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PHYSICO-CHEMICAL CHARACTERISTICS OF WASTEWATER AT A POLYETHYLENE BAG MANUFACTURING COMPANY IN BEKWAI MUNICIPALITY, GHANA

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ABSTRACT

This study investigated heavy metals and other physico-chemical parameters in effluents at a plastic manufacturing company in Bekwai municipality. Wastewater was sampled at different points of wastewater production and storage to help understand how unit operations affected effluent quality. Sampling and determination of physico-chemical parameters (pH, conductivity, total dissolved solids, total hardness, alkalinity) were carried out as described by the American Public Health Association (APHA). Heavy metals (Manganese (Mn), Mercury (Hg), Copper (Cu), Chromium (Cr), Arsenic (As), Cadmium (Cd), Lead (Pb), and Zinc (Zn)) were determined using Inductively Coupled Plasma Mass Spectrometry (ICP-MS) following standard protocol. The pH of the samples ranged from 7.59 – 8.1. The mean concentrations ranged from 0.001 to 0.069 mg/L, 0.001 – 0.037 mg/L and 0.013 – 0.017 mg/L for Pb, As and Cr respectively. Except for Pb and As, all physicochemical parameters and the remaining metals analysed values were below the permissible range for effluent discharge by the Environmental Protection Agency (EPA) of Ghana. A one-way analysis of the variance of all the heavy metals in the water samples analysed revealed statistically significant difference ($p < 0.05$) The estimated daily intake of Mn, Cu, Cr, Cd, Pb and Zn contained in the water samples analysed did not exceeded their recommended daily intake for children, however, As exceeded their acceptable daily intake of 0.0003 mg/kg/day for children. All metals were below their acceptable daily limit for adults. This result indicates the presence of toxic metals in effluent from polyethylene bag manufacturing companies which is of concern since these metals tend to bioaccumulate and affect aquatic life.

Keywords: effluent; polyethylene bag; heavy metals; physico-chemical

INTRODUCTION

Industrial wastewater is the primary cause of pollution in aquatic ecosystems,compromising water quality and posing risks to both human and ecological health (Chen *et al*., 2017; Du *et al*. 2020). Pollutants of major concern in industrial wastewater are heavy metals, nutrients, and emerging contaminants like pharmaceuticals. According to Dinis and Fiuza (2011), the majority of heavy metals are hazardous even at low concentrations, and Titilawo *et al*. (2018) found that their accumulation in bodily tissues over time may be harmful to human health. Due to its toxicity to living things through bioaccumulation, heavy metal contamination has drawn attention from all around the world (Ekmekyapar *et al*., 2012 ; Renzoni *et al*., 2015; Monteiro *et al*., 2017).

The chemical makeup of the influent wastewater and its treatment processes significantly impact the ultimate quality of sewage sludge, which is the principal by-product of the wastewater treatment process (Turek *et al*., 2019; Tytla *et al*., 2019). According to Okoh *et al*. (2007), various pollutants in wastewater accumulate in sewage sludge to the extent of 80–90%, hence discharging the sludge into waterbodies would significantly increase the organic load, decrease the levels of dissolved oxygen, and enrich nutrients. Most of the time, methods used to treat wastewater do not ensure the quantitative removal of many contaminants, which means that after discharge, there may be further environmental pollution (Tytla *et al*., 2019). The wastewater discharged may contain biological or chemical pollutants.

The Bekwai municipality presents a compelling case for such an investigation due to its unique concerns regarding industrial wastewater pollution. Its long history of gold mining has left a legacy of extensive environmental contamination (Akoto *et al*., 2023). Furthermore, rapid industrial growth, particularly the rise of polythene bag manufacturing companies, increase the concerns about the cumulative impact on the environment and public health.

Understanding the physicochemical properties of wastewater is fundamental for environmental scientists, engineers, and policymakers. These properties encompass a wide range of measurable characteristics, including pH, chemical oxygen demand (COD), biological oxygen demand (BOD), total suspended solids (TSS), and the presence of various contaminants, including heavy metals and organic compounds. Implementing measures to treat and dispose of wastewater properly aligns with the goal of promoting sustainable consumption and production patterns (Lukman *et al*., 2016). Chemical contamination from polyethylene bag manufacturing waste can harm aquatic ecosystems, impacting marine life and biodiversity (Asuquo, 2018). Mitigating water pollution from industrial activities supports the conservation and sustainable use of marine resources (García-Poza *et al*., 2022). Soil degradation resulting from improper disposal of manufacturing waste can have negative implications for terrestrial ecosystems and biodiversity (Kolawole and Iyiola, 2023). Addressing this issue contributes to the goal of protecting, restoring, and promoting sustainable use of terrestrial ecosystems (Opoku, 2019). Chemical contamination from manufacturing processes can pose risks to human health through exposure via water, soil, or food sources. Implementing measures to minimize pollution supports the promotion of health and well-being for all ages.

Due to its toxicity to living things through bioaccumulation, heavy metal contamination has drawn attention from all around the world (Ekmekyapar *et al*., 2012 ; Renzoni *et al*., 2015 and Monteiro *et al*., 2017). With a higher elemental density, heavy metals are often categorized as metals or metalloids. These are separated based on atomic number, density, or weight (Kumar *et al*., 2017; Ali and Khan, 2018). Heavy metals should have an atomic density of >41 g/cm3, according to a new criterion proposed by Ali *et al*. (2019), who used metals such as Cd, Cr, Co, Cu, Pb, Hg, Zn, among others as examples. According to Bansod *et al*. (2017), heavy metals, even in small concentrations, have a significant impact on terrestrial and aquatic ecosystems. This may be caused by a variety of sources, such as air emissions, which Kelly *et al*. (1996), identified as the main cause of soil and water contamination. These are the most hazardous and deadly water contaminants in terms of both natural habitats and human health (Kim *et al*., 2012).

Different amounts of heavy metals, or metallic chemical components with relatively large densities, are found naturally in the environment. According to Dinis and Fiuza (2011), the majority of heavy metals are hazardous even at low concentrations, and Titilawo *et al*. (2018) found that their accumulation in bodily tissues over time may be harmful to human health.

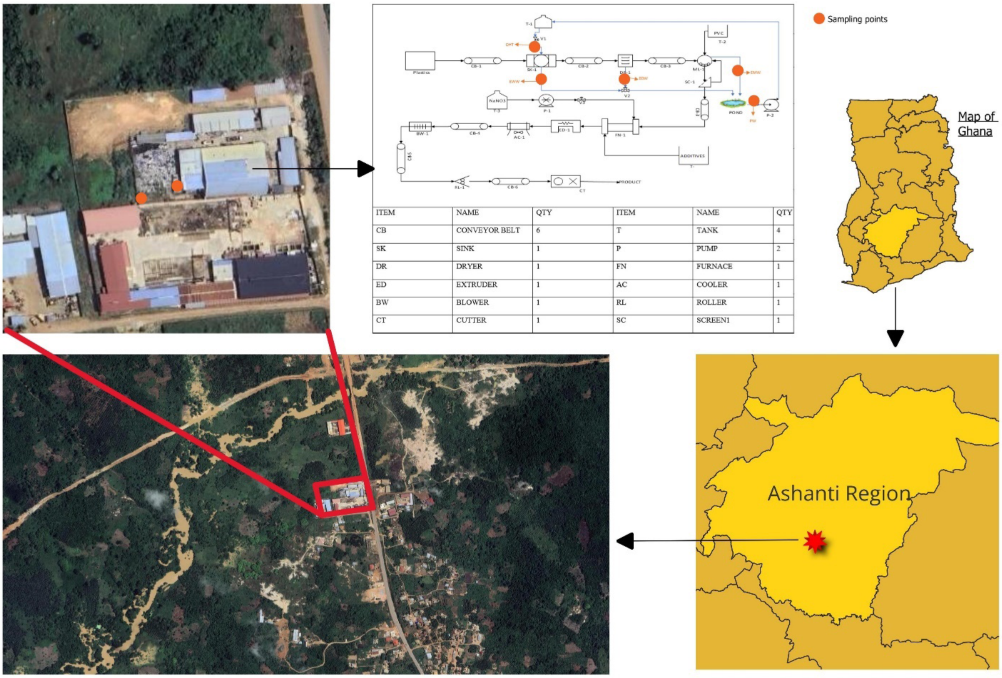
Many heavy metals and metalloids are dangerous even at low concentrations because heavy metals have negative effects on human health (Arora *et al*., 2008). Heavy metals cause oxidative stress by creating free radicals (Mudipalli, 2008). Furthermore, according to Malayeri *et al*. (2008), they might take the place of primary metals in pigments and enzymes. The most hazardous heavy metals in terms of their toxicity are As, Hg, Cd, Cr, Cu, Pb, Sn, and Zn (Ghosh, 2010).

The physicochemical properties of wastewater produced by polythene bag manufacturing companies in Bekwai play a pivotal role in assessing its quality, potential environmental impact, and suitability for treatment and reuse. They provide essential insights into the composition, reactivity, and behavior of wastewater constituents, which, in turn, inform decisions regarding appropriate treatment methods and regulatory compliance. The identification and quantification of potential pollutants helps in revealing the environmental risks as well assessing the effectiveness of existing treatment practices.

MATERIALS AND METHODS

Sampling area

The study was conducted at U Family Waste Plastic Company Limited, a manufacturing facility located in Bekwai municipality, in the Ashanti region near Anwia Nkwanta as shown in Fig 1. The study focused on the in feed and wastewater generated during the production of plastic products in the company's manufacturing plant. The manufacturing facility served as the primary source of data for the study. The research team collected samples of the process and wastewater generated in the plant for analysis.



ITEM	NAME	QTY	ITEM	NAME	QTY
CB	CONVEYOR BELT	6	T	TANK	4
SK	SINK	1	P	PUMP	2
DR	DRYER	1	FN	FURNACE	1
ED	EXTRUDER	1	AC	COOLER	1
BW	BLOWER	1	RL	ROLLER	1
CT	CUTTER	1	SC	SCREEN1	1

Figure 1: Map of U Family Waste Plastic Company Limited

Sampling

Water samples of influent and effluents were collected using 1500 mL polypropylene bottles between January and March 2023. In all, there were five sampling locations being feed (pond) water (PW), overhead tank (OHT), effluent from the washing (EWW), milling (EMW) , and drying units (EDW) of the manufacturing plant.

At each sampling location, samples were taken in triplicate for physiochemical, heavy metals, and nutrient analysis. Samples for heavy metal analyses were acidified toby adding 2 mLHNO_3 (Kanto Chemical Corp., Tokyo, Japan) and samples were transferred to the laboratory for analysis in coolers at a temperature of 4℃.

Chemical analysis

Physico-Chemical analysis

A Starter 3100M Bench multimeter (Ohaus Corporation, Parsippany, USA) was used to measure the temperature, pH and conductivity of the samples. The conductivity readings were used to estimate the total dissolved solides. Turbidity of the samples was determined using a HACH Turbidimeter model 2100N (Hach Company, Loveland, Colorado, USA). Alkalinity, chloride and hardness was determined titrimetrically, using a Metrohm Auto-titrator (Metrohm AG Inc, Herisau, Switzerland).

The anions (nitrate, sulphate, and phosphate) were determined using the Agilent Cary 60 UV-Vis spectrophotometer (Agilent Technologies, Santa Clara, USA). .

Metals analysis

About 500 mL of water samples were digested with 5 mL of 1:1 HNO_3 and HCl in line with the USEPA 3050B protocol (USEPA 1996). Aliquot of the digest was measured directly on ICP–MS; 7700 series, Agilent technologies, Tokyo, Japan) to determine the concentration of Ca, Mg, Na, and K.

Health risk assessment

Human health risk assessment involves the estimation of the probability of adverse health effects in humans who are exposed to metals in contaminated environments. It involves exposure assessment, the assessment of noncarcinogenic and carcinogenic risk (USEPA, 2012). Due to the behavioral and physiological differences, the human health risk was conducted for adults and children.

Exposure assessment

Estimated daily intake (EDI) was used to estimate human exposure to heavy metals through direct ingestion according to equation 1 adopted from USEPA methods (1992). Estimations were made for two groups: children (as a sensitive group) and adults (as the general population).

$$EDI = \frac{C \times IR \times EF \times ED}{BW \times AT} \qquad \textbf{Eqn 1}$$

Where EDI (mg/kg/day) is the estimated daily dose intake through ingestion, C is the concentration of metal (mg/kg) in the food, IR is the ingestion rate (kg/day), EF is the Exposure frequency, ED is the exposure duration, BW (Kg) is the standard body weight and AT is the time duration of human exposure. The parameters for calculating the estimated daily intake are presented in Table 1.

Table 1: Parameters for assessment of estimated daily intake (USEPA, 2012)

Parameter	Value
IR	0.2g/day for children and 0.1g/day for adults
EF	180 days/year
ED	6 years for children and 24 years for adults
BW	70kg for adults and 15kg for children
AT	365 *ED

Non- carcinogenic risk

Non-carcinogenic health risk involves estimating the likelihood that a given amount of a substance will have adverse health effects over a specified period. Non-carcinogenic health risk was estimated using the hazard quotient and hazard index.

Hazard quotient

The hazard quotient (HQ) was calculated according to equation 2. A hazard quotient is the ratio of the potential exposure to a substance and the level at which no adverse effects are expected (USEPA, 1989). The individual reference dose (RD) for the various heavy metals is presented in Table 2 adopted from USEPA, (2012).

$$HQ = \frac{EDI}{\mathrm{RD}}$$ **Eqn 2**

Hazard Index

The Hazard Index (HI) technique was used to evaluate the overall potential for non-carcinogenic health risks posed by many contaminants (USEPA, 1989). The hazard index for a mixture of pollutants is determined using equation 3 (USEPA, 1989):

$$\mathrm{HI} = \sum \mathrm{HQ}$$ **Eqn 3**

If the HI value is less than one, the exposed population is unlikely to experience obvious adverse health effects. If the HI value exceeds one, then adverse health effects may occur (USEPA, 1989).

Carcinogenic risk assessment

Carcinogenic risks are estimated by calculating the probability of an individual developing cancer over a lifetime as a result of exposure to the potential carcinogen. The carcinogenic health risk is calculated using a cancer slope factor as shown in equation 4. The cancer slope factor is an estimate of the probability that an individual will develop cancer if exposed to a chemical substance for a lifetime of 70 years.

$$\mathrm{LCR} = \mathrm{EDI} \times C\mathrm{SF}$$ **Eqn 4**

Where LCR is the lifetime cancer risk and CSF is the cancer slope factor (mg/kg/day).

LCR above 1×10^{-4} is viewed as unacceptable, risks below 1×10^{-6} are not considered to have significant health effects, and risk lying between 1×10^{-4} and 1×10^{-6} is considered an acceptable range (USEPA, 1989). The individual cancer slope factors as adopted from the USEPA 1989 are presented in Table 2.

Table 2: Reference dose and cancer slope factor (CSF) for heavy metals

Heavy metals	Ref Dose (mg/kg/day)	CSF (mg/kg/day)
Cd	0.001	0.0061
Cr	1.5	0.041
Pb	0.04	0.0085
Mn	0.14	
Zn	0.3	
Cu	0.04	
As	0.0003	1.5
Hg	0.0001	

Note: CSF values for metals such as Mn, Zn, Cu, amd Hg are unavailable.

Statistical analyses

Exploratory data analysis was used to determine the mean and standard deviations. Prior to statistical analysis, the normality of data was checked using the Shapiro-Wilks test and the data was found to have a normal distribution. Results were expressed as mean ± Standard deviation. Analysis of variance at a significant level of 0.05 was used to determine the significant difference between the physicochemical parameters. Principal Component Analysis (PCA), was used to reduce the dimensionality of data to make the data more interpretative and Correlation analysis was performed to determine the relationship between the variables. PCA, correlation and exploratory data analysis were done using Statistical Package for the Social Sciences (SPSS) 24.

Quality control

A relative standard deviation of >20% was obtained for all duplicate samples. For quality control, certified reference materials, duplicates and reagent blanks were utilized and accepted with a recovery percentage greater than 90%.

The instrument was calibrated using standard solutions of the respective metals (to establish standard curves before metal analysis), and correlation coefficients of the obtained standard curves were greater than 0.999. All chemicals and standard stock solutions were of analytical-reagent grade (Wako Pure Chemicals Industries, Ltd., Osaka, Japan). The limits of detection (LOD), calculated as three times the standard deviation of ten blank solution measurements, divided by the slope of the calibration curve (µg/L) were Cd (0.001) Cr (0.003) Pb (0.002) Mn (0.034) Zn (0.0019) Cu (0.008) As(0.001), and Hg(0.009), respectively.

RESULTS

Physicochemical Parameters

The results for physicochemical parameters are presented in Table 3. The results range from 7.59 - 8.1, 27 - 28.3 °C, 492 - 6112 µs/cm, 7.11 - 22.5 NTU, 290 - 344 mg/L, 3 - 15 mg/L, 26.6 - 40.54 mg/L, 1.32 - 18.4 mg/L, 3.55 - 10.95 mg/L, 98.1 - 160.5 mg/L, 32.2 - 45.7 mg/L, 45.3 - 65.1 mg/L, 9.3 - 26.6 mg/L and 377.56 - 588.96 mg/L for pH, Temperature, Conductivity, Turbidity, TDS, TSS, Chloride, Phosphate, Sulphate, Ca, Mg, Na, K, hardness respectively. There was a statistically significant difference (P = 0.001) between the different parameters (Table A1). However, no statistically significant difference (P > 0.05) was observed when the results for the same parameter were compared. (Table A2). Except for conductivity and phosphate which exceeded the WHO threshold limit for the WHO criteria, all other parameter results were below their WHO threshold limit.

Table 3: Concentration of physicochemical parameters of water from a plastic company in Bekwai

Location	pH	Temperature	Conductivity	Turbidity	TDS	TSS	Chloride	Nitrate	Phosphate	Sulphate	Alkalinity	Ca	Mg	Na	K	Hardness
		°C	µS/Cm	NTU	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
OHT	7.97 ± 0.01	27.6 ± 0.13	492.7 ± 0.25	13.6 ± 1.02	305. ± 4.32	6. ± 0.02	27.15 ± 5.34	0.18 ± 0.03	1.38 ± 0.34	9.94 ± 0.54	464 ± 13.34	98.1 ± 1243	32.2 ± 8.75	54.6 ± 9.92	12.12 ± 0.16	377.56 ± 18.33
EWW	7.95 ± 0.01	27. ± 0.15	513.8 ± 0.43	7.11 ± 0.54	290. ± 6.54	3. ± 0.03	27.72 ± 4.32	0.1 ± 0.02	18.4 ± 0.64	3.55 ± 0.23	461 ± 12.56	120.5 ± 6.23	39.8 ± 3.86	45.3 ± 7.34	9.3 ± 0.19	403.84 ± 12.22
EMW	7.81 ± 0.02	26.8 ± 0.13	521.2 ± 0.26	11.5 ± 0.93	298. ± 9,23	4. ± 0.02	26.61 ± 6.54	1.46 ± 0.01	1.45 ± 0.34	10.18 ± 0.64	441 ± 5.93	110.4 ± 9.86	38.5 ± 5.65	59.9 ± 12.43	20.3 ± 0.32	433.8 ± 10.54
EDW	7.42 ± 0.03	27.1 ± 0.18	571.6 ± 0.43	11.1 ± 1.13	332. ± 2.54	4. ± 0.01	33.46 ± 9.34	0.75 ± 0.03	1.24 ± 0.56	9.92 ± 0.25	452 ± 15.42	130.6 ± 13.54	38.3 ± 15.43	50.7 ± 10.5	19.8 ± 0.22	483.08 ± 19.21
PW	8.1 ± 0.04	28.3 ± 0.14	612.7 ± 0.65	22.5 ± 1.43	344. ± 9.45	15. ± 0.06	40.54 ± 8.43	3.19 ± 0.04	1.89 ± 0.66	10.95 ± 0.62	442 ± 8.95	160.5 ± 16.34	45.7 ± 12.22	65.1 ± 6.54	25.6 ± 0.86	588.96 ± 23.32
WHO	6.5 - 8.5		500	<5	500		250	45	2.5	250	500		50			

Concentration of heavy metals

Heavy metals in water from the plastic company were in the range of 0.037 - 0.067 mg/L, 0.011 - 0.031 mg/L, 0.013 - 0.017 mg/L, 0.001 - 0.037 mg/L, below detection (bd) - 0.001 mg/L, 0.001 - 0.069 mg/L, 0.078 - 0.112 mg/L for Mn, Cu, Cr, As, Cd, Pb and Zn respectively (Table 4). Hg was not detected in all the samples tested. A one-way analysis of the variance of all the heavy metals in the water samples analysed revealed statistically significant differenceP<0.05) (Table A1). Tukey test revaled significant difference (p=0.0012) between Cr and Cd (Table A1). was observed between the different heavy metals tested. Considering the analysis of variance among sampling sites, no statistically significant difference (p = 0.99) was observed between the different sampling points for Mn, Hg, Cr, Cu, Cd and Zn. The results for the heavy metals tested were all found below their respective WHO criteria with the exception of As and Pb.

Correlation between water quality parameters in water from a plastic company from Bekwai

A high correlation was observed between conductivity and turbidity (0.700), conductivity and TDS (0.910), conductivity and TSS (0.729), conductivity and chloride (0.963), conductivity and nitrate (0.812), conductivity and Ca (0.959), conductivity and Mg (0.826), conductivity and Na (0.515), conductivity and K (0.835), TDS and chloride (0.933), TDS and NO_3 (0.706), TDS and sulphate (0.632), TDS and Ca (0.798), TDS and Mg (0.518), TDS and Na (0.867), TDS and K (0.749). The anions chloride, nitrate and sulphate correlated positively with Ca, Mg, Na and K (0.53<r<0.959). As, Cd and Mg correlated positively with Ca and Mg (0.69<r<0.84) (Table 5).

Table 4: Concentration (mg/L) of heavy metals in water from a plastic company in Bekwai

Sample Id	Mn	Hg	Cu	Cr	As	Cd	Pb	Zn
OHT	0.067±0.01	bd	0.011±0.003	0.014±0.02	0.001±0.003	bd	0.001±0.001	0.114±0.03
EWW	0.037±0.03	bd	0.031±0.004	0.014±0.01	0.034±0.002	0.001±0.001	0.043±0.03	0.078±0.02
EMW	0.038±0.02	bd	0.012±0.004	0.017±0.03	0.032±0.002	0.001±0.001	0.064±0.02	0.090±0.03
EDW	0.058±0.04	bd	0.011±0.002	0.013±0.01	0.034±0.001	0.001±0.001	0.054±0.03	0.106±0.01
PW	0.045±0.06	bd	0.013±0.005	0.013±0.01	0.037±0.002	0.001±0.001	0.069±0.05	0.114±0.02
WHO	0.5	0.0005	2	0.05	0.01	0.003	0.01	3

	pH	**Temperature**	**Conductivity**	**Turbidity**	**TDS**	**TSS**	**Chloride**	**Nitrate**	**Phosphate**	**Sulphate**	**Alkalinity**	**Ca**	**Mg**	**Na**	**K**	**Hardness**	**Mn**	**Cu**	**Cr**	**As**	**Cd**	*Pb*	*Zn*
pH	1																						
Temperature	0.575	1.000																					
Conductivity	-0.058	**0.584**	1.000																				
Turbidity	0.457	**0.908**	0.700	1.000																			
TDS	-0.127	**0.699**	0.910	0.777	1.000																		
TSS	0.561	**0.941**	**0.730**	**0.972**	**0.743**	1.000																	
Chloride	0.114	**0.769**	**0.964**	**0.803**	**0.934**	**0.846**	1.000																
Nitrate	0.337	0.651	**0.820**	**0.869**	**0.706**	**0.867**	0.803	1.000															
Phosphate	0.238	-0.310	-0.309	-0.566	-0.562	-0.357	-0.296	-0.429	1.000														
Sulphate	-0.123	0.428	0.420	**0.690**	**0.638**	0.501	0.416	0.571	-0.986	1.000													
Alkalinity	0.025	-0.141	-0.642	-0.514	-0.459	-0.456	-0.488	-0.836	0.461	-0.550	1.000												
Ca	0.136	0.618	**0.959**	**0.663**	**0.799**	**0.756**	**0.949**	**0.801**	-0.060	0.195	-0.557	1.000											
Mg	0.251	0.418	**0.827**	**0.518**	**0.536**	**0.638**	**0.768**	**0.800**	0.129	0.018	-0.669	0.922	1.000										
Na	0.391	0.605	**0.516**	**0.868**	**0.537**	**0.778**	**0.530**	**0.877**	-0.689	0.793	-0.757	0.434	0.426	1.000									
K	-0.078	0.446	**0.836**	**0.750**	**0.793**	**0.671**	**0.751**	**0.901**	-0.671	0.760	-0.896	0.704	**0.639**	0.819	1.000								
Hardness	0.090	0.649	**0.983**	**0.788**	**0.882**	**0.816**	**0.960**	**0.908**	-0.337	0.466	-0.709	0.956	**0.858**	0.643	0.875	1.000							
Mn	-0.253	0.276	-0.132	0.143	0.284	0.015	0.007	-0.301	-0.526	.441	0.486	-0.291	-0.634	-0.059	-0.118	-0.190	1.000						
Cu	0.272	-0.282	-0.268	-0.525	-0.540	-0.312	-0.258	-0.370	0.998	-0.973	0.408	-0.013	0.188	-0.642	-0.626	-0.289	-0.572	1.000					
Cr	0.035	-0.596	-0.508	-0.326	-0.631	-0.414	-0.645	-0.083	-0.073	0.038	-0.331	-0.539	-0.234	0.173	-0.044	-0.417	-0.441	-0.063	1.000				
As	-0.200	-0.110	**0.647**	0.049	0.298	0.148	0.470	0.487	0.250	-0.168	-0.639	**0.699**	**0.841**	0.081	0.489	0.617	-0.744	0.292	-0.026	1.000			
Cd	-0.257	-0.223	**0.569**	-0.043	0.213	0.045	0.370	0.421	0.258	-0.191	-0.635	**0.612**	**0.779**	0.038	0.448	0.536	-0.768	0.297	0.068	0.993	1.000		
Pb	-0.145	-0.004	**0.715**	0.268	0.407	0.305	0.530	0.696	-0.052	0.145	-0.867	**0.709**	**0.849**	0.397	0.726	0.725	-0.697	-0.001	0.128	0.937	0.930	1.000	
Zn	0.048	0.743	0.420	0.753	0.742	0.635	0.555	0.403	-0.781	0.802	-0.089	0.266	-0.059	0.558	0.486	0.433	0.749	-0.784	-0.482	-0.407	-0.478	-0.217	1

Principal component analysis

The dimension of the original datasets was reduced through the use of principal component analysis (PCA), which also made it simple to identify the sources of heavy metals. Based on the Eigenvalues criteria, where Eigenvalues greater than one were considered significant, the number of significant principal components (PCs) was calculated. Four PCs were obtained which explained 100% of the total variance. PC1 explained 52.9 % of the total variance and was highly loaded with Cd, Pb, Zn, Na and Mg. PC2 explained 23.5% of the total variance and is highly loaded with Alkalinity, K and Hardness. PC3 explained 13.8 5% of the total variance and is highly loaded with Conductivity, Turbidity, TSS, chloride, Nitrate, Mg, and Mn. PC4 explained 9.9% of the total variance and is highly loaded with temperature, conductivity, TDS, chloride, and potassium. Figure 1 shows the spatial distribution of the principal components. The closeness of variables indicates the strength of their correlation.

Table 6: Loadings of principal components

	Component			
	1	2	3	4
Temperature				0.971
Conductivity			0.707	0.65
Turbidity			0.756	
TDS				0.619
TSS			0.835	
Chloride			0.618	0.687
Nitrate			0.856	
Phosphate				
Sulphate		-0.985		
Alkalinity		0.979		
Ca	-0.793			
Mg	0.607		0.757	
Na	0.817			
K		0.745		0.6
Hardness		0.723		
Mn			0.687	
Cu	-0.831			
Cr		-0.975		
As			-0.945	
Cd	0.953			
Pb	0.96			
Zn	0.975			
% Variance	52.9	23.5	13.8	9.9

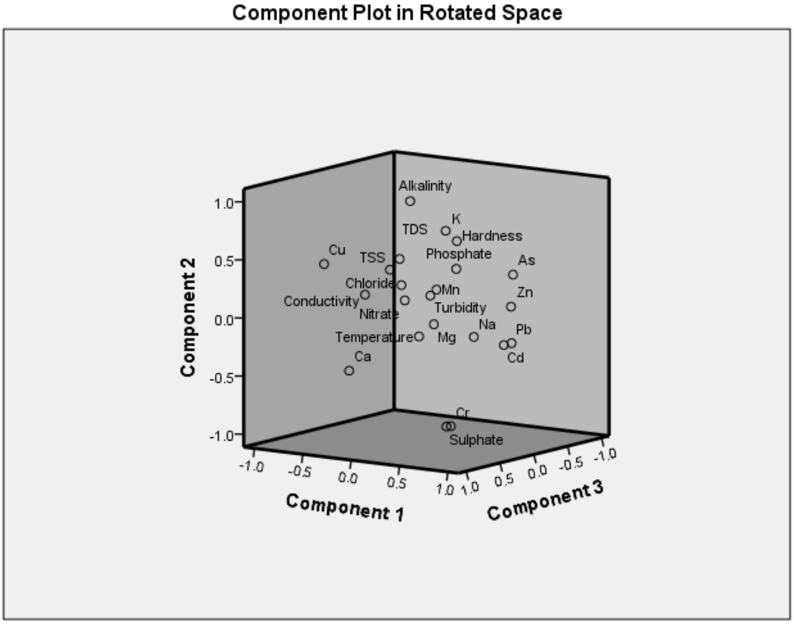


Figure 2: Loading plot of Principal components

Human health risk assessment

Estimated daily intake

Tables 7 and 8 present the estimated daily intake for children and adults respectively. Mn, Cu, Cr, Cd, Pb and Zn exceeded their recommended daily intake for children, however, As exceeded their acceptable daily intake of 0.0003 mg/kg/day for children. All metals were below their acceptable daily limit for adults. Generally, Arsenic in water from the OHT was low while that of the effluents (EMW, EWW, EDW and PW) were above the ADI for children. Metals in all sampling sites for adults were all within their daily limit.

Table 7: Estimated daily intake for children (mg/kg/day)

	Mn	Cu	Cr	As	Cd	Pb	Zn
OHT	0.0025	0.0004	0.0005	0.0000	0.0000	0.0000	0.0042
EWW	0.0014	0.0011	0.0005	0.0013	0.0000	0.0016	0.0029
EMW	0.0014	0.0004	0.0006	0.0012	0.0000	0.0024	0.0033
EDW	0.0021	0.0004	0.0005	0.0013	0.0000	0.0020	0.0039
PW	0.0017	0.0005	0.0005	0.0014	0.0000	0.0025	0.0042
ADI	0.14	0.04	1.5	0.0003	0.01	0.04	0.3

Table 8: Estimated daily intake for adults (mg/kg/day)

	Mn	Cu	Cr	As	Cd	Pb	Zn
OHT	0.0003	0.0000	0.0001	0.0000	0.0000	0.0000	0.0005
EWW	0.0001	0.0001	0.0001	0.0001	0.0000	0.0002	0.0003
EMW	0.0002	0.0000	0.0001	0.0001	0.0000	0.0003	0.0004
EDW	0.0002	0.0000	0.0001	0.0001	0.0000	0.0002	0.0004
PW	0.0002	0.0001	0.0001	0.0001	0.0000	0.0003	0.0005
ADI	0.14	0.04	1.5	0.0003	0.01	0.04	0.3

Hazard Quotient and Hazard Index

The results for hazard quotient and hazard index are presented in Table 9 and Table 10 for children and adults respectively. The HQ and HI were below the recommended limit of 1 for MN, Cu, Cr, Cd, Pb and Zn for both adults and children. The HQ for EWW, EMW, EDW, and PW for As exceeded the recommended limit of 1 for children. Similarly, the HI for As for both adults and children were high. Also, HI for EWW, EMW, EDW, and PW exceeded the recommended limit for children.

Table 9: Hazard quotient and Hazard index for children

	Mn	Cu	Cr	As	Cd	Pb	Zn	HI
OHT	0.018	0.010	0.000	0.123	0.000	0.001	0.014	0.166
EWW	0.010	0.029	0.000	4.185	0.004	0.040	0.010	**4.276**
EMW	0.010	0.011	0.000	3.938	0.004	0.059	0.011	**4.034**
EDW	0.015	0.010	0.000	4.185	0.004	0.050	0.013	**4.277**
PW	0.012	0.012	0.000	4.554	0.004	0.064	0.014	**4.659**
HI	0.065	0.072	0.002	**16.985**	0.015	0.213	0.062	

Table 10: Hazard quotient and Hazard index for adults

	Mn	Cu	Cr	As	Cd	Pb	Zn	HI
OHT	0.002	0.001	0.000	0.013	0.000	0.000	0.002	0.018
EWW	0.001	0.003	0.000	0.448	0.000	0.004	0.001	0.458
EMW	0.001	0.001	0.000	0.422	0.000	0.006	0.001	0.432
EDW	0.002	0.001	0.000	0.448	0.000	0.005	0.001	0.458
PW	0.001	0.001	0.000	0.488	0.000	0.007	0.002	0.499
HI	0.007	0.008	0.000	**1.820**	0.002	0.023	0.007	

Lifetime cancer risk (LCR)

Figures 3. and 4 present the lifetime cancer risk for children and adults respectively. The LCR for all metals were below or within the recommended guideline limit however, that of Arsenic exceeded the recommended guideline limit. Similarly, for children, Arsenic for sampling sites EWW, EMW, EDW and PW exceeded the limit while the influent was below the recommended limit. For adults, the LCR for all metals and sampling sites were below their recommended guideline limits.

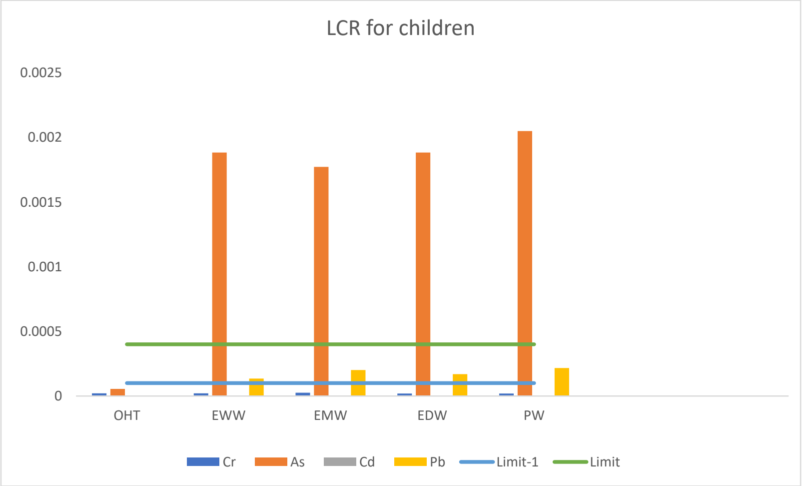


Figure 3: LCR for children

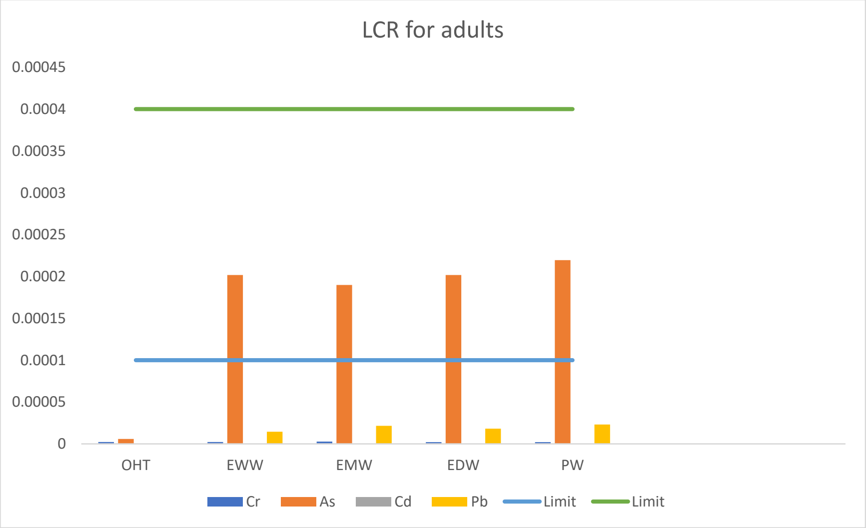


Figure 4: LCR for adults

DISCUSSION

Physicochemical parameters of water

The nature, quality and type of water are mostly determined by the physicochemical properties of the water. The physicochemical parameters of water from a plastic-producing company were assessed. There was a statistically significant difference between the physicochemical parameters indicating a great variability in data.

The pH of the samples were slightly alkaline.

The mean pH was within the WHO permissible limit of 6.5-8.5 which is acceptable for drinking water purposes. The slightly alkaline surface water in Obuasi could result from both natural and human activities, especially due to local mining operations. Research in the study area has shown that the pH of surface water is alkaline (Asare-Donkor *et al*., 2015). A subsequent study on the Sisa River in Kumasi Metropolis evaluated its water quality and health risks for children and adults, also confirming that the surface water is alkaline (Akoto *et al*., 2021). The discharge of heavy metals attached to organic particles into the water body is caused by low adsorption of heavy metals to organic constituents in aquatic systems. This is a result of competition between H^+ and heavy metals at organic molecules' binding sites (Liu *et al*., 2023; Wang *et al*., 2020). Similar to this, the pH adsorption edge is seen near neutral pH, which favors the release of heavy metals to some extent in comparison to higher pH (Liu *et al*., 2023). The pH of water from the plastic-producing company is found at the pH adsorption edge which means there is partial release of contaminants from materials and chemicals used for producing plastics. However, in the receiving pond water, the pH is highly alkaline as a result, chemical contaminants may not be bioavailable due to the adsorption of these particles to organic and sedimentary materials. The result for pH agrees with the findings of Ahmad *et al*. (2020), who recorded similar pH in effluent from a plastic company in Egypt.

The EC measurement reflects the water sample's ability to conduct an electric current, which has a connection to the concentration of ionized compounds in the water (Radojevic and Bashkin, 2006). The higher EC values of the effluent water indicate the presence of high concentrations of dissolved ions such as inorganic salts (WHO 2011; Radojevic and Bashkin 2006). The lower conductivity in the OHT compared to the effluent water and pond water indicates that the activities of the plastic-producing company result in the release of ions during the plastic production process. This corroborates the pH adsorption edge which partially favors the release of ions.

Total dissolved solids (TDS) are composed of calcium, chloride, and magnesium (Zhang *et al*., 2017). All sampling sites had TDS below the WHO threshold of 500 mg/L. TDS levels in bodies of water may be increased by human activities such as agriculture, water use, manufacturing, and mining (Caedo-Argüelles *et al*., 2013). The flavor of water can be changed by a high TDS. Similar to this, TDS readings exceeding 500 ppm necessitate additional testing for harmful particles like heavy metals that can harm both people and aquatic life.

Water used by the plastic producing company is perceived to be hard water as the mean total hardness was above 180mg/L (Diggs and Parker, 2009). There was a slight increase in the hardness from the OHT to the effluents and pond water which corroborates the findings that the activities of the plastic producing company result in the increase in ions in solution (Wu *et al*., 2020). Total hardness (TH) is often defined as the measured concentration of divalent metal cations. Calcium and magnesium happen to be the only two divalent cations present at a significant concentration in most fluids (Diggs and Parker, 2009). Calcium and magnesium ions are common parameters in natural waters and mostly present significant concentration. In plastic production, calcium carbonate particles are used as fillers to reduce cost of plastic materials used in the manufacturing process (Masami, 2023). This primarily serves as the main source of calcium in the effluent and pond water during the manufacturing process. Similarly, calcium carbonate may contain impurities such as magnesium and other heavy metals and can present significant concentration of these chemicals in the effluent.

Chlorides are important and widespread in the plastic industry because it mixes well with many other materials to create plastics with a wide variety of properties that match what is needed in the final products. Also, Vinyl chloride is one of the major by-product plastic productions (Turner and Vilella, 2021). This poses a severe health risk to humans as these toxins can produce sever illness like cancer, diabetes, neurological damage, reproductive and birth defects (Turner and Vilella, 2021). An overabundance of chloride in water is commonly used as a pollution indicator and as a tracer for water contamination (Loizidou and Kapetanios 1993). Water with a high chloride concentration has a salty flavor and can cause hypertension, osteoporosis, kidney stones, and asthma. (McCarthy, 2004). Similar to these, sulphates may originate from barium sulphate which is also used as fillers in the plastic companies (Turner and Filella, 2020). Excess sulphate can cause health related problems such as gastrointestinal irritation in the presence of high Ca and Mg (Suthar *et al*. 2009). The concentration of nitrates, sulphates, were all very low in the effluent and receiving pond and below their WHO threshold limit and does not pose any environmental impact. Organophosphorus serves as a source of phosphate and is used as an additive (flame retardants and plasticizers) in plastic producing companies and known to have a high environmental impact (Wang *et al*., 2020). This is because they are toxic to living soil biota along with valuable arthropods, fish, birds, human beings, animals, and plants (Mulla *et al*., 2020). The concentration of phosphate in OHT, EMW, EDW and PW were all below their respective WHO threshold limit of 2.5. However, the concentration of phosphate in EWW (18 mg/L) exceeded the WHO threshold limit implying the significant use of organophosphate in the plastic company in Tarkwa.

Heavy metal concentration of water

Heavy metals are natural components of the Earth's crust and can be released by natural processes, but often, anthropogenic activities are responsible for the majority of heavy metal pollution (Jafarzadeh *et al*., 2022). This is due to a number of factors, including mining activities, incorrect disposal of industrial effluent, industrial and agricultural practices, and more (Mohammadi, *et al*., 2020). Over time, heavy metals contamination has elevated to a global issue as they have the tendency to contaminate water, vegetables, fish, aquatic and terrestrial plants (Ahmad *et al*., 2010). Due to the toxicity of heavy metals, they have been linked to many health problems. For instance, excessive Cu has been linked to liver damage, while Zn may interact negatively with Cu. High-density lipoprotein (HDL) levels and immunological function have both been linked to zinc (Chasapis *et al*., 2012). Nickel could induce gastrointestinal discomfort, a rise in red blood cells, and a decrease in lung function at hazardous doses (Zambelli *et al*., 2016). High Pb concentrations cause health issues like elevated arterial pressure and behavioral issues (Esmaeilzadeh *et al*., 2019; Vasseghian *et al*., 2020). Additionally, extreme Cd exposure will result in health problems such as skeletal difficulties (Vasseghian *et al*., 2020). According to numerous studies, Cd is extremely hazardous and can lead to cancer. (Vasseghian *et al*., 2020; Jarup *et al*., 2000). Similarly, numerous studies have been conducted on the health consequences of other heavy metals, such as Cr, Pb, As, and Hg (Rai *et al.,* 2019; Jaishankar *et al*., 2014; Mengistu, 2021). Therefore, understanding heavy metals and their potential sources of contamination is a crucial component of risk management and prevention for human health implications.

The research assessed the concentration of heavy metals in effluents from a plastic producing company. The results showed that there was no significant difference between the source water and effluent for Mn, Cu, Cr, Cd and Zn and they were all below their WHO threshold limit implying they do not present any environmental impact. However, a high significant difference was observed between the source water and the effluent and receiving water for As and Pb. The corroborated that during the production process of plastics, contaminants which may have a high a high environmental impact are released.

In the past, hazardous metals (including metalloids) like arsenic, cadmium, chromium (VI), and lead were the basis for many additives and catalysts used in plastics. Hazardous chemicals continue to be present in plastics circulating in society despite subsequent regulations since they are present in numerous products and recycled goods. Metals may remain in plastics as catalytic or reaction residues (Takahashi *et al*., 2008, Filella, 2020). In plastics, metal-based additives can serve a variety of purposes, including those of biocides, antibacterial agents, lubricants, and flame retardants. However, according to Murphy (2001) and Janssen *et al*. (2016), their main use is as stabilizers, color pigments, and inert fillers. Fillers make plastic more rigid and durable while also lowering the price of the final product since they are frequently less expensive than the underlying polymer. Mineral fillers used in industry include hydrated magnesium silicate (talc), calcium carbonate, and barium sulfate (barytes) (Ganie *et al*., 2023). Phthalocyanines, coordination complexes of copper that mimic the structures of porphyrins, are an example of a synthetic organic pigment, while oxides and sulfides make up the majority of inorganic pigments. Some inorganic pigments have multiple uses. For instance, ZnO and Sb_2O_3 both behave as white pigments but also work synergistically as fungicides and flame retardants. These serves as the major source of heavy metals in metalloids in effluents from plastic companies. The high concentration of As and Pb in effluent from the plastic company in Bekwai agrees with the findings of Odumber *et al*., (2023); Turner and Filella, (2021); Ganie *et al*., (2021).

Sources of contaminants in water from plastic company in Bekwai

Pearson correlation was used to identify the relationship between the parameters. The high correlation between conductivity and these physicochemical parameters corroborates with the knowledge that these ions accounts for the electrical conductivity of many waters. Also, a significant correlation was found between the heavy metals As, Cd and Pb , Ca and Mg. This means that these metals originate from similar sources (Osae *et al*., 2022). This corroborates the findings which showed that the heavy metals in the effluent water were obtained from the additives used in the plastic production process. Magnesium silicate (talc), calcium carbonate used as additives are the main source of As, Cd and Pb (Ganie *et al*., 2023).

Similarly, PCA was used to help reduce the dimension the data to make the data easily interpretable. PC1 which explained 52.8% of the total variance is highly loaded with Ca, Mg, Cd, Pb and Zn. This implies that these metals present significant toxicity in effluents from the plastic production company. There is significant use of Calcium carbonate, and Sodium carbonate at the plastic production company in Bekwai. PC2, PC3 and PC4 which are highly loaded with physicochemical parameters explains and physical and chemical mechanisms and facilitates the release of chemical pollutants in water from the plastic company. This is highly evident in the spatial plot of the principal components that show a close relationship between the individual parameters. The source of chemical contaminants and the physicochemical properties of the water all originates from the activities at the plastic production site.

Impact of plastic production activities on the receiving pond water

The research assessed the impact of the plastic production activity on the receiving pond water. Water from an overhead tank (OHT) is pumped through a EWW, EMW, EDW, which comes out as an effluent into a receiving pond water (PW). The results from analysis of variance showed that, the physicochemical parameters of the OHT were not statistically significant from that of the effluents (EWW, EMW, EDW) and the pond water (PW). Similarly, the physicochemical parameters of the effluents were not statistically significant form that of the pond water. Furthermore, the physicochemical parameters of the effluents ((EWW, EMW, EDW) were not statistically different. This however suggest the activities of the plastic production process does not affect the physicochemical parameters of the water throughout the production process. Similarly, the physicochemical parameters of the receiving pond water are not affected by the production process.

For the heavy metals, however, there was a statistically significant difference between the As and Pb content in the overhead water when compared to the EWW, EMW, EDW, and the PW. However, there was no statistically significant difference in the heavy metal content (including As and Pb) of the effluents (EWW, EMW, EDW) and the PW. Furthermore, there was no statistically significant different between the heavy metal content of the effluents. This high content of As and Pb in the effluent and PW which was not seen in the OHW corroborates our initial assertion that Magnesium silicate (talc), and calcium carbonate which are rich in As and Pb are used as additives by the plastic production company (Ganie *et al*., 2023). During the plastic production process, the OHT which has very low concentration of heavy metals is contaminated with As and Pb through the addition of additives which is further introduces to the receiving pond water. Other heavy metals have no statistically significant difference between all water sources. The lack of significant different between the effluent water and the pond water suggest that the physicochemical parameters and the chemical constituents of the pond water and the effluent coming out of the plastic production process are similar which suggest that overtime, the water quality of the pond water has been changed due to a continuous influx of effluent from the plastic company. This suggest that the plastic production process has a major impact on the water quality of the receiving pond water.

Human health risk assessment

A direct route into the food chain is provided by the buildup of heavy metals in contaminated water (Rai *et al*., 2019; Vanisree *et al*., 2021). In order to calculate the non-carcinogenic health risk, the EDI, HQ, and HI were used. According to Jaishanker *et al*. (2014), daily intake is directly correlated with the amount of heavy metal exposure. In general, the metal concentrations in all samples were within the recommended daily range. EWW, EDW, EMW, and PW also have high HQs for children. While samples may contain various metals, the hazard quotient solely addresses particular heavy metals. While samples may contain various metals, the hazard quotient solely addresses particular heavy metals. It becomes crucial to calculate the hazard index, which considers each individual metal involved in risk evaluation. EMW, EDW, EWW, and PW all had significant hazard indices for children which were over the advised limit. The high arsenic concentration, which was beyond their limit for both adults and children, was the cause of the elevated HI. Turner *et al*. (2021) claim that several additives used in the manufacture of plastic include high levels of arsenic, which has resulted high effluent arsenic levels.

The carcinogenic risk associated with heavy metals is an are concerned globally due to the increased cancer incidence. This is due to the possibility that heavy metals may increase the chance of developing cancer (Cao *et al*., 2014). Numerous recent studies have demonstrated the link between heavy metals and some cancer types (Adimalla, 2020; Fei *et al*., 2018, Qiao and Feng, 2013). For instance, Fei *et al*. (2018) assessed the relationship between food contaminated with heavy metals and the incidence and severity of cancer in both adults and children; Adimalla *et al*. (2020) examined the relationship between heavy metals in soil and their health risks for adults and children in India and found that high concentrations of arsenic and chromium may be linked to an increased risk of cancer in both adults and children. In Hangzhou, China, Fei *et al*. (2018) examined the correlation between heavy metal-contaminated food and the prevalence and geographic distribution of stomach cancer and discovered a statistically significant relationship. Sohrabi *et al*. (2018) found evidence for the involvement of heavy metals in the development of colon cancer based on a cross-sectional analysis of the tissue levels of trace elements conducted in Tehran. Due to the detrimental effects on health, prolonged exposure to heavy metals is not advised. Heavy metals in effluents from the plastic company was found to pose carcinogenic health risk due to the high arsenic content. Children were found to be at a higher risk that adult.

This study has important implications for environmental and public health, identifying arsenic and lead as key contaminants and highlighting their health risks. Statistical analysis bolsters the credibility of these findings. However, conducted at a single plastic-producing company, its results may not apply to other industries. The study offers a snapshot of water quality, emphasizing the need for long-term monitoring to evaluate trends and mitigation effectiveness. It also overlooks the socioeconomic impacts of water pollution on local communities. Despite these limitations, the study provides valuable insights into the environmental and health risks tied to plastic production.

CONCLUSION

The study evaluated the physico-chemical properties of pond water and effluents from a plastic manufacturing company in Ghana. While the physicochemical properties of the water sources fell within acceptable limits, no significant differences were observed between the water quality of the effluents and the pond water, indicating similarities. Arsenic (As) and lead (Pb) levels in the effluents and pond water exceeded recommended guidelines, indicating a concerning environmental impact. The study identified both carcinogenic and non-carcinogenic health risks, particularly for children exposed to elevated arsenic concentrations. It recommends implementing stringent monitoring of heavy metal releases, conducting regular health assessments for affected workers and communities, and pursuing further research on the long-term ecological impacts of plastic production.

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Declaration of conflict of interest

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