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Impact analysis of solid waste disposal on open duming yards on leachate pollution: An investigation of the Hubli city

Suresh, B.; Madhu, J.; Aravinda, H.B.;

Department of Civil Engineering, Bapuji Institute of Engineering and Technology, Davangere – 577004, Karnataka, INDIA Affiliated to Visvesvaraya Technological University, Machhe, Belagavi, Karnataka 590018, India.

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Abstract: India's solid waste production processes along with features have drastically changed as a result of rapid industrialization, growth, and changes in lifestyle. To look into the impacts of leachate percolate on groundwater, samples of leachate and groundwater were obtained from landfills in Hubli, Karnataka, India. Certain physico-chemical factors and such as the content of heavy metals were measured using groundwater and leachate collections. The current analysis assesses the impact of leachate from Municipal Solid Waste (MSW) dumps on the groundwater quality in Hubli, the Indian state of Karnataka. The physico-chemical properties of leachate and groundwater samples were used to calculate the Leachate Pollutant Index (LPI) and the Water Quality Index (WQI). The leachate pollution index indicates that the leachate from the dump site is highly contaminated. The Hubli municipal solid waste disposal facility appears to be at a mature development stage based on the pH of 7.5 found in the leachate. WQI indicates percentage of groundwater that is good, poor, unsuitable for consumption by humans, and extremely bad is, respectively, 61, 23, 9, and 4%. The main component assessment yielded three basic components (cumulative variance: (80.4%), the first of which showed the largest percentage of variation (36%), suggesting the effects of human as well as natural factors. Hierarchical cluster analysis is used to display three distinct cluster types, types of water in the research location. Because leachate affects the availability of groundwater, it is advisable to construct a carefully built landfill site to avoid leachate from penetrating into the groundwater.

Keywords: Leachate, WQI, LPI, cluster, underground.

Introduction

Landfills are one of the main threats to groundwater sources, trash dumped in open landfills or dumps is prone to groundwater inflow or precipitation infiltration. Some of the breakdown products leak into the water traveling through the waste deposit when the first interstitial water in the deposited solid wastes gradually evaporates. A liquid with an infinite number of organic and inorganic components is called a ‘leachate’ (Alam *et al*., 2020; Naveen *et al*., 2018; Nagarajan *et al*., 2012). This leachate accumulates near the landfill's base as it percolates through the ground (Chatterjee, 2010). Groundwater contamination is more common in locations near landfills because leachate from the landfills may act as a source of pollution. Such contamination of supplies endangers the local resource users and ecology. There have been a lot of studies lately on how waste leachate affects surface and groundwater (Kamboj *et al*., 2020; Naveen *et al*., 2018; Mor *et al*., 2006). Many techniques have been used to assess contamination of subterranean water. It can be assessed by estimating the pollutants through mathematical modeling or by measuring them empirically (Saarela, 2003).

* Corresponding author E-mail: drbssmg@bietdvg.edu

In developing countries, municipal solid waste (MSW) is frequently disposed of improperly in open spaces, endangering the ecosystem greatly (Ogwueleka, 2009). Most MSW is frequently disposed of without any restrictions or safety precautions in low-elevation areas near cities. Dust, dirt, and 70–80% organic garbage make up the bulk of MSW from Asian cities. Non-biodegradable materials present in MSW, including plastics, textiles, and electrical gadgets, should not be used with sustainable methods of management (Das, *et al*., 2019). The MSW landfill site has been designated as a significant source of contamination for soil, groundwater, and water on the surface because to the seepage of leachate (Marshall & Farahbakhsh, 2013).

Rainfall, weathering, the terrain of the dumping areas, biological processes, and other hydrogeological elements all have a major impact on the leaching of MSW by 40 human activities (Hosseini Beinabaj *et al*., 2023). The physical and chemical characteristics of MSW and the pattern of flow into the groundwater determine how leachate pollutants diffuse and disperse into the groundwater. Forty-three leachate elements with rainwater have been shown to infiltrate groundwater due to the breakdown of waste components during rainy seasons (Abd El-Salam *et al*., 2015). Most cases of severe groundwater pollution are found within 200 meters of a dump site, and most cases of contamination of the groundwater are found within 1000 meters (Bharat & Singh, 2009).

The potential for leachate from the adjacent dumping site to pollute surrounding areas is a major factor contributing to the risk of groundwater contamination in areas near landfills (Buerge, *et al*., 2009).

Groundwater pollution poses a significant concern to both the surrounding ecosystem and neighborhood groundwater resource users. Due to the sharp rise in populace, research on the effects of landfill leachate on surface and groundwater has increased significantly in recent years (Slack, *et al*., 2005). The pollution of surface and groundwater can be evaluated by measuring the contaminants experimentally or by estimating them using mathematical modeling. The influence of leachate percolation on groundwater quality from an open landfill site in Hubli Dharwad, Karnataka, India, was calculated in the current study. In order to determine the potential connection between groundwater contamination and leachate, a number of physicochemical characteristics, particularly heavy metals, were examined in the collected specimens of groundwater (Buerge *et al*., 2009).

If MSW landfill leachate is not adequately collected, processed, and disposed of, it may seep through soil layers and enter aquifers, which is the primary cause of pollution of waterbodies (i.e., ground and surface). Making polluted groundwater safe to drink may be very expensive and difficult for its complexity of contaminants, Depth of Contamination and impact of contaminants are reasons (Bharat & Singh, 2009: Mor *et al*., 2006). When landfills lack leachate containment that is, collection as well as treatment mechanisms the problem is worse in developing nations. Therefore, in order to stop leachate from landfills from polluting the underlying soils and aquifers of groundwater, it is imperative to employ the appropriate treatment/remedial measures (Vasanthi *et al*., 2008)

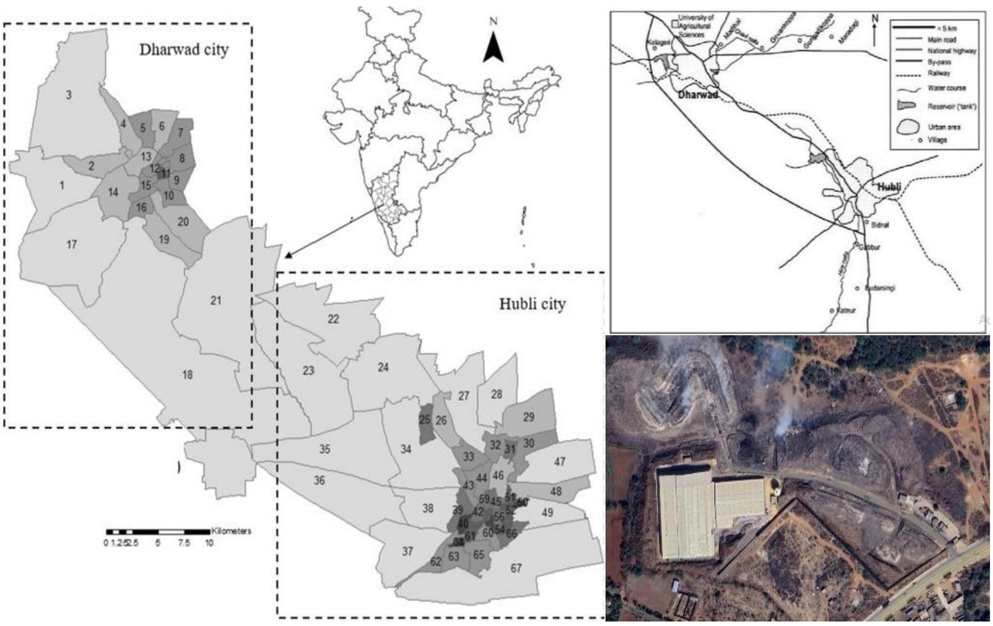

Figure 1: Map displaying the Hubli-Dharwad city's location.

In an area of 89.36 km^2, Hubli City has 1,596,123 residents as per the 2011 census. By 2008, 500 MT of solid garbage were produced daily in Hubli; 495 MT of the rubbish was collected daily. According to estimates, 25% of the garbage produced in the city is left uncollected at the source. By 2011, trash generation was expected to reach 735 MT/day at a rate of 0.41 kg/capita/day due to population growth (Swachh Bharat Mission: Solid Waste Management (Manual, 2016 & Census of India, 2011). According to Hubli Nagar Nigam (HNN) (2007), the overall makeup of trash is composed of other inert wastes (33.45%), recyclable materials (15.30%), and quickly biodegradable stuff (54.36%). These wastes are mostly made up of commercial garbage from stores and trading centers, street litter, garden waste, garbage from kitchens, and residential waste.

However, Hubli City's municipal solid waste management situation is now unacceptable. The Hubli Nagar Nigam (HNN) recommended creating a specially constructed landfill site gradually, taking into account wind rows, covered trucks for garbage collection, composting methods, and pelletised waste for use as industrial fuel (Figure 1) in order to appropriately dispose of waste.

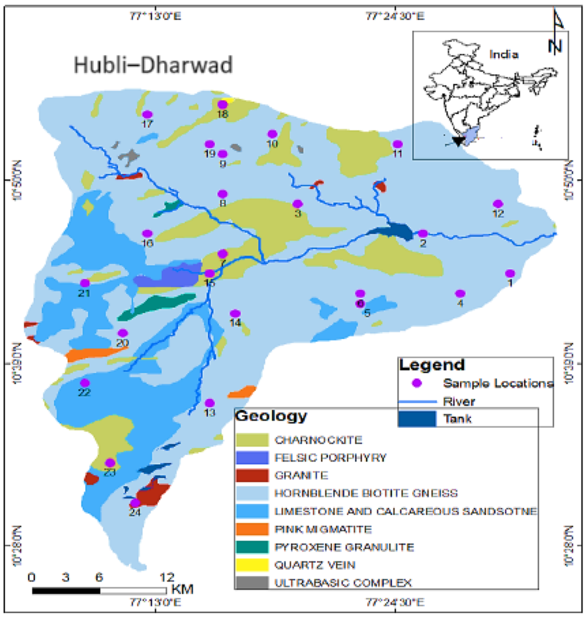

Figure 2: Location map of the studied area.

The bulk of the Hubli district's geologic formation, which is made up of Cretaceous, Tertiary, and Alluvial deposits. As seen in Figure 2, the study region is composed of clays, sandy clays, gravelly sandstone, and sands. The thickness of these formations ranges from thirty to 400 meters. The hydrological characteristics of each of these geological formations control the availability, distribution, and flow of groundwater. They produce irregular, unconfined, and semi-confined aquifers. The aim of the present study was to appraise the impacts of leachate percolation on groundwater quality in Hubli city.

Literature review

Many chemicals found in the leachate generated by waste disposal facilities have the potential to contaminate groundwater. It is possible to assess the effect of such sites on groundwater by the concentration of possible pollutants at many designated monitoring locations. The groundwater quality in the vicinity of a municipal solid waste disposal plant was examined in this study (Bhalla *et al.*, 2011). The groundwater monitoring shows how the leachate from the landfill site is affecting the neighboring areas' groundwater quality through subsurface percolation. It was noted that most of the parameters' concentrations were rising with time.

Mohan & Gandhimathi, (2009) examined the characterization of the solid waste and the groundwater effect of the leachate from the main dumping site in Perungudi, Chennai. The chemical and physical parameters that were determined were pH, total hardness, electrical conductivity, the total quantity of dissolved solids, significant cations like Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}, major anions like NO_{3}^{2-}, Cl^{-}, and SO_{4}^{2-}, and heavy metals like Pb, Cu, Mn, Cd, Cr, and Zn. Chennai Corporation supplies the Perungudi disposal facility with 1650 tonnes of Municipal Solid Waste (MSW) every day. The leachate is created when MSW breaks decomposed anaerobically. The examination of groundwater samples demonstrated that leachates from disposal sites provide a significant hazard to the adjacent aquifers.

Alao, (2023) assessed on effect of leachate on soil and groundwater quality using geophysical and physicochemical analysis of water techniques in dumpsite. Data collection at disposal sites and a sample station was conducted using geo-electrical resistivity. The impact of the landfill's leachate plumes on the soil and the quality of groundwater was examined.

Kanmani & Gandhimathi (2013) appraised the soil samples near the municipal solid waste (MSW) open dumpsite in Ariyamangalam, Tiruchirappalli, Tamil Nadu. The purpose of the sampling was to determine the concentration of heavy metals in order to understand the heavy metal pollution arising from leachate migration from an open dumping site. At the location, between 400 and 470 tonnes of solid municipal waste are disposed of. Solid waste characterisation was carried out on municipal solid trash, both current and older, in order to ascertain the basic composition of the waste that is disposed of at the disposal site.

Methodology

Bore and dug wells that are operational and consistently used for household and drinking reasons were chosen for sampling. Fifty groundwater examples and a five different leachate samples were collected in

April 2021 from the research region's bore wells (hand pumps) and solid waste disposal site. The sample bottles had been cleaned by first rinsing them in distilled water and then applying a 1 M solution of acid preservative. According to the instructions of WHO (2012), samples of water from hand-pumped bore wells were collected after ten to fifteen minutes of pumping in order to remove any standing water. While metal samples were collected in separate clean plastic bottles, filtered, and acidic using nitric acid to a pH below 2.0 to minimise precipitate and adsorption on container walls, major anions as well as cations were evaluated in water samples collected in polyethylene plastic bottles.

50 millilitres of the leachate sample were digested in 10 millilitres of a concentrated form of HNO_3 at temperatures of 80 degrees Celsius until the solution became clear in order to assess the concentration of heavy metals in the sample (APHA 2005). 100 millilitres of distilled water were subsequently added to the mixture after it had been run through the Whatman filter paper to restore volume (Bashir et al., 2009). The concentrations of iron (Fe), chromium (Cr), cadmium (Cd), zinc (Zn), lead (Pb), manganese (Mn), and arsenic (As) in leachate and groundwater were measured using atomic absorption spectroscopy (Nagendran *et al*., 2006; WHO, 2012).

Meters measuring electrical conductivity (EC) and pH were used, respectively. Using the conventional approach, the EC meter was also used in the field to measure total dissolved solids (TDS). Using an Orion ion selective electrode 4 Star, fluoride (F) was measured. The open reflex digesting technique was used to estimate the Chemical Oxygen Demand (COD), and the Winkler method's azide modification was used to estimate the Biological Oxygen Demand (BOD). The computed equilibrium of charges of the anion and the cation was typically (APHA, 2005).

Results and discussion

1. Characterisation of leachate and chemistry of groundwater

The leachate's physico-chemical characteristics are mainly determined by the water content and waste makeup. In order to characterise the leachate, a sample was taken in April 2021. Table 1 displays the leachate. The pH of the leachate from a landfill sample is 7.5. Leachate is commonly stated to have a pH range of 4.5 to 9. The pH of juvenile landfill leachate is less than 6.5, but the pH of aged landfill leachate is higher than 7.5. Bahaa-eldin *et al*. (2010) reported that the average value of pH was 6.7 for the municipal landfill leachate in Malaysia indicating the young leachate and the waste degradation was at its late stage of acidic phase. Since the considerable amount of volatile fatty acids, the initial stages of leachate production have a pH of less than 6.5. But volatile fatty acids are converted into the gases carbon dioxide and methane during the methanogenic stage, which makes the leachate's pH alkaline. The alkaline content of the leachate indicates the dumping site's maturation to old phase.

Chen (1996) studied the effects of landfill age and rainfall on landfill leachate in Taiwan, the results showed that BOD and COD concentrations (296 and 3340 mg/l, respectively) were below the values of the present study and indicated that the leachate had reached the mature stage. Studies have indicated that there is a great deal of variation in the content of landfill leachate, both from the same and distinct sources. In the current study, BOD ranged between 9260 and 10,800 mg/l with a mean value of 9,936 mg/l and COD values ranged between 11,980 and 15,470 mg/l with an average of 14,432 mg/l. Ratio of BOD5/COD (0.68) indicated that the leachate had high biodegradability through anaerobic phase. Numerous variables, including because of the release of large resistant organic molecules from solid waste content of the solid waste, the dimensions and level of compaction of the particles, the hydrodynamics of the site, the age of the landfill, the temperature and moisture conditions, and the amount of accessible oxygen, affect the pace and features of leachate generation. The age of a landfill has a big impact on how much leachate forms there. The pH range of 3.7 to 6.5 seen in leachate created in landfill during the first five years of rubbish deposition suggests the existence of ions made up of carboxylic and bicarbonate acids. In the current study reveals that, Hubli, a city that is growing quickly, has inadequate solid waste management (SWM) and inadequate disposal of solid waste facilities, which increases the risk of contamination to both surface and groundwater. Previous studies have shown that the increasing urbanisation is resulting in human influences on weathering rocks, which are subsequently degrading groundwater quality.

The solid waste disposal plant in Hubli appears to be in an advanced stage of development based on the pH found in the current study. Fifty groundwater samples were haphazardly taken at and around the solid waste disposal site. Leachate from the landfill is gravely polluting the groundwater of nearby wells, according to a thorough analysis conducted to determine the consequences of collecting of solid waste from municipalities on groundwater in Hubli. This finding confirmed the results of the present work where the range of conductivity extended from 36,750 to 41,798 µS/cm with a mean value of 39,846 µS/cm and the mean value of dissolved inorganic solids was 26,578 mg/l.

The mean concentration of heavy metals and major ions in the leachate and groundwater from samples collected at different radial distance from the landfill is shown in Table 1. Similar results were obtained by Hassan & Ramadan (2005) who reported the mean values of Zn and Mn were 0.724 and 0.730 mg/l, respectively. Higher results were obtained by Olivero-Verbel *et al.* (2008) who studied composition and toxicity of leachates from a MSW landfill in Colombia and found that the Ni concentrations ranged between 0.173 and 0.359 mg/l. The results identify the landfills as the point source of all pollutants since groundwater flows away from the site and pollution concentrations sharply decline as one walks away from them. However, the research area's perimeter (>3.5 km) has significant concentrations of EC, TDS, Cl, NO3, and Na because of localised human sources such agricultural activities, animal excrement, pesticide and fertiliser usage, and localised home waste pollution (Igbinosa & Okoh, 2009).

Table 1: Groundwater samples from surrounding areas in the Hubli region and the leachate characterisation of the dump site.

Parameters	Concentration in landfill Leachate (mg/1)	Groundwater Sample Harmony at a Radial Distance from the Landfill			
pH	9.5	<1.5 km	1.5-2.8 km	2.8-3.8 km	< 3.8 km
TDS	15,605	9.89	9.8	9.8	9.4
Na	9,178	1469	986	478	549
EC (µs/cm)	1690	549	749	659	216
Ca	809	518	1.59	88.96	240
K	840	94	94.8	64.52	54
CI	149	9.58	57.96	62.62	6.5
HCO_3	215	140	165	22.6	214
NO_3	590.89	589	22.65	2.61	13.65
SO_3	218	59.89	10	2.49	225
F	0.9	0.51	55.4	1.59	1.8
PO4	15.59	2.98	1.59	6.5	1.98
SiO2	559	55.8	64.28	2169	359
Fe	109	49	69.94	214	6.98
TH	890	5.96	6.51	1.96	99.2
Cr	0.95	0.987	0.25	0.51	0.21
Zn	0.08	0.085	0.89	0.96	0.54
Pb	00.9	0.541	0.96	0.84	0.58
Mn	5.96	0.95	0.47	0.63	0.96
As	0.489	0.21	0.89	0.51	0.21
Cd	10.90	0.98	0.96	0.88	0.01

2. Leachate Pollution Index (LPI)

One method for estimating the potential for contamination from leachate at dump sites is the leachate index (LPI). The LPI, which is based on several leachate pollution parameters at a certain time and has a hypothetical range of 5 to 100 (like a unit), expresses the entire contamination from leachate potential of a landfill. A minimum number of 5 units of leachate pollutant ensures that the LPI value does not fall to zero, even in situations when certain pollutants do not demonstrate any pollution. An increasing scale index, where a larger number (LPI >35) indicates a poor ecological situation (Kumar & Alappat, 2005). Calculation of sub-index values: Table 2 uses the sub index curve to quantify the LPI, Bpi, and sub-index rates for each pollutants variable. The Bpi values may be obtained by locating the leachate pollutant sub-index score where the horizontal axis of the relevant sub-index curves intersects with the leachate concentrations of chemicals.

Table 2: The Leachate Pollution Index (LPI) for the landfill in the vicinity of Hubli.

Leachate Characteristic	Observed values except pH	Individual Pollution ratings (p_i)	Significant	Pollutant weight (w_i)	Overall Pollution Ratings (p_i)
TDS	9.8	4.8	9.896	0.518	0.949
BOD	8900	18.96	3.968	0.849	0.14
COD	4989	18.98	9.89	0.50	0.989
Ammonia Nitrogen	1498	29	0.896	0.842	3.8
pH	1499	58	9.898	0.548	9.589
Total Iron	549	59	48.95	1.08	15.59
Zinc	984	46	3.065	0.609	5.965
Total Chromium	90	9.0890	6.541	0.559	9.589
Lead	46.99	99	9.590	0.210	4.098
Arsenic	1.059	45	3.690	0.549	0.659
Chloride's	0.69	96	5.496	0.650	5.690

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

Classification of water quality for residential use a straightforward and practical technique for determining a decline in water quality is the Water Quality Index (WQI). WQI enhances the efficacy of preventative actions and aids in the better management of water quality concerns (Longe & Balogun, 2010). It is a crucial factor in determining whether water is suitable for drinking. The drinking requirements as suggested by BIS 10500 (2003) have been taken into account while calculating WQI Table 3.

$$W_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \ldots\ldots\ldots\ldots 2$$

Table 3: Chemical variables' relative weight.

Chemical Parameters	BIS (mg/1)	Weight (W_i)	Relative weight (W_i)
Ca	320	6	0.096
Mg	79	4	0.097
Alkalinity	30	5	0.2196
CI	210	9	0.2968
TDS	246	6	0.596
F	218	9	0.896
NO_3	0.2	9	0.589
SO_4	54	7	0.416
PO_4	0.9	4	0.222
K	0.6	5	0.650
Na	0	6	0.050
Silicate	0	1	0.549
		$\sum w_i = 98$	$\sum w_i = 1.59$

$$q_i = \left(\frac{C_i}{S_i}\right) \times 100 \ldots\ldots\ldots 3$$

$$SI_i = W_i \times q_i \ldots\ldots\ldots\ldots 4$$

$$WQI = \sum SI_i \ldots\ldots\ldots\ldots 5$$

3. Principal Components Analysis (PCA)

Numerous variable analysis of statistics Multivariate methods of statistics help reduce the dimension of information and collect relevant data for the assessment of water quality when it comes to the categorisation, modelling, and interpretation of large datasets from environmental surveillance programs. This method of classifying groundwater is quantitative and independent, enabling connections to be made between chemical characteristics and samples of ground water as well as the grouping of samples. This study employed Principle Component Analysis (PCA) and Hierarchical Clustering (HCA), two multidimensional statistical approaches that were carried out using IBM SPSS statistics versions 19.0.1

PCA was used to help locate the sources of the contaminants. In order to analyse correlations between the variables that are visible, it is frequently used to reduce data and extract a limited number of latent elements (principal components, or PCs) (Ouyang *et al*., 2005). This data transformation technique looks for basic structural elements that a multivariate dataset is thought to contain. Table 4 shows the principal components loading for each of these variables with a variance. Three component shows a small number of high loadings that are either positive, negative, or close to 0.

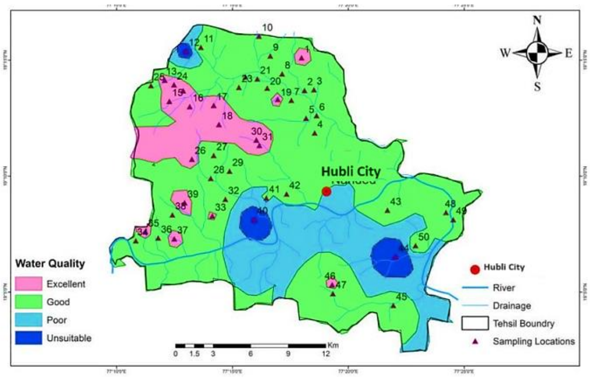

Figure 3: The dump site's surroundings and the water quality index's spatial dispersion.

Table 4: PCA loadings of important principal component variables (N = 21).

Parameters	Component Matrix Rotation		
	Component 1	Component 2	Component 3
Ca	-0.989	0.965	-0.965
K	0.059	0.094	-0.972
Na	0.962	0.049	-0.049
HCO3	0.098	-0.099	-0.090
CI	0.049	-0.895	-0.049
Mg	-0.089	-0.089	0.549
PO_4	0.690	0.596	0.004
F	0.549	0.659	0.096
SiO_2	0.595	0.896	-0.049
TH	0.499	-0.496	-0.549
Alkalinity	0.596	0.001	-0.512
EC	-0.416	0.041	-0.849
pH	0.965	0.549	0.074
TDS	0.890	0.549	0.579
Eigen Value	8.964.0	1.8	1.9
% of Variance	69.0	19.5	14.0
Cumulative %	36.6	45.69	98.8

4. Hierarchical Cluster Analysis (HCA)

The most popular multivariate statistical approaches in environmental research are HCA. It is used in the process of classifying hydrogeochemical data. HCA permits the categorisation of groundwater collections based on chemical structural similarities. Unlike PCA, which often uses two or three PCs for display, cluster analysis utilises all of the variation or information included in the original data set (Lkr *et al*., 2020). The dendrogram was visually inspected and used as the basis for categorising 21 groundwater data Figure 4.

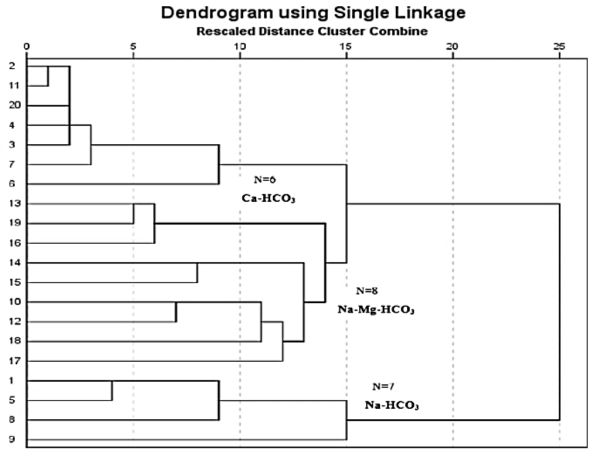

Figure 4: Groundwater samples hierarchical dendrogram (N = 21).

Six samples that are clustered together in cluster 1 have minimal levels of pollution. These samples had low TDS values, ranging from 320 to 424 mg/l.

Cluster 2 consists of eight samples that share locations that are significantly polluted. Members of this cluster include water types of Na, Mg, and HCO_3, with TDS values ranging from 349 to 591 mg/l, indicating a moderate level of salt. This type of water is sometimes referred to as mixed water (Ouyang, *et al*., 2005).

Seven samples are clustered in cluster 3, which is defined by locations near a landfill that was discovered to be extremely contaminated as a result of the input from home and agricultural trash. Their TDS levels range from 365 to 794 mg/l, indicating a high salinity. Cluster 3 of the analysis focused on a type of water that was primarily classified as Na–HCO_3. HCO_3 should be the most prevalent anion in the groundwater if Na is mostly obtained via the weathering of rocks (Tripathi *et al*., 2019).

Conclusion.

Based on the current study's findings, it is determined that the groundwater quality around Hubli City's Dharwad landfill is gradually declining as a result of landfill leachate leaching, and that the area is unsafe for drinking because the majority of the physico-chemical parameter values exceed the WHO and BIS recommended permissible limit of drinking water standards. The majority of the pollutants had positive loading, according to factor analysis, MSW has an influence on groundwater quality. Groundwater is essential for providing water to both urban and rural areas in emerging nations. Leachate from the municipal solid waste dumping plant has significantly contaminated the groundwater near wells, according to the facility's effects.

It has been established that the HDMC dumpsite is a municipal solid waste landfill that is not designed. The dumping yard does not have a bottom liner, leachate collecting system, or treatment system available. Consequently, the leachate that is generated finds its way into the environment. Moreover, leachate, which is produced when unsorted municipal solid waste is dumped in an unlined landfill, degrades the quality of groundwater.

Numerous wells situated at a significant distance from the disposal site exhibited no alterations in their quality of groundwater. The Hubli landfill's leachate has a lower viscosity due to the low concentration of contaminants such as TKN, BOD, Cl, and COD, which suggests a moderate value of LPI. Only 9% of the samples from groundwater are deemed unsafe for consumption by humans, compared to the WQI, with a majority of samples being of acceptable quality. Multivariate statistical approaches (PCA and HCA) using a groundwater sample show that the top four PCA component explain 80.4% of the overall variance in the dataset.

The natural and anthropogenic component, or PCA, is the first component and is linked to the dissolution of soil and minerals in various rock types and sediments. Strongly positive loading in EC, TDS, alkaline levels, and HCO3 are its defining characteristics. Using cluster analysis, the 21 sample locations were divided into three clusters according to common characteristics. This process helped to uncover trends in water quality and the sources of contamination. The pH of the leachate from the Hubli dumping site indicates that it is a recognised disposal location. It is recommended that in the future, an engineered disposal site be created in order to control the impact of leachate on the groundwater in the hydrological region.

Because of its high water quality, this study might be very helpful in the future in protecting groundwater supplies near the open MSW dump site from being harmed. The modelling method might be helpful for assessing the long-term emissions of the pollutants from MSW leachates as well as for safeguarding groundwater supplies.

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