Assessment of municipal solid waste landfilling practices on the groundwater quality and associated health risks: a case study of Mardan-Pakistan

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Abstract
This study was conducted to investigate the quality of groundwater affected due to the municipal solid waste (MSW) used as a landfill. To assess the impacts, 13 groundwater samples were collected from solid waste dumping sites (SWDS) and 13 from safe sites (SS). Groundwater was analyzed for pH, turbidity, electrical conductivity (EC), total hardness (TH), Cl−, Ca2+, K+1, NO−2, NO−3, SO4−2; heavy metals such as Pb, Cr, Mn, Cu, Ni, Zn, Cd, Fe; biological parameter such as total coliform. Waste samples collected from SWDS showed that food and garden waste had the highest percentage by weight (30.5%) followed by fines (17.3%). The two groups (SWDS and SS) differ significantly for the mean value of EC, TH, Na, Ca, NO3−, SO4−2, Ni and TC. Samples collected from SWDS (84%) were found contaminated with total coliform (TC) ranged 2–22 (No./100 ml). It was analyzed that concentration of total dissolved solids (TDS), pH, EC, TH, NO3−, SO4−2, NO2−, Ca2+, Na+, TC, Cr, Ni, Zn, Cd and TC were more in the samples collected from 70–130 feet than 140–200 feet. TC found in 70–80 feet depth was significantly different from the rest of the groups. A questionnaire survey was also conducted from the people living near the dumping sites to assess the frequency of the water-related disease the community is suffering from. The results of the questionnaire survey revealed negative correlation between the diseases and distance from the landfill sites, and significant correlation was only observed for typhoid, cholera, skin allergies and gastroenteritis. The study confirmed that using MSW as a fill material has contaminated the groundwater quality, and leveling of land through MSW is not safe. Deep drilling is recommended for extraction of groundwater in the contaminated area to minimize the associated health risks.

Keywords Total coliform · Groundwater · Municipal solid waste · Health risks

Introduction
Water is an important factor of life sustainability on earth, and without it existence of life is not possible. Assessment and monitoring of water quality are important, and variability of physicochemical parameters of drinking water quality is directly concerned with human health (Muhammad et al. 2010). Due to growing population, the demand for fresh water has increased throughout the world, especially in arid and semi-arid regions (Raju et al. 2011). The water quality on the other hand is getting deteriorated due to many factors, and solid waste is one such factor. It has negative impacts on the environment as well as on the health of the human beings. The poor management of municipal and industrial effluents as well as solid waste contaminates the natural water resources because a large amount of toxins along with other...
 chemically mixed with water bodies when these wastes come in contact with it (Leoni et al. 2005; Mishra et al. 2019). Generally, MSW contains biological waste apart from paper, glass, plastic and metals (Mohsenizadeh et al. 2020) and the presence of different contaminants and coliform bacteria and other pathogens in drinking water indicate their contact with contamination (Faroq et al. 2008). A large variety of pathogens including coliform bacteria are present in the degraded material and leachate of MSW (Betta et al. 1996; Dos Santos et al. 2022). Such type of waste when not treated properly may cause serious damages to human health and environment. It may cause respiratory tract infection and skin diseases (Egbenyah et al. 2021). Further, presence of toxic heavy metals, such as mercury, arsenic, cadmium and chromium, in MSW is also reported in the literature, which are carcinogenic in nature (IARC, 2018). A study conducted by Wang et al. (2022) in different landfills of China showed that Cr was the dominating heavy metal pollutant, and Zn and Cd were less obvious.

Solid waste has increased due to the increase in population and race to improve the living standards (Usmani et al. 2020). Solid wastes are classified into hazardous, clinical, municipal and radioactive waste, while municipal waste is characterized as domestic, industrial or institutional (Tang et al. 2020). Predominantly in urban areas of developing countries, solid waste dumps pose great threats as apparent from the above paragraph to the groundwater source which is a key source of domestic water supply in these areas (Farid et al. 2012). Municipal solid waste dumps can contaminate the groundwater resources with bacteria and other pathogens (Al-Sabahi et al. 2009).

Pakistan is among the world’s arid regions, and most of the population is dependent on groundwater to fulfill their water requirements for drinking and other domestic purposes. On the other hand, due to prevailing climatic conditions, water scarcity is increasing day by day. Pakistan has been listed among the countries that will have renewable water resources below the calculated threshold of 1500 m³/capita/year by the year 2030 (Rijsberman, 2006). The availability of water has dropped from 2172 m³/capita in 1990 to 1306 m³/capita in 2015 (Hassan, 2016). In these circumstances, protection of available water sources is of utmost importance for Pakistan and has become a serious concern over the last few decades. Dependence on groundwater and indiscriminate usage have led to overexploitation of this resource. Moreover, threats to water contamination have increased with the increase in population and industrialization (Khan et al. 2018). Lack of awareness among the general public regarding proper management of municipal solid waste further worsens the situation.

Mardan, the locals are using municipal solid waste, preferably having high percentage of inert and earth particles, for the leveling of their residential lands without adopting any safety measures. Houses have already been constructed on such lands and hence were best suited for identifying the impacts of MSW on groundwater quality. This practice of the locals may pose threats to the groundwater sources and ultimately to human health. Previously, no known research work has been carried out on this issue. Therefore, this research study was designed to assess the impacts of municipal solid waste landfill practices on groundwater quality and associated health risk. Findings of this study will be beneficial for creating awareness in the countries where solid waste dumps are located near the water resources.

Methodology

Study area

This study was conducted in the urban region of district Mardan which is the second most populous district of the Khyber Pakhtunkhwa province, Pakistan. It lies between latitude 34° 05′ to 34°32′ North and longitude 71° 48′ to 72° 25′ East, located about 14 km northeast of Peshawar (Tufail et al. 2013). According to the TMA Mardan, total estimated population of the area was 4000 to 5000 inhabitants, mostly belonging to the middle class. Groundwater is used for drinking and other domestic purposes in the area. Hand pumps and pressure pumps are used for extraction of groundwater.

Collection of waste samples at dumping sites

Wastes from the dumping sites (which were not compressed and leveled and yet to be used to build a residential area) were collected and analyzed through European commission methodology (user version 2004) and Ireland-EPA guidelines for MSW characterization to understand the types of wastes used for leveling of the ground. The European commission methodology SWA-Tool provides a waste analysis methodology to be used at a local and regional level. The methodology establishes minimum standards, which a waste analysis should always meet such as sorting procedures, sorting categories, definition of statistical accuracy and common reporting guidelines. This enables the comparability of results between different waste analyses.

Sample collection

Total 26 drinking water samples were collected from the study area. Samples were collected from SWDS (n = 13) and SS (n = 13) (Fig. 1A, B). Those areas where the locals
have used municipal solid waste for leveling their residential lands were termed as solid waste dumping sites (SWDS) in this paper, while the areas where municipal solid waste was not used for leveling residential lands were termed as safe sites (SS). The SS were selected at least at a distance of 1000 m from the solid waste dumping sites. All the samples were collected in 1.5-L polypropylene bottles. The bottles were rinsed with 1:1 concentrated HNO₃ and triple distilled water of Milli Q prior to use. The depth of the source was also recorded. The samples were taken from 70 to 200 feet depth to check the concentration of contaminants at various depths. The samples were stored at < 08 °C and transferred to the laboratory within 4 h for analysis. The permissible limits set by Pakistan-National Environmental Quality Standards’ 2010 (Pak-NEQS) were used for analyzing the quality of the water samples for various selected parameters (Table 1).

During the field survey, district headquarter hospital (DHQ) Mardan was also visited, and information was collected regarding waterborne diseases in the locals of SWDS. This data was used to assess the health impacts of the contaminated groundwater on the local inhabitants.
Table 1  Results of water quality parameters collected from SWDS and SS compared against National Environmental Quality Standards (NEQS)

|          | pH  | Turb. (NTU) | E.C. (µS/cm) | TDS (mg/l) | COD (mg/l) | TH (mg/l) | Na⁺ (mg/l) | K⁺ (mg/l) | Ca²⁺ (mg/l) | SO₄²⁻ (mg/l) | Cl⁻ (mg/l) |
|----------|-----|-------------|--------------|------------|------------|-----------|------------|-----------|-------------|--------------|-----------|
| SWDS     | Min | 6.9         | 0.6          | 705        | 390        | 170       | 46         | 1.3       | 40          | 89           | 15.6      |
|          | Max | 8.2         | 8.96         | 2380       | 1206       | 573       | 276        | 7.6       | 95          | 376          | 147       |
|          | Avg | 7.54        | 2.33         | 1353.31    | 772.38     | 337.23    | 112.46     | 3.69      | 61.85       | 170.62       | 65.34     |
|          | St. dev | 0.41      | 2.20        | 596.66     | 295.09     | 141.18    | 68.91      | 1.82      | 16.52       | 83.64        | 45.34     |
| SS       | Min | 6.7         | 0.79         | 837        | 550        | 2         | 167        | 43        | 1.8         | 39           | 79        |
|          | Max | 8.2         | 2.2          | 1084       | 774        | 12        | 354        | 97        | 4.6         | 60           | 121       |
|          | Avg | 7.2         | 1.4          | 963.0      | 642.4      | 5.3       | 237.1      | 64.4      | 2.8         | 49.9         | 95.4      |
|          | St. dev | 0.52      | 0.54        | 104.93     | 71.40      | 3.68      | 70.02      | 19.21     | 0.95        | 8.91         | 15.13     |
| NEQS     |     |             |              |            |            |           |            |           |             |              |           |
|          | pH  | 6.5–8.5     | <5           | <1000      | 500        | 200       | 12         | 75        | 250         | 250          |           |
| SWDS     | NO₃⁻ (mg/l) | 14        | 0.00        | 0.00       | 0.00       | 0.00      | 0.00       | 0.00      | 0.00        | 0.00         | 22        |
|          | NO₂⁻ (mg/l) | 52        | 2.1         | 0.052      | 0.049      | 0.027     | 0.061      | 0.448     | 0.011       | 0.09         | 0.122     |
|          | Cr (mg/l) | 1082      | 0.02        | 0.01       | 0.01       | 0.01      | 0.15       | 0.002     | 0.02        | 0.03         | 0.04      |
|          | Pb (mg/l) | 28.62     | 0.50        | 0.50       | 0.50       | 0.50      | 0.50       | 0.50      | 0.50        | 0.50         | 0.50      |
|          | Cd (mg/l) | 10.13     | 0.65        | 0.65       | 0.65       | 0.65      | 0.65       | 0.65      | 0.65        | 0.65         | 0.65      |
|          | Cu (mg/l) |            |              |            |            |           |            |           |             |              |           |
|          | Zn (mg/l) |            |              |            |            |           |            |           |             |              |           |
|          | Fe (mg/l) |            |              |            |            |           |            |           |             |              |           |
|          | Ni (mg/l) |            |              |            |            |           |            |           |             |              |           |
|          | Mn (mg/l) |            |              |            |            |           |            |           |             |              |           |
|          | TC (No./100 ml) |   |              |            |            |           |            |           |             |              |           |
| SS       | NO₃⁻ (mg/l) | 10.0      | 0.0         | 0.0        | 0.0        | 0.0       | 0.0        | 0.0       | 0.0         | 0.0          | 0.0       |
|          | NO₂⁻ (mg/l) | 28        | 0.8         | 0.028      | 0.071      | 0.038     | 0.028      | 0.273     | 0.026       | 0.08         | 0.08      |
|          | Cr (mg/l) | 19.4       | 0.33        | 0.01       | 0.01       | 0.01      | 0.02       | 0.10      | 0.01        | 0.00         | 0.04      |
|          | Pb (mg/l) | 5.97       | 0.36        | 0.01       | 0.03       | 0.01      | 0.09       | 0.01      | 0.00        | 0.02         | 0.02      |
| NEQS     | 50       | 3          | 0.05        | 0.05       | 0.01       | 2         | 5          | 0.02      | 0.5         | 0            |           |
Analysis of physicochemical parameters

Groundwater was analyzed for pH, turbidity, electrical conductivity (EC), total hardness (TH), Cl⁻, Ca⁺², K⁺¹, NO₃⁻, SO₄⁻², pH, chlorides and hardness were measured with pH meter, chloride test kit (Hanna 3815), hardness turbidity meter (HI96735 Hanna), respectively. Ca⁺², K⁺¹ and NO₃⁻ were measured with Hanna model No. HI83200, TDS with HI98129 and EC with HI98130 meters. Portable turbid meter (2100P ISO, Hach), sodium meter (HI 931,101), nitrate meter (HI96786) and sulphate meter (HI76751 and HI38001) were used for the measurement of turbidity, sodium, nitrate and sulphates, respectively.

Analysis of heavy metals

The heavy metals such as Pb, Cr, Mn, Cu, Ni, Zn, Cd and Fe were analyzed through atomic absorption spectrophotometer (Perkin Elmer AAS 700) as per American Public Health Association (APHA), 1998 guidelines.

Analysis of total coliform

Total coliform tests were conducted by using membrane filter method (method no. 9222-B) according to the procedure set by American Public Health Association (APHA)’ 1998. Analytical grade chemicals and materials were used for analysis.

Questionnaire survey

Questionnaire survey was conducted from 500 respondents (250 males and 250 females) living at different distances (living on the sites leveled by MSW (0–100 m), 101–400 m, 401–700 m and 701–1000 m) from the dumping sites. The age of the respondents ranged 15–40 years. Different diseases were selected from the literature including diarrhea, dysentery, typhoid, ringworm, cholera, malaria, skin allergies and gastroenteritis. The respondents were given different options (never, at least once in 2 months, once in 4 months, once in 6 months, once in a year and more than a year) and were asked to select any one option against the mentioned diseases.

Statistical analysis

Statistical analyses and graphical representation of the data was conducted through SPSS v. 23. Pearson correlation was conducted to find out the relationship between depth and different parameters and to analyze the relationship between distance from the dumping sites and diseases.

Results and discussion

Waste samples collected from the solid waste dumping sites (n = 13) showed that food and garden waste had the highest percentage by weight (30.5%) in the SWDS followed by fines (17.3%). Besides these, paper and cardboard (3.4%), glass (3.7%), metals (0.3%), plastics and rubber (3.9%), wood (2.7%), textile and rags (3.7%), leather and non-recyclable plastic (5.9%), complex products (4.2%), inert (6.4%), healthcare waste (2.2%) and other (15.8%) constitute the waste identified (Fig. 2).
Physicochemical parameters

Comparison between water samples taken from SWDS and SS

Water samples collected from SWDS and SS showed that pH, Cl−, K− and NO2− were within the permissible limit for all the sites (both SWDS and SS), and there was no significant difference in the mean values of pH, turbidity, TDS, Cl−, K− and NO2− for both sites. Only 8% and 31% SWDS showed turbidity (range: 0.6–8.96 NTU) and TDS (range: 390–1206 mg/l) beyond the permissible limit set by Pak-NEQS’ 2010, respectively, while all the SS were within the limits for the above mentioned parameters (Table 1). The two groups (SWDS and SS) differ significantly for EC, total hardness, COD, Na, Ca, NO3− and SO4−2. The SS showed these mentioned parameters within the permissible limit. But 54%, 15%, 15%, 8% and 15% SWDS showed that EC (range: 705–2380 µS/cm), total hardness (range: 170–573), Na (range: 46–276), Ca (range 40–95), NO3− (range: 14–52) and SO4−2 (range: 89–376) were beyond the permissible limit (Table 1). The high value of EC is due to the high concentration of dissolved ions in the groundwater and clearly indicates that leaching of waste has taken place from the landfill sites (Kumar and Alappat, 2005). The high value of COD in the SWDS samples indicates the high fraction of biodegradable waste (Somani et al. 2019). For heavy metals, drinking water of SWDS and SS showed that Pb, Cu, Zn, Fe, Mn were within the permissible limit, while for Cr only 8% and for Ni 38% drinking water samples from SWDS showed results beyond the permissible limit (Table 1). The results for the Cd showed that 46% samples from SWDS and 38% SS were beyond the permissible limit. However, SWDS and SS differ significantly (P < 0.05) for Ni only.

Regarding TC results, 62% SWDS and 43% SS showed the sample were beyond the permissible limits. Contamination was recorded in the samples of both zones, but the level of contamination was much higher in the samples of SWDS as compared to SS (Fig. 3). TC found in the samples of SWDS ranged 2–22, while only 43.3% of TC was found in the samples collected from SS that ranged 2–7. High percentage of TC as well as EC, total hardness, Na, Ca, NO3− and SO4−2 and Ni in the sample collected from SWDS indicates the possible percolation of leachate in the groundwater from the solid waste landfills. These results are analogous to the findings of Mor et al. (2006) and Chonattu et al. (2016).

Samples collected from some areas of the safe zone also showed the presence of TC. Possible reasons for this contamination may be the poor sanitary and hygiene conditions (Shar et al. 2008) as in some areas the same poor conditions were observed. However, comparatively higher concentration of TC and higher contamination percentage of SWDS samples indicate possible contamination of the groundwater sources due to leachate percolation.

Depth wise comparison of water quality parameters in SWDS

Water samples collected from various SWDS were collected from different depths. The depth where significant difference was found is given in Table 2. It is pertinent from the results that TC found in 70–80 feet depth was significantly different from the rest of the groups. Similarly, significant difference regarding different parameters for various depths was recorded for K+, Ca++, NO3−, Pb, Cu and Fe. The correlation found between depths and various parameters is given in Table 3. It is clear from the table
that most of the parameters are negatively correlated with the depths, and as the depths increase the concentration of these parameters decreases. The level of groundwater contamination due to MSW landfill or dumps depends upon various factors among which depth of the source is more prominent (Mor et al. 2006).

While analyzing the water samples, it was found that pH, EC, TDS, COD, TH, NO\textsuperscript{−}\textsubscript{3}, SO\textsubscript{4}\textsuperscript{−}2, NO\textsubscript{2}\textsuperscript{−}, Ca\textsuperscript{+}2, Na\textsuperscript{+}, TC, Cr, Ni, Zn, Cd and TC were more in the sample collected from 70–130 feet than 140–200 feet depth. The percentage difference between the two is given in Fig. 4. The number of TC was assessed against the depth of sampling sources, and it was found that the contamination of groundwater has an inverse relation with depth of the source (Fig. 3). The results showed that 81.82% samples collected from groundwater sources having depth less than 140 feet were found contaminated. On the other hand, only 22.22% samples collected from sources having depth of 140 feet or above were found contaminated.

Natural filtration capability of the earth may be the possible reason for decrease in the level of contamination with increase in depth of the groundwater sources. Earth layers filter the fluid when it passes through it (Kilpatrick et al. 2018). Hence, the greater the traveling distance of the fluid, the higher will be the filtration. Therefore, the deep water sources were found safe as compared to the shallow water sources. Depending on the type of waste including municipal solid waste, the leachate is formed and contains many contaminants which may include pathogens, organic and inorganic pollutants, toxic metals and xenobiotic organic compounds (Christensen et al. 2001; Huang et al. 2009; Joseph et al. 2020). The chemical composition of leachate is dependent on the type of waste and is published in various studies (Lü et al. 2008; Öman and Junestedt, 2008). The risk posed by the leachate containing toxic substances is the accumulation of these substances in soils and then infiltration into groundwater and becoming part of the food chain when this water is consumed by the living beings (Alam et al. 2020; Ngelinkoto et al. 2014; Poté et al. 2008). Heavy metals are found to be beyond the permissible limit in the soil of landfill sites (Agbeshie et al. 2020; Essien et al. 2019; Gujre et al. 2021). The seepage from MSW landfill site has considerable impact on the quality of groundwater (Singh et al. 2016). Research conducted by Yusof et al. (2009) analyzed high organic contents, Cd and Mn in the river near an active uncontrolled landfill and influences of leachate in the form of inorganic nitrogen and heavy metals such as Cr, Fe, Mn and Ni. They observed the impacts of leachate on the nearby river. The current study also confirms that high EC, total hardness, Na, Ca, NO\textsubscript{3}\textsuperscript{−} and SO\textsubscript{4}\textsuperscript{−}2, Cr, Ni and TC were observed in the samples taken from SWDS, and few samples showed high turbidity and TDS. Leaching of the contaminants from the waste depends on the fixation

![Table 3 Correlation between different water quality parameters with depth](image)

| Parameters | Depth Pearson correlation | Sig. (2-tailed) | Parameters | Depth Pearson correlation | Sig. (2-tailed) |
|------------|-------------------------|----------------|------------|-------------------------|----------------|
| pH         | .284                    | .348           | NO\textsubscript{3} | -.396                  |
| Turbidity  | .177                    | .564           | NO\textsubscript{2} | -.038                  |
| EC         | -.447                   | .126           | Cr         | -.256                  |
| TDS        | -.367                   | .218           | Pb         | .307                   |
| COD        | -.524                   | .066           | Cd         | -.163                  |
| TH         | -.520                   | .068           | Cu         | .776                   |
| Na         | -.438                   | .134           | Zn         | .320                   |
| K          | .295                    | .328           | Fe         | .181                   |
| Ca         | -.536                   | .039           | Ni         | -.518                  |
| SO\textsubscript{4}   | -.541                   | .036           | Mn         | .427                   |
| Cl         | .113                    | .713           | TC         | -.592                  |

![Fig. 4 Percentage difference between water quality parameters in drinking water (140 feet below and above)](image)
of these contaminants in the soil and their transportation to the groundwater (Pejman et al. 2017). Raju et al. (2009) explained leaching of contaminants takes place due to permeation and percolation with rain water. As the dumping sites are open and rainy seasons are observed in the study area, therefore, leaching of contaminants takes place due to the water percolation. According to a report published by UN-Habitat and UNESCAP (2012) on Mardan landfill sites, the observed sites were without soil cover, and there was no compaction applied. Almost 60 to 70 tons of wastes were dumped, and there is no collection of leachate or gas from these sites. A report published by GoP (2021) reported that soil of the Mardan is “very soft—soft to firm to stiff lean clay/silty clay/silt/silt/ up to a depth of 7.0 m underlain by medium dense to very dense poorly graded sand with silt/silty sand.” These facts confirm the finding of the study that the leachate percolates from the soil and contaminated the groundwater. Another study conducted by Mishra et al. (2019) also showed almost the same results by observing considerable amount of TDS, EC, NO$_3^-$ and PO$_4^{3-}$ in the groundwater samples taken from near the landfill site thus concluding that groundwater quality is significantly affected by leachate percolation. Similarly, Fernández et al. (2014) observed the impacts of leachate plume up to 900 m from the landfill site. As the leachate reaches the saturated zone, it forms a plume which spreads in the direction of flow of water and contaminates the groundwater (Vasanthi et al. 2008). The current study observes that these contaminants were more in the 70–80 feet than the 120 feet depths.

Questionnaire survey and data collected from the hospitals

According to the survey results, 41% respondents suffered from diarrhea that were living at a ground leveled with MSW or 100 m within dumping sites at least once in a year. Similarly, 25% suffered from typhoid, and 26% suffered from skin allergies at least once in a year (Table 4). According to the respondents, 18% suffered from gastroenteritis at least once in 4 months. The results of the questionnaire survey revealed negative correlation between the diseases and distance from the dumping site. However, significant correlation was only observed for typhoid, cholera skin allergies and gastroenteritis (Table 5). No correlation was observed between the gender and the age of the respondents with diseases.

Consumption of the contaminated water may pose health risk to the local community due to bacteriological contamination, and this is among the major threats to drinking water and ultimately to human health (Azizullah

| Diseases                  | Frequency | Distance from dumping site |
|---------------------------|-----------|----------------------------|
|                           |           | 0–100 m       | 101–400 m  | 401–700 m | 701–1000 m |
| Dysentery                 | a         | 3             | 1          | 0         | 0          |
|                           | b         | 19            | 16         | 10        | 4          |
|                           | c         | 1             | 2          | 1         | 2          |
| Diarrhea                  | c         | 2             | 1          | 0         | 0          |
|                           | d         | 4             | 3          | 0         | 1          |
|                           | e         | 41            | 27         | 14        | 7          |
| Typhoid                   | e         | 25            | 15         | 8         | 6          |
| Ringworm                  | d         | 15            | 6          | 3         | 4          |
|                           | e         | 0             | 1          | 0         | 0          |
| Cholera                   | c         | 5             | 1          | 0         | 1          |
|                           | d         | 15            | 8          | 5         | 5          |
|                           | e         | 2             | 4          | 0         | 2          |
| Malaria                   | d         | 18            | 15         | 6         | 4          |
|                           | e         | 4             | 1          | 1         | 1          |
| Gastroenteritis           | b         | 18            | 10         | 1         | 3          |
|                           | c         | 25            | 15         | 7         | 3          |
|                           | d         | 10            | 1          | 0         | 0          |
|                           | e         | 4             | 1          | 0         | 2          |
| Skin allergies            | a         | 1             | 1          | 0         | 2          |
|                           | b         | 0             | 0          | 1         | 0          |
|                           | c         | 12            | 2          | 4         | 2          |
|                           | d         | 26            | 21         | 8         | 3          |
|                           | e         | 8             | 7          | 1         | 1          |

a = once in 2 months; b = once in 4 months; c = once in 6 months; d = once in a year; e = more than a year
et al. 2011). To assess the health risk to the locals due to consumption of contaminated drinking water, waterborne diseases data were collected from the DHQ hospital Mardan. However, in Pakistan proper assessment and quantification of waterborne diseases is a hard job due to lack of record maintenance at hospitals (Aziz, 2005). The data collected from the DHQ hospital revealed that the residents of SWDS suffered frequently from diarrhea, dysentery, typhoid and skin diseases. According to the hospital sources, approx. 2500 patients/day were visiting outpatient department (OPD), out of which 22% suffered from waterborne diseases. During the rainy seasons, this percentage rose to 35–40% of the total patients attending OPDs, wherein almost 75% were from the regions of SWDS. This high burden of waterborne diseases in the study area confirmed that the groundwater sources of the study area were not safe. Similar results were reported by the United Nations International Children’s Emergency Fund (UNICEF) that waterborne diseases are responsible for about 20 to 40% of all the patients in hospitals of Pakistan among which typhoid, giardiasis, cryptosporidiosis, dysentery, cholera and other gastrointestinal problems account for one-third of all deaths in the country.

**Conclusion**

In this study, samples were collected from sites leveled with solid waste and compared with the samples of safe zone. The results showed that the level of contamination was comparatively much higher in the solid waste dumping sites samples. Questionnaire survey and hospital data also confirmed the negative health impacts of the contaminated water. Thus, it can be concluded from the study that the use of MSW for leveling of residential lands is not safe, and this practice has contaminated the groundwater of the study area. Therefore, this practice should be discouraged, and the concerned government departments shall play their role to ensure human health safety and to avoid any potential risk. To minimize health risk, deep drilling should be done for extraction of groundwater where there is possibility of contamination from MSW. Regular monitoring of groundwater sources near landfill sites is recommended by the study.

**Table 5** Correlation between distance from dumping sites and diseases suffered by the respondents

|                   | Diarrhea | Dysentery | Typhoid | Ringworm | Cholera | Malaria | Skin allergies | Gastro |
|-------------------|----------|-----------|---------|----------|---------|---------|----------------|--------|
| Pearson correlation| −.150    | −.063     | −.349** | −.116    | −.206*  | −.073   | −.279**        | −.328**|
| Sig. (2-tailed)   | .035     | .533      | .000    | .248     | .039    | .470    | .005           | .001   |

*The mean difference is significant at the 0.05 level
**The mean difference is significant at the 0.01 level

**Author contribution** MI and HK contributed to the study conception and design. Field survey and lab analysis were performed by MI and SAK. Questionnaire was prepared by AR, and questionnaire survey was conducted by JA. The first draft of the manuscript was written by SN and MI. Figures and graphs were prepared by SN and NA. Data analysis and statistical techniques were applied by SN and SK. All the associated health risk assessment was conducted by AR. All authors discussed the results and approved the final manuscript.

**Data availability** All data generated or analyzed during this study are included in this published article.

**Declaration**

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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