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Effect of Agrochemical Use on the Drinking Water Quality of Agogo, a Tomato Growing Community in Ashanti Akim, Ghana

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Abstract The effect of agrochemical use in agricultural activities on the drinking water quality of ground and surface water within Agogo, a prominent tomato growing area in the Ashanti region of Ghana was assessed by monitoring physicochemical parameters, trace metals and microbial quality of two water sources. Levels of contamination were greater in surface water than groundwater. Trace metal levels (mg/L) were 1.40, 0.12, 0.08 and 0.18 in surface water and 0.08, 0.10, 0.05 and 0.08 in groundwater for Fe, Pb, Zn and Cd, respectively. Lead and Cd in surface and groundwater exceeded USEPA maximum acceptable levels (MCLs) for drinking water. Bacterial indicator numbers (geometric means/100 mL) in surface water varied from 9.35×10^5 to 1.57×10^{11} for total coliforms, 4.15×10^4 to 2.10×10^7 for faecal coliforms and 2.80×10 to 3.25×10^2 for enterococci, but none was found in groundwater.

Keywords Agrochemicals · Heavy metals · Water quality · Vegetable farmers · Ghana

The use of agrochemicals such as pesticides and fertilisers constitutes an important aspect of modern agriculture, as they are needed to control various pests and improve soil fertility. The benefits are increased supplies of food, but problems arise when significant amounts of agrochemicals accumulate as residues in soils or migrate into our drinking water supplies (Robinson et al. 2007). Under such circumstances, agrochemicals are of great health concern to both humans and grazing livestock (Hamilton and Crossley 2004).

In Ghana, agrochemicals usage has been quite intense in some communities (Ntow 2001). A typical case is that of Agogo, a village in the Ashanti Akim District of the Ashanti region where agrochemicals application has proceeded at an intense rate for several decades. About 80% of cultivated crop in this village is tomato, which is cropped all year round: major season (October–February), mid season (March–June) and minor-season (July–September). Most of the agrochemicals used by these farmers include banned and restricted products such as aldrin, chlordane, dieldrin and dichlorodiphenyltrichloroethane (DDT) (Ntow et al. 2006). Additionally, pesticides meant for the control of cocoa and coffee diseases; confidor 200SL, champion 80WP, funguran-OH 50WP and kocide 101WP, cypercal 50EC and polythrine; were all applied in tomato production at Agogo.

Given the increased risk of contaminant transport of these residues into surface water, provision was made for boreholes and hand-dug wells at Agogo. Nevertheless, we presume that this shift to alternate drinking water sources might only provide temporary relief, since the residues potentially could reach groundwater. Indeed, there is considerable evidence that implicates agrochemical applications in the accumulation of heavy metals in agricultural soils and contamination of both surface and groundwater sources (Atafar et al. 2010).

This study focused on the effect of agrochemicals application on some water quality parameters in the Agogo farming community in Ghana where pesticides and fertilizers have been intensely applied for several decades. There was also a cursory investigation regarding some sociological factors affecting the ability of farmers to properly apply these chemicals.

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Materials and Methods

The study area, Agogo, lies between latitude 6° 45′, 7° 00′ N and longitude 1° 50′, 10° 00′ W in the moist semi-deciduous forest zone of Ghana and stretches along the banks of River Afram. The study area was divided into three zones for sampling purposes. Zone 1 constitutes communities drained by the Agyaa stream, zone 2 is drained by Kowire River and zone 3 by Onyim River (Fig. 1).

Surface water samples were collected from the Agyaa Stream in zone 1, Kowire River in zone 2, and Onyim River in zone 3 (Fig. 1). Two sampling points of at least 400 m apart were selected for each river (Fig. 1), with one of the sampling points located at the point of intense agricultural activity and the second further downstream. Samples were collected at a depth of 10 cm from the surface. Groundwater samples were collected from six communities, two from each zone. From zone 1, samples were taken from Ananekrom and Serebouso; zone 2, Brohabebome and Nyamebekyere and zone 3, Onyimaso and Pataban (Fig. 1). These communities were purposively selected, based on proximity to the surface water sources and intense agricultural activities. Water samples were drawn from community boreholes at 2-month intervals, coinciding with the dry, mid and rainy seasons in Ghana, for assessment of the effect of seasonal variations on the various parameters. From each sampling point triplicate water samples were collected in sterilized 500 mL Duran Schott bottles and transported in ice-chests to the laboratory for water quality analyses.

Standard methods were used to determine conductivity, pH, turbidity and total dissolved solids (TDS). Total hardness was determined by titration using EDTA and Eriochrome Black T indicator. Anions (Fl^-, NO_3^-, SO_4^{2-}, PO_4^{3-} and Cl^-) were determined by means of ion chromatography with conductivity detector. Iron, Pb, Zn and Cd were determined by the Atomic Absorption Spectrometry (AAS) using Smith Hieftje 11 Spectrometer with detection limits of 0.005 mg/L for Fe, 0.01 mg/L for Pb, 0.002 mg/L for Zn and 0.001 for Cd. Total and faecal coliforms and enterococci were determined using the MPN and membrane filtration methods as described by Obiri-Danso et al. (2003).

Separate questionnaires were administered to vegetable farmers and agrochemicals dealers within Agogo. Since respondents mostly could not read and write English, the questions were read out for them in the local dialect and their responses were written. Farmers were interviewed on zonal basis to determine their knowledge and extent of use of the different agrochemicals. Purposive sampling method was used, based on the intensity of farming activities. Twenty farmers from each zone (thus, for the 3 zones, n = 60) and all agrochemical sellers (14) within Agogo were interviewed on their knowledge, application and handling of agrochemicals.

Trace metals and physicochemical data were analysed using a one-way and two-way Analysis of Variance (ANOVA) by a completely randomized design to test any significant differences among the zones, sampling points and seasons. This was done using the GENSTAT statistical

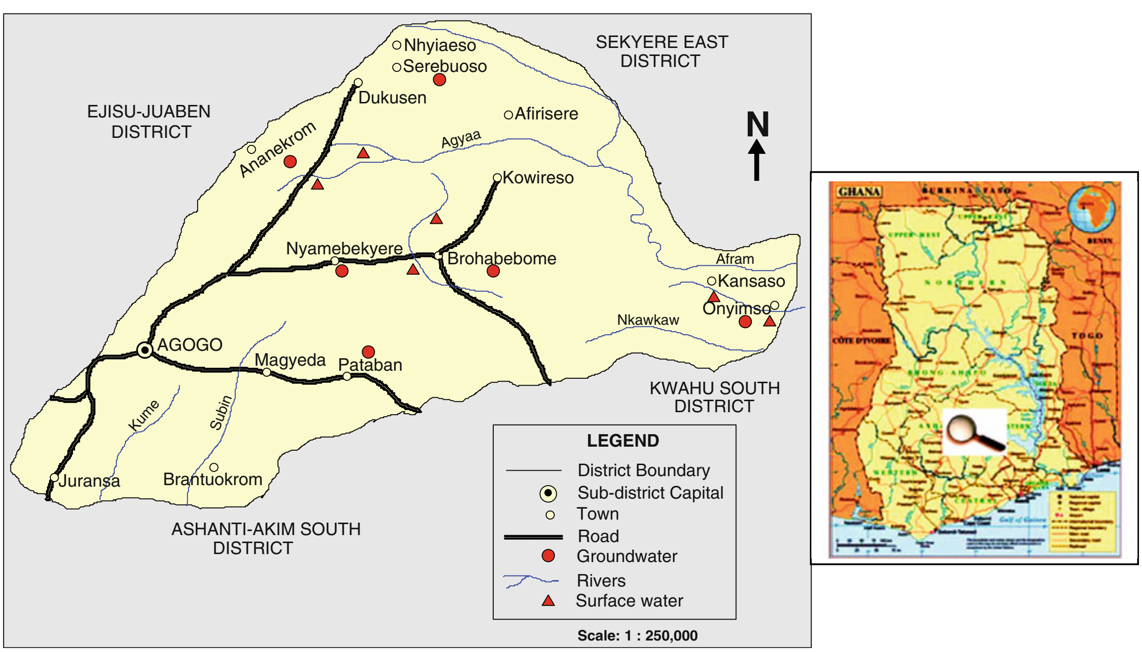

Fig. 1 Map of Agogo showing sampling points for surface water and boreholes

package. For microbiological analysis, raw data were transformed by adding a value of one to all scores in order to eliminate data points of zero. Each datum point was then converted to $\log_{10}$ in order to harmonize the values for easy interpretation. Response from the survey was analysed using simple descriptive statistics, by way of frequency and percentage estimations.

Results and Discussion

pH for surface water ranged between 5.7 and 6.4, whiles it ranged between 5.1 and 6.7 for groundwater. So generally, pH for both surface and groundwater was slightly acidic and averagely within WHO drinking water guideline range of 6.5–8.5 (WHO 2006). pH measurements did not show any seasonal variation. Surface water from zone 3 sampling points, Onyimaso and Pataban, were very turbid, particularly measurements downstream (in Pataban) were way beyond WHO guideline value of 75 NTU for drinking water (Fig. 2). Seasonal variations observed in turbidity levels were not statistically significant. Total hardness, total dissolved solids (TDS), conductivity, nitrate, sulphate and chloride did not constitute a problem in both surface and groundwater. Values recorded for these parameters were generally within WHO guidelines for drinking water of 500 mg/L, 1,000 mg/L, 1,500 μS/cm, 50 mg/L, 250 mg/L and 250 mg/L respectively. Total hardness, TDS and conductivity results are presented in Fig. 2. Comparatively, total hardness was quite high in groundwater from zone 3, but this was still within the guideline limit. Mean nitrate, sulphate and chloride concentrations were in the following respective ranges: 0.01–0.10, 0.59–2.59 and 3.66–13.02 mg/L. Akoto et al. (2010) have reported the following ranges for physicochemical parameters of surface water in the Owabi watershed in Ashanti Region of Ghana: pH (6.75–7.40), TDS (28–197 mg/L), nitrate (0.01–0.17 mg/L), sulphate (12.1–32.0 mg/L) and chloride (18–61 mg/L). Monitoring studies of Subin River, which flows through the industrial and commercial areas of Kumasi, the capital city of the Ashanti Region of Ghana, indicated water pH that ranged from 6.89 to 7.65, electrical conductivity (EC)—from 822 to 1,821 μS/cm and TDS—from 409 to 913 mg/L (Adomako et al. 2008). Concerning groundwater, Fianko et al. (2009) recently investigated the relationship between land use and groundwater quality in the Eastern Region of Ghana and reported the following range of results: pH (4.49–6.95), conductivity (107–1,053 μS/cm), TDS (59.92–589.7 mg/L), nitrate (0.01–66.0 mg/L), sulphate (0.03–181 mg/L) and chloride (5.1–158 mg/L). The physicochemical data recorded in our present study for the Agogo area were consistent with the ranges of values reported in the aforementioned studies. This suggests that common physicochemical parameters such as pH, EC, turbidity, TDS and some major ions in surface and groundwater at Agogo, following the agrochemical applications, were not differently affected in comparison to water quality-land use relationships from other parts of the country.

Trace metal levels were generally higher in surface water compared to groundwater samples, although these variations were not statistically significant ($p > 0.05$). Mean Pb concentrations in surface water at Agogo ranged between 0.10 and 0.12 mg/L. In groundwater, it was ranged between 0.09 and 0.105 mg/L. In both cases, the Pb concentrations exceeded the USEPA maximum contaminant level (MCL) of 0.015 mg/L for Pb in drinking water (USEPA 2009). There was marked seasonal variation in Pb concentrations, with significantly high levels measured in the rainy season ($p < 0.001$) (Fig. 3). Mean Fe levels in surface water varied from 0.06 to 1.40 mg/L, with zone 3 recording the highest and zone 1 the lowest. However, Fe concentrations in groundwater samples were relatively lower (0.028–0.082 mg/L) compared to surface water samples. Although all the borehole water samples were within the USEPA standard value of 0.3 mg/L for Fe, surface water samples from zones 2 and 3 exceeded this value. Seasonal differences in Fe levels were not statistically significant (Fig. 3). Cadmium levels in surface waters from the three zones varied between 0.01 and 0.18 mg/L and in borehole water from 0.015 to 0.085 mg/L. Generally, mean Cd level in the surface water (0.087 mg/L) was about twice the average amount measured in ground water samples (0.042 mg/L) (Fig. 3). Cadmium in surface and groundwater both exceeded the USEPA MCL of 0.005 mg/L. Cadmium levels did not change significantly among seasons. Zinc concentrations in all the surface and groundwater samples were within the USEPA drinking water MCL of 5.0 mg/L. Zinc levels ranged between 0.037 and 0.08 mg/L for surface water and 0.043 and 0.053 mg/L for groundwater. The water samples also contained more zinc in the rainy season compared to the dry season ($p = 0.03$).

Regarding the metals considered in this study, Pb and Cd, which were in concentrations beyond the USEPA permissible limits for drinking water, clearly constituted an environmental risk concern in surface and groundwater within the Agogo farming community. Compared to reported data from other parts of Ghana, the Pb and Cd concentrations in surface and groundwater in Agogo were high. For instance, the heavy metal pollution profile of streams serving the Owabi reservoir in Kumasi, Ghana, indicated that Pb levels ranged between 0.01 and 0.03 mg/L (Akoto et al. 2008). The major human activities within the Owabi watershed included metal fabrication, auto garages, residential, farming, road construction as well as municipal waste disposal. For the Subin River that drains the Kumasi municipality, the mean amount of Cd measured in this water ranged from 0.002 to 0.05 mg/L (Adomako et al. 2008). In Tarkwa, a

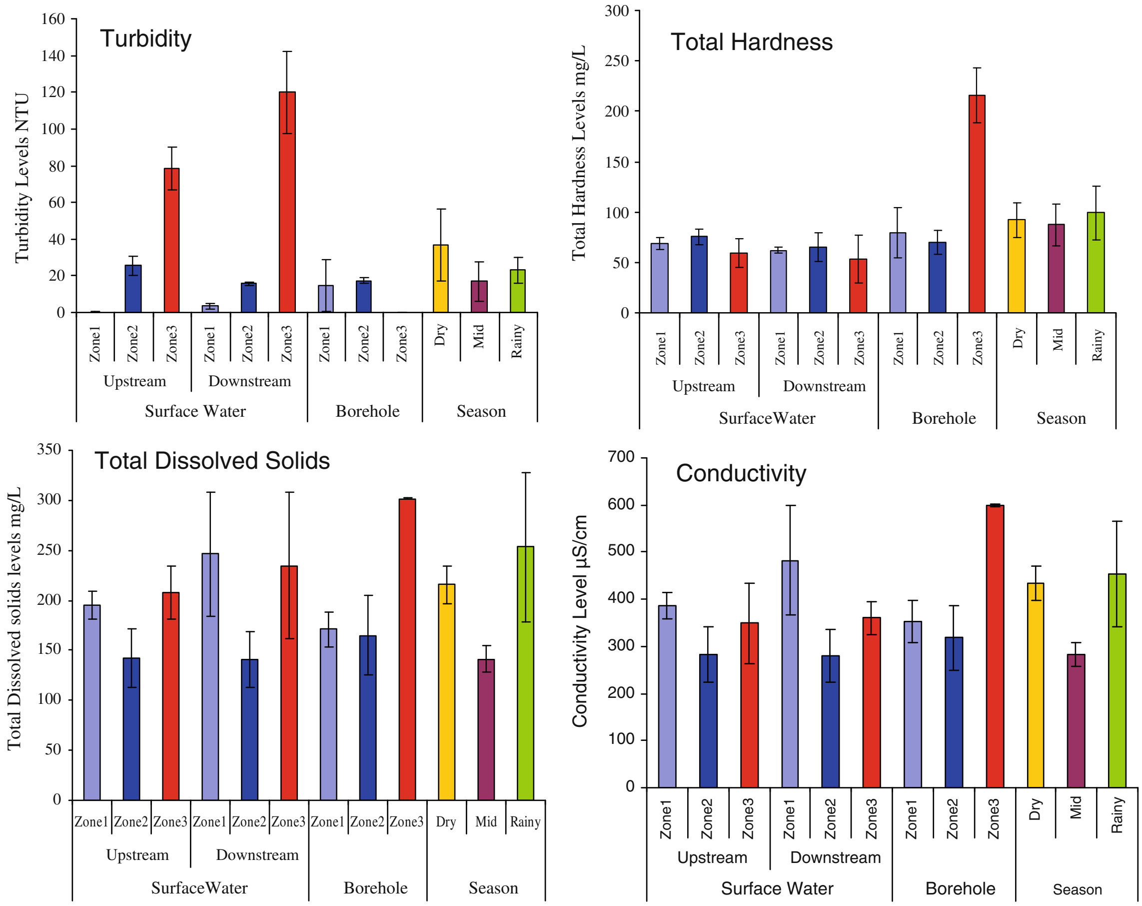

Fig. 2 Levels of some physicochemical parameters in surface and groundwater at Agogo

historical mining community in Ghana, Asante et al. (2007) had reported Pb concentrations in drinking water sources to range as follows: borehole (0.10–0.32 µg/L); well (0.03–42.9 µg/L) and river/stream (0.02–3.71 µg/L). Asante et al. (2007) also reported Cd concentrations as follows: borehole (0.01–0.16 µg/L); well (0.04–0.08 µg/L) and river/stream (<0.01–0.13 µg/L). In Dumasi, in the Wassa West District in the Western Region of Ghana, a major cocoa farming area in the country and as such receives moderate agrochemical applications, heavy metals determinations in borehole water indicated mean concentrations of 0.005 and 0.002 mg/L for Pb and Cd respectively (Obiri 2007). These examples of water quality investigations represent areas of land use activities that were quite different from the extent of agrochemical applications within the Agogo community. As mean Cd and Pb concentrations were slightly lower in these other studies, we consider that comparatively, cumulative agrochemical applications at Agogo, might have had a greater effect in contributing the respective metals to surface and groundwater.

On the assumption that the extent of Pb and Cd contaminations in the water sources at Agogo was linked to the agrochemicals application, a cursory investigation was undertaken regarding the kinds of agrochemicals applied in this area. Broadly, farmers indicated the common names of pesticides applied in the Agogo area as follows (known active ingredients are indicated in italics): Champion WP (*copper hydroxide*), Kalach (*glyphosate*), Polytrine (*profenofos and cypermethrin*), Topsin (*thioallophanate*), Dithane M4 (*mancozeb*), Chemosate 360SL (*simazine*), Roundup (*glyphosate*), Cytoate (*cypermethrine and dimethoate*), Kocide (*copper hydroxide*), Cypercal P336EC (*cypermethrine*), Funguran (*copper hydroxide*), Ambush 10 EC (*permethrin*), Thiodan (*endosulfan*), DDT, Rando, Root Destroyer (*copper sulphate*), Ammonia, Karate (*lambda-cyhalothrin*), Glycel (*glyphosate*) and Calliherbe. These represent a cross-section of pesticides that were applied at Agogo and generally fall within the list of pesticides reportedly applied in vegetable farming in Ghana (Ntow et al. 2006). According to Ntow (2001), many of these agrochemicals meant for crops such as cocoa and coffee were misapplied for tomato cultivation. In addition, the farmers applied various kinds of fertilisers, which are also of concern regarding heavy metal contamination (Atafar

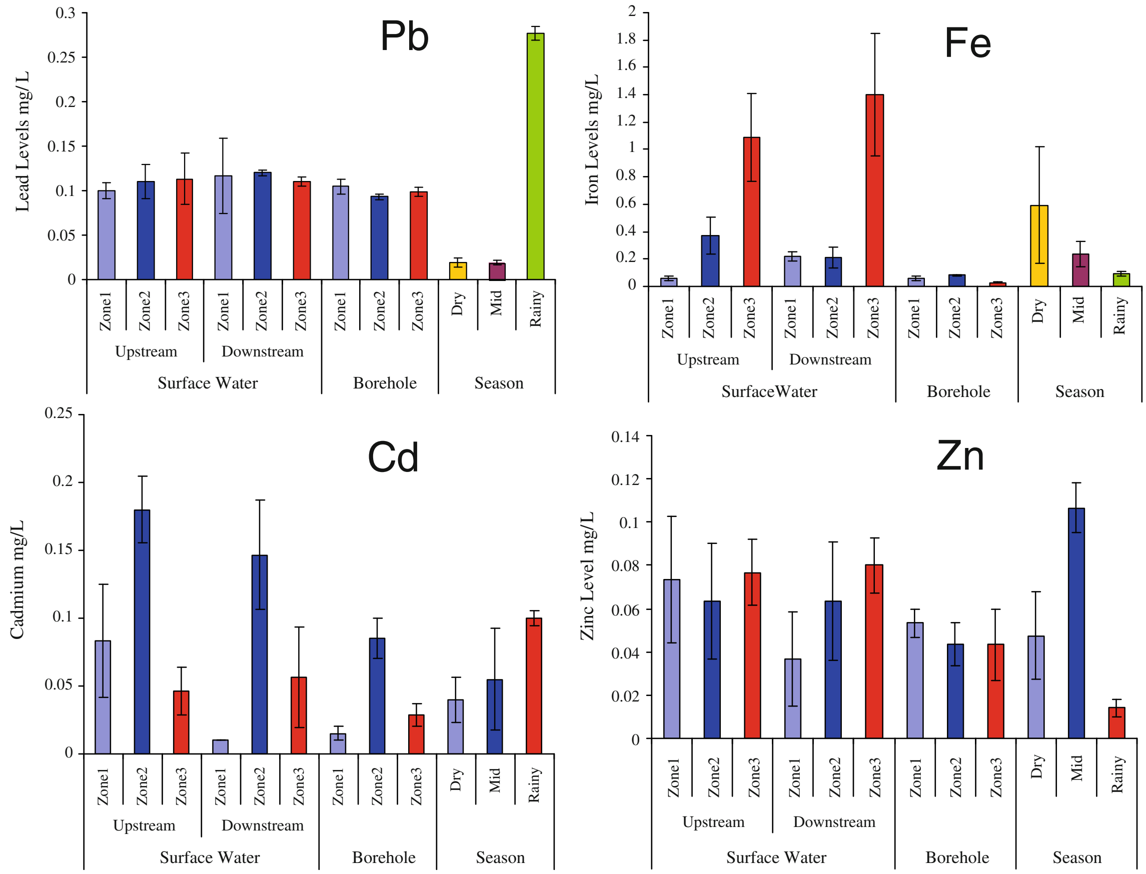

Fig. 3 Lead, iron, cadmium and zinc concentrations in surface and groundwater at Agogo

et al. 2010). Generally, in incidents of trace metal contaminations following agrochemical applications, linkage has been made to metal contaminant residues in the agrochemical products. We assume such a hypothesis to explain the presence of heavy metal contamination in water sources at Agogo.

Bacterial indicator numbers in surface water samples were generally high in all the three zones; ranging from $\log_{10}$ 4.61 to 11.17 for total coliforms, $\log_{10}$ 3.86 to 7.32 for faecal coliforms and from $\log_{10}$ 1.46 to $\log_{10}$1.52 for enterococci (Fig. 4a). None of the surface water samples met the WHO standard of 0 cfu/100 mL for drinking water. However, no bacterial indicator organisms were detected in the borehole water samples. Bacterial indicator numbers were higher in the wet season compared to the dry season (Fig. 4b). The absence of bacterial indicator organisms in the borehole water from all the zones emphasized very well-maintained borehole heads, supervised by the World Vision International Office in the Agogo area. This, indeed, supports the argument that well-maintained borehole heads markly improves borehole water quality, especially with regards to microbial contamination. Conversely, the poor microbial quality of the surface water was attributed to two potential factors: (1) cattle grazing in the Agogo watershed and (2) poor sanitation facility of the area. Fulani herdsmen from neighbouring West African countries seasonally bring their livestock to graze on green pastures in these zones. Faecal dropping from the cattle and the cattle egrets birds that follow might have contributed significantly to the bacterial loading in the water bodies. Lack of proper sanitation facilities within the communities may also promote microbial contamination of surface water sources. The microbial loading in the surface waters were comparable to that in River Subin, an urban river in Kumasi, Ghana (Obiri-Danso et al. 2005). It was also consistent with the microbial characteristics of streams in the Owabi watershed (Akoto et al. 2010). Most rivers and streams in Ghana are of poor microbial quality, thus, the situation observed in the Agogo community might be reflecting this common trend. From Fig. 4, it was realized that enterococci numbers were consistently low compared to the coliforms, confirming the poor survival rate of the former when photo-exposed (Locas et al. 2008).

In Ghana, the problem of trace metal associated contaminations with agrochemical applications may be compounded in view of the way agrochemicals are retailed by petty traders to local farmers in small communities.

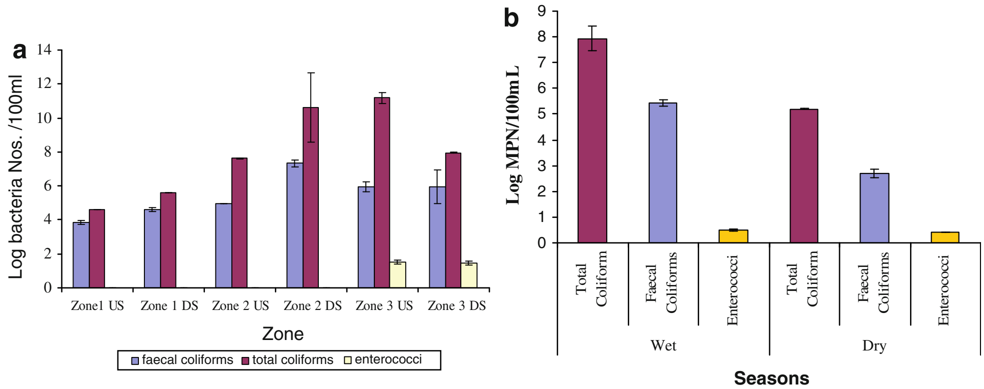

Fig. 4 **a** Indicator bacterial numbers in surface water samples from Agogo **b** Seasonal variations in levels of indicator organisms

Community agrochemical dealers usually repackage or rebottle agrochemical products and resell in bits to subsistence farmers. These dealers are unskilled, lack requisite knowledge and sometimes adulterate products in a quest to maximize profit. In investigating the kind of agrochemicals applied in the Agogo area, we considered common sociological factors, which might influence the way farmers and petty agrochemical dealers handle these chemicals. The age distribution of the farmers who applied these chemicals ranged from 20 to 60 years with the 31–40 age group being the highest (40%). None of the farmers interviewed (n = 60) had Senior High School education. Twenty-three percent (23%) had no education at all, while the rest did not go beyond Junior High School. This is reflected in farmers' poor reading abilities, as 63.3% either had reading problems or could not read at all. Thus, majority of the farmers had great difficulty in understanding instructions that were written on agrochemical containers. More than half of the farmers (58%) practiced crop rotation, with only 1.7% practicing the fallow system and 36.7% practicing continuous farming. The fallow system is almost impossible because of the unavailability of land. All the farmers indicated that they used agrochemicals to control pests and improve soil fertility, but only 38.3% had any form of training to use such chemicals. Only 16.7% of farmers sought information on agrochemical application from Agricultural Extension Officers. The rest mostly relied on self knowledge or on other farmer friends. 63.3% of farmers reported some form of failures upon agrochemical application, which they thought were related to factors such as wrong timing, wrong formulation or wrong application. It is however our opinion that many of these failures, in which expected outcome upon agrochemical applications was not realized, may also relate to the issue of local adulterations of products. The study had response from all the agrochemical dealers in the Agogo community (n = 14). Almost 80% of the dealers did not go beyond primary education and 85.7% of them did not have any professional training in the sale and handling of these agrochemicals. These factors may partly account for the indiscriminate use of agrochemicals by the vegetable farmers who themselves lack requisite knowledge and training to handle the chemicals.

In summary, among the four trace metals considered, Pb and Cd posed significant environmental risk in surface and groundwater within the Agogo community, while Fe and Zn did not. This inference followed the fact that Zn and Cd concentrations in both surface and groundwater exceeded the USEPA MCLs for the respective metals. We assumed that these heavy metals were introduced as contaminants in applied agrochemical products. The physicochemical characteristics of the surface and groundwater at Agogo were consistent with data on water sources from other parts of the country with varying land-use applications. Good borehole management kept out bacterial indicator organisms in borehole water, but surface water showed poor microbial quality attributed to cattle grazing events and poor prevailing sanitation. It was suggested that some of the agrochemical linked contaminations might possibly be due to misapplication (on the part of users) or adulteration (on the part of local sellers) of the products. Therefore, appropriate education on the proper handling, use and disposal of agrochemicals, targeting both sellers and users of the product, is required to reduce the environmental impact of agrochemicals in affected communities in Ghana.v

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