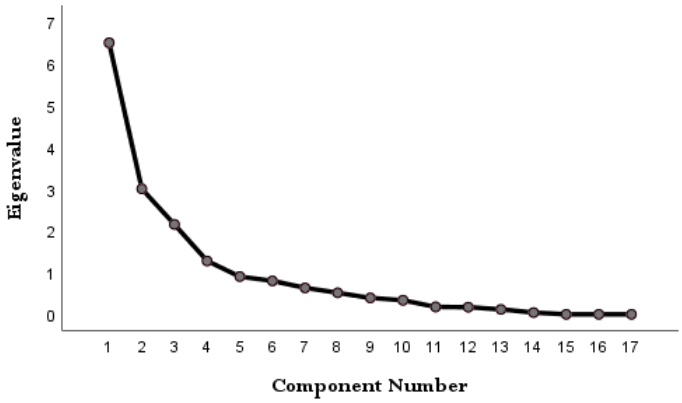


Figure 4: Scree plot of principal components

For the interpretation of factors, vaximax rotation technique is applied, which is the most popular rotation technique [35].PCA was calculated by using Varimax and Kaiser normalization method which extracted four main principal components cumulatively responsible for approximately 76% of the total variance in the hydrochemical data. Factor loadings are classified as 'strong', 'moderate' and 'weak' as per loading values of >0.75, 0.75–0.50 and 0.50–0.30, respectively [36]. The component plot in the rotated space is presented in figure 5.

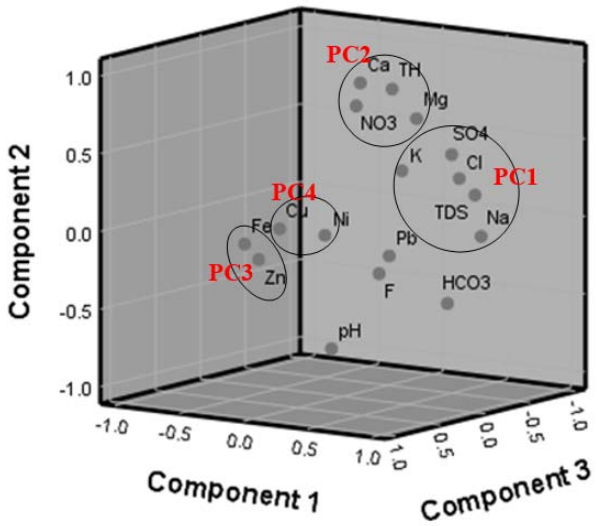


Figure 5: Component plot in rotated space for groundwater around the dumping site

The first component, PC1 with an eigen value of 6.49explains about 38.2% of the total variance and has strong positive loading (>0.75) for EC (0.95), Na^{+} (0.97), Cl^{-} (0.87), SO_4^{2-} (0.78) and moderate positive loading for Mg^{2+} (0.59) and K^{+} (0.50). PC1 thus corroborates with the results of CA that these major ions contribute positively to the total dissolved solids of the groundwater and decide the major water quality of the study area.

PC2 represents17.64 % of the total variance with an eigen value of approximately 3.0, which consists of a strong positive loading of TH (0.90), Ca^{2+} (0.91), Mg^{2+} (0.74) explained the direct relation of Ca-H and Mg-H that cumulatively contributes to TH of groundwater. Moderate positive loading of SO_4^{2-} (0.51) and NO_3^{-} (0.76) is due to sewage and anthropogenic activities in and around dumping site.

Component 3, PC3 having 12.63 % of the total variance with an eigen value of approximately 2.15. This

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component basically extracted because of two heavy metals Fe and Zn, have very strong loadings of 0.83 and 0.85 respectively.

Similarly, component 4, PC4 having 7.51 % of the total variance with eigen value of approximately 1.28 also extracted due to strong and moderate positive loadings of Ni (0.79) and Cu (0.68) heavy metals, favors the output of correlation analysis that the source and mobilization of these heavy metals is same. The presence of Fe, Zn, Ni and Cu in the study area could be attributed to the anthropogenic origin viz. domestic waste containing trash of these metals, industrial waste, atmospheric deposition and municipal sewage etc.

Table 4: Varimax rotated component matrix of groundwater samples

Variables	PC 1	PC 2	PC 3	PC 4	Communalities
pH	-0.093	-0.814	-0.005	0.212	0.716
TDS	0.949	0.265	-0.114	-0.036	0.984
HCO_3	0.629	-0.487	-0.263	-0.172	0.732
Cl	0.873	0.373	-0.046	0.037	0.905
SO_4	0.777	0.510	-0.099	-0.026	0.875
NO_3	0.065	0.758	-0.055	-0.173	0.612
F	-0.026	-0.387	-0.438	0.284	0.423
TH	0.378	0.905	-0.008	0.016	0.963
Ca	0.105	0.912	-0.043	0.127	0.860
Mg	0.594	0.742	0.030	-0.100	0.914
Na	0.970	-0.005	-0.152	-0.056	0.966
K	0.502	0.401	0.061	0.388	0.567
Fe	-0.185	-0.029	0.830	0.138	0.743
Ni	-0.163	-0.095	-0.032	0.792	0.664
Cu	-0.190	0.012	0.435	0.677	0.684
Zn	-0.065	-0.114	0.845	0.084	0.738
Pb	0.377	-0.165	0.023	0.630	0.567
Eigenvalue	6.490	2.999	2.148	1.277	
Variability (%)	38.175	17.640	12.637	7.510	
Cumulative (%)	38.175	55.815	68.452	75.962	

c) Hierarchical Cluster Analysis (HCA)

Hierarchical clustering analysis (HCA) is used for interpretation of data by clustering the samples and parameters that decide the geochemistry of particular study area. In clustering, Ward method with Euclidean distance is used to measure the similarity between various datasets. A graphical depiction of the hierarchical clustering along with the corresponding distance to reach a linkage is called Dendrogram. The dendrograms were prepared for Q mode considering the 17 variables and R-mode for all water samples.

d) Q- mode hierarchical cluster analysis

The emerged dendrogram shown in figure 6 reveals three distinct clusters for 17 chemical variables details of which is presented in table 5. These clusters suggest that there are three distinct sets of influences that affect the groundwater samples.

Cluster I signifies maximum variables viz. pH, Ca^{2+}, Mg^{2+}, K^+, SO_4^{2-}, NO_3^- and F^- which are perhaps due to the geogenic processes like weathering and dissolution of minerals and among heavy metals Fe, Zn, Pb, Ni, and Cu are expected due to the major anthropogenic contamination. Cluster II constitutes TH, Na^+, Cl^- and HCO_3^- which may be considered as carbonate hardness controlled cluster and gets impact from leachate infiltration. Cluster III represents of total dissolution of all ions (TDS) which is considered as salinity controlled cluster and helps to decide the degree of pollution of groundwater of the study area.

Table 5: Results of hierarchical cluster analysis of chemical variables

Cluster	Chemical variables
I	pH, F, K, Ca, Mg, NO_3, SO_4, Fe, Zn, Pb, Ni, and Cu
II	Cl, Na, HCO_3, TH
III	TDS

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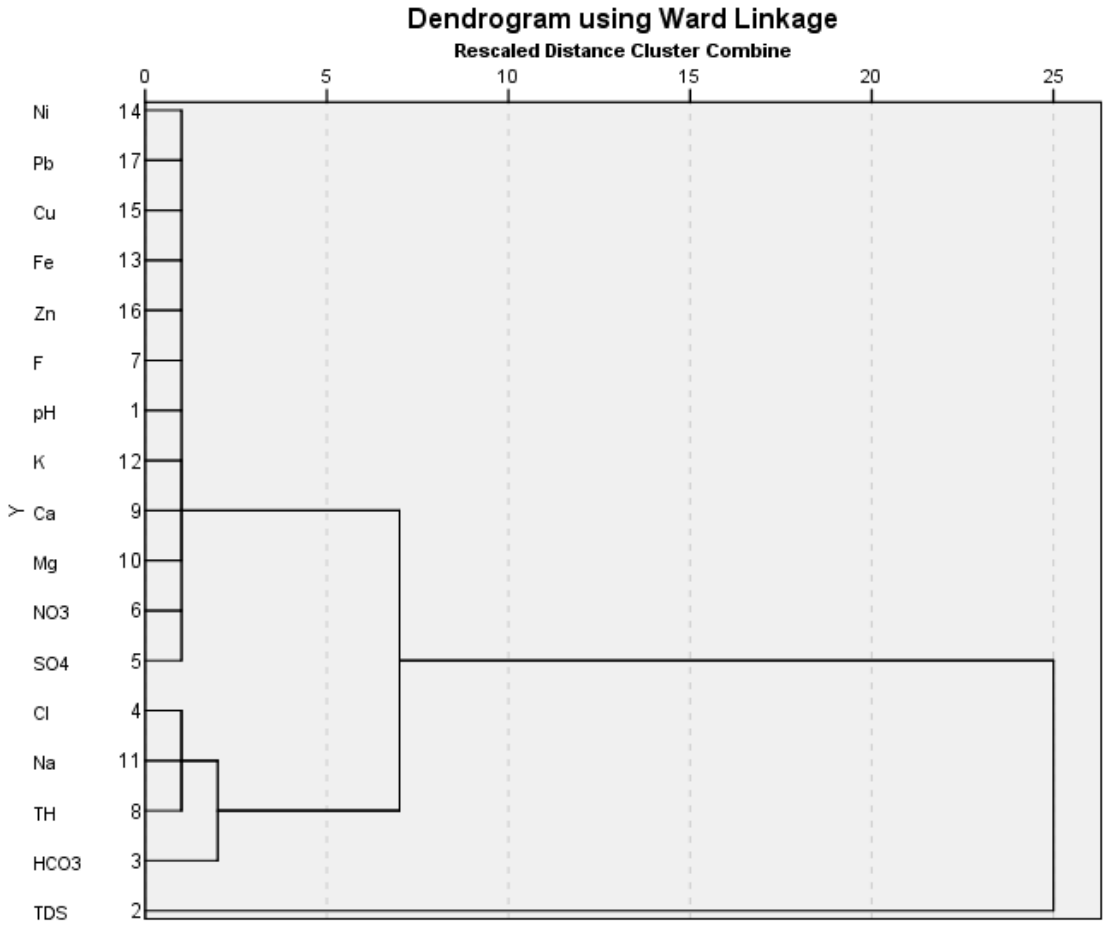


Figure 6: Dendrogram for 17 variables from cluster analysis in Q-mode

e) R- mode hierarchical cluster analysis

HCA of groundwater samples presented by Dendrogram for R mode analysis shown in figure 7 has also resulted in three statistically illustrated groups designated as Group I, Group II and Group III. Around 38.5% of the groundwater samples fall under the Group I, 46.2% under Group II and 15.3% under Group III. The average value for the quality parameters for each group is presented in table 6.

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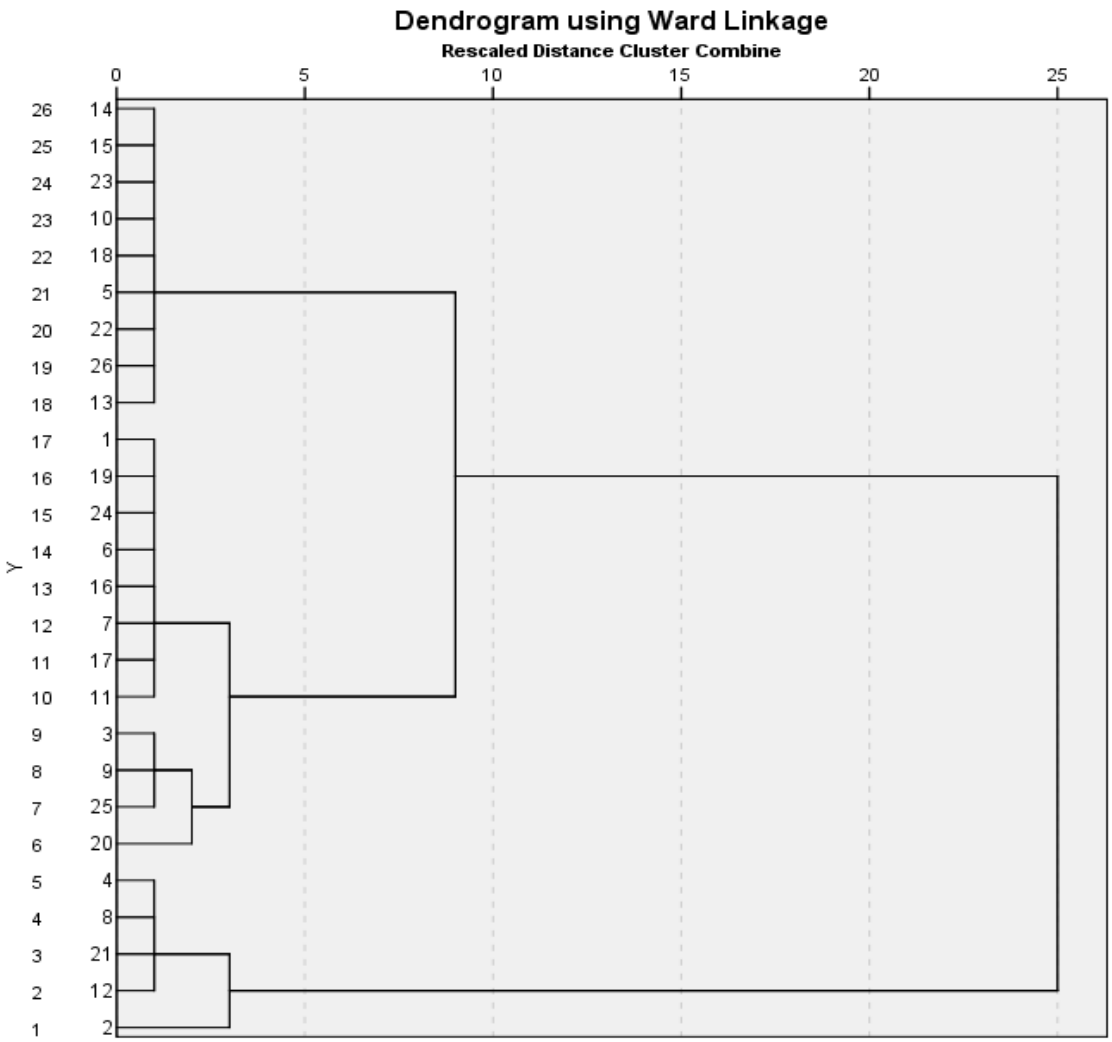


Figure 7: Dendrogram for 17 variables from cluster analysis in R-mode

Table of R mode reveals that Group I has 34.6% samples where the concentrations of all the parameters are within the permissible limit of BIS, 10500. Group II comprising 46.15% samples which have high average value of nitrate which is attributed to the anthropogenic pollution. In contrast to Group I & II, Group III is associated with very high TDS (average value 3019 mg/l) and also the concentrations of other chemical parameters exceed the permissible limits of BIS, 10,500. This group possesses high salinity and high concentrations of chloride, nitrate, calcium, and magnesium may be owed to excessive use of fertilizers in agricultural lands, dry ash deposition from burning plants, industrial effluents, domestic waste and landfill leachate.

Table 6: Average value for the water quality parameters for each Group

Group	pH	TDS	HCO_3	Cl	SO_4	NO_3	F	TH	Ca	Mg	Na	K	Fe	Zn	Pb	Ni	Cu
I	8.07	804	532	101	36	22.6	1.21	228	45	28.5	118	2.80	.989	0.60	.007	.006	0.01
II	8.03	1712	789	384	132	70.66	1.57	305	51	42.92	484	3.32	.559	0.32	.016	.004	0.01
III	7.82	3019	755	900	381	67.80	1.11	560	72	92.4	818	5.66	.077	0.55	.015	0.00	0.00

Bold indicates the highest average value parameters amongst different Groups.

VII. Conclusions

The chemical analysis of the groundwater samples collected from the study area revels the water quality of the area has an impact not only from the natural rock water interaction but also from the leachate generation from the dumping site which is infiltrating through the soil. About 65% samples are under hard to very hard category. TDS is very high owing to the major role of variables like Na^+, Cl^-, SO_4^{2-} and Mg^{2+} in turn contributing to the various geochemical processes. The positive correlation of Cl^- with Na^+, SO_4^{2-}, Mg^{2+}, TH and

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K^+ is indicating the impact of leachate. The infiltration and enrichment from organic degradation is reflected by SO_4^{2} with its strong correlation with Na and Mg and moderate correlation with Ca^{2+} and K^+. High Nitrate is directly pointing towards the anthropogenic actions. With the aid of PCA, total four PC's are extracted which account for 76% of total variance of hydrochemical data of the study area. PC1 decides the major quality of the groundwater of the study area having 38.2% total variance. PC2 has 17.64% total variance which has strong positive loadings of TH, Mg and Ca and moderate positive loadings of SO_4^{2-} and NO_3^{2-}. PC3 and PC4 having total variance of 12.63% and 7.51% having strong loadings of heavy metals Fe & Zn and Ni & Cu respectively. The dendrograms of Q and R modes classifies the chemical parameters and groundwater samples in three clusters each which directly indicates the alteration water quality of the study area not only geogenic but also due to intrusion of the contaminants generated by the anthropogenic activities in the area especially the dumping of Municipal Solid Waste. The three clusters formed in Q mode in HCA are affected by bicarbonate ion, salinity and hardness and TDS.

In wrapping up and arriving to the conclusion of all analysis indicates that lining system and collection of leachates followed by its proper treatment is required with regular monitoring of the air, soil and water quality parameters. Municipal corporation shall device apposite combination of technology to segregate the waste, make reuse of waste, processing of organic waste, restricting bio-medical waste disposal so as to minimalize the load on the dumping site. If not, these pollutants can be hazardous both for human health and agricultural products in irrigated areas.

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