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RESEARCH PAPER

POTENTIAL GROUNDWATER POLLUTION FROM IMPROPER OIL AND METAL WASTE DISPOSAL IN SUAME, GHANA

E. K. Appiah-Adjei*[1], **N. F. Appiah[1] and **K. A. Adjei**[2]
[1]*Department of Geological Engineering, KNUST, Kumasi*
[2]*Department of Civil Engineering, KNUST, Kumasi*
**Corresponding author: ekappiah-adjei.soe@knust.edu.gh*

ABSTRACT

Suame is an industrialized hub in Kumasi, Ghana, that is noted for vehicle repairs and servicing, sale of automobile spare parts, and metal fabrication. Some of these activities generate huge volumes of waste oil and metals that are often disposed off indiscriminately into the environment. These could pose a threat to the quality of groundwater in the area, especially if they continuously accumulate in the environment. This study, therefore, investigated the potential impact of the waste disposal on groundwater quality in the area. The methods employed involved mapping all the potential waste oil spillage sources and sampling the soils in such areas (at 0 – 30 and 30 – 60 cm depths) and groundwater supply points for laboratory analyses to determine the presence of the waste. In all, 36 samples (comprising 12 soil and 24 groundwater) were analysed for the presence of heavy metals including Cd, Ni, Cu, Pb, Zn and Cr, which were used as trace elements for the presence of the waste in the samples. Computed geo-accumulation indices from the results show the soils are moderately to heavily polluted with Cd and Pb whilst the groundwater, when compared to the WHO drinking water guidelines, is polluted with Pb and Ni. Although the source of the high Pb content observed could be attributed to its transport directly from the activities in the area, the presence of high Ni makes it inconclusive since the Ni in the soil was within the concentration expected of the parent rock geochemistry. This notwithstanding, the study has indicated that groundwater in the area is not safe for human consumption unless the lead and nickel concentrations are reduced to acceptable standard for drinking.

Keywords: *Groundwater quality, pollution, waste disposal, Suame, Ghana*

INTRODUCTION

Groundwater plays a very important role in meeting the water needs of many communities in the world. In Ghana, it serves as the main source of water supply for inhabitants in rural areas and as a supplementary source of meeting the increasing water demands in urban areas. Mostly, the resource is considered ‘pure’ and, generally, assumed to be of very good quality due to the ‘filtering’ action that takes place in its transport through geologic media (Lewis *et al*., 1982). However, this view may no longer be valid in many instances since increasing industrialization and agriculture activities due to population growth continue to generate tonnes of domestic, industrial and agricultural wastes, which are sometimes disposed off into the environment improperly and transported to the underlying aquifers to pollute them. Besides, groundwater may, naturally, be contaminated through its interactions with geologic media when it dissolves undesirable concentrations of inorganic chemicals from the geologic media (Fawell and Nieuwenhuijsen, 2003; Todd and Mays, 2005).

Groundwater pollution from anthropogenic activities such as mining (Xu and Usher, 2006; Lusilao-Makiese *et al*., 2013), smelting and metal fabrications (Garg and Totawat, 2004; Hu et al., 2014; Ettler, 2016), sewage and waste disposal (Chettri and Smith, 1995; Kacaroglu and Gunay, 1997; Adepelumi *et al*., 2001), use of fertilizers (Chen *et al*., 2007; Parris, 2011; Shen et al., 2011), and leakage/spillage of stored oil and gas (Ojiegbe, 2006; Haest *et al*., 2010) have been reported in several areas. These activities often release harmful chemicals into the environment, which are then transported to the aquifers through recharge waters or interactions with surface water when deposited in them. The common potentially toxic contents of the effluents from these activities are heavy metals such as Chromium (Cr), Cadmium (Cd), Lead (Pb), Zinc (Zn), Copper (Cu), Nickel (Ni), and Mercury (Hg), which when dissolved in water at even lower concentrations render it unsafe for drinking. These metals are responsible for deaths caused by kidney and liver diseases (Friberg *et al*., 1986) and can, significantly, inhibit the growth of plants and reduce their yields (Chibuike and Obiora, 2014).

Research has shown that there is always a connection between the crude oil contamination and increase in heavy metal concentration in soils around oil production facilities (Newbury, 1997). Unlike many organic pollutants, which eventually degrade to carbon dioxide and water, heavy metals tend to accumulate in the environment and can be transported from one environment to the other depending on their chemical mobility (Duffus, 2002; Ahmadipour *et al*., 2014). Thus they could be used to trace the source of pollution in an environment and evaluate its toxicity (Richard and Richard, 1977).

The operational activities in Suame, an industrialized area in Kumasi, Ghana, generate lots of metal and oil wastes, which are disposed off indiscriminately into the environment and could pollute the groundwater that the inhabitants rely on to meet their daily water needs. Unfortunately, the groundwater is deemed ‘pure’ and not treated before consumption like the surface water; hence its pollution could have very serious health implications on the populace. This study, therefore, evaluates the potential impact of waste oil and metal disposal on groundwater quality in the area. The methods employed involved mapping all the potential groundwater supply points and pollution sites in the area and tracing the presence of heavy metals in the groundwater and soils (at different depths) to evaluate their possible pollution from activities in the area.

MATERIALS AND METHODS

Description of study area

The study area, Suame, is located in the Kumasi Metropolis of Ghana within latitudes $6^o35'$ to $6^o40'$ N and longitudes $1^o30'$ to $1^o35'$ W. The area, known to have been established in the 1960s, is highly industrialized with over 12,000 workshops involved in vehicle repair and servicing, metal fabrication, automobile spare parts sales, and micro to medium sized enterprises employing over 200,000 workers (Obeng, 2002; Azongo, 2007; Adeya, 2008). These workshops are mainly concentrated in a community of about 0.5 km^2 within the study area called “Magazine” (shown in Fig. 1).

Available estimates indicate that activities in the area comprise 60% vehicle repair, maintenance and servicing, 20% manufacturing, fabrication and machining, and 20% sales and services (Obeng, 2002; SMIDO, 2012).

The topography of the area is generally undulating with elevations ranging from 250 to 350 m above sea level. The area falls within the moist semi-deciduous forest zone of Ghana and experiences a double maxima rainfall regime that spans from March to November with a relatively dry period in August. The mean annual rainfall and temperature of the area computed from daily data spanning from 1951 to 2011 are 1410 mm and 26^{o}C respectively. The geology of the area is mainly made up of metasediments intruded by basin type granitoids (Kesse, 1985). The rocks are highly fractured and deeply weathered; thus making borehole prospects in the area fair to good, especially in the areas where quartz veins dominate.

In the past, water supply to the populace in the area was mainly from two surface water treatment plants within the Kumasi Metropolis. However, population growth and unreliable supply from the treatment plants, sometimes, have led to many homes and communities in the area switching to hand-dug wells and boreholes to meet their daily water needs. Due to the industrialization of the study area, a lot of liquid and solid wastes comprising metals, oil and biodegradable materials are generated. Large quantities of these wastes are often improperly disposed off in open spaces and drains in the area (JICA, 2013; Acheampong *et al.*, 2016) and these sometimes end up in both the surface water and groundwater sources, which the inhabitants depend on for their daily water supply needs.

Sampling and laboratory analyses

As part of the study, all the groundwater supply points (i.e. boreholes, hand-dug wells and springs) and potential oil spillage sites (i.e. garages, filling stations and lube bays for oil change) in the area were mapped to know their distribution. Alongside the mapping, questionnaires were administered to the inhabitants and artisans to seek information on historical groundwater quality in the area and the quantity of spillages from the potential pollution sites. The information gathered through these processes contributed significantly to the planning and selection of sampling points.

Thirty-six (36) samples, comprising 24 groundwater and 12 soil samples were collected from the study area for laboratory analyses to evaluate the potential groundwater pollution from the improper oil and metal disposal in the area. Fig. 1 shows the distribution of the sampling locations in the study area. The 24 groundwater samples, evenly distributed across the study area, were collected from 19 hand-dug wells, four boreholes and one spring just after the rainy season. Nine of these water samples were taken within Magazine, where the industrial activity is very intense, whilst the remaining samples were taken at the other areas within Suame. The groundwater was sampled into 500 ml volume plastic bottles following standard sampling protocols (APHA, 1989), kept at 4ºC in an ice chest containing ice cubes, and transported to the laboratory within the same day for analyses. The twelve soil samples were taken at six different locations within the Magazine area (Fig. 1), which were close to waste disposal sites. The samples were obtained by hand digging, collected with a stainless steel spatula and kept in labelled plastic bags. At each location, two samples were taken at depths of 0 – 30 cm and 30 – 60 cm for the laboratory analyses.

At the laboratory, all the samples were analysed for the presence of the heavy metals Cd, Ni, Cu, Pb, Zn and Cr. Commonly, these metals are found in areas with activities similar to the study area; hence they could be used as good indictors to trace transport of the waste oil and metal disposed in the area into the aquifers. The concentration of heavy metals in the groundwater samples were measured using the Atomic Absorption Spectrophotometer (AAS) whilst its contents in the soil samples were measured

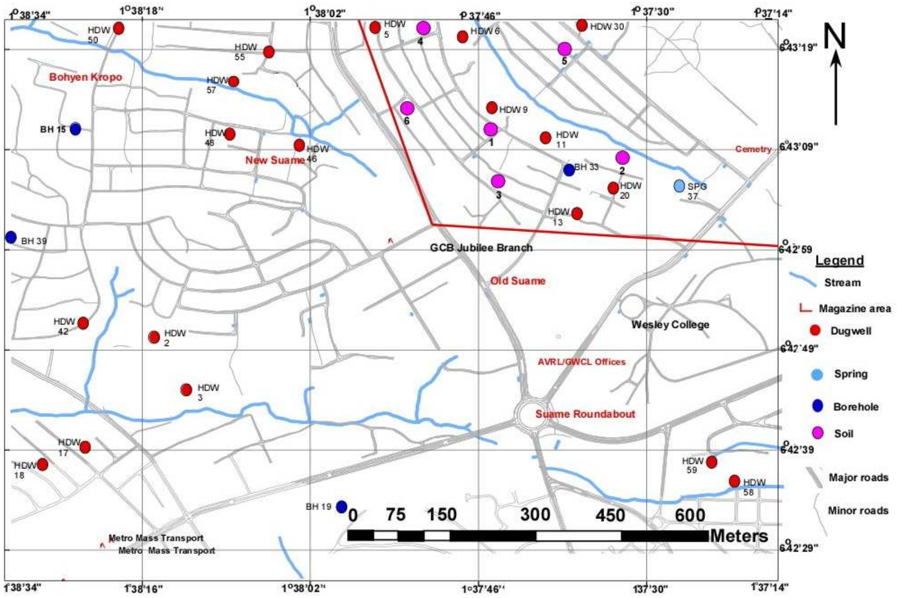


Fig. 1: Distribution of sampling locations in the study area (Magazine is the area bounded red on the map)

with the X-Ray Fluorescence spectrometer (XRF).

Data analyses

Generally, the suitability of water for any particular use is assessed by comparing it to an acceptable quality standard or guideline developed to ensure its safe use. Over the years, the World Health Organization (WHO) has developed a series of water quality guidelines that indicate the various health risks associated with exposure to unwholesome water (WHO, 2011), which have been adopted or modified for local use by most countries. These guidelines represent the concentration of a constituent in water that would not result in any significant health risk over a lifetime of consumption and have been applied in several studies worldwide including Ghana (Apambire *et al*., 1997; Abdul-Razak *et al*., 2009; Ansa-Asare *et al*., 2009; Nkansah *et al*., 2010; Annapoorna and Janardhana, 2015; Krishna kumar *et al*., 2015). Thus the measured heavy metal concentrations in the groundwater samples from the laboratory were analysed spatially and in comparison with the acceptable WHO (2011) guideline values for drinking water. The spatial analyses involved combining the field data, especially location coordinates of the sampling points, with the quality parameters to create maps for graphical evaluation of the variation and distribution of groundwater quality in the study area.

Also, the index of geoaccumulation (I_{geo}), used in determining the enrichment of metals in soils relative to their background values, was calculated to aid in assessing the extent of heavy metal pollution in the soils. This index is fully explained in Müller (1969) and was computed using Eqn. (1):

$$I_{geo} = \log_2 \frac{C_n}{1.5B_n} \qquad (1)$$

where *Cn* is the measured concentration of metal in the soil and *Bn* is the geochemical background value in the earth crust (i.e. crustal value). The crustal values used in the computations were obtained from Taylor (1964). The geochemical indices obtained from the computations were used to determine the heavy metal pollution of the soils based on the categorization in Table 1.

Table 1: Classes of pollution based on index of geoaccumulation (Müller, 1969)

Class	I_{geo} Value	Soil quality
0	< 0	Unpolluted
1	0 – 1	Unpolluted to moderately polluted
2	1 – 2	Moderately polluted
3	2 – 3	Moderately to heavily polluted
4	3 – 4	Heavily polluted
5	4 – 5	Heavily to extremely polluted
6	> 5	Extremely polluted

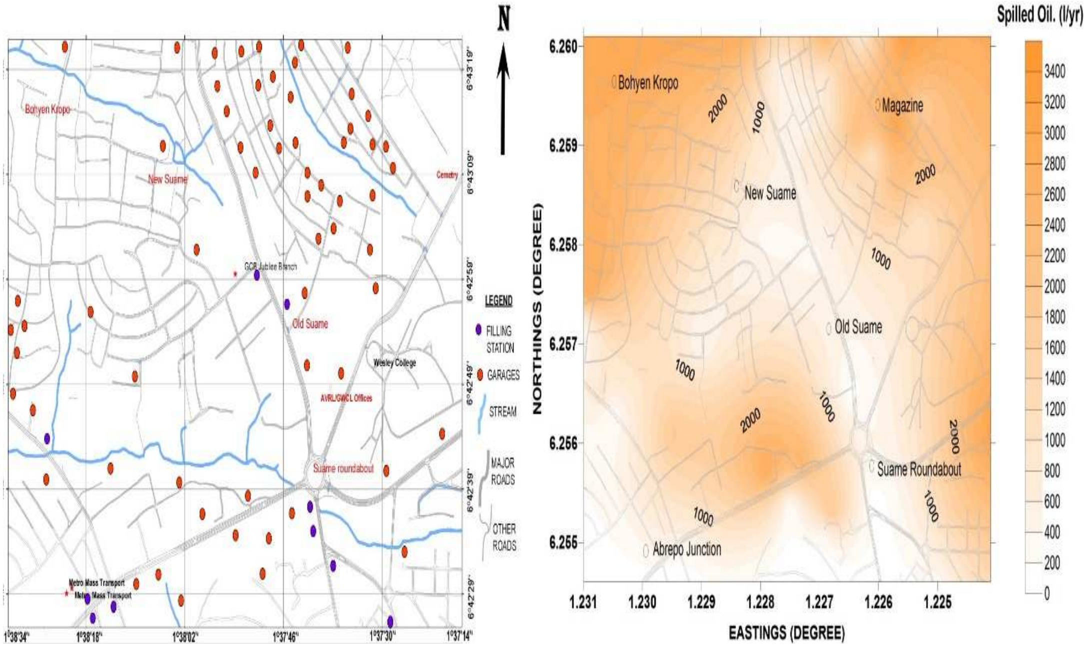
RESULTS AND DISCUSSION

Mapping and questionnaire administration

A total of 63 groundwater supply points comprising 46 hand-dug wells (HDW), nine boreholes (BH) and eight springs (SPG) were mapped in the study area. Out of these, 27 were located within the Magazine area where industrial activities are more intensive while the remaining ones were located in the nearby communities. The HDWs were enclosed with concrete cases above the ground and covered either with a metal or wooden slab with about 90% of them having interior concrete linings. Also, 62 % of the HDWs were bucket-drawn whilst the remaining 11%, 18%, 3% and 6% were fitted with hand pumps, mechanized, abandoned and uncompleted, respectively.

Generally, the questionnaire responses, based on the specific questions asked, indicate that the quality of groundwater in the area was good for drinking and no case of water related disease has been reported in the area. Surprisingly, some affirmed that the groundwater was better in taste and, some even, preferred using it to the treated pipe-borne water. However, 25% of both the hand-dug wells and boreholes directed their water to reservoirs for filtering before supplying them for use whereas about 10% of the HDWs were also purged at regular periods for purposes of cleaning the well and water. These practices were very typical in areas where the water is commercialized. The static water elevation in the area ranges from 186 – 294 m with an average of 269 m above mean sea level.

Fig. 2 shows the distribution of the mapped potential oil waste pollution sites (i.e. garages and filling stations) and annual spillages of oil in the area. It is observed that most of the garages are clustered within the Magazine area. The questionnaire responses indicate that waste oil from the garages are usually collected by the operators and sold to sawmill operators who use it to preserve wood and lubricate their chainsaws. However, most of the garages do not have efficient means of collecting the waste oil; hence lots of them still spill into the environment and have even hardened portions of the soil in some areas. The estimated oil waste



(a) (b)

Fig. 2: Distribution of (a) potential oil waste pollution sites and (b) annual waste oil spillages from the garages in Suame area

spilled by the garages in the area ranges from 203 to 3,120 litres per year with a total of 58,032 litres of waste oil spilled to the environment annually and an average of 1,415 litres of waste oil per year per garage. These estimates were based on the questionnaire responses with respect to the number and types of vehicles serviced by the garages and the quantities of used oil spilled to the environment in the process. Comparatively, the filling stations spill very low amounts of oil, recording a total of 2,263 litres per year, because they have relatively efficient ways of managing their activities than the garages.

Heavy metals in soils

Table 2 presents the measured concentrations of heavy metals in the soils, which generally vary across the area and with depth. However, their mean concentrations were in the order Cr > Zn > Pb > Cu > Ni > Cd and each decreased with depth except for Cr, which increased with depth. Similarly, the calculated geoaccumulation indices for the heavy metals in the soil samples at the 0 – 30 cm and 30 – 60 cm depths are presented in Table 3 and they each vary with depth.

The concentration of Cadmium in the soil at both depths exceed the crustal value (Taylor, 1964) and is very evident in the computed I_{geo}, which indicates that the soil is moderately to extremely polluted with Cd (Müller, 1969). The pattern of its distribution within Magazine area, however, differs at both depths (Fig. 3). It increases in the north-eastern direction from the centre at the 0 – 30 cm depth, but decrease radially away from the centre at the 30 – 60 cm

Table 2: Concentration (ppm) of heavy metals in the soils at 0 – 30cm and 30 – 60cm depths

	0 – 30 cm depth						**30 – 60 cm depth**					
SP	Cd	Ni	Cu	Pb	Zn	Cr	Cd	Ni	Cu	Pb	Zn	Cr
1	1.6	19	45.7	65.6	213.9	526	7.6	34.7	173.4	592.9	745.7	134.0
2	1.5	7.7	11.2	28.6	37.6	67	1.4	12.2	11.6	23.5	148.2	763.0
3	1.7	18.4	60.1	83.5	161.1	141	1.8	21.7	16.3	1.6	21.5	378.0
4	1.7	11.5	126.5	195.3	325.1	116	1.5	16.8	15.5	1.8	32.2	351.0
5	11.9	27.7	151.6	521.8	819.7	116	1.5	19.3	19.5	1.0	18.7	574.0
6	2.0	76.8	531.9	192.8	273.8	1077	2.1	30.9	100.2	38.7	67.5	698.0
Mean	3.4	26.9	154.5	181.3	305.2	340.5	2.7	22.6	56.1	109.9	172.3	483.0
C_v	0.15	75.0	50.0	12.5	70.0	100.0	0.15	75.0	50.0	12.5	70.0	100.0

C_v is crustal value (Taylor, 1964); SP means sample

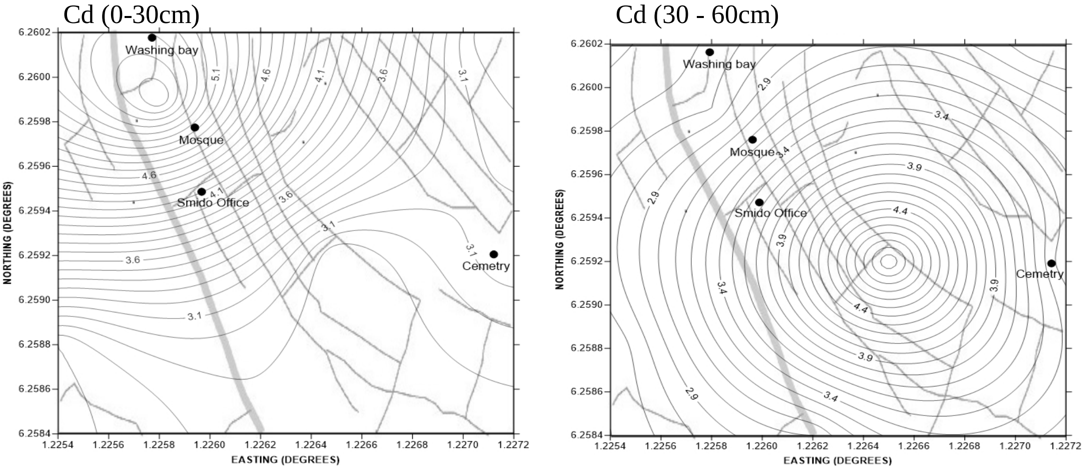
Table 3: Geoaccumulation indices for heavy metals at 0 – 30 cm and 30 – 60 cm depths

	0 – 30 cm depth						**30 – 60 cm depth**					
SP	Cd	Ni	Cu	Pb	Zn	Cr	Cd	Ni	Cu	Pb	Zn	Cr
1	2.8	-2.6	-0.7	1.8	1.0	1.8	5.1	-1.7	1.2	5.0	2.8	-0.2
2	2.7	-3.9	-2.7	0.6	-1.5	-1.2	2.6	-3.2	-2.7	0.3	0.5	2.3
3	2.9	-2.6	-0.3	2.2	0.6	-0.1	3.0	-2.4	-2.2	-3.6	-2.3	1.3
4	2.9	-3.3	0.8	3.4	1.6	-0.4	2.7	-2.7	-2.3	-3.4	-1.7	1.2
5	5.7	-2.0	1.0	4.8	3.0	-0.4	2.7	-2.5	-1.9	-4.2	-2.5	1.9
6	3.2	-0.6	2.8	3.4	1.4	2.8	3.2	-1.9	0.4	1.0	-0.6	2.2

depth. The source of the high Cd content could be attributed to the improper disposal of wastes from vehicle servicing, metal plating and used batteries in the area.

Similar to the Cd, the concentrations of both Cu and Zn in the topsoil were mostly above the crustal value, but decreased to below it at depth in all, but two of the sites. However, the soil is described as unpolluted to moderately polluted with both Cu and Zn based on their I_{geo}. The two sites with increased Cu and Zn at depth were located downslope and closer to the stream running through the area; hence, they may have received some depositions from the upslope areas. Commonly, wastes from welding and scrap metal fabrication of automobile body parts and wiring produced from copper could be the source of the high Cu in the soils. On the other hand, electroplating and galvanizing activities as well as the improper disposal of waste from zinc-carbon batteries in the area could be the anthropogenic source of the Zn metal.

Unlike the Cd, the Pb concentrations exceeded the crustal values in the top soil (0 – 30 cm) and decreased sharply at the 30 – 60 cm depth, Cd (0-30cm) Cd (30 - 60cm)



Pb (0-30cm) Pb (30-60cm)

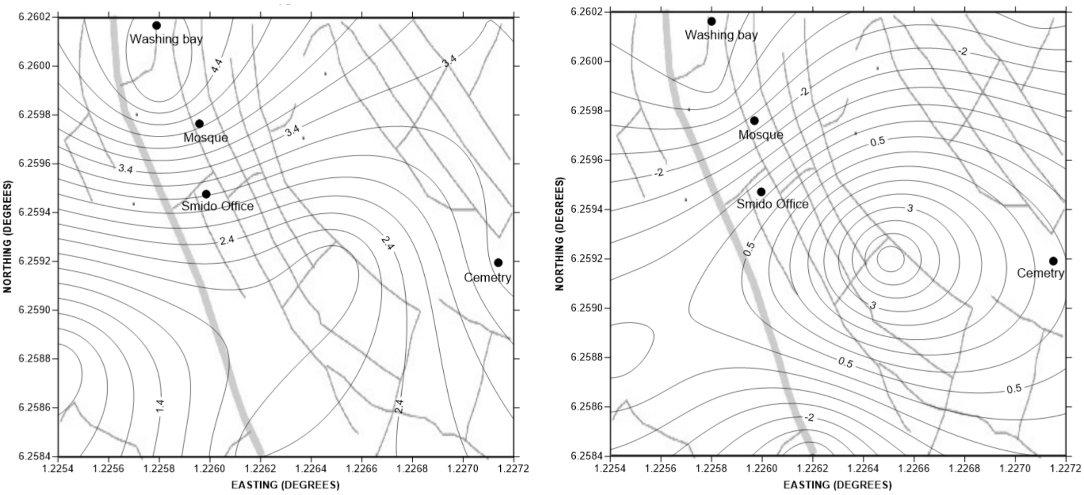


Fig. 3: Distribution of geoaccumulation indices of Cd and Pb in the soils of the Magazine area in Suame at 0 – 30 cm and 30 – 60 cm depths

except for site 1, with half of them below the crustal value. This is reflected in the computed I_{geo}, which indicates that the soil is moderately to heavily polluted with Pb in the top soil, but unpolluted to heavily polluted at bottom soil. The extent of its pollution in the area (Fig. 3) increases northwards, but is unpolluted in the same direction at the 30 – 60 cm depth. The cause of the high Pb accumulation within the topsoil may be due to its poor mobility within the soils because of its high density or ability of the soils to adsorb them. The exception for site 1 may be due to wastes from direct welding and vehicle servicing activities at the site coupled with its downslope location. Like the Cd, the potential source of the Pb in the soils could be from the anti-knock additives in the waste oils, used lead-acid batteries and waste from welding disposed indiscriminately in the area.

The concentrations of Ni in the top soil and at depth were all within the crustal value except for one sample (i.e. SP6 at 0 – 30 cm), which was slightly above the crustal value. This indicates that the concentration of Ni in the soils reflect the normal concentration of the parent rock and is in conformity with results obtained by Acheampong *et al.* (2016). On the contrary, the Cr concentration of all the samples, except SP2 at 0 – 30 cm depth, exceeded the crustal value of 100 ppm. Their concentrations were largely higher at depth than at the top and the computed I_{geo} described them as unpolluted to moderately polluted. Unlike other metals, the Cr is more naturally occurring and is found in plants and animals aside the geologic media. Thus, its high concentrations above the norm cannot be attributed to only the wastes from metal fabrication and metal plating activities in the area.

Heavy metals in groundwater

Table 4 shows the concentrations of all the heavy metals analysed in the groundwater samples from the study area. Apart from Pb and Ni, all the heavy metals analysed had their concentration values within the acceptable WHO drinking water guideline values. The Pb and Ni concentrations that were above the WHO guideline values occurred in 84% and 92%, respectively, of the samples.

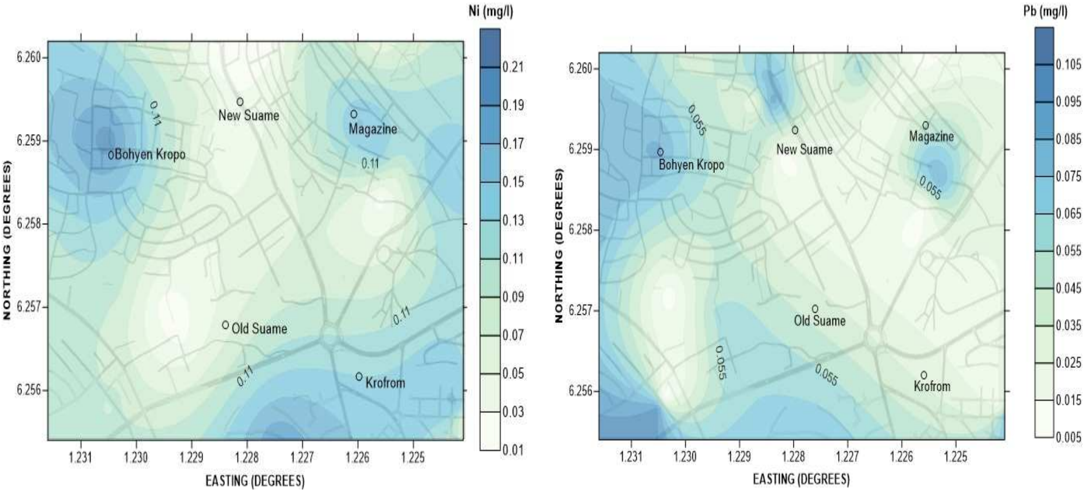
Table 4 : Concentrations (in mg/l) of the heavy metal ions in the groundwater

SAMPLE ID	Pb	Cu	Cd	Cr	Ni	Zn
HDW 2	0.055	0.020	<0.002	0.002	0.020	0.034
HDW 3	0.062	0.015	<0.002	0.026	0.026	0.066
HDW 5	0.018	0.016	<0.002	0.021	0.022	0.034
HDW 6	0.061	0.054	<0.002	0.02	0.106	0.052
HDW 9	0.015	0.033	<0.002	0.022	0.115	0.022
HDW 13	0.013	0.032	<0.002	0.021	0.020	0.021
HDW 17	0.010	0.061	<0.002	0.003	0.094	0.087
HDW 18	0.099	0.010	<0.002	0.006	0.088	0.064
HDW 20	0.087	0.081	<0.002	0.004	0.073	0.099
HDW 30	0.007	0.084	<0.002	0.003	0.054	0.093
HDW 42	0.009	0.064	<0.002	0.002	0.092	0.028
HDW 46	0.010	0.027	<0.002	0.005	0.043	0.011
HDW 48	0.054	0.022	<0.002	0.001	0.048	0.018
HDW 50	0.041	0.024	<0.002	0.001	0.091	0.067
HDW 55	0.077	0.034	<0.002	0.002	0.024	0.077
HDW 57	0.025	0.033	<0.002	0.002	0.068	0.076
HDW 58	0.073	0.051	<0.002	0.007	0.066	0.099
HDW 59	0.021	0.027	<0.002	0.001	0.155	0.086
SPG 37	0.029	0.043	<0.002	0.005	0.149	0.120
HDW 11	0.031	0.038	<0.002	0.008	0.155	0.113
BH 15	0.088	0.061	<0.002	0.003	0.205	0.094
BH 19	0.075	0.055	<0.002	0.003	0.187	0.099
BH 33	0.074	0.054	<0.002	0.004	0.135	0.095
BH 39	0.079	0.068	<0.002	0.003	0.106	0.097
Min	0.007	0.010		0.001	0.020	0.011
Max	0.099	0.084	<0.002	0.026	0.205	0.120
WHO	**0.01**	**1**	**0.003**	**0.05**	**0.02**	**3**

Although Cd was very significant in the soil at both the 0 – 30 cm and 30 – 60 cm depths to levels of heavily polluting them, its levels in the groundwater were all below 0.002 mg/l. This, possibly, is an indication that the soil had been adsorbing the Cd (Ramachandran and D'Souza, 1999; Meng *et al*., 2008) from the recharge waters and protecting the groundwater from Cd pollution. The situation may persist as long as the adsorptive capacity of the soil is not exceeded and Cd transport through the soils has not reached it breakthrough point. On the other hand, continuous discharge of Cd waste into the environment with time would overcome the situation and pollute the groundwater.

Fig. 4 shows the distribution of Ni and Pb concentrations in the groundwater of the Suame area. Generally, the concentration of Ni in groundwater for almost the whole study area is above the WHO acceptable limit (Fig. 4a), except in some isolated locations (i.e. south of Magazine, north of Old Suame and west of New Suame) where they are within the acceptable limits. There is no regular pattern in its distribution in the area, but it tends to decrease away from Magazine, Bohyen Kropo and Krofrom areas towards the area between New Suame and Old Suame. The observed higher concentrations of Ni in the groundwater is quite surprising since it was not observed in the soils at both the 0 – 30 cm and 30 – 60 cm depths. Potentially, its source may be from interaction of the groundwater with surface water in the area since the groundwater levels are very shallow and up to almost the ground surface in some locations.

Similarly, the Pb concentrations in the groundwater for most of the study area (Fig. 4b) were above the WHO guideline value, except in isolated locations south of Bohyen Kropo, Magazine and New Suame. Like the Ni, the Pb distribution in the groundwater of the area does not show any distinct pattern, but tends to have higher concentrations within the Magazine area and, then, east of Krofrom towards Bohyen Kropo. Traces of Pb above the crustal values were also observed in soils with depth and may be an indication of its transport from the ground surface through the soil to the groundwater. Prolonged usage of the groundwater without



(a)

(b)

Fig. 4: Distribution of (a) nickel and (b) lead concentrations in groundwater of the study area

reducing Ni and Pb to acceptable levels may have long term health effects on the consumers. Excessive Pb and Ni in water could be removed by filtration using activated carbon (Aziz *et al.*, 2005; Onundi *et al.*, 2010; Karnib *et al.*, 2014) and thin film composite membranes (Barakat, 2011; Le and Nunes, 2016) among others.

CONCLUSIONS

The study has investigated the potential impact of waste oil and metal disposal on groundwater quality in Suame, Ghana, through mapping of the potential sources and quantities of waste oil spilled and their effects on both soil and groundwater through heavy metal presence. The study results indicate that a total of sixty-three groundwater supply points (comprising 46 hand-dug wells, 9 boreholes and 8 springs) are located in the study area; out of which 27 are within the Magazine area. Also, 72 potential oil waste pollution sites (comprising 62 garages and 10 filling stations), spilling an estimated 60,295 litres of waste oil annually with about 96% from the garages, were mapped.

The evaluation of heavy metal presence in the soils indicates that Ni concentrations in the soils, generally, reflect the parent rock lithology and has not polluted the soil. However, the soils were observed to be unpolluted to moderately polluted with Cu, Cr and Zn, and moderately to heavily polluted with Pb and Cd. Unlike the soils, the heavy metals presence in the groundwater of the area were mostly within acceptable limits except for Pb and Ni. 84% and 92% of the groundwater supply points had their levels of Pb and Ni, respectively, above the WHO guideline values for drinking water. The Pb levels in the groundwater was not surprising since traces of it were observed in the soils (i.e. at depths of 0 – 30 cm and 30 – 60 cm) indicating its transport from the oil waste spills or activities on the ground surface through the soil. The high Ni levels, on the other hand, could not be traced directly to activities on the ground surface since they were not observed in the soils. Thus, it makes attributing groundwater pollution in the area, entirely, to the waste oil spillages and activities in the area inconclusive. This notwithstanding, the study has showed that the groundwater in the area is unsuitable for drinking because it is polluted with high levels of Pb and Ni. The groundwater, therefore, requires some prior treatment for the Pb and Ni contents to be reduced to acceptable limits before being used as drinking water.

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