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Seasonal variation in the nitrate concentration of groundwater samples surrounding the Dangkor Municipal Solid Waste Landfill

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Groundwater is classified as polluted if it contains sufficient chemical or biological contaminants to cause harm to living organisms. Nitrates are a common groundwater contaminant. In developing countries, a common source of nitrates in aquifers is Municipal Solid Waste (MSW) landfills, where they are produced from the decomposition of organic wastes. Nitrate pollution may cause groundwater quality surrounding MSW landfills to deteriorate if the issue is not managed. This research aims to investigate the presence and concentration of nitrates in leachate and groundwater samples surrounding the Dangkor landfill in Phnom Penh and recommend an effective approach for effectively monitoring and controlling these levels. Nitrate levels in leachate sampled from the landfill and groundwater sampled from surrounding tube wells was analyzed to assess (i) the seasonal variation in nitrate concentrations; (ii) spatial variation in the nitrate contamination of aquifers surrounding the landfill; and (iii) compliance with WHO standards. Groundwater samples were collected from three different wells at four sampling points located 500, 1000, 1500, and 2000 m from a reference point at Dangkor MSW landfill. Each sample was analyzed for the presence of nitrates before the concentration was analyzed. The results had several limitations but they suggest that there is no significant relationship between nitrate concentration in groundwater and distance from the landfill. Recorded nitrate levels were well within WHO guidelines for domestic use (50 mg/L) and as such, landfill leachate is not contributing to unsafe nitrate levels in groundwater aquifers between 500 m and 2000 m from the landfill site.

Keywords: nitrates, leachate, groundwater, municipal solid waste landfill

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Introduction

Groundwater is water sourced from an aquifer or a porous layer of rock and sand. It is commonly used for domestic purposes such as drinking or washing, as well as for agriculture (Standley 2000). Groundwater accumulates in aquifers through the infiltration of surface water, which needs to be balanced with extraction rates. The quality of water from aquifers may be affected by broad range contaminants as a result of industrial pollution or natural processes (Wakida & Lerner, 2005). One source of groundwater contamination in many ASEAN countries is the burning or dumping of municipal solid waste (Seng et al., 2013; Seng et al. 2011; Ngoc & Schnitzer, 2009). In Cambodia, the dangerous practice of the open burning of solid waste in landfills has only relatively recently declined (COMPED, 2016). The capital of Cambodia, Phnom Penh, is experiencing rapid urbanization, which when combined with rapid population growth has resulted in negative impacts from poor waste management (Mun, 2016). In 2017, 1800 tons of municipal solid waste (MSW) was produced daily in Phnom Penh (Xaypanya et al., 2017). This is expected to rise to 3000 tons per day by 2030 (COMPED, 2013). MSW in the city has been disposed in an open landfill at a 32-hectare site in Dangkor since 2009 when the capacity of the Steung Mean Chey landfill was exceeded and it was decommissioned (Mom, 2009). Leachate management in (MSW) landfills in developing countries is a serious environmental problem. Often, leachate infiltrates surrounding aquifers, causing the domestic water supply of local residents to become polluted.

Nitrates are an inorganic pollutant associated with landfill leachate (Mor et al., 2006). As such, they may be used to indicate groundwater pollution associated with landfills (Ribbe et al., 2008). When landfill leachate enters groundwater reserves, it forms a plume, which spreads in the direction of the flow of the groundwater (Dharmarathne & Gunatilake, 2013). This water requires advanced treatment before it can be safely used. These treatments include distillation, reverse osmosis, or ion exchange (Kapoor et al., 1997). In 1984, the US Environmental Protection Agency (US EPA) stated that open landfills were a major threat to groundwater quality.

Leachate is the liquid component that drains from landfills. It's chemical composition varies widely (Mor et al., 2006). It contains nutrients (nitrogen and phosphorous), microorganisms, salts, and heavy metals and can be hazardous (Dharmarathne et al., 2013; Umar et al., 2010; Kulikowska & Klimiuk, 2008). As water moves through MSW when it rains or floods, leachates may be released and access groundwater reservoirs, which represents a significant risk (Alslaibi et al., 2011; Almasri, 2007). High nitrate levels in leachate can affect both surface water and groundwater quality. This is an issue that has attracted the attention of researchers globally (Jaya & Amir 2015; Bialowiec et al., 2012; Matthews et al., 2009; and Mangimbulude et al., 2007). Some impacts associated with nitrate contamination include: methemoglobinemia, or 'blue baby syndrome', which occurs in young children who consume excessive volumes of water contaminated with nitrates (Ribbe et al., 2008; Gupta, 2001; Gelbrerg et al., 1999; Comly, 1945); stomach cancer; and the eutrophication of water bodies, which produced toxins that reduce the level of available oxygen and impacts biodiversity in aquatic ecosystems. Furthermore, nitrous oxide, a potent greenhouse gas, is produced when nitrates in a water body undergo a process of denitrification (Stanley, 2000).

Cambodia has a tropical climate with clearly defined seasons, a rainy or wet season between May and October; and a dry season between November and April. During the wet season, when there are high levels of precipitation, leachate is more likely to enter aquifers, but in a chemically diluted form. In the dry season, leachate entering aquifers is likely to be of a lower volume but more highly concentrated with contaminants such as nitrates. This study examines the seasonal variation of nitrate concentration in both leachate and groundwater in areas surrounding the Dangkor MSW landfill. If the mechanism of leachate containing nitrates entering aquifers is as described; a gradient in nitrate concentration will be observed along the pathway of groundwater flow from the landfill. This study aims to determine the nitrate concentration in raw leachate being dispersed from the landfill and its impact on the nitrate concentration in groundwater extracted from tube wells surrounding the landfill. The tube wells were selected on the basis of their physical distance from a reference point at Dangkor. Nitrate concentrations in the leachate and groundwater samples from the tube wells was recorded monthly and monitored across a portion of both the wet and dry seasons. These values were compared with the World Health Organization (WHO) guidelines for nitrates in groundwater. This research is expected to provide valuable information for chemistry students, waste management authorities, and residents, who access groundwater surrounding landfill sites for domestic use. It may be used to raise awareness about potential public health and environmental risks associated with leachate contamination of groundwater reserves in Phnom Penh. Dangerous concentrations of nitrate observed when monitoring tube wells would alert citizens of these dangers. However, even concentrations within WHO guidelines are of public interest and may influence hygiene behaviors. It is hoped that this study will result in improved MSW management policies in Phnom Penh and practices that mitigate the risks from leachates, such as the use of a sanitary landfill.

Nitrate contamination of groundwater from the Dangkor landfill

Disposal of MSW in an open dumpsite is a low-cost waste management practice used in many developing countries. When leachate is formed in these landfills and is released from piles of municipal waste, it becomes a source of groundwater and soil pollution (Alslaibi, 2011; Misra & Mani 1991). Landfill leachate is a liquid comprising many contaminants including: dissolved organic matter, such as alcohols, acids, aldehydes; inorganic compounds, such as sulfates, nitrates, and chlorides; heavy metals, such as lead, copper, nickel, and mercury; and xenobiotic organic compounds, such as PCBs and dioxins (Alslaibi, 2011; Mor et al., 2006). Leachate can infiltrate and accumulate in soil and aquifers if a landfill is not effectively sealed. Leachate is transported by groundwater flows and persists in groundwater reserves (Mor et al., 2006; Fadiran et al., 2005). In Cambodia, groundwater from tube wells is often consumed without prior treatment. When hazardous chemicals are present in this water, it may cause harm to domestic water users (Wakida & Lerner, 2005).

Nitrates are produced via nitrification processes in the landfills involving the organic nitrogen present in the waste. Nitrates are a significant component of leachate that is dispersed from MSW landfills. Nitrification, the biological process that produces nitrates, is a process stimulated by two groups of bacteria, *Nitrosomonas* and *Nitrobacter* (Jaya et al., 2015; Stanley, 2000). Common causes of nitrates in groundwater include landfill leachate and nitrate infiltration from fertilizers used in agriculture (Wakida & Lerner, 2005; Standley 2000). Other sources of nitrates in groundwater include wastewater treatment plants and atmospheric nitrogen, which become biologically available after lightning strikes (Anderson & Levine, 1986; Chameides et al., 1977).

Nitrates are usually the most water-soluble component of leachates and the first to be leached into groundwater from the unsaturated zone of MSW landfills (Vinod, 2015). The transport of nitrates is advected and then dispersed by groundwater flows, where it becomes part of the nitrogen cycle via denitrification processes (Pasten-Zapata et al., 2014; Almasri, 2007; Mor et al., 2006). Inorganic sources of nitrates include chemical fertilizers in the form of salts such as ammonium, sodium, potassium, or calcium nitrate (Vinod et al., 2015; Pastén-Zapata et al., 2014; Wakida & Lerner, 2005; Standley, 2000). These salts become dissolved in water at ambient temperatures and pressures. Organic sources of nitrates are derived from the decomposition of plants (Wakida & Lerner, 2005). Nitrates are colorless, odorless, and tasteless when present in groundwater and can only be detected and quantified via chemical analysis (APHA, 1994). Analytical methods for determining nitrate concentrations include UV spectrophotometry, ion chromatography, the use of nitrate electrodes, the cadmium reduction method, as well as others (APHA, 1994). Nitrate-nitrogen (NO_3^--N) present in groundwater samples may be detected first by reducing NO_3^--N to nitrite and then using a coloring reagent. The presence of nitrates in the solution is indicated by an amber color. If present, the nitrate concentration may then be determined using UV-Vis spectrophotometer at a wavelength of 550 nm. The nitrate concentration may then be interpreted in terms of its source and compared with permissible WHO standards for drinking water (Mor et al., 2006). This method is commonly used in the literature for determining the concentration of nitrate ions in groundwater as it is simple to conduct, rapid, and effective, even if there is cadmium contamination present in the sample (Patton & Kryskalla, 2013; Patton & Kryskalla, 2011; Campbell et al., 2006).

There are several impacts that may result from the presence of nitrates in groundwater. For example, methemoglobinemia or 'blue baby syndrome' occurs when infants consume excessive amounts of nitrate (Ribbe et al., 2008). In effect, nitrate is not toxic until it is transformed to a nitrite ion. Nitrite oxidizes and transforms iron in the blood to produce methemoglobin (metHb), instead of hemoglobin (Hb). This interferes with the capacity of blood to transport of oxygen throughout the body (Kim-Shapiro et al., 2005). Stomach cancer is another potential public health risk associated with nitrate pollution. When nitrostable compounds in the human stomach react with nitrite produced from nitrates in groundwater, N-nitroso compounds are formed, which are known to be carcinogenic (WHO, 2011). High nitrate consumption has also been linked to gastric cancer and birth defects (congenital malformations), as well as cardiovascular and thyroid problems

(WHO, 2011, Addiscott & Benjamin, 2004). If groundwater is contaminated with nitrates, it may be treated via a range of physio-chemical processes including ion exchange, biological denitrification, chemical denitrification, reverse osmosis, electrodialysis, or catalytic denitrification. The most feasible method is ion exchange (Kapoor et al., 1997).

Study area and methodology

Dangkor landfill is situated approximately 15 km from the center of Phnom Penh. It commenced operation in 2009 following the closure of another landfill at Steung Mean Chey. The nitrate concentration of raw leachate from the landfill, as well as groundwater sampled from tube wells surrounding the landfill, was conducted for a period of seven months between June and December 2017. Fresh leachate was sampled from a leachate stream draining from a waste pile at Dangkor landfill. Groundwater samples were collected from villages at four intervals from a reference point at the landfill. These villages were all located in Spean Thmor including Ha (500 m), Baku (1000 m), and Prek Chrey I (1500 m), and Prek Chrey II (2 000 m) (Table 1, Figure 3.1). Leachate and groundwater samples were collected monthly over a period of seven months bridging parts of the wet and dry season. For each survey location, three tube wells were selected at random, within a 0.5 km radius of the village from which to collect groundwater samples. Five replicate samples were collected from the pump storage tank of each selected tube well. Similarly, five replicate samples of leachate were collected from the reference point at the landfill. In total, 65 samples (60 x groundwater and 5 x leachate samples) were collected in each sampling run. All samples were collected in 50 mL falcon tubes with no headspace and an airtight cap.

Samples were stored in a cool box with ice and transported to a laboratory at the Royal University of Phnom Penh within three hours of the sample being taken. Upon arrival, they were immediately analysed for nitrate levels using a UV-Vis spectrophotometer.

Each leachate sample was filtered (Whatman, 20 µm filter paper) to remove dense particles. Then, 10 mL of each filtered sample was mixed with NitraVer 5 reagent and shaken for one minute. The mixture was left to stand for ten minutes to observe whether an amber color was present. A color change within 10 minutes indicated the presence of nitrate in the sample. The nitrate concentration of each positive sample was measured using a UV-Vis spectrophotometer (Genesys, 10) at wavelength of 550 nm. The same procedure was repeated for the analysis of groundwater samples (Table 2), eliminating the filtration step. Analysis of results from the spectrophotometer was completed using Beer's law, which shows that nitrate concentration is directly proportional to the absorbance of the samples.

Figure 1. A map of showing the location of MSW landfill, and the four groundwater sampling points.

Source: Google maps, 2018

NB: This map illustrates the locations of groundwater sampling locations at Ha (L1); Ba Ku (L2), Prek Chrey I (L3) and Prek Chey II (L4).

Table 1. Specific location of sampling and the distances from landfill.

Distance from landfill	Village
0.5 km	Ha
1 km	Baku
1.5 km	Prek Chrey I
2 km	Prek Chrey II

Table 2. Equipment used UV-Vis spectrophotometer (Genesys 10S).

50 mL and 15 mL plastic falcon tubes
Cooling box and ice
Scissors
Filter papers (Whatman, 20 µm)
Micropipettes (5 mL and 1 mL)
NitraVer 5 nitrate reagent (Hach, USA)
Potassium nitrate crystals

A working standard was prepared by dissolving 0.163 g of potassium nitrate (KNO_3) crystals (China) in 1 L of distilled water, with a NO_3^--N concentration of 22.62 mg/L (Figure 2). This was then diluted to a range of concentrations between 0.05 mg/L to 14.50 mg/L. This was used to plot a nitrate calibration curve (nitrate concentration vs. absorbance) using Beer's law. A linear regression was performed (Y = 0.0091X + 0.0015) giving an R^2 of value 0.9970.

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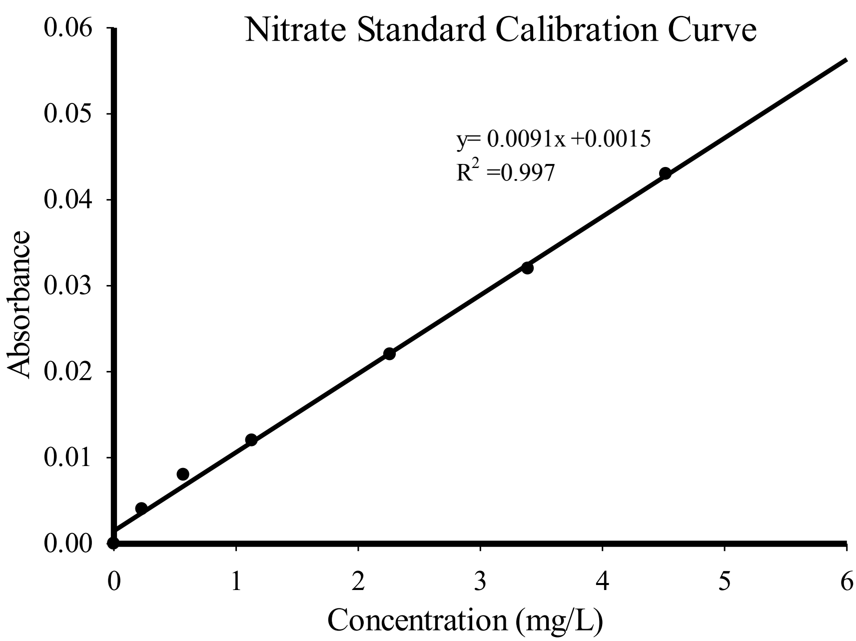
The significance of the relationship between the nitrate levels in the groundwater sample at each sampling location was tested using a one-way analysis of variables (ANOVA) test performed using the Statistical Package for Social Science (SPSS). The significance of seasonal variability over the wet and dry seasons was also tested. The aim was to investigate whether the mean nitrate concentration varied significantly across each sampling location. The accuracy of the calibration curve was also tested using a spike recovery method. Nitrate standards were added to samples of unknown concentrations and prepared using the same procedure used for the groundwater and leachate samples. The recovery of the nitrate concentration in the spike samples was found to be within an acceptable range (97 to 116 %).

Figure 2. Standard calibration curve for nitrate.



Findings and Results

Nitrate concentration in groundwater

The results for nitrate concentration (mg/L) in groundwater at the four sampling locations spaced at 500 m intervals from a reference point at Dangkor landfill are shown in Table 3. The nitrate concentration varied greatly across each location and month. The lowest concentration was recorded at Ha village, 500 m away from the landfill in November 2017 at 0.86 mg/L. The highest concentration was recorded at the same site in July 2017 at 14.49 mg/L. However, variation in the data collected at each of the sampling sites was not significant ($p>0.05$, ANOVA test–one way, test) (Table 4). During the monitoring period, the nitrate concentration at each site for all sampling locations varied between approximately 2 mg/L and 8 mg/L, with exception of the tube wells at Ha village (location 1) in July and November.

Table 3. Mean (± standard deviation, n=5) nitrate concentrations (mg/L) for groundwater samples collected between June and December 2017 at incremental distances from the municipal solid waste landfill.

Location	June	July	August	September	October	November	December
1	2.84±1.20	14.49±22.76	2.70±2.22	5.23±2.11	4.26±2.75	0.86±1.04	2.50±0.41
2	5.09±3.14	3.78±1.61	4.31±3.50	5.27±0.61	3.54±1.63	1.66±0.65	4.55±2.48
3	4.27±2.53	5.17±2.86	2.42±1.17	4.38±2.21	5.82±2.70	1.57±1.09	3.04±1.48
4	2.35±1.16	2.01±1.05	6.20±3.54	8.18±6.74	3.22±1.40	1.54±1.20	3.24±3.30

NB: Location 1, 2, 3 and 4 are 500, 1000, 1500 and 2000 m away from the landfill, respectively. A statistical comparison for each month that a sample was taken using an ANOVA test gives values for f and p for each location as 1: 0.804, 0.583; 2: 0.916, 0.512; 3: 1.554, 0.232, and 4:1.687, 0.197, respectively.

In June and November, the nitrate concentration recorded at Baku village (Location 2) was higher than at other locations. If it is assumed that a groundwater plume containing leachate flows sequentially from Ha village

(Location 1) to Baku village (Location 2) to Prek Chey I & II (Location 3 & 4) away from the reference point at the landfill, then the nitrate concentration would decrease from a high value at Location 1 to a low value at Location 4. However, this scenario was not observed for any month during the monitoring period.

To investigate whether the nitrogen concentration varied overall with distance from a reference point at the landfill, data from each location was combined across every month (June to December) and a mean value calculated. This resulted in a nitrate concentration for Location 1, 2, 3, and 4 of 4.7 ± 8.5; 4.0 ± 2.2; 3.8 ± 3.5; and 4.1 ± 4.8 mg/L, respectively. However, no statistically significant relationship effect was identified from this approach (ANOVA test, F: 0.155 P: 0.926).

To test the seasonal effect on nitrate concentration in groundwater, data from all four locations was combining and averaged for the period between June and October (wet season) and November to December (dry season), respectively (Table **5**). There is a clear difference between the levels of nitrates in the groundwater samples between the seasons, with the wet season value (4.78 mg/L), almost double the dry season value (2.45 mg/L).

Table 4. Seasonal effect on nitrate concentration (mg/L) in groundwater

	Wet season (n=60)	Dry season (n=25)	*F*	*P*
Mean ± std	4.78 ± 5.43	2.45 ± 1.84	4.364	0.04

NB: An one-way ANOVA test was performed

The nitrate concentration for all the groundwater samples collected in the study was well within WHO guidelines (50 mg/L) (Figure 2). The guideline is approximately three times higher than the highest nitrate concentration observed during monitoring. In Figure 4, the nitrate concentration in the leachate was shown to be higher than the WHO guidelines. It varied from less than 200 mg/L in November to a maximum recorded value of 550 mg/L in July (Figure 3). The nitrate concentration in the leachate is strongly correlated with monthly groundwater concentrations for Location 1 (r=0.809, Pearson correlation test), and poorly correlated with Locations (2, 3, and 4) (r <0.5).

Figure 3. Mean nitrate concentration for the four sampling locations, compared with the WHO guideline for nitrate concentration in groundwater (red-dotted line).

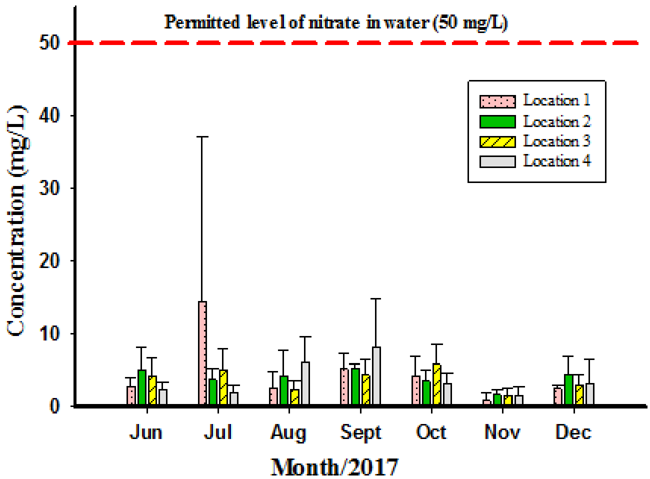
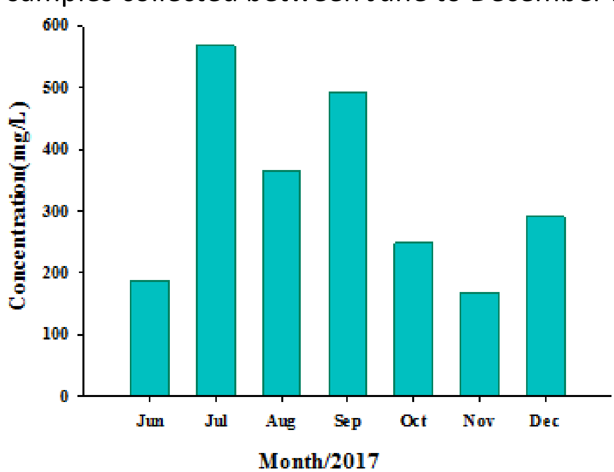


Figure 4. Mean nitrate concentrations (mg/L) for raw leachate drainage samples collected between June to December 2017.



Discussion

The standard nitrate concentration vs. absorbance calibration curve in Figure 2 has an R^2 value of 0.997, which indicates that the standard was not the cause of fluctuating values recorded for nitrate concentration. Table 4.1 shows that highest nitrate concentration recorded during monitoring was 14.50 mg/L in July collected from Ha village, 0.5 km from the landfill site. For a greater distance, 2 km from the landfill site, the recorded nitrate concentrations in the groundwater samples were generally less than 2 mg/L. Excluding the result from Ha village in July, the maximum groundwater nitrate concentration recorded was less than 10 mg/L. The concentration fluctuated, ranging between 2 mg/L and 8 mg/L. The outlying value may be the result of a significant leakage of leachate into an aquifer at that time or low rainfall in July resulting in a more concentrated release of leachate. It may also have been related to the infiltration of fertilizer used in the area.

The lowest values for nitrate concentration, between 0.9 mg/L and 1.5 mg/L, were recorded in November. These results may have been caused by heavy rain in November, diluting the leachate and thus nitrate levels in the groundwater. Overall nitrate concentrations recorded in groundwater between 0.5 km and 2 km from the landfill were much lower than the guideline recommended by the WHO of 50 mg/L. The highest average nitrate concentration was recorded in July at 14.50 mg/L. This suggests that that nitrate present in the groundwater surrounding the landfill does not pose a health risk to residents in the area.

The maximum nitrate concentration recorded in the leachate sampled from the landfill was also in July (550 mg/L), with another high value recorded

September (500 mg/L). These concentrated nitrate values may have been caused by low rainfall in early July and September. The lowest nitrate concentration in the leachate samples was recorded in November, which is when the nitrate values in the groundwater samples were also low.

Table 5 shows that the f-values calculated were always greater than $f_{critical}$-values, and the p-values were always lower than 0.05, except for the November data. This suggests that the linear distance from the landfill in the direction of sampling does not significantly affect the concentration of nitrate in the groundwater. Even in November, the nitrate concentration in the tube wells does not vary with distance from the landfill site as the f-value is lower than $F_{critical}$-value, and the p-value is greater than 0.05.

In some months the recorded nitrate levels in the leachate samples appear to be related to the nitrate levels in the groundwater samples at Ha village (Location 1) but not any of the other sampling locations. However, this correlation was not statistically tested. The poor correlation between the nitrate concentrations at each of the sampling location may be related to hydrogeological conditions and their impact on the groundwater flow that transports the leachate plumes to aquifers at each sampling location. For example, in a study in India, groundwater flow at different depths varied significantly. Leachate transport was more heavily by horizontal flows and percolated much more slowly through the soil profile (Srivastava & Ramanathan, 2008).

The monitoring period used for this study was clearly not sufficient to make conclusions about seasonal variation in nitrate concentration in groundwater samples surrounding the MSW landfill. The collection of localized rainfall data at Dangkor would also enable a clearer analysis of the influence of each season. There was a significant change in rainfall conditions between 2017 and the previous year, which also led to further changes in the recorded concentration of nitrates in this study. This is why the nitrate levels in the groundwater and leachate samples fluctuated throughout the monitoring period. Notwithstanding this, the recorded nitrate levels were significantly lower than WHO guidelines (50 mg/L) for nitrates in aquifers.

Recommendations

This research provides some insight into the impact of leachate from the Dangkor MSW Landfill on nitrate levels in aquifers surrounding the site. The study collected groundwater samples over a portion on the wet season (June to October) and the dry season (November to December) in 2017 and analyzed the level of nitrate present in each sample. However, this investigation has limitations for a number of reasons. Firstly, there is limited data from periods with minimal rainfall. Thus, it is not possible to draw strong conclusions about the seasonal variability nitrate levels due to leachates from the landfill. Secondly, localized hydrogeological conditions for groundwater flow and their impact on nitrate concentrations in the aquifers are not well understood. In effect, the research found a reverse hypothesis for some months. For example, in August and September, nitrate concentrations in groundwater samples increased the further away from the source of the leachate. The mechanism of nitrate contamination from landfill leachate may be different to how they were conceptualized in the experimental design. It may be that other sources of nitrates are also affecting the data such as fertilizers and manure from agricultural production or other areas where organic waste accumulates. Notwithstanding this, the recorded nitrate levels in the groundwater samples in a range of 500 to 2000 m from the reference point at the landfall were significantly lower than the WHO guidelines of 50 mg/L. However, this result is not conclusive, as the monitoring period was limited and not sufficient for understanding the characteristics of groundwater flow in the study area. Any general conclusions made about the impact of nitrates sourced from landfill leachate in aquifers surrounding the landfill needs to take this into account.

The study has documented some short-term observations regarding the nature of negative impacts from nitrates from landfill leachate on the environment in Phnom Penh. However, the seasonal variations and long-term trends associated with nitrate levels in groundwater samples surrounding the landfill are still unknown. This may be addressed in future research by:

- Conducting long-term monitoring of groundwater surrounding the MSW landfills
- Considering how samples are collected from the sampling sites, including the landfill in terms of understanding the mechanisms for leachate (and nitrate) transport in groundwater occur. Samples should be collected at a range of depths to better understand the nature of groundwater flows.
- Considering other potential sources of nitrates in the study area, such as fertilizer and manure from agricultural production, and how they may access aquifers.
- Considering other types of contaminants that the presence of nitrates in groundwater surrounding the landfill may indicate may be indicated such as phosphates and sulfates in leachates, or heavy metals.

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Conclusion

This research has monitored nitrate concentrations in groundwater surrounding the Dangkor MSW landfill over a portion of the wet (June to October) and dry (November and December) seasons in Phnom Penh. However, the seasonal impacts are difficult to assess from this data as there is a very limited period of low rainfall assessed, while actual rainfall at the landfill site has not been recorded. In addition, the results obtained were not as expected, with the nitrate concentration often being higher further away from the landfill site. For example, nitrate concentrations at the sampling point at Prek Chey II (Location 4) in August and September recorded some of the highest concentrations of nitrates (6.20 mg/L and 8.18 mg/L) for the entire monitoring period. There are a number of reasons why this may have occurred. Nitrate contamination in groundwater samples may be from other sources. Alternatively, hydrological conditions and soil type may mean the mechanisms for both leachate and nitrate transport in groundwater flows may be significantly different to the original hypothesis. Notwithstanding this, a one-way ANOVA analysis has found that no significant relationship exists between nitrate concentrations in groundwater samples surrounding the Dangkor landfill and the distance from the source of leachate pollution.

However, the maximum level of nitrates recorded in an area of between 500 and 2000 m from the source of 14.50 mg/L is well within WHO guidelines of 50 mg/L for nitrates in groundwater. This suggests that groundwater extracted for domestic users in this zone is safe, in terms of nitrates. However, many unknowns remain with respect to the risks associated with leachate entering groundwater reserves in the vicinity of the

MSW landfill. Future research should consider hydrogeological conditions and soil conditions and how they affect how leachate is transported in the groundwater, other sources of nitrate contamination, and what other types of contaminants may be indicated by the presence of nitrates in the groundwater.

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Author Biographies

Sreng Soknet has an MSc in both Environmental Sanitation and Analytical Chemistry. She is highly skilled in chemical safety, separation methods, spectrum analysis environmental toxicology, high-performance liquid chromatography, and gas chromatography. She has a research interest in the utilization of wastes for food processing

Sorya Proum has completed a PhD on the chemical ecology of the Brunei estuarine system with respect to acidification and heavy metal pollution. She is a currently a lecturer and a researcher at Department of Chemistry at the Royal University of Phnom Penh. Sorya teachings Analytical Chemistry is currently researching heavy metal pollution in surface water in Cambodia. Her research interests include the impact of climate change, freshwater acidification, and heavy metal pollution on ecological systems. She has published in peer-reviewed journals such as Marine Biology, Regional Studies in Marine Science, and Scientia Bruneiana. She has also presented research at the International Conference on Biodiversity, Ecology and Conservation of Marine Ecosystems and the 7th International Symposium on Energy.

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Annex

Table 5. Statistical data analysis of nitrate concentration in groundwater at each sampling location from June to December

	F	P-value	F critical
June	6.7674	0.0006	2.7694
July	4.9163	0.0042	2.7694
August	7.9958	0.0002	2.7694
September	4.3864	0.0080	2.7826
October	5.6823	0.0018	2.7694
November	2.6170	0.0599	2.7694
December	3.2092	0.0298	2.7694

NB: The values for f were higher than $f\text{-}_{critical}$ values for every month during the monitoring period, except for November, where $f\text{-}_{critical}$ was higher than f. Accordingly, p-values higher were than 0.05 in all months except for November.

Table 6. Recovery Percentages for the nitrate calibration curve

Sample	**C spike (mg/L)**	**C unspike (mg/L)**	**C added (mg/L)**	**%Recovery**
June	10.54	8.11	2.50	97
July	14.72	10.69	3.98	101
August	12.91	8.26	4.00	116
September	10.44	5.96	4.00	112
October	11.75	7.59	4.00	104
November	5.66	1.80	4.00	97
December	4.10	0.09	4.00	100

Table 7. Quality Control

Appointed Conc (mg/L)	**Exact Conc (mg/L)**
16	16.40
12	12.36
8	8.27
4	2.73
0	0

Table 8. ANOVA analysis result

Source of Variation	**SS**	**Df**	**MS**	**F**	**P-value**	**F crit**
Between Groups	72.24925	3	24.08308	6.767437	0.000565	2.769431
Within Groups	199.2856	56	3.558671			
Total	271.5348	59				