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# Effect of waste landfill site on surface and ground water drinking quality

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**Keywords**
drinking water quality; heavy metals pollution index; landfill; municipal solid waste; principal component analysis; water quality index.

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## Abstract

Drinking water quality of surface and underground water within 1.34 km from a waste landfill site in Kumasi, Ghana was investigated. Physico-chemical properties and heavy metal concentrations were analysed to determine water quality and pollution indices. It was found that turbidity of 83% of hand dug wells, 50% of the streams and 33% of boreholes were higher than World Health Organisation (WHO) standards for drinking water. Water quality index (WQI) showed that 25% of the water sources are of excellent quality, while 50%, 15% and 5% are good quality, poor quality, very poor quality and unsuitable for drinking, respectively. Heavy metal pollution index (HPI) indicated that the water sources were above the critical limit for drinking water (HPI > 100). Principal component analysis (PCA) revealed 75.30% and 70.88% of the total variance for the physico-chemical parameters and heavy metals, respectively. The findings concluded that cadmium concentrations in all the water sources were extremely higher (0.0122–0.1090 mg/L) than WHO limit (0.003 mg/L), rendering them unwholesome for consumption.

## Introduction

The two most important sources of water are ground and surface. The wide range of water usage as a key resource in our daily activities goes through domestic, agricultural, transportation, industrial and health care (Winter *et al*., 1998). Usually, in developing countries, small households and small communities rely on ground water, while big communities and urban areas depend on surface water such as rivers and lakes, which are mostly treated at water treatment facilities. Contamination of these water sources would render them unwholesome for consumption and may be costly and difficult to treat.

Management of solid waste is a major challenge in several countries, especially in developing countries with high rate of population growth. In developing countries, mostly, solid wastes are dumped in engineered landfilled sites (Shaker and Yan, 2010) or nonengineered landfilled sites (Rana *et al*., 2018; Sharma *et al*., 2019). Landfills have been identified to have serious threat to the environment if not handled and operated appropriately (Talalaj and Biedka, 2016). The magnitude of this menace depends on the composition as well as the quantity of leachate and gases.

In Ghana, the most common means of municipal solid waste disposal is by the use of landfill. Rapid urbanization of Kumasi, the second largest city in Ghana and the regional capital of the Ashanti region has caused the city to enlarge its boarders to many rural areas in the region. This has increased the pressure on the available municipal solid waste disposal facilities. Presently, Kumasi is estimated to have about 2.3 million inhabitants producing approximately 0.75 kg solid waste/person/day (Miezah *et al*., 2015). Waste produced by households, markets, schools, etc. are transported to the landfill site by the use to garbage trucks and tricycles. This is because it is the cheapest form of solid waste treatment (Kusi *et al*., 2016). Greater fraction of waste from Kumasi metropolis are dumped and compacted into layers at the landfill site. However, because of the harm caused by landfills, which is usually attributed to improper management most people are unwilling for landfills to be developed near their communities in Kumasi.

Improper management and control have high potential of causing fires and explosions, vegetation damage, unpleasant smell, soil contamination, groundwater pollution and air pollution (Calvo *et al*., 2005; Aziz and Maulood, 2015). Also, decomposition of the organic fractions of landfill wastes produce greenhouse gases, especially methane (Sharma *et al*., 2019), which contribute to global warming.

Wastes dumped at landfills are subject to either groundwater infiltration from precipitations or erosion to surface water sources. By percolation of water through the waste

substances, it picks up a variety of colloidal inorganics and organic compounds while transporting to the bottom of the landfill (Lone *et al*., 2012). The resulting contaminated water is termed "leachate" and can permeate through the soil, surface and ground water in the vicinity of landfill sites, which pollutes both surface and ground water within the immediate surroundings in the subsoil (Bhalla *et al*., 2012) through a combination of chemical, physical and microbial processes of the dumped waste (Kjeldsen *et al*., 2010). Exposure of ground water to leachate is further increased by excess rainwater (Nagarajan *et al*., 2012). Leachate may contain organics, inorganic salts and heavy metals within it (Mojiri *et al*., 2014; Rana *et al*., 2018). These leachate constituents are mainly a function of the age of the landfill and the degree of waste stabilisation (Talalaj and Biedka, 2016). Due to slow reaction kinetics, predominant stabilisation of leachate by biological methods has been found to be less effective, posing serious adverse effects on the environment (Kulikowska *et al*., 2019).

The exposure to the leachate constituents above the permissible tolerant limits could be associated with surfeit of bioaccumulation metal poisoning-related symptoms and diseases, such as, neurological disease, asthma, depression, internal bleeding, vomiting and convulsion, ataxia, cardiovascular diseases (CVDs), diarrhoea, cancer, hypertension, pneumonitis, degenerate body joints, anaemia and gastrointestinal disorders (Farombi *et al*., 2012; Abarikwu *et al*., 2013).

The sources of odour such as leachate, landfill gases and deposited materials are a very significant issue of landfills (Maheshwari *et al*., 2015; Rana *et al*., 2018; Sharma *et al*., 2019). The health and environmental threats resulting from landfills calls for proper management and operation. Hence, extensive studies have been conducted to investigate the health and environmental effects of waste landfill on humans and the environment (Cumar and Nagaraja, 2011; Singh *et al*., 2016; Rana *et al*., 2018; Sharma *et al*., 2019). In their study, Rana *et al*. (2018) determined the leachate pollution index (LPI) and the water quality index (WQI) for different landfill sites in India and found that the leachate generated are contaminated and that the quality of groundwater improved with an increase in the downwind distance.

However, geotechnical properties of landfill waste can differ significantly from one geographical location to another due to different waste types and compositions, climate conditions, site hydrology (Talalaj and Biedka, 2016; Feng *et al*., 2017). These factors among others such as leachate interaction with the environment and precipitation may affect the characteristic properties of leachate from waste landfills (Singh *et al*., 2016; Rana *et al*., 2018). According to Owusu-Nimo *et al*. (2019), the waste stream in the Oti landfill site in Kumasi contains 47% putrescible organics and 39% of plastics, with glass waste representing 5%, which varied after 5 years. Hence, a study into the effect of landfill contamination on drinking water quality of nearby communities is essential. Also, reports that quantifies the "safest" distance from water sources near landfill sites in Ghana are limited in literature. Hence, the results from this study would provide a framework of drinking water quality near engineered waste landfilling sites, particularly for communities in Ghana as well as other developing countries with identical geotechnical properties where the practice is common.

The purpose of this study, therefore, is to investigate the effect of Kumasi waste landfill on drinking water quality of water sources in the nearby communities. The investigation will specifically include physical and chemical water quality parameters to determine if they meet the drinking quality standards of WHO and Ghana Standards Authority (GSA). The study will further investigate possible heavy metals in the water sources. Water quality and pollution evaluation indices will be employed to quantify and understand the quality of the water sources. The study will also use statistical methods to identify the various possible sources that affect water quality and the influence of landfill distance on water quality.

## Materials and methods

### Area of study

Oti-Dompoase landfill is sited at the Asokwa sub-metro with the coordinates 6°37′12′′N 1°35′16.8′′W. The landfill site is used to treat the about 1200 tons of solid waste collected daily in the Kumasi Metropolis. It was commissioned in 2003 and expected to have a life span of 15 years (Amoah, 2013). Being the largest solid waste management facility in Kumasi, it covers about 5000 ha (Addo *et al*., 2015). Currently, the landfill site is managed by the Kumasi Metropolitan Waste Management Department (KWMD).

### Water sampling and analytical methods

To assess the quality of water resources at the study area, a total of 20 different water samples were collected and analysed during the wet (rainy) season in the months of April–July. In all, six samples were taken from hand dug wells, while 12 and two samples were taken from bore holes and streams, respectively. The sampling was conducted within a radius of 1.34 kilometers with each sampling location being marked (as shown in Fig. 1) with its GPS coordinate by the help of Trimble GPS (Juno 3d). The points which were picked in latitudes and longitudes of degrees, minutes and seconds, were thereafter plotted with Google Earth Software which gave a clear satellite imagery of the study area. Additionally, Google Earth was then used to

access ground measurement of the various sampling points (water sources) to the Landfill site for the analysis.

Water samples (600 mL each) were collected manually at each site into High-Density Polyethylene (HDPE) bottles. In accordance with standard protocols and methods of American Public Health Organisation (APHA, 2012), before the sampling, the HDPE bottles were acid-washed with 10 %, v/v hydrochloric acid (HCl) to avoid any contamination from metal and non-metal ions. The pre-washed bottles were rinsed trice with the water samples on the site before sample collection. The bottled water samples were stored in a cooler box and transported to the laboratory and stored in a refrigerator at a temperature of 4°C, and the samples were analysed within a period of 48 hours.

During sampling, parameters such as, pH, electrical conductivity (EC), total dissolved solids (TDS), dissolved oxygen (DO) and temperature were determined in-situ with Hanna Instrument (HI9829) according to APHA (2012) standard protocols. The turbidity of all the samples was determined using a Thermo Scientific turbidity meter (Orion AQ 3010) while alkalinity, chloride ($Cl^-$), total hardness (TH), calcium hardness ($Ca^{2+}$), magnesium hardness ($Mg^{2+}$) and total iron were analysed using titrimetric methods. Following APHA (2012) standard procedures, heavy metals concentration including copper, lead, iron, cadmium and manganese were determined by initially conducting acid digestion. The acid digestion was carried out by addition of 20 ml of already prepared acid reagent mixture containing eight parts of nitric acid: two parts of sulphuric acid: one part of perchloric acid to 1 g of the sample in a digestion tube and boiled at 200°C until all organic portion of the sample was digested and evaporated (to obtain transparent solution). The sample was allowed to cool to room temperature and about 50 mL of deionised water was added to it. The solution was then filtered through Whatman filter paper no. 42 into a 100 mL volumetric flask and make up to the 100 mL mark. Thereafter, the concentration of the heavy metals in the samples were analysed using Atomic Absorption Spectrophotometer (Analytik Jena novAA400p). All analyses were conducted in triplicates.

## Water quality index

WQI was used to examine the overall drinking water quality of each water source. WQI is useful for rating the combined effect of different water quality parameters on the overall quality of water (Kawo and Karuppannan, 2018; Rana *et al*., 2018). To calculate WQI, each water sample was assigned a weight ($w_i$), from which a relative weight ($W_i$) and then a quality rating scale ($q_i$) were estimated. Table 1 provides the assigned $w_i$ values for each water parameter according to the relative relevance of each parameter for drinking

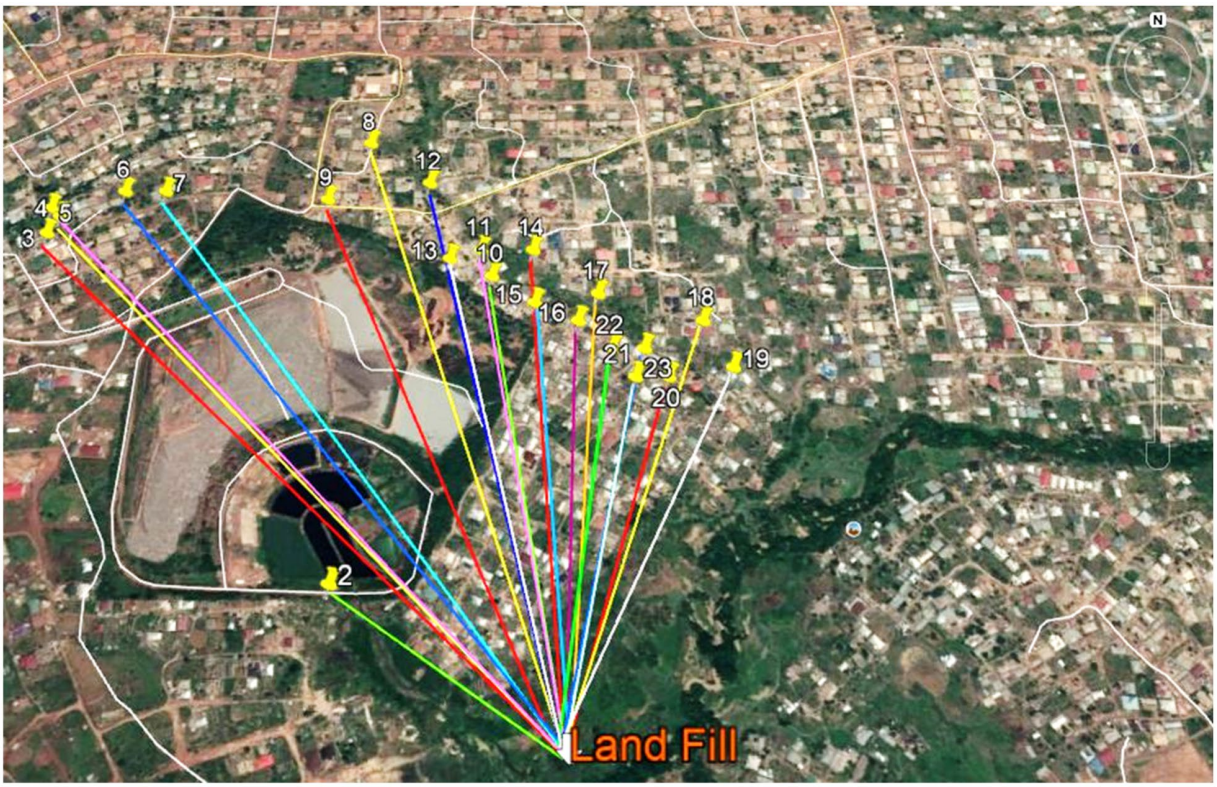


**Fig. 1.** Satellite image of distance sampling points from Oti Landfill site. [Colour figure can be viewed at wileyonlinelibrary.com]

**Table 1** Relative weight of parameters for calculating WQI

| Quality Parameter | WHO/GSA (mg/L) | Weight ($w_i$) | Relative Weight ($W_i$) |
|---|---|---|---|
| TDS | 1000.0 | 5 | 0.139 |
| EC | 1000.0 | 4 | 0.111 |
| Turbidity [a] | 5.0 | 5 | 0.139 |
| pH | 8.5 | 4 | 0.111 |
| DO | 8.0 | 1 | 0.028 |
| Alkalinity | 300.0 | 4 | 0.111 |
| TH | 500.0 | 2 | 0.056 |
| $Ca^{2+}$ | 75.0 | 2 | 0.056 |
| $Mg^{2+}$ | 50.0 | 2 | 0.056 |
| $Cl^{-}$ | 250.0 | 3 | 0.083 |
| Fe | 0.5 | 4 | 0.111 |
| | | $\Sigma w_i = 36$ | $\Sigma W_i = 1$ |

[a]Unit of turbidity is in NTU.

water purposes (Srinivasamoorthy *et al*., 2008; Singh *et al*., 2016) based on the WHO (2011) and GSA (2013) drinking water standards. Parameters which have the major effect on water quality were assigned the highest value of 5, whilst those with the minor effects were assigned the lowest value of 1.

The *Wi* values for the water sources are calculated using the Equation (1) below (Rana *et al*., 2018):

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

where *n* is the number of parameters considered. Computed $W_i$ values for the water quality parameters are presented in Table 1.

The $q_i$ based on the water quality parameters was determined by dividing the determined concentration of each water parameter ($C_i$) by the corresponding WHO/GSA standard value ($S_i$) and multiplied by 100 (Rana *et al*., 2018):

$$q_i = \frac{C_i}{S_i} \times 100 \tag{2}$$

Finally, WQI was calculated as follows (Rana *et al*., 2018):

$$\mathrm{WQI} = \sum_{i=1}^{n} q_i \times W_i \tag{3}$$

**Table 2** Water quality rating and type (Sahu and Sikdar, 2008)

| WQI range | Water quality rating |
|---|---|
| <50 | Excellent water |
| 50–100 | Good water |
| 100–200 | Poor water |
| 200–300 | Very poor water |
| >300 | Water unsuitable for drinking |

The range of water quality rating is presented in Table 2 as reported by Sahu and Sikdar (2008).

## Heavy metal pollution index

Heavy metal pollution index (HPI) was used to evaluate the contamination level of the water sources. The HPI method gives an indication of the overall quality of the water sources in relation to heavy metals. The HPI method was developed by assigning a weightage ($W_i$) for each parameter, which reflects the relative significance of each quality under consideration. It is inversely proportional to the $S_i$ of each parameter (Mohan *et al*., 1996). HPI was determined using Equation (4) (Mohan *et al*., 1996):

$$\mathrm{HPI} = \frac{\sum_{i=1}^{n} W_i \times Q_i}{\sum_{i=1}^{n} W_i} \tag{4}$$

where $Q_i$ is the sub-index of the *i*th parameter and it is calculated using Equation (5):

$$Q_i = \sum_{i=1}^{n} \frac{\{M_i - I_i\}}{S_i - I_i} \times 100 \tag{5}$$

where $M_i$ is the measured heavy metal concentration of the ith parameter, $S_i$, and $I_i$ are the standard value (i.e. the highest permissible value), and the ideal value (i.e. maximum desirable value) for drinking water, respectively, taken from the WHO (2011) and GSA (2013) standards. HPI calculation is summarised in Table 3.

## Heavy metal evaluation index (HEI)

The HEI method like the HPI gives an overall quality of the water with respect to heavy metals. The HEI was

**Table 3** HPI calculation for each parameter

| Heavy metals | Standard permissible value ($S_i$) (ppb) | Highest permissible value ($I_i$) (ppb) | Unit weightage ($W_i$) |
|---|---|---|---|
| Fe | 300.0 | 100.0 | 0.003 |
| Cd | 10.0 | 3.0 | 0.100 |
| Cu | 2000.0 | 50.0 | 0.001 |
| Pb | 15.0 | 10.0 | 0.067 |
| Mn | 400.0 | 100.0 | 0.003 |

computed using the following equation (Edet and Offiong, 2002):

$$HEI = \sum_{i=1}^{n} \frac{H_c}{H_{mac}} \quad (6)$$

where $H_c$ is the monitored value of the ith parameter and $H_{mac}$ is the maximum admissible or desirable WHO/GSA value (for drinking water) of the ith parameter.

### Statistical analysis

#### *Regression analysis and ANOVA*

A Response Surface Methodology (RSM) using of a Central Composite Rotatable Design (CCRD) was applied to analyse the influence of the landfill site distance on water quality properties and heavy metal composition. Design Expert 11.1.0.1 software (Statease, Minneapolis, MN, USA) was used for the CCRD and statistical analysis of variance (ANOVA), which resulted in 40 tests (4 factorial points, 5-star points, and 4 central points, 7 responses). Each variable was set at $-\alpha$, and $\alpha$ (where $\alpha$ = 1.414) in each case.

#### *Principal component analysis (PCA) and hierarchical cluster analysis (HCA)*

IBM-SPSS statistics version 23 was used for PCA and HCA. Separate analyses were done for the sources of heavy metals and physico-chemical parameters. These variables were grouped based on similar scale and variations, as these may reveal the various effects on ground water (Manikandan *et al*., 2014; Singh *et al*., 2016).

PCA was used to identify the possible sources of heavy metals and physico-chemical variables. PCA analysis is used to reduce the data (Manikandan *et al*., 2014) and helps to identify the source of pollutants (Gibrilla *et al*., 2011). Varimax rotation with Kaiser Normalisation was used to perform factor analysis (Howitt and Cramer, 2005), which facilitates the interpretation of PCA results by minimising the number of variables with a high loading on each component (Boateng *et al*., 2015).

HCA was utilised to identify groups of water samples with similar contents of heavy metals and physico-chemical parameters. The analysis creates a dendrogram or cluster tree as the samples are grouped by ranking or linking inter-sample similarities in a data set (Diaz and Hollmen, 2002). For heavy metal analysis, iron (Fe) and cadmium (Cd) were used as these were the only variables with detectable concentrations; whilst total iron was also included.

## Results and discussion

### Physical water quality characteristics

Table 4 shows the physical water quality characteristics of surface and ground water samples that were analysed near the Oti Landfill site in Kumasi, Ghana. Temperature values were higher than the WHO/GSA standard value (25°C). This was because the average temperature in Kumasi during the experiment was around 28 to 32°C. Temperature between 20 and 45°C are optimal temperatures for the growth of mesophilic bacteria such as human pathogens (Prescott *et al*., 1999). Also, warm water conditions promote the growth of nuisance microorganisms, which could lead to the development of unpleasant odour and taste in drinking water (Pangborn and Bertolero, 1972).

Out of the 12 boreholes, the average turbidity values of four samples (representing 33.33 %) were remarkably higher than the WHO limits for drinking water quality, whilst 83.33 % and 50.00 % of the hand dug well and surface water sources, respectively, were higher than the WHO limits. Turbidity in the water sources is due to suspended particles or colloidal matter, which may be caused by the transfer of leachate from the landfill site to the water sources through ground water infiltration from precipitations or erosions to the surface water sources. According to WHO (2011), high levels of turbidity can protect microorganisms against disinfection, stimulate the growth of bacteria and result in high demand of chlorine and can also reduce the effectiveness of physical disinfection methods such as UV irradiation, as the particulates may impair light transmission through the water. Turbidity in surface water may also be due to microorganisms that are harmful to human health. Due to visible cloudiness, high levels of turbidity can negatively affect drinking acceptability of the water (WHO, 2011). Hence, the water sources with high turbidity pose risks to human health; and hence, require treatment before consumption.

The levels of TDS were below the WHO limits for all the water samples. Similarly, only conductivity level of the surface water, which is 1.34 km away from the landfill site is higher than WHO limit for drinking water quality.

### Chemical quality characteristics

Chemical water quality characteristics of the ground and surface sources are presented in Table 5. About 66.67% of borehole samples have slightly acidic pH below the recommended minimum WHO value of 6.50, whereas 83.33% and 50.00% of hand dug well and surface water, respectively, have pH values less than 6.50.

**Table 4** Physical water quality characteristics of surface and ground water near waste landfill site

| Samples | Distance from landfill pit (km) | Temperature (°C) | Turbidity (NTU) | TDS (mg/L) | Conductivity (μS/cm) |
|---|---|---|---|---|---|
| WHO/GSA standard | | 25.00 | <5.00 | <1000.00 | <1000.00 |
| 1A (borehole) | 0.43 | 27.58 | 2.34 | 63.00 | 127.00 |
| 2B (hand dug well) | 0.63 | 29.75 | 14.78 | 69.00 | 137.00 |
| 3A (borehole) | 0.65 | 29.10 | 2.69 | 61.00 | 122.00 |
| 4A (borehole) | 0.67 | 28.24 | 302.00 | 59.00 | 119.00 |
| 5B (hand dug well) | 0.69 | 28.72 | 8.63 | 97.00 | 195.00 |
| 6B (hand dug well) | 0.70 | 27.44 | 1.03 | 82.00 | 153.00 |
| 7A (borehole) | 0.74 | 27.42 | 1.34 | 71.00 | 141.00 |
| 8A (borehole) | 0.77 | 27.41 | 1.52 | 102.00 | 205.00 |
| 9A (borehole) | 0.78 | 26.45 | 8.56 | 126.00 | 253.00 |
| 10B (hand dug well) | 0.82 | 28.13 | 36.40 | 179.00 | 358.00 |
| 11A (borehole) | 0.86 | 28.25 | 3.87 | 81.00 | 162.00 |
| 12A (borehole) | 0.88 | 28.25 | 2.27 | 75.00 | 150.00 |
| 13B (hand dug well) | 0.88 | 27.46 | 34.36 | 162.00 | 326.00 |
| 14C (stream) | 1.04 | 28.48 | 1.40 | 71.00 | 142.00 |
| 15A (borehole) | 1.06 | 27.10 | 8.74 | 469.00 | 937.00 |
| 16A (borehole) | 1.22 | 26.67 | 0.79 | 46.00 | 87.00 |
| 17A (borehole) | 1.26 | 26.73 | 0.76 | 38.00 | 77.00 |
| 18B (hand dug well) | 1.28 | 27.62 | 3.31 | 97.00 | 193.00 |
| 19A (borehole) | 1.29 | 27.99 | 14.29 | 73.00 | 147.00 |
| 20C (stream) | 1.34 | 25.72 | 15.95 | 542.00 | 1080.00 |

A, borehole; B, hand dug well; C, stream. NG, no guideline value (i.e. not of health concern at levels found in drinking water).
[a]For maintenance of aquatic life.

The lower pH is caused by decomposed organic material within the landfill site that are transferred to the water sources. The carbon dioxide that is released during decomposition combines with the water to form carbonic acid (Bhalla *et al*., 2014), which results in lower pH. It has been reported that leachate pH less than 6.5 is an indication that the landfill site is young (less than 5 years) (Bhalla *et al*., 2014), whilst leachate from older landfill sites have pH above 7.5 (Vathsalan *et al*., 2017), which is caused by the generation of methane (Bhalla *et al*., 2014). Heavy metals tend to be more toxic at lower pH because they are more soluble. Hence, the water sources with lower (or acidic) pH may be harmful for consumption.

All other chemical quality parameters were within the WHO limits. However, hardness above about 200 mg/L may cause scale deposition in treatment works, pipes and tanks, and will result in high soap consumption which will cause formation of scum, whilst heating will form deposits of calcium carbonate scale (WHO, 2011). More than half of the water sources have total hardness above 200 mg/L; representing 50% of the borehole sources (244.76–701.19 mg/L), 67% of the hand dug well (277.83–496.13 mg/L), and 50% of the surface water with the highest value being 826.88 mg/L. Levels of total iron above 0.30 mg/L cause stains in laundry and plumbing fixtures and may develop turbidity and colour in the water (WHO, 2011). As shown in Table 2, only 17% of the borehole water sources within 0.67 km from the landfill site have iron levels above 0.30 mg/L. The surface water source which was 1.34 km from the landfill site contains the highest level of iron (0.60 mg/L).

## Heavy metals concentration

Heavy metals concentrations in water are very important as these also determine the toxicity of ground and surface waters. The levels of heavy metals found in the water sources near the Oti Landfill site in Kumasi, Ghana are presented in Table 6. The levels of heavy metals namely Cu, Pb and Mn in the water sources were below detection. The concentration of Cd in all the water sources were extremely higher than the WHO guideline value. Cd is carcinogenic and causes toxicity to the kidney with a long biological half-life of 10–35 years in humans (WHO, 2011). Cd levels in the surface water decreased with increasing distance from the landfill site. Exceptionally higher Cd values (0.1090–0.3050 mg/L) were found in hand dug wells which are about 0.7 km from the landfill site; with concentrations generally decreasing as the distance from the landfill site increased with the exception of a few samples that did not follow the trend. For the boreholes, apart from samples taken at 0.78 and 1.06 km away from the landfill site, the

**Table 5** Chemical water quality characteristics of ground and surface water near Oti landfill site

| Samples | Distance from landfill pit (km) | pH | DO (mg/L) | Alkalinity (mg/L) | Chloride (mg/L) | Fe (mg/L) | TH (mg/L) | $Ca^{2+}$ (mg/L) | $Mg^{2+}$ (mg/L) |
|---|---|---|---|---|---|---|---|---|---|
| WHO/GSA standard | | 6.50–8.50 | <8.00[a] | <500.00 | <250.00 | <0.30 | <500 | 75 | 50 |
| 1A (borehole) | 0.43 | 6.16 | 2.98 | 35.00 | 7.50 | 0.16 | 291.06 | 92.61 | 198.45 |
| 2B (hand dug well) | 0.63 | 6.06 | 2.24 | 46.00 | 12.50 | 0.20 | 178.61 | 58.21 | 120.39 |
| 3A (borehole) | 0.65 | 5.69 | 3.45 | 14.50 | 38.74 | 0.31 | 112.26 | 37.04 | 75.41 |
| 4A (borehole) | 0.67 | 5.88 | 3.00 | 19.50 | 6.25 | 0.43 | 119.07 | 23.81 | 95.26 |
| 5B (hand dug well) | 0.69 | 5.64 | 3.40 | 14.00 | 26.24 | 0.24 | 138.92 | 44.98 | 93.93 |
| 6B (hand dug well) | 0.70 | 6.24 | 2.14 | 35.00 | 5.00 | 0.15 | 304.29 | 92.61 | 211.68 |
| 7A (borehole) | 0.74 | 7.03 | 3.45 | 49.00 | 8.75 | 0.15 | 357.21 | 124.36 | 232.85 |
| 8A (borehole) | 0.77 | 6.74 | 3.66 | 58.50 | 6.25 | 0.10 | 436.59 | 132.30 | 304.29 |
| 9A (borehole) | 0.78 | 6.85 | 2.56 | 81.00 | 6.25 | 0.08 | 132.30 | 23.81 | 108.49 |
| 10B (hand dug well) | 0.82 | 5.96 | 3.47 | 23.00 | 24.99 | 0.24 | 277.83 | 68.80 | 209.03 |
| 11A (borehole) | 0.86 | 5.42 | 1.59 | 19.00 | 23.74 | 0.10 | 191.84 | 52.92 | 138.92 |
| 12B (hand dug well) | 0.88 | 5.06 | 2.95 | 20.00 | 43.74 | 0.20 | 317.52 | 66.15 | 251.37 |
| 13A (borehole) | 0.88 | 6.40 | 2.92 | 28.00 | 11.25 | 0.08 | 284.45 | 68.80 | 215.65 |
| 14C (stream) | 1.04 | 5.15 | 3.62 | 9.50 | 19.99 | 0.10 | 112.46 | 26.46 | 86.00 |
| 15A (borehole) | 1.06 | 7.67 | 3.25 | 124.50 | 117.46 | 0.15 | 701.19 | 174.64 | 526.55 |
| 16A (borehole) | 1.22 | 5.71 | 3.48 | 25.50 | 11.25 | 0.18 | 52.92 | 18.52 | 34.40 |
| 17A (borehole) | 1.26 | 5.98 | 3.28 | 23.50 | 8.75 | 0.16 | 59.54 | 13.23 | 46.31 |
| 18B (hand dug well) | 1.28 | 6.82 | 3.00 | 54.00 | 13.75 | 0.20 | 496.13 | 177.28 | 318.84 |
| 19A (borehole) | 1.29 | 5.85 | 2.96 | 19.50 | 18.74 | 0.24 | 244.76 | 82.03 | 162.73 |
| 20C (stream) | 1.34 | 7.70 | 1.63 | 164.00 | 179.94 | 0.60 | 826.88 | 272.54 | 554.34 |

A, borehole; B, hand dug well; C, stream; NG, no guideline value (i.e. not of health concern at levels found in drinking-water).

**Table 6** Heavy metal concentration in surface and ground water near waste landfill site

| Sample ID | Distance from Land fill Pit | Fe (mg/L) | Cd (mg/L) | Cu (mg/L) | Pb (mg/L) | Mn (mg/L) |
|---|---|---|---|---|---|---|
| WHO standard | (Km) | <0.3000 | <0.0030 | <2.000 | <0.0100 | <0.4000 |
| 1A (borehole) | 0.43 | 0.0210 | 0.0765 | 0.0000 | 0.0000 | 0.0000 |
| 2B (hand dug well) | 0.63 | 0.0890 | 0.0587 | 0.0000 | 0.0000 | 0.0000 |
| 3A (borehole) | 0.65 | 0.0000 | 0.0745 | 0.0000 | 0.0000 | 0.0000 |
| 4A (borehole) | 0.67 | 0.0000 | 0.0589 | 0.0000 | 0.0000 | 0.0000 |
| 5B (hand dug well) | 0.69 | 0.0540 | 0.3050 | 0.0000 | 0.0000 | 0.0000 |
| 6B (hand dug well) | 0.70 | 0.0194 | 0.1090 | 0.0000 | 0.0000 | 0.0000 |
| 7A (borehole) | 0.74 | 0.0246 | 0.0380 | 0.0000 | 0.0000 | 0.0000 |
| 8A (borehole) | 0.77 | 0.0164 | 0.0260 | 0.0000 | 0.0000 | 0.0000 |
| 9A (borehole) | 0.78 | 0.0109 | 0.0974 | 0.0000 | 0.0000 | 0.0000 |
| 10B (hand dug well) | 0.82 | 0.0340 | 0.0380 | 0.0000 | 0.0000 | 0.0000 |
| 11A (borehole) | 0.86 | 0.0579 | 0.0256 | 0.0000 | 0.0000 | 0.0000 |
| 12B (hand dug well) | 0.88 | 0.0310 | 0.0122 | 0.0000 | 0.0000 | 0.0000 |
| 13A (borehole) | 0.88 | 0.0174 | 0.0220 | 0.0000 | 0.0000 | 0.0000 |
| 14C (stream) | 1.04 | 0.0491 | 0.0525 | 0.0000 | 0.0000 | 0.0000 |
| 15A (borehole) | 1.06 | 0.0000 | 0.0923 | 0.0000 | 0.0000 | 0.0000 |
| 16A (borehole) | 1.22 | 0.0220 | 0.0262 | 0.0000 | 0.0000 | 0.0000 |
| 17A (borehole) | 1.26 | 0.0232 | 0.0262 | 0.0000 | 0.0000 | 0.0000 |
| 18B (hand dug well) | 1.28 | 0.0127 | 0.0447 | 0.0000 | 0.0000 | 0.0000 |
| 19A (borehole) | 1.29 | 0.0332 | 0.0188 | 0.0000 | 0.0000 | 0.0000 |
| 20C (stream) | 1.34 | 0.0000 | 0.0178 | 0.0000 | 0.0000 | 0.0000 |

A, borehole; B, hand dug well; C, stream; NG, no guideline value (i.e. not of health concern at levels found in drinking-water). Levels of Cu, Pb and Mn were below detection limit.

levels of Cd decreased with increased in distance from the landfill site (details of ANOVA have been discussed below). The extremely high levels of Cd in all the water sources mean that their consumption will be harmful to human health, and therefore require treatment to reduce the Cd concentration to the levels below the permissible guideline value.

There is no guideline value for metal iron; however, levels above 0.30 mg/L will still affect the taste and appearance of drinking water (WHO, 2011), as explain above. None of the water sources have metal iron concentration above the WHO/GSA permissible standard.

Contamination of the streams is caused by erosion especially during rainfall, whilst that of the boreholes and hand dug wells are due to infiltration or permeation of the landfill leachate through the water (Bhalla *et al*., 2012; Lone *et al*., 2012). Both erosion and leaching are affected by slope steepness of the land and soil characteristics such as texture and permeability. This may be the reason for the extreme pollution level of the surface water, which was 1.34 km farthest away from the landfill site. However, it must be noted that the erosion and leaching factors are beyond the scope of this paper; hence, it is recommended that further studies should be conducted to investigate how these factors affect contamination of water sources near the Oti landfill sites.

## Evaluation of water quality based on WQI

The values of WQI and the corresponding quality of the water sources based on the classification by Sahu and Sikdar (2008) have been presented in Table 7. The results indicated that, for all the water sources, 25% are of excellent quality (WQI < 50), 50% are good quality water (WQI = 50–100), 15% are poor quality water (WQI = 100–200) and 5% are very poor quality water (WQI = 200–300) and water unsuitable for drinking (WQI > 300). Specifically, of all the water sources, 20% of the boreholes are water of excellent quality, whilst 30%, and 5% are good quality water, poor quality water and water unsuitable for drinking, respectively. For the hand dug well, 20% and 10% are good and poor quality water, respectively; whilst 5% of the surface water are of excellent and poor quality. The borehole within 0.67 km from the landfill site is unsuitable for drinking purposes due to the extremely high concentrations of turbidity and Fe. The very poor quality of the surface water that is 1.34 km from the landfill is due to the high levels of conductivity, turbidity, hardness and Fe.

Based on the QWI values, the distance from the landfill to the water sources does not have direct influence on water quality standards. This is similar to the earlier discussion on the physico-chemical characteristics of the water sources. Rana *et al*. (2018) reported WQI values in the

**Table 7** Water quality index of the water sources

| Samples | Distance from landfill pit (km) | WQI | Water quality rating |
|---|---|---|---|
| 1A (borehole) | 0.43 | 57.49 | Good water |
| 2B (hand dug well) | 0.63 | 81.44 | Good water |
| 3A (borehole) | 0.65 | 43.99 | Excellent water |
| 4A (borehole) | 0.67 | 880.29 | Water unsuitable for drinking |
| 5B (hand dug well) | 0.69 | 61.63 | Good water |
| 6B (hand dug well) | 0.70 | 55.38 | Good water |
| 7A (borehole) | 0.74 | 63.38 | Good water |
| 8A (borehole) | 0.77 | 72.54 | Good water |
| 9A (borehole) | 0.78 | 59.64 | Good water |
| 10B (hand dug well) | 0.82 | 158.55 | Poor water |
| 11A (borehole) | 0.86 | 48.00 | Excellent water |
| 12A (borehole) | 0.88 | 54.99 | Good water |
| 13B (hand dug well) | 0.88 | 154.92 | Poor water |
| 14C (stream) | 1.04 | 31.93 | Excellent water |
| 15A (borehole) | 1.06 | 145.67 | Poor water |
| 16A (borehole) | 1.22 | 26.24 | Excellent water |
| 17A (borehole) | 1.26 | 26.33 | Excellent water |
| 18B (hand dug well) | 1.28 | 86.58 | Good water |
| 19A (borehole) | 1.29 | 88.13 | Good water |
| 20C (stream) | 1.34 | 200.00 | Very poor water |

The letters A, B and C represent borehole, hand dug well and surface water, respectively.

range 70–185 for groundwater in India, and observed that the quality of groundwater within 2 km from the landfills is poor, which improved with an increased in the downwind distance after 2 km from the landfill site. This is in contrasts with the general results of this study.

## Pollution evaluation indices of water

### *Heavy metal pollution index (HPI)*

The HPI criteria values were developed by following the three classifications presented by Edet and Offiong (2002) for the purpose of drinking water. The values were computed using the averages of the values, and the different levels of pollution were demarcated by a multiple of the average values. Hence, the proposed HPI criteria for the water sources in this study are summarised as follows: low (HPI < 400), medium (HPI = 400–800), and high (HPI > 800). The values in Table 8 show that 60% of the water sources are low polluted, 35% within the medium pollution zone, while 5% are highly contaminated. It can be observed that except the hand dug well which is 0.88 km from the landfill site, HPI values of all the other water sources were above the critical limit of 100 proposed for drinking water by Prasad and Bose (2001). Boateng *et al*. (2015) in their study on hand-dug wells from the Ejisu-Juaben Municipality in Ghana, reported HPI values ranging from 319.20 to 688.05, which were all above the critical value of 100. Although their study area was to the west of the Kumasi Metropolitan Assembly and in the same region, a direct comparison cannot be made, because the two study areas were not in the same vicinity. Also, their water sources were not near a waste landfill.

### *Heavy metal evaluation index (HEI)*

Like HPI, the HEI values are divided into three classes using a multiple of the mean value to categorise the different levels of contamination as low (HEI < 16), medium (HEI = 16–30), and high (HEI > 30). The HEI values ranged from 4.38 to 36.53 with a mean of 16.02. As per the classification above, 60% of the water sources fall within the low contaminated zone, 25% are classified as medium contaminated and 15% fall within the high polluted zone. It can be observed that the HPI and HEI values show similar trends at the various sampling areas, except a few samples. Although a direct relationship between landfill distances to the water sources was not established, it was observed that after 1.22 km from the landfill, heavy metal contamination of the water sources reduced, falling within the low polluted zone. In a different study in the Ejisu-Juabeng Municipality in the Ashanti region of Ghana, Boateng *et al*. (2015) found that 58% of groundwater samples are within the low polluted zone, while 32% fall within the medium zone and 10% within the high contaminated zone.

## Statistical analysis

### *Principal component analysis (PCA)*

PCA was used to further examine the extent of contamination of the water samples and source identification. The Varimax rotation was used to maximise the sum of the variance of the factor coefficients (Gotelli and Ellison, 2004) and this helped to explain the groups that influenced the water sources (Boateng *et al*, 2015). Tables 9 and 10 show the components, variable loadings, and the variances. Using Kaiser Normalization, components having Eigen values greater than unity were retained (Singh *et al*., 2016), in which two principal components were obtained given a total variance of 75.30% and 70.88%, respectively, for the physico-chemical parameters and heavy metals in the water sources. Positive PCA scores suggest that the parameters that are significantly loaded on a specific component affect the quality of the water sources, while negative values

**Table 8** Evaluation of water quality based on HPI and HEI

| Samples | Distance from landfill pit (km) | HPI | Degree of pollution | HEI | Degree of pollution |
|---|---|---|---|---|---|
| 1A (borehole) | 0.43 | 607.70 | Medium | 25.71 | Medium |
| 2B (hand dug well) | 0.63 | 460.81 | Medium | 20.46 | Medium |
| 3A (borehole) | 0.65 | 590.42 | Medium | 24.83 | Medium |
| 4A (borehole) | 0.67 | 461.60 | Medium | 19.63 | Medium |
| 5B (hand dug well) | 0.69 | 227.61 | Low | 10.71 | Low |
| 6B (hand dug well) | 0.70 | 875.50 | High | 36.53 | High |
| 7A (borehole) | 0.74 | 289.25 | Low | 12.91 | Low |
| 8A (borehole) | 0.77 | 190.08 | Low | 8.83 | Low |
| 9A (borehole) | 0.78 | 779.63 | Medium | 32.58 | High |
| 10B (hand dug well) | 0.82 | 289.34 | Low | 13.01 | Low |
| 11A (borehole) | 0.86 | 187.18 | Low | 9.11 | Low |
| 12A (borehole) | 0.88 | 157.06 | Low | 7.51 | Low |
| 13B (hand dug well) | 0.88 | 74.27 | Low | 4.38 | Low |
| 14C (stream) | 1.04 | 409.23 | Medium | 17.99 | Medium |
| 15A (borehole) | 1.06 | 737.41 | Medium | 30.77 | High |
| 16A (borehole) | 1.22 | 191.79 | Low | 8.95 | Low |
| 17A (borehole) | 1.26 | 191.80 | Low | 8.97 | Low |
| 18B (hand dug well) | 1.28 | 344.47 | Low | 15.03 | Low |
| 19A (borehole) | 1.29 | 130.79 | Low | 6.60 | Low |
| 20C (stream) | 1.34 | 122.21 | Low | 5.93 | Low |
| Maximum | | 875.50 | | 36.53 | |
| Minimum | | 76.27 | | 4.38 | |
| Mean | | 366.01 | | 16.02 | |

The letters A, B and C represent borehole, hand dug well and surface water, respectively.

**Table 9** Rotated component matrix of two component model for physico-chemical parameters

| | Component | |
|---|---|---|
| Parameters | PC 1 | PC 2 |
| Temperature, °C | –0.584 | 0.230 |
| TDS | 0.942 | 0.149 |
| Conductivity | 0.941 | 0.149 |
| Turbidity, NTU | –0.153 | 0.827 |
| pH | 0.816 | –0.194 |
| DO, ppm | –0.360 | –0.435 |
| Total Iron, ppm | 0.559 | 0.749 |
| Alkalinity, mg/L | 0.948 | –0.005 |
| Total Hardness, mg/L | 0.947 | –0.060 |
| Calcium hardness, mg/L | 0.909 | –0.107 |
| Magnesium hardness, mg/L | 0.946 | –0.037 |
| Chloride, mg/L | 0.879 | 0.199 |
| Eigen Value | 7.220 | 1.063 |
| % of Variance | 65.635 | 9.666 |
| Cumulative % | 65.635 | 75.301 |

**Table 10** Rotated component matrix of two component model for heavy metal parameters

| | Component | |
|---|---|---|
| Parameters | PC 1 | PC 2 |
| Fe, ppm | 0.629 | –0.401 |
| Cd, ppm | 0.833 | 0.196 |
| Eigen Value | 1.810 | 1.025 |
| % of Variance | 45.246 | 25.634 |
| Cumulative % | 45.246 | 70.880 |

indicate that those parameters do not affect water quality (Boateng *et al*., 2015). Liu *et al*. (2003) classified component loadings according to absolute loading values as follows: "strong" (<0.75), "moderate" (0.75–0.50), and "weak" (0.50–0.30). Strong positive loading dominated by PC1 in the water sources is shown in TDS, conductivity, pH, alkalinity, TH, $Ca^{2+}$, $Mg^{2+}$ and Cd. The moderate positive loading is indicated in total iron and Fe (as a heavy metal). These accounted for 65.64% and 45.25% of the total variance for the physico-chemical parameters and heavy metals, respectively. The presence of the components in PC1 are derived from leachate of mixed sources of the landfill and other anthropogenic activities. High loadings of cadmium in the water sources may be due to agricultural activities such fertilizers produced from phosphate ores (WHO, 2008) and/or leachate of e-waste such as batteries and electroplating materials at the landfill.

The 9.67% and 70.88% of total variance for physico-chemical parameters and heavy metals, respectively, is attributed to PC2 with higher positive loadings for turbidity, and total iron, and weak positive loadings for TDS,

conductivity, $Cl^-$ and Cd. The high turbidity in PC2 may be due to ground water infiltration from precipitation or erosion of suspended or colloidal matter.

### *Hierarchical cluster analysis (HCA)*

HCA was used to determine the relationship among the various parameters by grouping the water sources based on their similarities in physico-chemical and heavy metal compositions. As shown in Fig. 2, the 20 water sources produced two clusters for the physico-chemical characteristics based on spatial similarities and dissimilarities. The first cluster includes TDS, conductivity, magnesium and total hardness. TDS and conductivity correspond to medium polluted borehole sample sites, while total and magnesium hardness relate to low polluted hand dug well and borehole sample sites. The second cluster consist of pH, DO, temperature, alkalinity, chloride, turbidity and calcium hardness. The DO and calcium hardness correspond to high polluted borehole sample sites, whilst the remaining parameters relate to low polluted borehole sample sites.

HCA of heavy metal compositions show one cluster of Fe and Cd. The presence of Cd reveals anthropogenic contribution of contamination and was identified in the higher polluted level. The Fe originated from lithogenic contribution source of contamination (Boateng *et al*., 2015) and was found generally in low polluted levels, except a few sample sites such as surface water and two borehole sites.

### *Regression analysis and ANOVA*

In general, the experimental data fitted to a sixth-order polynomial model, mainly, quadratic as linear relationship could not be established between the parameters and

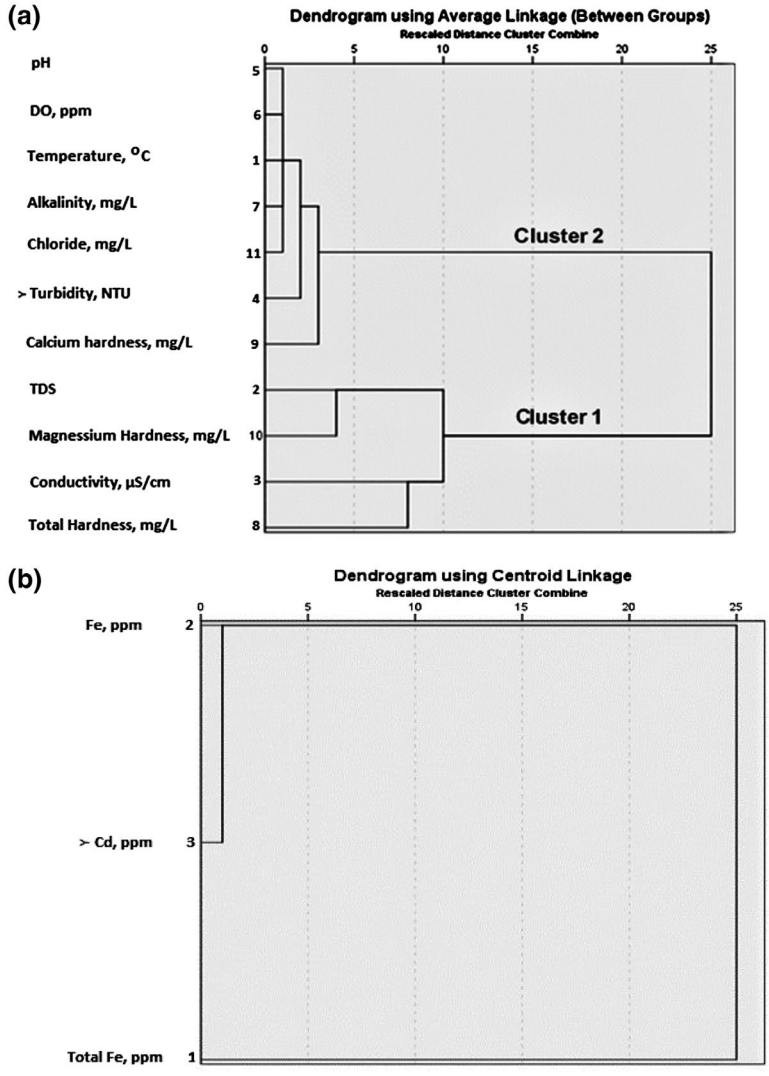


**Fig. 2.** Hierarchical dendrogram of water sources near Oti Dompoase landfill site: (a) physico-chemical parameters; and (b) heavy metals composition.

distance from the landfill site. The validation of the accuracy of the quadratic model was tested with analysis of variance (ANOVA) with the confidence level of 95%. To determine how well the CCRD fitted the experimental data obtained, the parameters $R^2$ and p-value were used. Table 11 shows the ANOVA results of the established model for the physicochemical characteristics and heavy metals found in the water sources.

Waste landfill site distance significantly affects the levels of chloride and DO in the water sources. In the case of pH, conductivity, alkalinity and TDS, P-values are higher than 0.0500 indicating that landfill distance do not significantly influence these parameters. Waste landfill site distance from the water sources does not have significant effect on the levels of Cd, Fe and turbidity in the water sources as P-values are higher than 0.0500. However, interactions between the landfill site distance (D), temperature (T) and other higher terms significantly affect Chloride, DO and TH with P-values ranging from 0.0110 to 0.02087.

It is worth mentioning that linear models were not found between the distance from the waste landfill site and the level of contaminants in the water sources. This may be due to erosion, infiltration and permeation or leaching factors previously explained above.

## Effect of waste landfill on water quality and the environment

Waste landfill is the most widely used waste management practice in developing and low-income countries. However, the results from this work show that waste landfill affects the drinking water quality of surface and ground water sources that are more than 1 km from the landfill site. The physical, chemical, aesthetic and biological quality characteristics of water sources have major influence on the health and safety of humans and the environment. This work found that the levels of Cadmium (Cd) and turbidity in surface and underground water sources within the surrounding area of the waste landfill site were extremely higher; whilst pH levels were lower, than WHO recommended guideline values for drinking water quality.

Water resources with high level of turbidity are caused by the presence of suspended particulate or dissolved solids in water scatters light beams, rather than being transmitted making it appear cloudy or murky. Some of these particulate solids may consist of sediment such as clay and silt, fine organic and inorganic matter, soluble coloured organic compounds, algae, and other microscopic organisms (MPCA, 2008; Sharma *et al*., 2019). The aesthetic quality (clarity) of the water resources is reduced due to high turbidity. Turbidity has major influence on living organisms that are directly dependent on sunlight, like aquatic plants since it reduces their ability to undergo photosynthesis. This, in turn, has an impact on other living organisms that rely on these plants for food and oxygen supply. Reduction of light penetration through the water sources also has important impacts because prey capture efficiency, prey selection and feeding mode are greatly affected. Also, at a very high level of turbidity the opercular cavity of fishes in respective water bodies may become blocked and at a lower concentrations, particles tend to coat the gill surface and inhibit gaseous diffusion, nitrogenous excretion and ion exchange (Appleby and Scarratt, 1989).

The pH value is an important feature of polluted water as it is a measure of the acidity or basicity of the water. The pH change of water affects plant growth including morphology, photosynthesis and nutrient absorption (Zhao *et al*., 2013). Furthermore, the pH of water has an effect on the solubility of fertilizers, the effectiveness of insecticides and fungicides before being applied to crops (Argo, 2013). Typically, the higher the pH of water, the lower the solubility of these materials in the cultivation field. Majority of aquatic life prefer pH of 6.5–9.0; this makes the water sources with low pH level unfavourable as a habitat for such organisms (FEI, 2013). Acid deposition has many harmful ecological effects when the pH of most aquatic systems falls below 6.0 and especially below 5.0 (Lenntech, 2019). As the pH approaches 5.0, non-desirable species of plankton

**Table 11** Results of analysis of variance (ANOVA)

| Response | Model | Significant model terms | *F*-value | $R^2$ | *p*-value |
|---|---|---|---|---|---|
| Chloride | Quartic | D, $D^2T^2$ | 7.47 | 0.5776 | .0250 |
| Fe | Sixth | DT, $DT^3$ | 4920.55 | 0.9989 | .0112 |
| Cd | Sixth | D, T, DT, $D^2$, $T^2$, $D^2T$, $DT^2$, etc. | 415544.32 | 0.9996 | .0012 |
| DO | Quadratic | D, T, DT, $D^2$, $DT^2$, $D^3$, $D^2T^2$, etc. | 4.33 | 0.8200 | .0012 |
| Turbidity | Sixth | D, DT, $D^2$, $T^2$, $DT^2$, $D^3$, $D^4$, $T^4$ | 2.84 | 0.6141 | .0110 |
| Alkalinity | Quadratic | N/A | 1.94 | 0.671 | .0777 |
| Total hardness | Sixth | N/A | 2.44 | 0.7195 | .0287 |
| pH | Sixth | N/A | 0.6 | 0.9146 | .7887 |
| Conductivity | Sixth | N/A | 4.84 | 0.9897 | .3451 |
| TDS | Sixth | N/A | 7.47 | 1.03 | .2812 |

and mosses may begin to invade, and populations of fish such as smallmouth bass disappear (Bouaoun and Nabbout, 2016). Low pH could cause chronic stress that may not kill individual fish, but result in aquatic organisms having lower body weight, smaller size and make fishes less active to compete for food and habitat (Lenntech, 2019).

Heavy metals are classified under environmental pollutant category due to their toxic effects on plants, animals and humans (Sharma and Agrawal, 2005). Anthropogenic activities such as landfilling have the potential of increasing the levels of heavy metals in water sources to toxic levels as identified by the extremely high concentrations of Cd in this research. The impact of Cd on aquatic organisms may be due to the transfer of pollutants from various diffuse or point sources of the landfill into the water sources. Higher Cd concentration may be poisonous to metal sensitive enzymes, resulting in growth inhibition and death of the organisms. Cadmium has no essential biological functions in living organisms (Kumar *et al*., 2010); its presence poses great threat to aquatic organisms especially, to fishes which is one of the major sources of protein rich food for humankind (Singh and Ajay, 2011). Sub-lethal effects in fish present in water sources, notable malformation of the spine as well as structural and function alterations in various vital organs including liver, kidney, gill and intestine have been reported (Kumar and Singh, 2010). Uptake of high doses of Cd by plants through irrigation with polluted water aids its accumulation along the food chain thereby posing potential threat to human and animal health. Cadmium exert toxic effects on the kidney, the skeletal and respiratory system and it is classified as a human carcinogen. Cadmium accumulates primarily in the kidneys, and its biological half-life in humans is 10–35 years (WHO, 2008). The excretion of low molecular weight (LMW) proteins in urine indicates tubular dysfunction caused by toxic exposure to Cd (Wallin *et al*., 2014). Additionally, bioaccumulation due to drinking water containing high levels of Cd or by consumption of food containing high Cd could lead to impairment in calcium metabolism and the formation of kidney stones (WHO, 2008).

Table 11 shows that is it possible to model the influence of landfill distance on drinking water quality characteristics of water sources near municipal waste landfill sites. Such information would be required if selecting and designing sites for municipal waste landfill. The health and environmental threat resulting from the high levels of contaminants in the water sources within 1.34 km from the waste landfill sites calls for the need to site landfills farther away from communities and water sources. In addition, periodic analysis and proper monitoring of water resources near existing landfill sites are needed to understand the extent of pollution caused by waste landfills and the selection of appropriate treatment technologies required to reduce the level of contaminants to acceptable legal limits.

## Conclusions

**(1)** In this work, surface water sources, boreholes and hand dug wells within a radius of 1.34 km from a waste landfill site in Kumasi, Ghana, were analysed to investigate the effect of the waste landfill site on the drinking water quality of nearby communities.

**(2)** The WPI showed that 15% of the water sources are of poor quality, while 5% are very poor quality and water unsuitable for drinking purposes.

**(3)** HPI of the water sources were above the critical limit of 100, except the hand dug well 0.88 km from the landfill, and that 5% of the water sources are highly polluted, whilst HEI indicated that 15% of the water sources are within the highly contaminated zone.

**(4)** PCA revealed 75.30% and 70.88% of the total variance for the physico-chemical parameters and heavy metals, respectively.

**(5)** The ANOVA results indicated that except chloride and dissolved oxygen, the distance from the water sources to the landfill site do not have any significant effect on the levels of the other physico-chemical properties.

**(6)** The findings from this study indicate that hand dug well, borehole and streams within 1.34 km from the Oti-Dompoasi waste landfill site in Kumasi, Ghana are not safe for drinking as the Cd concentrations are extremely higher (0.0122–0.1090 mg/L) than the WHO limit of 0.003 mg/L for drinking water; and hence, requires treatment to reduce the contaminants to the acceptable limit.

**(7)** However, further research is required to investigate the effect of soil characteristics and landscape on the level of pollutants in water sources near the landfill site.

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## Conflict of interest

None.

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