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Assessment of surface waters and pollution impacts in Southern Ghana

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ABSTRACT

Illegal mining and inappropriate use of agrochemicals have exacerbated surface water pollution in Ghana. The quality of water has changed, and knowledge of their current condition is important for formulating policies to conserve the country's water bodies. This study assessed the quality of surface waters in Ghana's Pra River Basin. A survey of 344 local farmers randomly sampled was conducted and a physicochemical analysis of 33 water samples collected from 25 rivers in the basin. Boreholes are the main source of drinking water for 85% of farmers, and they assessed water quality by its appearance. Rainwater provides over 50% of the water needed by the respondents for domestic use. River water was mainly used for crop production and only secondarily for domestic use. At more than 80% of the sampled sites, pH, Fe and P were above the WHO recommended values, while Pb was exceeded at 30% of the sites. Cu, Hg, As and Fe were above permissible levels for irrigation, especially near the mining areas. The poor quality of river water makes it unusable despite its availability. A more effective and efficient land-use policy focusing on buffer zone protection is recommended to minimise water quality degradation in the basin.

Key words: environmental pollution, Ghana, irrigation, small-scale mining, water quality, water resources

HIGHLIGHTS

- Surface water are mainly used for crop production in the Pra River Basin.
- Mercury, Copper, Arsenic and Iron concentration levels exceed the permissible limits for irrigation in mostly mining communities.
- Surface water is available but the level of pollution limits its usability.
- Sustainable land management practices can reduce rate of surface water pollution in small-scale mining zones.

1. INTRODUCTION

Freshwater is undergoing a series of changes due to both natural and anthropogenic activities exacerbated by climate change (Krysanova *et al.* 2005) with dire consequences, such as water scarcity and declining quality. Inappropriate sanitation practices are one of the most significant causes of water pollution worldwide, especially in developing countries (Sun *et al.* 2021). Water is an important driver of economic development in sub-Saharan Africa (SSA), as it is an essential natural resource for agriculture, manufacturing, health and mining. The limited freshwater available to development in SSA is not being used sustainably. The constant use of agrochemicals in agriculture contaminate fresh water bodies and the environment (Montanarella *et al.* 2016). The anthropogenic influence is exacerbated by the rapid growth of artisanal and small-scale mining activities in SSA, especially in Ghana (IGF 2018).

In Ghana, the advent of earth moving equipment in small-scale mining (legal or illegal) has increased surface water pollution throughout the country (CONIWAS 2011; Crawford *et al.* 2015; Forkuor *et al.* 2020). The majority of miners in Ghana work informally, without the security of a licence (Barenblitt *et al.* 2021), partly due to challenges with securing

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land and a licence. This informality has led to a number of environmental and social problems in the country, particularly the pollution and destruction of water bodies, the degradation of farmlands and the negative health impacts of working in hazardous conditions (Barenblitt *et al.* 2021).

Recently, there has been an increasing number of empirical studies assessing water quality in Ghana. For example, Asare-Donkor & Adimado (2016) showed that mercury levels were higher in sediments, followed by water and fish, and indicated the possibility of mercury transport from a mining site to non-mining locations. Bansah *et al.* (2018) found that water was significantly polluted by turbidity, manganese and iron in descending order above the acceptable limits in Bonsa River, located in the Tarkwa-Nsueam Municipal District in Western region. The study focused on the Bonsa River with only one sample from a tributary which had a water quality index below the upper limit for potability. Duncan *et al.* (2018) assessed the concentration levels of heavy metals in the Pra River Basin from sediments collected during both wet and dry season. Concentrations (mg/kg) were found to be higher in the wet season ($As = 0.175$, $Cd = 3.206$, $Pb = 335.381$, $Fe = 1{,}354.513$) compared to the dry season ($As = 0.002$, $Cd = 7.279$, $Pb = 135.863$, $Fe = 1{,}138.551$). The seasonality in concentration could be exacerbated by climate change. Obeng *et al.* (2019) investigated the impact of illegal mining activities (*galamsey*) on the forest ecosystem in local communities and found that over 70% of the respondents were extremely concerned about the decline in the quality of water resource and the drying up of streams and rivers due to *galamsey*. Attiogbe *et al.* (2020) found human activities like *galamsey*, liquid waste discharge and leachate from dumping sites to be the main contributors to the higher level of zinc in Lake Amponsah at Bibiani in Western region of Ghana. Tahiru *et al.* (2020) assessed the impact of land use land cover changes on water quality in the Nawuni catchment of the White Volta Basin over a ten-year period (2007–2017) and observed that levels of ammonia, turbidity and total coliforms continued to increase over the period studied, while closed savannah, bare lands, grassland or farmland and settlement increased in the same period. A strong correlation was found between land use and water quality, indicating the influence of changes in land use on water quality.

It is observed from these existing studies that less attention has been paid to the water quality of Pra River Basin. Hence, little empirical knowledge is available on the quality and accessibility of surface water resources (rivers) for farming (drinking and irrigation) in the basin, especially now that small-scale mining operations are being monitored. Accessibility in this study refers to the period of time and effort it takes a household to reach an available water source for use. Sustainability of surface water quality, especially of rivers to meet human needs, can be achieved via regular monitoring and assessment. Given the knowledge gap, this study aimed to assess the quality of water available to farmers and their attitudes towards its accessibility for both domestic use and crop production in the Pra River Basin. The study contributes to the debate on the impact of small-scale mining and intensive fertiliser use in agriculture on the availability and accessibility water resources for rural dwellers in Ghana. This study also aims to inform about the status of clean water for food production, which is in line with the Sustainable Development Goals' (SDGs) number 6 (clean water and sanitation) and number 3 (good health and well-being) as outlined in the United Nations' Agenda 2030. The purpose is to provide important lessons to address water quality issues not only in Ghana's Pra River Basin, but also in other regions and nations with similar conditions, especially in SSA.

2. MATERIALS AND METHODS

2.1. Study area

The study is located in the Pra River Basin, the largest of the south-western river systems in Ghana, cutting across Ashanti, Eastern, Central and Western regions (Figure 1). The basin area is approximately 23,000 km^2 and lies between 4°58′N to 7°11″N and 0°25′W to 2°13′W latitudes and longitudes, respectively. The basin is the main source of water for three regional capitals (Kumasi, Cape Coast and Sekondi), including all the districts within the basin. Agriculture thrives in the basin, which has the highest production of tuber crops in Ghana (Nutsukpo *et al.* 2013). This is due to a suitable climate with average annual rainfall ranging between 1,315 mm and 1,553 mm with a bimodal pattern (Bessah *et al.* 2020) and average annual temperature ranging between 26.10 °C and 27.30 °C (Bessah *et al.* 2018). The geology of the basin characterised by Tarkwaian, Birimian, Cape Coast and Discove granitoid complex system, has attracted both large-scale and small-scale mining companies (CONIWAS 2011; Tay *et al.* 2014). Competition between land users and the unsustainable approach of farming (excessive use of agrochemical and land clearing) as well as mining, especially illegal small-scale mining (popularly known as *galamsey*), are major threats to water sustainability in the basin (Donkor *et al.* 2006; Tay *et al.* 2014; Awotwi *et al.* 2018; Duncan *et al.* 2018).

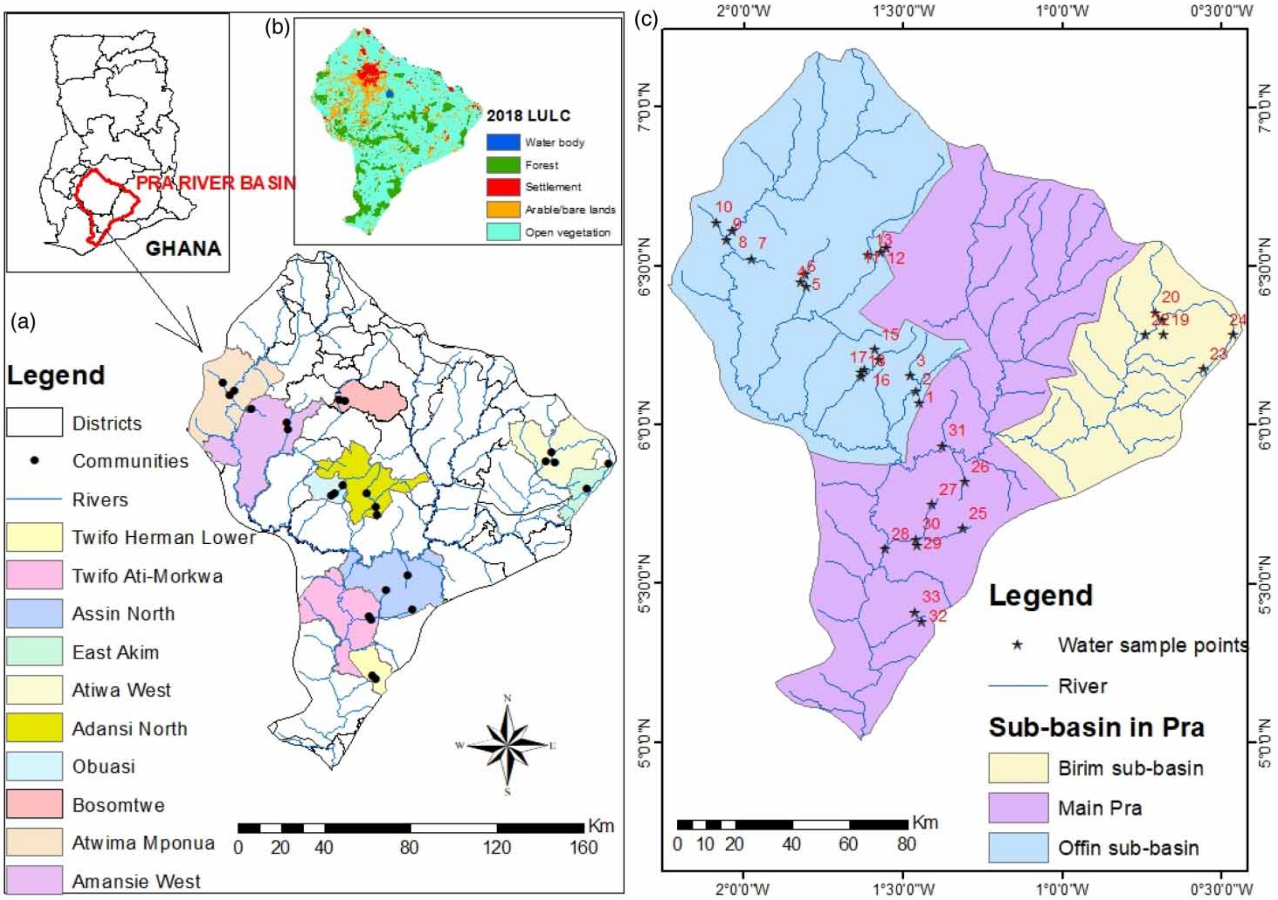

Figure 1 | Map showing (a) districts, (b) land use land cover map and (c) sub-basins of the Pra River Basin. *Source:* Authors' design, 2020.

The two major competing land uses (mining and agriculture) in the basin have been expanded over the years in the Pra River Basin. Awotwi *et al.* (2018) showed that agricultural land increased between 7 and 51% from 1986 to 2016, while mining increased in the range of about 11–162% from 2004 to 2016. Boakye *et al.* (2019) showed that the Offin sub-basin (Upper and Lower Offin) expanded in mining area by about 98 km^2 from 2008 to 2018, while Birim sub-basin experienced a mining area expansion of 33.44 km^2 in the same period. The Pra sub-basin also had a mining expansion of about 35 km^2 (Boakye *et al.* 2019). Small-scale mining in the Offin and Pra sub-basins are mostly done on the river using mercury.

Demand for food production and resource extraction in the basin is rising due to the rapid increase in the migrant population and could have an adverse or additional impact on the demand for quality water resources for residents. There is a nationwide campaign to protect the environment in the basin, especially to fight illegal mining and protect water resources (CONIWAS 2011; Agbozo & Spassov 2019). Due to the drainage pattern of the basin, people who draw their water from the lower stream are mostly affected by negative activities at the upper stream although they may not be involved in such activities (Ansa-Asare *et al.* 2014).

This research was carried out based on primary data obtained *in loco* directly by the first author, while visiting all the assessed areas. This includes data gathered through original surveys with local farmers and collection of water samples in selected points of the Pra River Basin, as described in the following subsections.

2.2. Perception survey analysis

Random points' algorithm in ArcGIS 10.3 was used to spatially select ten districts from the basin for the study. This method was used to control biases in determining the extent of small-scale mining and agriculture on river systems in the basin at polluted source and non-source locations. A total of 344 respondents from a determined sample size (n) of 399 using the Yamane simplified formula (Equation (1)) for proportions at precision error of $\pm 5\%$ (Singh & Masuku 2014) were interviewed (Figure 1(a)).

$$\text{Sample size } (n) = 1 + N(e)^2 \qquad (1)$$

where N is the population under study and, e is the precision or sampling error which is usually 0.10, 0.05 or 0.01.

Three communities located close to a river in the sampled districts were purposely selected and 14 households interviewed per community. The aim of this sampling approach was to investigate the influence of anthropogenic activities on water availability for both domestic and farming activities. Some communities were not accessible due to flooded roads, so they were excluded from the study. A semi-structured questionnaire consisting of open and closed-ended questions, covering socio-economic characteristics and water quality issues was used to determine the perceptions and practices of farmers from selected districts. The language used to administer the questionnaire was Asante *Twi* (local language of the study area). The data obtained from the questionnaire were coded directly and analysed in the IBM Statistical Package for Social Sciences (SPSS) using descriptive statistics such as mean, standard deviation, maximum, minimum and rankings of categorical variables.

2.3. Water sampling and laboratory analysis

A total of 33 samples were randomly collected from river systems and their tributaries (Figure 1(b)) in the ten districts, where the questionnaire was administered (Figure 1(a)) between May and June 2019. The months of data collection that fell during the main rainy season in the catchment were suitable for identifying other natural factors that could influence surface water quality. It also reduced the possibility that rivers or surface waters were not available for sampling due to drought. The Garmin Etrex handheld GPS was used to collect the coordinate of the sampled points (Figure 1). Acceptable protocol standards were used for sampling of water according to the American Public Health Association (APHA) (1989). Plastic bottles of 500 mL were rinsed in the river thoroughly before samples were collected in the direction of flow. After collection samples were immediately placed in a cooler box with ice blocks to preserve the natural state of the sample transportation to the laboratory. Heavy metals (arsenic (As), cadmium (Cd), copper (Cu), iron (Fe), mercury (Hg), and lead (Pb)) analysis was conducted at the SGS Laboratory Services Ltd in Tema, Ghana, using the inductively coupled plasma–optical emission spectrometry instrument (Nexion 300x ICP). All other analyses were done at the Environmental Quality Engineering Laboratory at the Kwame Nkrumah University of Science and Technology in Kumasi, Ghana. Total dissolved solids (TDS), electrical conductivity (EC) and pH were determined with the Palintest multi-meter whereas the gravimetric method was used to determine total suspended solids (TSS). The DR 3900 spectrophotometer was used to analyse for total phosphate (TP1), total phosphorus (TP2), nitrate-nitrogen ($N\text{-}NO_3$) and ammonia-nitrogen ($N\text{-}NH_{4+}$) using the acid persulphate digestion, cadmium reduction and Nessler methods, respectively. Total nitrogen (TN) was obtained by the Kjeldahl method in the Velp 139 distillation equipment.

The relationship between physicochemical parameters was assessed with Pearson correlation, whereas the difference between concentration of parameters at the three sub-basins (Pra, Birim and Offin) was done with the Kruskal–Wallis one-way non-parametric ANOVA (H-test) at $p < 0.05$ significant level. In order to determine the specific variations that were significantly different at the sub-basin level, the Dunn test at $p < 0.05$ was used (Dinno 2017). These statistical analysis and plots were done using the R software package.

3. RESULTS AND DISCUSSION

The presented results cover the background of farmers and their perception of water quality, physicochemical properties of rivers and sub-basin influence on water quality.

3.1. Farmers' view on water quality and sources of contamination

Of the 344 respondents interviewed, men were in the majority. Most of the farmers were old with an average age of 49 years, and had 20 years of farming experience (Table 1). The majority of the respondents were married and had completed junior high school. About 15% of the respondents had no formal education and only 3.8% had been schooled to the tertiary level. The survey data show that most of the respondents had access to electricity, transport to market and basic school facilities.

Table 1 | Status of available water for domestic use in the sampled communities

Sources of water	Water sources used by the entire community (%)	Water sources used by respondents' households (%)
River	42.44	32.56
Community borehole	95.06	90.41
Well	7.56	6.40
Public tap	4.94	1.45
Household pipe	4.07	0.58
Household borehole	9.30	8.43
Variable	**Description**	**Percentage (%)**
Medium of assessing cleanliness of available water to respondents		
Appearance	Clearness of water surface	70.1%
Taste	How they like the flavour after drinking	14.5%
Depth	How deep the well or borehole was dug	2.9%
Treatment	The frequency of treatment	2.6%
Scent	The pleasantness of the scent	2.3%
Period of use	Period of use in community without disease outbreak	2.0%
Lab analysis	Scientific investigation in a certified lab	0.9%
Quantity of daily water demand		
Less than 5 buckets	Less than ~170 litres per day	2.6%
5 to 10 buckets	Between 170 and 340 litres per day	42.2%
11 to 20 buckets	Between 374 and 680 litres per day	48.0%
More than 20 buckets	More than ~680 litres per day	7.3%

Very few respondents had access to piped water, indicating that the majority relied on river and surface water. Most respondents were engaged in agriculture, only a few in professional services. Trade was the most common secondary occupation.

Boreholes were the main source of drinking water in the study area (Table 1), followed by river water. The local river water was often used without any filtration system or decontamination process, apart from sieving of macro-particles. The supply of treated drinking water as a public service through waterpipes is rare in the study area. This trend in the community was based on the respondents' perception in this study (Table 1). About 66.8% of the respondents considered water for domestic activities to be clean and the level of cleanliness was mainly judged by appearance (70.0% of the respondents) (Table 1). Only 2.0% of respondents reported that they treated their water before use. These respondents depended on rivers for domestic use and the treatment methods used were potash alum, filtering (use of sieves), sedimentation and boiling. Most respondents who used surface water (river) did not treat it before use and, according to information from informal interviews, this was a common practice, although more than half of the residents depended on groundwater (borehole) for domestic use. Almost half of the respondents (48.0%) indicated that their households used an average of 527 litres of water per day for domestic chores such as cooking, bathing, washing and drinking (Table 1). Water closet toilet facilities were not common in the surveyed communities and those who had it did not have personal boreholes in their homes to provide water for flushing purposes.

The rivers were mainly used for drinking and farming operations (livestock and cropping activities). The majority of respondents practised pure rainfed agriculture whereas 38.1% combined rainfed with irrigation (Table 2). Rivers were used mainly for farming (32.0% of total respondents and 84% of respondents engaged in irrigation). Borehole, community well and public taps were normally used for plant nursery management and mixing of agrochemicals. According to 81.4% of the respondents, rivers for on-farm activities are polluted based on appearance (70.0%) assessment (Table 2). The state of major rivers in the Pra River Basin during the study period are presented in Figure 2. The main cause of river pollution was illegal mining (*galamsey*) followed by farming (Table 2). Changes in climate in the basin resulted in increased runoff generation, while the severe dry season impacted on water quality. Despite the extent of pollution in these communities, only a few of the

Table 2 | Sources and status of water for farming activities

Variable	Percentage of respondents under each category (%)
Type of farming	
Rainfed	61.90
Rainfed and irrigation	38.10
Source of water for irrigation	
River	32.00
Borehole	6.40
Community well	0.60
Public tap	0.60
Perceived cause of river pollution	
Small-scale mining (*galamsey*)	33.70
Agriculture (buffer clearing and agrochemicals)	22.90
Municipal waste	10.70
Increased runoff (due to changes in season and climate)	8.40
Dam construction on river	4.10
Swimming in river	2.30
Sand winning and siltation	2.10

respondents indicated that their communities were addressing it, mainly through awareness creation and *galamsey* abatement. They fight *galamsey* by refusing to sell their lands for such activities. The low response to the fight against *galamsey* could be due to the high prices offered by the land miners to landlords. Therefore, landowners prefer to sell their land to miners instead of leasing it to settlers for agriculture.

3.2. Observed trend of water scarcity by respondents and constraints to its sustainability

The assessment of the perceived trend of water scarcity in the basin showed that water for domestic purposes was scarce in the past as indicated by 73.8% of respondents because rivers and hand-dug wells were the only source of water. Currently, water scarcity (physical inaccessibility of water) is not common in the communities according to 68.6% of the respondents due to the emergence of boreholes (groundwater). About 73% of respondents perceived that water demand has increased, while 24.4% observed a decrease in demand. The measures taken by respondents to improve water availability were rainwater harvesting (domestic use = 57.8%, farming = 0.6% and both = 39.2%) and increasing the size of water storage facility (domestic use = 18.3%, farming = 2.6% and both = 6.4%). However, the sustainability of adaptation strategies specifically for domestic use was constrained by the lack of storage facilities (49.1%), deteriorating quality of rainwater at storage (11.6%), finance (9.9%), inadequate boreholes in communities (7.3%) and polluted rivers (1.2%). Reliance on rivers for domestic use has drastically reduced since communities in Ghana started using boreholes. Respondents also indicated that access to credit (32.0%) to either dig boreholes or purchase storage facilities, provision of storage facilities (23.3%), construction of more boreholes in communities (15.7%), and provision of chemicals for water treatment at the household level (2.3%) are necessary to achieve sustainable water supply. The construction of water reservoirs on farms and boreholes was perceived by respondents as a possible source of water for farming in the study area.

3.3. Physicochemical characteristics of rivers in the Pra River Basin

The range of the physicochemical properties varied depending on locations and permissible limits of global and international standards for drinking and irrigation purposes (Table 3 and Supplementary Material, Appendix A). The high deviation from mean or variation in datasets was as result of samples from or close to mining sites in the basin. The pH of 81.8% of the locations was below the World Health Organization (WHO) acceptable range (6.5–8.5) of drinking water quality and below the FAO accepted irrigation water quality (WHO 2011; Kumar & Puri 2012; IRMA 2018). Furthermore, aquatic life is only possible in 18.2% of the rivers assessed, as a pH < 6.0 is not conducive to aquatic life and can also be corrosive

Figure 2 | The state of some sampled rivers and communities in the Pra River Basin. *Note:* The field campaign was done in the months of May and June 2019. The potential source/source of pollution for (a)–(f) and (j)–(m) is *galamsey* while agriculture could be responsible for the pollution of (g) and (h). Runoff and municipal waste are responsible for the pollution of (i) and (n). Details are presented in Supplementary Material, Appendix A. *Source:* Authors' photographs from the field, 2019.

(Behar 1997). Total suspended solids (TSS) were very high (>2,000 mg/L) and high (500–2,000 mg/l) at 9.1% and 6.1% of the locations, respectively, although there is no specific WHO standard, except for turbidity in the range of 1–5 NTU. However, it is recommended to keep the TSS at a level that light can penetrate (WHO 2006; Fondriest Environmental Inc 2014). A TSS value above 100 mg/L was recorded at 18.2% of the locations, indicating that almost 44% of the sites were polluted by sediment exports in high quantities. Behar (1997) indicated that surface water usually has conductivity in the range of 50–1,500 μS/cm (1 μS/cm = 1 μmho/cm); however, a condition of 150–500 μS/cm is required for sustainable aquatic life. Although the conductivity was within the permissible limits at all locations, one location (Nkwantin River in Adansi Asokwa District) it is not suitable for aquatic habitation (except microbiota) as it was above 1,000 μS/cm (Supplementary Material, Appendix A). The permissible total dissolved solids' (TDS) levels for drinking and irrigation were within the acceptable limits by WHO and FAO (IRMA 2018). Nitrogen levels were minimal at all locations, with the highest values of 1.90 mg/L (Ndwine River), 6.40 mg/L (Danyame River) and 5.32 mg/L (Subin River) for nitrogen ammonia, nitrogen nitrate and total nitrogen, respectively (Supplementary Material, Appendix A). The intensive river flow could contribute to the limited nitrate concentration, as groundwater from areas in Ashanti region within the basin has been reported to contain up to 508 mg/L (Rossiter *et al.* 2010). These concentrations were within the WHO permissible drinking water quality standard.

The USEPA accepts total phosphorus in the range of 0.01–0.04 mg/L as good quality for drinking (Gullatt 2015). Phosphorus levels above 0.1 mg/L increase the rate of eutrophication (Oram 2019). Therefore, 81.8% of the locations were beyond the permissible phosphorus range for drinking, and 97% were already in the range of likely accelerated eutrophication. This could be due to the high fertilisers use for crop production in the basin, especially for vegetable production along the river systems and in the buffer zones, which calls for appropriate sampling procedures for monitoring (Haraldsen & Stalnacke 2005).

Table 3 | Distribution of measured parameters in the Pra River Basin and its sub-basins

	Pra River Basin ($n = 33$)				**Offin sub-basin ($n = 17$)**		**Birim sub-basin ($n = 6$)**		**Pra sub-basin ($n = 10$)**		**WHO limits**
Parameters	**Mean**	**Standard deviation**	**Minimum**	**Maximum**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**	**Mean**	**Standard deviation**	**(Drinking)**
pH	6.0103	0.3862	4.8200	6.7700	5.8794	0.3607	6.1817	0.3806	6.1300	0.3883	6.5–8.5
TSS (mg/L)	538.3939	1,456.9165	9.0000	6,970.0000	914.4118	1,974.8048	144.1667	140.4755	135.7000	228.3550	500.00
EC (μS/cm)	141.6758	185.3703	49.3000	1,104.0000	172.2059	247.8460	91.4000	22.7177	119.9400	93.3511	–
TDS (mg/L)	87.7948	114.8410	31.0000	684.0000	106.7676	153.6645	56.6680	14.0849	74.3628	57.8777	1,200.00
Total nitrogen (mg/L)	2.8848	0.8501	1.6800	5.3200	3.2282	1.0053	2.1933	0.3722	2.7160	0.3505	10.00
Total phosphate (mg/L)	0.3024	0.2022	0.0900	1.1400	0.3394	0.2572	0.1717	0.0605	0.3180	0.1070	0.0001
Total phosphorus (mg/L)	0.1012	0.0658	0.0300	0.3700	0.1165	0.0825	0.0567	0.0216	0.1020	0.0358	0.0001
N-NO_3^- (mg/L)	1.5788	1.0934	0.4000	6.4000	1.4765	0.6524	1.3667	0.7916	1.8800	1.7306	50.00
N-NH_4^+ (mg/L)	0.4970	0.3777	0.0800	1.9000	0.4371	0.4365	0.3783	0.1971	0.6700	0.3122	10.00
Pb (μg/L)	9.8684	15.3772	0.0180	68.4510	18.7322	17.2651	0.0320	0.0093	0.7018	2.1325	10.00
Hg (μg/L)	0.4976	1.7735	0.0050	7.5660	0.5116	1.8281	0.0172	0.0116	0.0156	0.0107	6.00
As (μg/L)	28.6282	67.8037	0.0020	294.4290	53.4072	86.6754	0.0547	0.0595	0.7850	2.2587	10.00
Cd (μg/L)	0.3816	0.4281	0.0010	1.3660	0.7116	0.3413	0.0030	0.0014	0.0479	0.1396	3.00
Cu (μg/L)	35.5788	75.6339	0.0360	403.7870	67.9531	95.5319	0.0780	0.0196	1.8428	5.5133	2,000.00
Fe (mg/L)	26.7528	80.0771	0.1250	429.1450	50.2155	107.7752	1.5013	1.9820	2.0173	1.6590	0.10

*Limits of nitrogen and phosphorus were obtained from EPA (EPA 2018).

Note: Phosphorus levels are health advisories limit in a child of 10 kg for a life time.

The assessment of heavy metals showed that cadmium (Cd) and copper (Cu) were within the permissible limits for drinking water quality at all locations. The result also showed that 3.0%, 18.2%, 30.3% and 100% of the locations had mercury (Hg), arsenic (As), lead (Pb) and iron (Fe) levels, respectively, which are above the WHO limits for drinking water (WHO 2011). Toxic heavy metals usually accumulate with acute or chronic exposure, leading to various detrimental effects on human health, from brain dysfunctions to several types of cancer and other diseases. For irrigation purposes, Cd was acceptable in all sampled rivers. However, 3.0%, 9.1% and 24.2% of sampled locations for Cu, As and Fe, respectively, were above the permissible level by FAO limits (IRMA 2018). In addition, 3.0% of the locations had Hg levels higher than those required for irrigation under the Australia–New Zealand and Philippines standards, while Pb concentration was within acceptable limit compared to the South African standard (IRMA 2018). The reported concentrations of the analysed parameters were measured in the rainy season and could possibly be higher in the dry season. von der Heyden & New (2004) indicated that water volume decreases in the dry season, which increases the concentration of chemical contaminations compared to the high volume of water in river channels during the rainy season.

Despite the industrial and biological importance of some physicochemical parameters, some metals can be harmful even at very low concentration in water (Verma & Kaur 2016). Abnormal growth and undesirable changes occur in living organisms, including humans, when permissible limits of these physicochemical parameters are exceeded (Verma & Kaur 2016). Due to excessive contamination of water with As, Hg, Fe and Pb in this study, the inhabitants are more vulnerable to cancer either through direct intake of the water or through food crops produced with it, as heavy metals do bio-accumulate (Khan *et al.* 2015). Studies on rice fields have shown that heavy metals in water used for rice production pose a health risk to humans. Cd and Pb posed a health risk to residents of the Jin-Qu Basin of China (Guo *et al.* 2020). Both natural and anthropogenic activities can cause heavy metals to enter water at undesirable concentrations. The concentration of As, Cd, Hg and Pb could cause a major environmental problem as it increases during acid rain (Verma & Kaur 2016). Increasing mining activities, especially illegal small-scale surface mining, could be a major reason for the high levels of As, Cd, Hg, Fe and Pb concentrations at some of the sampled locations (Supplementary Material, Appendix A). Rossiter *et al.* (2010) also reported higher concentration of Pb for domestic use in the Ashanti region, particularly in mining communities in the Pra River Basin. Lei *et al.* (2015) identified Cd as a major contributor to health risk in the mining areas of Hunan Province in China through the consumption of white rice. The assessment of the health risk of these heavy metals in the vegetables produced in the Pra River Basin would inform farmers about the quality of their product and the need for policy intervention to avert negative health impacts on residents. Agricultural activities, which are currently intensified through the use of fertilisers and other agrochemicals, are the main source of nitrogen (total, nitrate, ammonia) and phosphorus in the basin (IRMA 2018). Although arsenic is a naturally occurring chemical, the intensification of agrochemical use could contribute significantly to the high levels at some of the sampled locations (Bessah *et al.* 2021). The other heavy metals are released mainly through mining activities (Rossiter *et al.* 2010; IRMA 2018).

3.4. Relationships between water quality parameters at sub-basins' level

The Pearson correlation at $p < 0.05$ showed a strong positive relationship between Cu and Fe ($r = 0.99$), total phosphate and total phosphorus ($r = 0.96$), Cu and Pb ($r = 94$), Pb and Fe ($r = 89$), Cu and As ($r = 81$), As and Pb ($r = 0.77$) and As and TN ($r = 0.76$) (Figure 3). The relationship between Cu, Fe and Pb could be attributed largely to illegal mining along the rivers (CONIWAS 2011). The relationship between Pb and Cu confirms the presence of mines close to water bodies. In the study area (Ashanti Region), high levels of As were found in soils and rivers close to mines (Garelick *et al.* 2008). The correlation between As and TN suggests the transport pathway of the pollutants via runoff into the rivers, as both metals accumulate in soils by attaching to organic matter sediments (Yang *et al.* 2010). There was a moderate correlation between TN and Cu ($r = 0.66$), TN and Pb ($r = 0.66$), TN and Fe ($r = 0.63$), TN and TSS ($r = 0.58$), Pb and Cd ($r = 0.58$), EC/TDS and Hg ($r = 0.57$), TSS and Pb ($r = 0.56$), TN and Cd ($r = 0.53$) and Cd and Cu ($r = 0.53$). The correlation between TSS and heavy metals confirms that runoff is the main medium for transporting pollutants from the mines into the rivers. In addition, the agricultural lands are not far enough from the mines so that heavy metals, TN and TSS were transported to a similar extent, showing a significant correlation. Competition between farmers and miners for land in the basin and limited land tenure policies make it difficult to move mines away from farms to reduce heavy metal pollution of agricultural soils (Arah 2014). This could mean that TN from farms and heavy metals from the mines were transported into the rivers at the same rate or that one land use is situated behind the other one in terms of location, while the sloping landscape supported runoff through both farms and mines into the rivers.

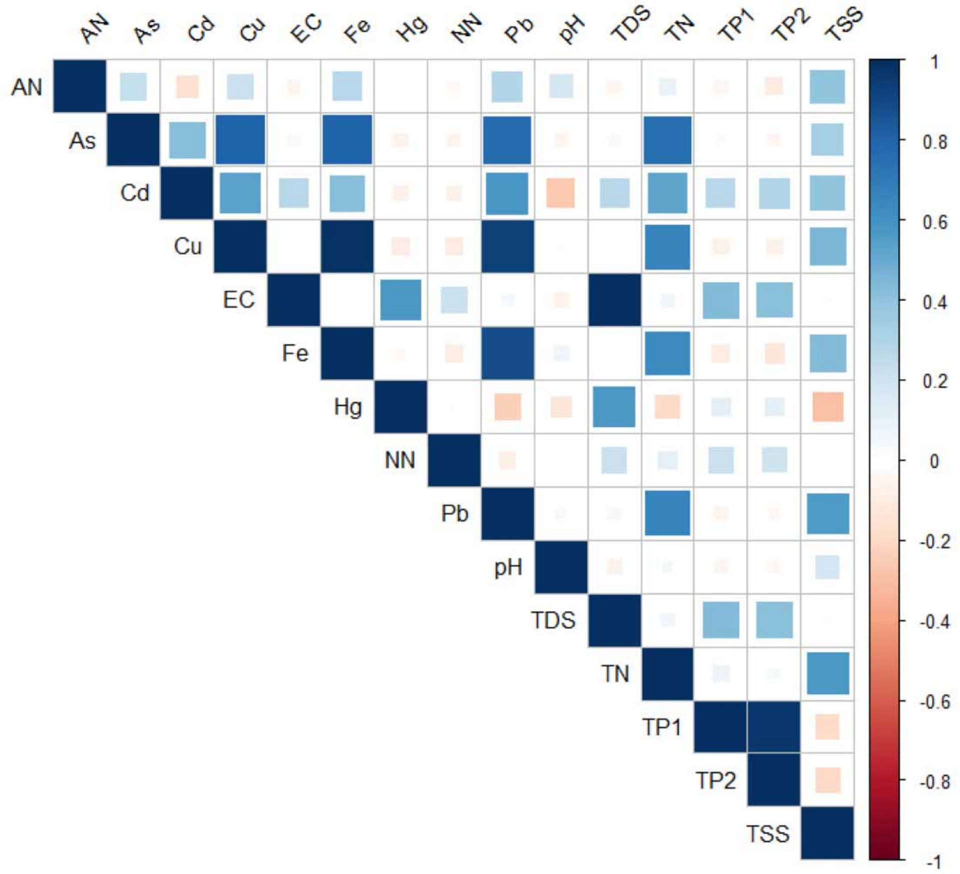

Figure 3 | Pearson correlation between assessed water quality parameters of sampled rivers in the Pra River Basin. *Note:* TSS, total suspended solids; EC, electrical conductivity; TDS, total dissolved solids; TN, total nitrogen; TP_1, total phosphate; TP_2, total phosphorus; NN, nitrate nitrogen (NO_3–N); AN, ammonia nitrogen (NH_4^+–N); Pb, lead; Hg, mercury; As, arsenic; Cd, cadmium; Cu, copper; Fe, iron. *Source:* Authors' design, 2020.

A one-way ANOVA with the Kruskal–Wallis H test at 95% confidence level among the three sub-basins in the study area indicated no significant differences for pH, TSS, EC, TDS, TP_1, TP_2, N-NO_3 and N-NH_{4+} (Table 4). The TN concentration between Birim (2.193 ± 0.372 mg/L) and Offin (3.228 ± 1.005 mg/L) sub-basins was significant at $p = 0.02497$. This could be due to the intense vegetable production in wetlands and buffer zones in the Offin Basin, especially in the Atwima Mponua, Amansie West, Obuasi East and Adansi Asokwa Districts by the adoption of inorganic fertilisers. All assessed heavy metals showed no significant difference between Pra and Birim sub-basins, probably because of the similar levels of illegal mining (*galamsey*) operations in these locations (Supplementary Material, Appendix A; Boakye *et al.* 2019). Offin sub-basin recorded the highest mean values of As, Cd, Cu, Fe, Hg and Pb at 53.407 ± 86.675 ppb, 0.712 ± 0.341 ppb, 67.953 ± 95.532 ppb, 50.215 ± 107.775 mg/L, 0.512 ± 1.828 ppb and 18.732 ± 17.265 ppb, respectively. Therefore, concentration of heavy metals in Offin was significantly different from Birim and Pra (Table 4). Moreover, Offin showed a high variation in concentration of physicochemical parameters at sampled locations with highest values in Amansie West District sampled rivers (Table 4; Supplementary Material, Appendix A).

4. CONCLUSIONS

The study found that respondents had limited ability to identify clean water. They judged the cleanliness of water by its appearance; therefore, water available for domestic activities mainly from boreholes is perceived as clean compared to river sources. This shows that most respondents were not sufficiently aware about the problems of water pollution, its main causes and possible impacts. River water was the second most used source of water for domestic chores, but there is little or no treatment of the water before use. Water demand in the basin is perceived to be increasing; however, the increasing

Table 4 | Kruskal–Wallis H test and Dunn test of comparison of physicochemical parameters in the Pra River Basin

Parameters	**Kruskal–Wallis H-test (*p*-value)**	**Comparison of significant variance**	**Dunn test (*p*-value)**
pH	0.197	None	
Total suspended solids (TSS)	0.938	None	
Electrical conductivity (EC)	0.566	None	
Total dissolved solids (TDS)	0.566	None	
Total nitrogen (TN)	0.010	Birim–Offin	0.02497
Total phosphate (TP_1)	0.063	None	
Total phosphorus (TP_2)	0.071	None	
Nitrate nitrogen ($N\text{-}NO_3$)	0.861	None	
Ammonia nitrogen ($N\text{-}NH_{4+}$)	0.047–0.05	None	
Lead (Pb)	6.64×10^{-6}	Birim–Offin Offin–Pra	9.93×10^{-4} 8.50×10^{-6}
Mercury (Hg)	0.009	Offin–Pra Birim–Offin	0.019824 0.905091
Arsenic (As)	0.002	Offin–Pra Birim–Offin	0.006984 0.001868
Cadmium (Cd)	9.49×10^{-6}	Offin–Pra Birim–Offin	4.12×10^{-4} 2.67×10^{-5}
Copper (Cu)	6.12×10^{-6}	Offin–Pra Birim–Offin	3.04×10^{-4} 1.96×10^{-5}
Iron (Fe)	0.0003	Birim–Offin Offin–Pra	0.001258 0.001206

number of boreholes has slowed down the trend of water scarcity experienced in the past. Rain water was harvested mainly for domestic use. River water was considered unsuitable for farming as it is polluted by small-scale illegal mining (*galamsey*). This pollution is exacerbated by unsustainable agricultural practices in the basin, such as excessive use of agrochemicals and farming within buffer zones, i.e., without the protection of riparian vegetation.

Phosphorus levels detected at most sampling locations showed that eutrophication in the basin is accelerating, possibly due to increased fertilisation from crop production. The excess amount of heavy metals puts the residents at risk of both carcinogenic and non-carcinogenic effects through consumption of food produced with the contaminated water. The heavy metals and high concentration of sediments could be attributed to the small-scale mining activities in the basin. In addition, the diversion of rivers for *galamsey* operations contributes to the distribution of the heavy metals and nitrogen in the basin. In general, heavy metal and nitrogen concentrations were significantly higher in the Offin sub-basin than in the Pra and Birim sub-basins, indicating increased small-scale illegal mining and chemical-intensive crop production.

Regular surveillance of surface water quality is key to sustainable water management. The condition of the rivers requires treatment in the short term, while sustainable agriculture and small-scale mining policies are needed in the long term to improve the quality of surface water resources for residents of the Pra River Basin. Water treatment for heavy metals is costly and technologically challenging to implement in the region. Therefore, policy measures need to be urgently implemented to stop illegal mining and promote more effective natural remediation approaches for water purification. Conservation of riparian forests and improved soil conservation measures on local farms are essential to prevent water pollution, in addition to compliance with Ghana's environmental regulations at local mining sites. To this end, improvement in surveillance systems of the Pra River Basin and investments in local agronomical assistance via agriculture extension officers, sanitation infrastructure (construction and restoration of treatment plants), environmental awareness of farmers, and legal enforcement of the small-scale mining certification are key strategies. Further research into site-specific benefits of ecosystem services such as landscaping along rivers, types of vegetation for enhanced water purification and the trend of sustainable land use change are crucial to improve not only the environmental quality of the Pra River Basin, but also the public health of local communities.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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