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Physiochemical, Bacteriological, and Heavy Metals Assessment of Groundwater Quality Near Solid Waste Dumping Site

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Abstract

This study has investigated the impact of dumping sites on groundwater quality in Hazar Khwani, Peshawar, Pakistan. Twelve water samples were randomly selected, with four reference samples collected far from the dumping site and eight representative samples taken within a one-kilometer vicinity. These samples were analyzed for physiochemical parameters and fecal contamination. The results showed that mean values for pH, total dissolved solids (TDS), electrical conductivity (EC), total hardness (TH), chloride (Cl), and total alkalinity (TA) are from 6.13 to 6.83, 657.92 to 2392.2 mg/L, 696.91 to 2658 µS/cm, 394 mg/L to 1030 mg/L, 32 to 573 mg/L and 318 to 716 mg/L respectively. The mean concentrations of heavy metals for zinc (Zn), cadmium (Cd), chromium (Cr), copper (Cu), and nickel (Ni) were from 0 to 0.018 mg/L, 0.01 to 0.087 mg/L, 0.04 to 0.142 mg/L, 0 to 0.08 mg/L, and 0.02 to 0.09 mg/L, respectively. Total and fecal coliform contamination was found in 7 out of 12 water samples. The analysis revealed negative correlations between distance and TDS, EC, chloride, Cd, Cu, Cr, and Ni, with particularly strong negative correlations observed for Cd, Cu, and Cr. Depth was negatively correlated with pH, TH, TA, Cu, and Zn, but positively with TDS, EC, chloride, Cd, and Ni. Strong positive correlations were found among TDS, EC, TH, and chloride, and between Cd-Cu, Cd-Cr, and Cu-Cr. Negative correlations were seen for Cd-Ni, Cu-Ni, Cr-Zn, and Zn-Ni. The samples that surpassed the Pak-NEQS and WHO limits had 75% TDS, 58% TA, 8% Cl, 42% TA, 92% EC, 67% Cd, 67% Ni, 83% Cr, and 58% bacteriological contamination. To reduce any negative effects, waste disposal should be properly monitored.

***Keywords*: Investigation; impacts; Hazar Khwani; fecal contamination; negative effects.**

1. Introduction

Water is the most fundamental necessity for life and survival (Panditet et al., 2023). Solid waste disposal sites release leachate into the water, thereby affecting the quality of groundwater (Abiriga et al., 2020; Wu et al., 2014). Water is contaminated by solid waste because it forms a liquid called leachate, also known as waste juice, which passes through materials and dissolves soluble inorganic and organic waste (Lindamulla et al., 2023). Toxic heavy metals have been known to be released from municipal solid waste disposal sites into the soil and aquatic life through leachates, endangering surrounding lands and groundwater before reaching surface water. It may accumulate toxicants to the point of underlying surface and groundwater contamination, which could have detrimental consequences on the ecosystem and public health (Tope et al., 2024; Sarma Bora et al., 2023).

Management of solid waste is a major issue worldwide as a result of industrialization and population growth, and the volume of waste is increasing (Wu et al., 2014). The most common and oldest solid waste strategy is to dispose of waste in open landfill areas (Patil et al., 2013). These old strategies of solid waste disposal have been criticized for being unscientific, environmentally unfriendly, and chaotic (Gupta et al., 2019). Several types of environmental and health problems, such as the production of leachate, which pollutes subsurface water and soil due to improper solid waste management. The disposal sites produce bad smells as well as providing a good environment for several disease-carrying vectors, such as mosquitoes and flies (Nizami et al., 2015).

Human/animal waste, mining activities, overutilization of fertilizers and pesticides, domestic, municipal, industrial wastes with incorrect treatment, and the dispensing of hazardous metals are the primary reasons for the contamination of ground and surface water (Reza et al., 2011). In the last ten years, contamination of groundwater has increased a lot, and it has become an utmost concern for the environment. With the growing population, the amount of garbage produced has also increased, making it the biggest environmental problem today. People started to leave trash anywhere, and that waste started to harm the ecosystem (the quality of the drinking groundwater in particular) the most (Riaz et al., 2016).

Improper disposal of municipal solid waste (MSW), a widespread issue in developing countries, presents a risk to both the environment and human health. The rapid growth of industry, urbanization, and population is a major contributor to the increasing generation of MSW (Sarma Bora et al., 2023). Management and disposal of municipal solid waste and associated activities in developing countries are facing several problems (Abiriga et al., 2020; Lindamulla et al., 2023; Hredoy et al., 2022). Numerous researchers across the world have implemented different methodologies to investigate the effect of solid waste on groundwater quality. Several scientists revealed that the deterioration of groundwater properties and landfill relationships (Longe et al., 2010; Abd El-Salam et al., 2015).

Furthermore, the surrounding water quality and living environment of the neighboring area were evaluated. Poor solid waste management can lead to various health issues such as diarrhea, typhoid, hepatitis, vomiting, and renal damage. Heavy metals can negatively affect mental and neurological functions and disrupt metabolic processes, causing dysfunction in various human body systems. For instance, lead (Pb), at elevated levels of Pb, can impair intellectual performance in children and inhibit cognitive development in adults. Cadmium, another harmful metal, can lead to kidney damage, impair the skeletal and reproductive systems, and contribute to other health issues (Sarma Bora et al., 2023). According to Riaz et al. (2016), about 75% of the world's diseases are caused by waterborne pathogens. Like other countries, Pakistan is susceptible to the contamination of groundwater by leachates as a result of improper handling of solid waste materials. In Pakistan and India, large towns have resorted to unplanned, inefficient, and unprocessed dumping practices for disposing of solid waste (Akbar et al., 2022).

As a result, dumpers are bringing attention to the detrimental environmental effects of dumpsites in larger cities like Peshawar that lack the infrastructure to handle the amount of trash generated by using macabre humor to highlight their increasing alienation from nature. Peshawar is experiencing major environmental challenges as a result of a failure of the authorities to adequately manage solid waste issues, growing urbanization, rapid industrialization, and a lack of public understanding about the difficult issue (Fida et al., 2023).

The open dumping of waste in landfills is responsible for the increasing environmental problems. Improper waste disposal methods not only pollute the air, land, and water but also clog open drains and smaller canals and ruin the aesthetics of the city. The goal of the current study is to ascertain how solid waste affects groundwater resources in Hazar Khwani, Peshawar, and to analyze groundwater samples for the concentration of heavy metals, biological, and physicochemical pollutants. We also conducted investigations into the relationship between physical, chemical, and biological groundwater quality parameters and the depth and distance from the dumping site.

2. Methods and Materials

2.1 Study Area

The capital of Khyber Pakhtunkhwa, Peshawar, is located at 71°33'36.48" E and 34°1'33.30" N. It has a 1257 km² area (Fig. 1). The average yearly temperature of Peshawar is 22ºC, with 404 mm of precipitation, indicating a semi-arid climate. The total efficiency of the Municipal Solid Waste Management (MSWM) system in the study region is inadequate, and the aesthetics of the city are harmed. The Tehsil Municipal Administration (TMA) of Peshawar is responsible for managing the solid waste generated in the city (Ahmad et al., 2021).

2.2 Solid waste dumping site

The dumping site chosen for this study is the Hazar Khwani municipal solid waste dumping site. The Hazar Khwani dumping site, which spans a 25acres of land next to Hazar Khwani, Peshawar, is one of the biggest and oldest dumping sites in Khyber Pakhtunkhwa and is owned by the local government. Waste is gathered from business centers such as restaurants and educational institutions, as well as in urban regions. The solid waste dumping has been carried out continuously for several years without any kind of appropriate control. Moreover, not only solid waste but also fecal deposition occurs there.

2.3 Sampling

A total of 12 water samples were obtained, with 8 samples collected within 1 km of the dumping site (representative samples) and 4 samples collected away from the dumping site (reference samples) (Fig. 2). Overall, the samples were collected from two tube wells, one hand pump, and nine boreholes. Both tube wells are operational; the Pakistan Water and Power Development Authority (PWPDA) is responsible for one, while the Municipal Corporation of Peshawar (MCP) is responsible for the other. From each sampling point, triplicate portions were collected. The bottles were thoroughly cleaned and rinsed three times with water samples before the samples were collected.

Separately cleaned and sterilized 100 ml plastic bottles were used for bacteriological examination. Nitric acid (HNO_3) was added to the samples as a preservative before heavy metal analysis. Special precautions were made to ensure that no unintentional contamination occurred during sampling. The depth and distance from the dumping location were both recorded. Mobile GPS (Global

Positioning System) was also used to record coordinates.

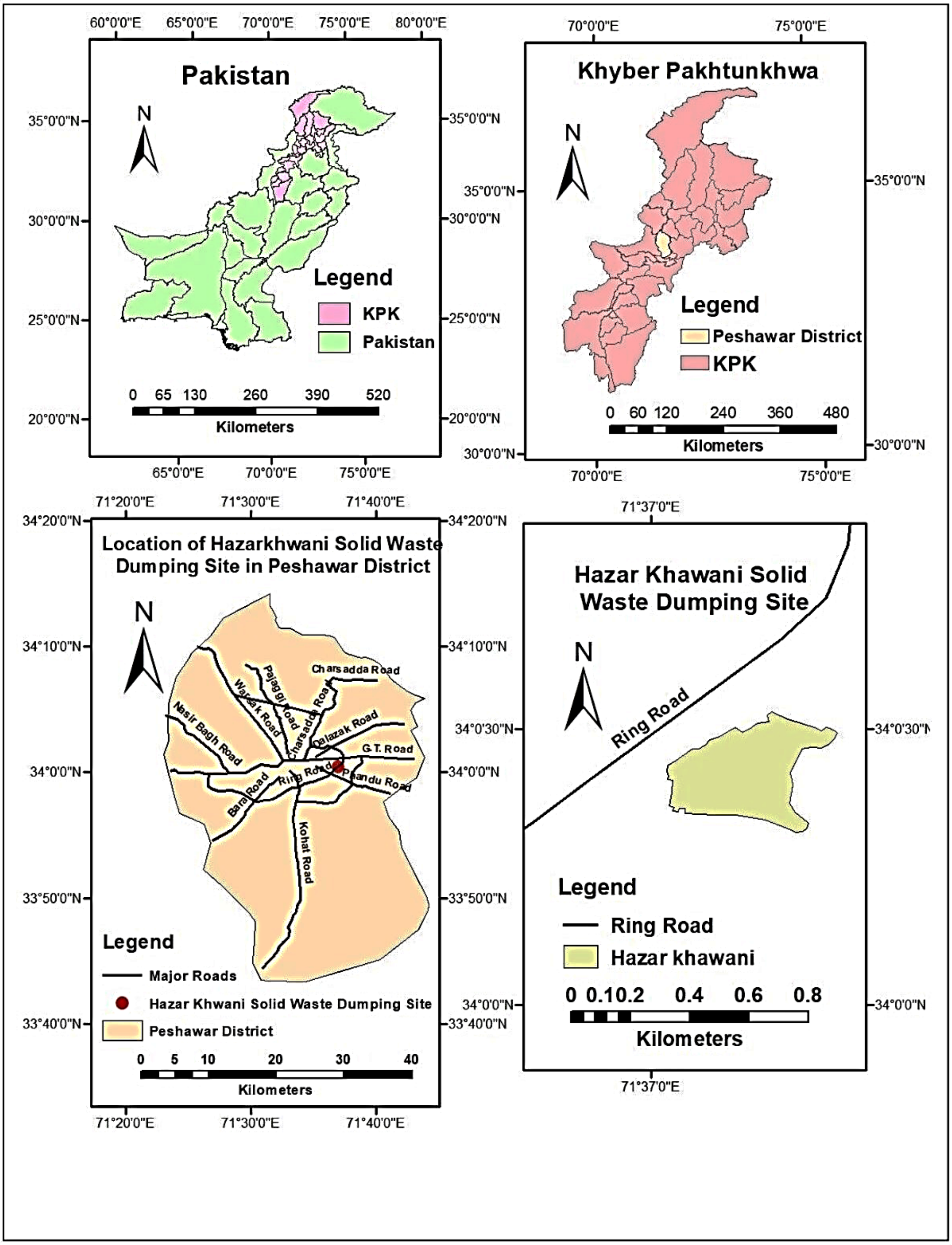

Fig. 1. Location of Hazar Khwani solid waste dumping site in Peshawar.

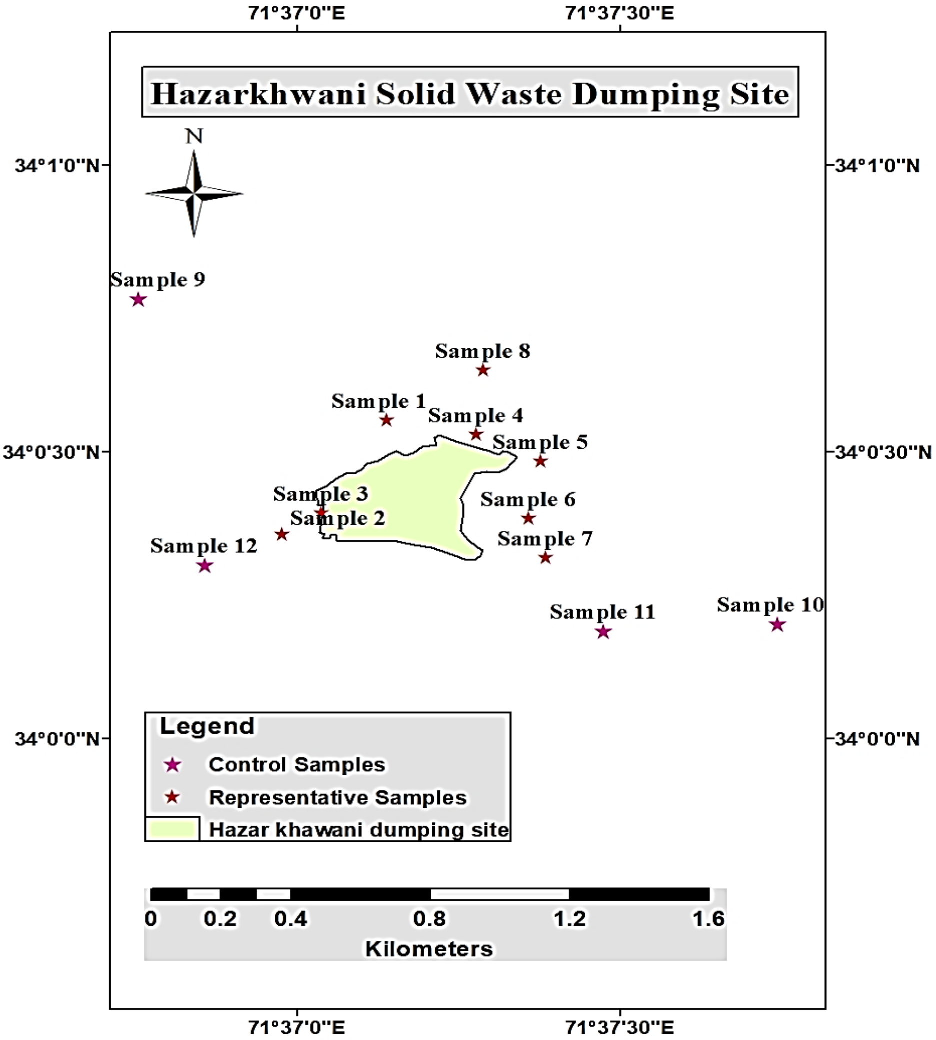

Fig. 2. Groundwater sample locations around the dumping site.

Each sampling bottle was properly labeled with the sample ID before being transported to laboratories for further analysis in accordance with the American Public Health Association Standard Method (Rice et al., 2017). Table 1 provides specific information regarding the location of the samples.

Several physicochemical parameters that were recorded include electrical conductivity (EC), pH, total alkalinity (TA), total hardness (TH), chloride (Cl), total dissolved solids (TDS), and bacteriological parameters (total and fecal coliform). The pH was determined using a pH meter. A TDS/EC meter was used to measure EC and TDS. The Titration method was used to determine total alkalinity, total hardness, and chloride following the standard method for examination of water and wastewater (Rice et al., 2017). The Atomic Absorption Spectrophotometer (AAS) was used to analyze heavy metals like nickel (Ni), zinc (Zn), chromium (Cr), copper (Cu), and cadmium (Cd) Following collection, the samples were moved to a laboratory and kept at 20°C for additional examination using an atomic absorption spectrophotometer under normal working factors (APHA, 2012). The Most Probable Number (MPN) approach was employed for bacteriological examination (total and fecal coliform bacteria). Separate, sterile tubes were used to collect the samples. All of the samples were collected, taken to the lab, and kept below 4 °C for bacterial examination.

Table 1: Details about sample locations.

No. of Samples	Latitudes	Longitudes	Description	Distance from dumping site (m)	Depth (feet)
1	34° 0'33.39"N	71°37'8.52"E	Borehole	130	150
2	34° 0'21.45"N	71°36'58.57"E	Borehole	116	170
3	34° 0'23.65"N	71°37'2.45"E	Tube well (MCP)*	8	200
4	34° 0'31.91"N	71°37'16.86"E	Tube well (PWPDA)**	85	169
5	34° 0'29.06"N	71°37'22.87"E	Borehole	111	90
6	34° 0'23.14"N	71°37'21.76"E	Borehole	165	80
7	34° 0'19.00"N	71°37'23.31"E	Borehole	250	155
8	34° 0'38.60"N	71°37'17.48"E	Hand Pump	230	50
9	34° 0'45.98"N	71°36'45.22"E	Borehole	1052	75
10	34° 0'12.00"N	71°37'44.52"E	Borehole	1023	70
11	34° 0'11.28"N	71°37'28.36"E	Borehole	1010	60
12	34° 0'18.20"N	71°36'51.40"E	Borehole	1013	120

MCP* *Municipal Corporation of Peshawar*
PWPDA* *Pakistan Water and Power Development Authority*

3. Results and discussion

3.1 Physiochemical Analysis

The analysis showed that the pH of representative water samples around the dumping site is from 6.57 to 6.83, while in the controlled area, water samples, the value varied from 6.13 to 6.63 (Table 2). The groundwater sample's pH was observed to range from 6.4 to 7.7 around solid waste dumping sites in a previous study (Kamboj and Choudhary, 2013). Similarly, the findings of a previous research study around solid waste dumping sites in Egypt showed that the pH of water samples varied from 7.0 to 7.8 (Abd El-Salam et al., 2015).

The mean TDS values ranged from 667.92 mg/L to 2329.2 mg/L in representative samples, while in the controlled area, the TDS mean values varied from 931.3 mg/L to 1193.37 mg/L. According to World Health Organization (WHO) guidelines and Pakistan National Environmental Quality Standard (Pak-NEQS), the permissible limit of TDS for drinking water is 1000 mg/L. The analysis shows that 75% of samples exceed the standards, as shown in Table 4. A study on waste sites in Sargodha city revealed their impact on public health and the environment. The finding showed that the TDS in water samples close to the landfill site ranged from 784 mg/L to 1996 mg/L on average, whereas TDS concentrations in samples from the control area ranged from 193 mg/L to 987 mg/L (Murtaza et al., 2020). The study by Abbas et al. (2018) found that the level of TDS in water samples from solid waste disposal sites ranged from 539 mg/L to 2404 mg/L, while the values in controlled areas ranged from 422 mg/L to 1996 mg/L. The water samples collected near the disposal sites with high TDS values meant higher inorganic material concentrations.

The EC of the water samples ranged from 696.91 µS/cm to 2658 µS/cm in the study area, while in the controlled area, the EC values ranged from 1390 µS/cm to 1781 µS/cm (Table 2). The analysis shows that 92% of samples have crossed the WHO standard (Table 5). Water samples from the landfill's vicinity of the landfill have elevated EC levels. Elevated levels of EC were identified, ranging from 163 to 1744 µS/cm (Sugirtharan et al., 2015). The mean value for EC in groundwater samples near the dumping site ranged from 793 µS/cm to 3535 µS/cm, while in controlled area samples, the value varied from 621 µS/cm to 2936 µS/cm (Abbas et al., 2018). Similarly, the EC value for representative area samples ranged from 773 µS/cm to 2981 µS/cm, but in controlled area samples, the value varied from 587 µS/cm to 1005 µS/cm (Murtaza et al., 2020). High levels of cations and anions are indicated by a high EC concentration. The depth and separation between the source point and the disposal site affect the value of EC. This is a blatant indication of how a dump site affects the subsurface water quality.

The recommended value for total hardness (TH), as suggested by Pak-NEQS and WHO, is 500 mg/L. The current investigation found that the average value of TH ranged from 294 mg/L to 1030 mg/L in the water samples collected from various locations. In the controlled region, the concentration of TH was found to vary from 467 mg/L to 649 mg/L, as shown in Table 2. According to the current analysis, 58% of the samples surpass the established standards, as seen in Table 5. Research on groundwater pollution near a municipal solid waste dumping site shows that the total hardness (TH) in groundwater samples close to the landfill area ranged from 296 mg/L to 1388 mg/L (Mor et al., 2006). A study on the effect of the municipal site on groundwater quality was carried out in Pakistan's Jhang City. The level of TH ranges from 170 mg/L to 1070 mg/L, crossing the maximum allowable limits in various sites (Riaz et al., 2016). A research work (Kamboj and Choudhary, 2013) found that the overall hardness ranged from 360 mg/L to 835 mg/L. The current study results showed similarity with previous study results. The high level of TH in the present study may be due to sedimentary rock and the dissolution of polyvalent salt from runoff and seepage originating from the adjacent disposal site.

Elevated concentrations of chloride (Cl) ions in water lead to an unpleasant taste. The Cl concentration in the water samples from the solid waste disposal site ranged from 32 mg/L to 573 mg/L, while in the water samples from the controlled area, it varied from 59 mg/L to 87 mg/L (Table 2). The recommended amount for Cl by the Pakistan National Environmental Quality Standards (Pak-NEQS) and the World Health Organization (WHO) is 250 mg/L (Khwaja et al., 2015). The analysis revealed that sample 8 exhibits an elevated concentration of chloride, above both the Pak-NEQS and WHO standards. The previous study noted that the concentration of chloride varied from 60 mg/L to 560 mg/L, exceeding the recommended limit of 250 mg/L (Kamboj and Choudhary, 2013). According to the current research findings, 8% of the samples were above the limit, as indicated in Table 4. As explained by previous research, the Cl concentration in representative groundwater samples ranged from 98.6 mg/L to 321.6 mg/L, and in controlled area water samples, the chloride concentration varied from 98.6 mg/L to 371 mg/L (Abbas et al., 2021). Likewise, the Cl concentration varies from 28 mg/L to 759 mg/L around landfill sites in previous research and exceeds the permissible limits for drinking purposes (Subramani et al., 2010).

Similarly, total alkalinity (TA) means values varied from 318 mg/L to 716 mg/L in representative water samples, while in controlled area water samples, the concentration varies from 425 mg/L to 523 mg/L (Table 2). The analysis shows that 42% of samples have crossed the WHO standard (Table 5). The mean value of TH alters with the distance and depth of the dumping sites and the water source. According to Riaz et al. (2016). The TA mean value of underground water samples varied from 315 mg/L to 768 mg/L. The minimum and maximum concentrations of total alkalinity in underground water samples near the dumping site were found to be 210 mg/L and 675 mg/L, respectively (Subramani et al., 2010).

Table 2: Analysis of Physiochemical parameters in selected groundwater samples.

No. of samples	pH	Total Dissolved Solids (mg/L)	Electrical Conductivity (µS/cm)	Total Hardness (mg/L)	Chloride (mg/L)	Total Alkalinity (mg/L)
1	6.7±0.152	1201.2±0.1	1792.84±1.07	583±2.98	167±0.9	482±2.08
2	6.83±0.02	1069.85±0.125	1596.8±1.1	416±3.08	54±0.99	568±1.91
3	6.62±0.01	667.92±1.015	996.91±0.8	294±4.01	32±1.01	318±4.01
4	6.6±0.09	849.56±0.04	1268±0.493	359±1.98	47±2.01	408±3.02
5	6.61±0.07	1269.91±0.01	1895±1.05	479±3.0	35±125	494±3.25
6	6.81±0.0305	1329.28±0.015	1984±1	784±2.42	182±2.02	716±4.1
7	6.6±0.2	1024.43±0.02	1529±0.624	545±3.05	37±2.00	512±2.13
8	6.57±0.08	2392.2±0.055	2658±0.305	1030±2.01	573±1.74	473±2.01
9	6.19±0.02	1019±0.5	1521±0.709	586±3.48	63±0.69	503±3.40
10	6.63±0.025	1193.37±0.1	1781±1.386	649±3.53	87±1.97	523±2.32
11	6.6±0.1	931.3±0.152	1390±1.539	467±2.87	59±3.55	425±2.67
12	6.13±0.03	1154.41±0.13	1729±0.55	590±2.23	62±2.08	489±4.21
Pak-NEQs	6.5-8.5	1000	NGVS*	500	250	
WHO guidelines	6.5-8.5	1000	NGVS*	500	250	500

NGVS No Guideline Value Set*

3.2 Heavy metals analysis

The analysis of heavy metals indicates that Cr was detected in significant amounts in the water samples, with mean values ranging from 0.04 mg/L to 0.141 mg/L. It is worth noting that the Pak-NEQS limit for Cr is set at 0.05 mg/L. All the representative samples have crossed the limit, while in control samples, sample 9 and sample 12 have crossed the standard of WHO and Pak-NEQS (Fig. 3). The heavy metal analysis shows that 83% of samples have crossed the standards for Cr (Table 5). The mean values of Cd varied from 0.01 mg/L to 0.087 mg/L, and all the representative water samples crossed the permissible limit, which accounts for 67% of the samples (Table 5), while control samples were on the borderline of Pak-NEQS. According to research conducted by Murtaza et al. (2020), the concentrations of Cd varied from 0.01 mg/L to 0.09 mg/L near the waste site, while away from the dumping site, the Cd value varied from 0.01 mg/L to 0.025 mg/L in groundwater samples. The average concentration of Ni ranges from 0.02 mg/L to 0.09 mg/L. Eight water samples were found to have a high percentage of Ni, whereas the rest of the water samples were within the permitted level set by Pak-NEQs. Analysis of Ni indicates that 67% of the samples have exceeded the established requirements, as shown in Table 5. The presence of Ni-Cd alloys, glass, and batteries at the dump site may be the cause of the high amounts of Cd and Ni in the water samples. Similarly, the presence of paints/pigments, glass, and leather as trash at the disposal location may be the cause of the high concentration of Cr. The range of concentrations for zinc (Zn) and copper (Cu) was 0–0.018 mg/L and 0–0.08 mg/L, respectively. A research study of groundwater quality near a municipal solid waste dumping site discovered that the content of Cu ranges from 0.02 mg/L to 0.16 mg/L (Sugirtharan et al., 2015). The current investigation found that the concentration of Cu and Zn was within the allowed range. Heavy metals that have migrated downward from solid waste material in a landfill site typically exist in the form of particulates, colloids, and dissolved organic compounds (Abiriga et al., 2020).

Table 3: Analysis of heavy metals detected in selected groundwater samples expressed as mean ± standard deviation based on triplicate analysis.

S No	Cd (mg/l)		Cu (mg/l)		Cr (mg/l)		Zn (mg/l)		Ni (mg/l)	
	Mean	±Std. D	mean	±Std. D	mean	±Std. D	mean	±Std. D	Mean	±Std. D
1	0.02	0.038	0.02	0.0058	0.14	0.0066	0	0.0139	0.09	0.0436
2	0.02	0.02	0.01	00068	0.14	0.0114	0	0.0073	0.03	0.0066
3	0.06	0.036	0.01	0.0057	0.12	0.0091	0	0.0149	0.03	0.0812
4	0.05	0.019	0.03	0.0035	0.13	0.0234	0	0.0175	0.03	0.0894
5	0.03	0.0047	0.03	0.0133	0.13	0.0103	0	0.0042	0.05	0.0493
6	0.09	0.042	0.08	0.0068	0.14	0.0153	0.16	0.0033	0.05	0.0323
7	0.06	0.0028	0.04	0.0087	0.11	0.0176	0.07	0.0133	0.05	0.0817
8	0.08	0.0265	0.05	0.0048	0.16	0.027	0	0.0182	0.05	0.1274
9	0.01	0.001	0	0.0015	0.08	0.0288	0	0.0114	0.002	0.0613
10	0.01	0.018	0	0.0013	0.04	0.0198	0.18	0.0151	0.02	0.0191
11	0.01	0.0067	0	0.0032	0.05	0.0067	0.02	0.0134	0.08	0.0214
12	0.01	0.0149	0.003	0.0025	0.06	0.0262	0.02	0.0064	0.01	0.0370

3.3. Bacteriological Analysis

Pathogenic microorganisms in groundwater are measured using the standard method. The World Health Organization (WHO) declared in 2014 that there should be no coliform bacteria in 100 milliliters of drinking water. Two particular bacteriological parameters were employed for the water investigation in this study. The study indicated that 6 out of 8 typical samples were found to be infected with both total and fecal coliform bacteria, whereas 1 out of 4 control area samples was found to be contaminated with total and fecal coliform bacteria (Table 4). The result shows that 56% of the samples were contaminated with total and fecal coliform bacteria (Table 5).

The findings indicate the presence of both total and fecal coliforms in the majority of the samples, suggesting that groundwater contamination may be occurring as a result of leachate percolation. The existence of fecal contamination serves as an indication that individuals who come into contact with this water may face a potential health hazard. The study of groundwater quality near a municipal solid waste dumping site discovered elevated levels of coliform bacteria in water samples (Sugirtharan et al., 2015). Feces from humans and animals that decompose naturally can be the source of total coliform and fecal coliform. Likewise, the physiochemical and bacteriological characteristics of the drinking water in Peshawar were investigated by Bacha et al. (2010). According to his results, 60% of the samples had fecal coliform contamination, and 90% of the samples had coliform contamination.

Table 4: Analysis of total and fecal coliform detected in selected groundwater samples.

No. of samples	Total Coliform bacteria (P/A)	Fecal Coliform bacteria (MPN/100ml)
1	Absent	<1.1
2	Present	5.1
3	Present	6.9
4	Present	5.1
5	Present	5.1
6	Present	2.2
7	Present	3.6
8	Absent	<1.1
9	Absent	<1.1
10	Absent	<1.1
11	Present	2.2
12	Absent	<1.1
NEQS	Absent	<1.1
WHO	Absent	<1.1

3.4. Correlation analysis

According to the correlation study, distance had a negative relationship with Ni (-0.242), EC (-0.34), TDS (-0.45), Cl (-0.15), Cu (-0.587), Cd (-0.606), and Cr (-0.906). There is a significant negative association between distance and Cd, Cu, and Cr. There was a weak association observed between distance and Zn (0.232), alkalinity (0.012), total hardness (0.143), and pH (0.466). Table 5 indicates a negative connection between depth and pH (-0.38), TH (-0.21), TA (-0.47), Cu (0.06), and Zn (-0.5). On the other hand, TDS, EC, Cl, Cd, and Ni showed a modest positive association with depth. These correlation analysis results align with the findings of Uddin et al. (2023) and Memon et al. (2023).

Table 5: Percentage of water samples exceeding WHO standards.

Water quality parameters	Samples	No. of samples exceeding the standard	% of samples exceeding the standard
TDS	12	9	75%
EC	12	11	92%
TH	12	7	58%
Cl	12	1	8%
TA	12	5	42%
Cd	12	8	67%
Cu	12	0	0
Cr	12	10	83%
Zn	12	0	0
Ni	12	8	67%
T-Coliform	12	7	58%
F-Coliform	12	7	58%

According to the correlation study, TDS-Cl (0.959), TH-Cl (0.859), TDS-TH (0.890), TDS-EC (1.000), EC-TH (0.891), and EC-Cl (0.958) all have substantial positive correlations. Heavy metal pair correlations include Cd-Cu (0.869), Cu-Cr (0.669), and Cd-Cr (0.668). It was discovered that Cu-Ni (-0.32), Cd-Ni (-0.209), Zn-Ni (-0.179), and Cr-Zn (-0.308) had a negative correlation.

4. Conclusion

The study concluded that the solid waste disposal site in Hazar Khwani is consistently causing degradation of the groundwater quality. The majority of the water samples analyzed did not meet the criteria set by the Pak-NEQS and WHO for several parameters, including TDS, hardness, chloride, alkalinity, cadmium, chromium, nickel, total coliform bacteria, and fecal coliform bacteria in certain samples. The correlation study showed that the pollutant concentration dropped with depth and distance from the solid waste disposal site. The research showed that in most of the samples, physicochemical, heavy metal, and bacteriological parameters have surpassed the standard limits. This could be attributed to the leachate generated from wastes and its percolation and filtration from the improper landfill located in the study area.

Table 6: Correlation between depth, distance, and water quality indicators.

Parameters	Distance	Depth	pH	TDS	EC	TH	TA	Cl	Cd	Cu	Cr	Zn	Ni
Distance	1												
Depth	-0.56	1											
pH	0.46	-0.37	1										
TDS	-0.45	0.10	-0.33	1									
EC	-0.34	0.10	-0.33	**1.00****	1								
TH	0.14	-0.20	-0.27	**0.89****	**0.89****	1							
TA	0.01	-0.47	-0.31	0.31	0.31	0.49	1						
Cl	-0.15	0.22	-0.32	**0.95****	**0.95****	**0.85****	0.13	1					
Cd	**-0.60***	0.17	-0.20	0.45	0.44	0.43	0.19	0.55	1				
Cu	**-0.58***	-0.06	-0.37	0.39	0.38	0.48	0.54	0.43	**0.86****	1			
Cr	**-0.90****	0.54	**0.68***	0.38	0.37	0.18	0.14	0.45	**0.66***	**0.66***	1		
Zn	0.23	-0.52	0.22	0.02	0.03	0.33	**0.59***	-	0.16	0.30	-0.30	1	
Ni	-0.24	0.32	**-0.60***	0.05	0.05	0.03	-0.03	0.11	-0.20	-0.03	0.27	-0.17	1

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

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

Future efforts should focus on improved landfill management with impermeable liners and regular groundwater quality monitoring for access to safe drinking water. Strengthening enforcement of environmental regulations, raising public awareness, and promoting alternative waste management strategies like recycling and composting can further mitigate risks. Continued research on pollutant movement and advanced remediation techniques is crucial to protect groundwater quality and public health.

Author Contribution

Haleema Yaqoob conceived the idea and designed the study, carried out experimental work, sample collection, and wrote the manuscript. Saeeda Yousaf supervised the whole study. Salma Khalid and Waheed Ullah wrote the manuscript and provided their technical input at every step. Anis Safir, Waqas Safir, and Muhammad Ilyas helped in sample collection and data analysis. Walid Soufan and Shahla Nazneen reviewed and approved the final version.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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