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Impact of the ban on illegal mining activities on raw water quality: A case-study of Konongo Water Treatment Plant, Ashanti Region of Ghana

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Keywords

“galamsey”, illegal mining, water quality, Mann-Kendal test, Konongo Water Treatment Plant, Anuru River

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Impact of the ban on illegal mining activities on raw water quality: A case-study of konongo water treatment plant, ashanti region of ghana

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Abstract

The Government of Ghana prohibited Artisanal and Small-Scale Mining (ASM) operations from 2017 to 2018 as part of its strategy to address the socio-environmental issues caused by illegal mining activities, also referred to as “galamsey” operations. This study assessed the trend in the water quality of raw water abstracted at the Konongo Water Treatment Plant (WTP) for treatment before and after implementing the ban on “galamsey” operations. The main source of raw water for the Konongo WTP is the Anuru River. Secondary data on physicochemical water quality from 2006 to 2019 was sourced from the Konongo WTP and the Ashanti Regional Water Quality Assurance Unit of Ghana Water Company Limited (GWCL). Mann-Kendall seasonality test was used to determine trends in the water quality data using XLSTAT statistical tool. The results showed a statistically significant (5% level of significance) upward trend in colour, turbidity, temperature, total iron, and sulphate before the ban on “galamsey” activities. There was statistically significant evidence of a downward trend in total hardness, calcium hardness, turbidity, total alkalinity, and chloride after the ban on “galamsey” operations. Overall, there was improvement in the quality of raw water after the ban.

Keywords: “Galamsey”, illegal mining, water quality, Mann-Kendal test, Konongo water treatment plant, Anuru river

1. Introduction

Globally, climate change and increasing pollution levels continue to threaten water resources [1]. This situation increased the scarcity of uncontaminated water supply [2]. Thus, Sustainable Development Goal (SDG) 6 seeks to promote and ensure the sustainable management of water and sanitation for everyone, including equitable access to safe drinking water, improvement of water quality, protection and restoration of water-related ecosystems.

In 2014, the number of people directly involved in illegal mining worldwide doubled to around thirty million. This figure was expected to reach 40.5 million in 2017. This continuous increase in the number of illegal miners is because of the rising mineral prices and the increased difficulties in making a living from

other activities, such as agriculture [3,4]. According to the Artisanal and Small-Scale Mining (ASM) Knowledge Sharing Archive (2017), the Republic of Congo and Sudan have an average of more than one million miners involved in ASM compared to an average of 500,000 to one million miners in Mali, Ivory Coast, Ghana, and Tanzania.

Africa has the largest platinum, gold, vanadium, chromite, manganese, and diamond reserves [5]. Unfortunately, Africa is saddled with the environmental burden of ASM; its effect reduces the benefit it receives from its minerals [6]. In some countries around the world, particularly in Africa, crops and agricultural land are degraded as a result of illegal mining activities thus affecting food production [7]. According to the Executive Secretary of the Ghana Water Resources Commission, as of 2017, about 60%

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of Ghana's water bodies had been polluted, with many in very critical condition. Studies have shown that “galamsey” polluted water bodies recorded high concentrations of physicochemical parameters (acidity, turbidity, colour, total suspended solids, and nitrates) that exceeded the WHO guideline [8,9]. Extracting minerals from alluvial deposits along waterways has been found to impact the total suspended solids (TSS), turbidity, iron, and colour of water sources, suggesting wastewater inflow from illegal mining activities and run-off [10]. These tremendous changes in the water quality result in a high cost of treatment at the water treatment plant to make it safe for consumption [11]. The disposal of mine wastewater is known to be associated with pollution-related changes to the physical and chemical water quality properties and macroinvertebrate communities in water. The physical and chemical changes include elevated water temperatures, salinity, pH, and modification of ionic composition [12]. In Latin America, in general, turbidity and colour were significant factors for defining operational aspects in local water treatment plants and guiding water treatment technology selection [13].

Heavy metal concentrations (arsenic, cadmium, manganese, mercury, lead, and others) in water bodies in “galamsey” affected communities have also exceeded WHO guidelines, therefore making the water sources unsafe for drinking purposes [8,9].

Illegal mining or “galamsey” reported in Ghana, has become the most debated issue because of its negative impact on water resources and water-dependent industries, such as the Ghana Water Company Limited. Addressing the menace has become a key challenge to authorities in Ghana. Most people engage in mining activities with no permits or licenses from the Minerals Commission, a regulatory body in Ghana [14,15]. Though mining, in general, has been a major contributor to the growth of the Ghanaian economy, it is worthy to note that it has also had devastating environmental impacts, especially on water bodies and water-dependent industries [14].

A state-owned utility company, Ghana Water Company Limited (GWCL), whose responsibility is to treat and supply potable water to the urban areas in Ghana, is concerned about the threats posed to water bodies through “galamsey” operations. GWCL has been compelled to shut down some plants due to high levels of water pollution and its association with high treatment expenses [16].

The search for interventions to mitigate illegal mining began in 1995 across the global south. Among the proposed interventions were legalisation, use of cleaner technology, and reduction of mercury use, of

which many countries due to numerous challenges have achieved marginal success [17]. Despite these interventions, evidence shows that the challenges of environmental pollution associated with illegal mining continue to arise [18–20].

As a result of the threats posed to water bodies by activities of illegal miners, environmentalists and other organisations initiated the ‘Stop “galamsey” Now’ movement in 2016, urging the Ghana Government to prohibit all ASM activities. The government agreed to prohibit ASM operations from March 2017 to December 2018 as a result of these campaigns [21]. To aid in Ghana's ASM sector reform, the Ghanaian Government constituted the Inter-Ministerial Committee on Illegal Mining (IMCIM). The government also created a task force (Operation Vanguard) out of the security service to “wage war” on “galamsey” operations [19]. It was expected that the water quality of most polluted water bodies would improve after implementing the ban on illegal mining activities.

Despite this intervention, there is little or no scientific evidence associating the impact the ban on illegal mining has had on the quality of water sources. This study, therefore, aims to contribute to this growing area of research by quantitatively assessing the impact of the implementation of the ban on illegal mining on the raw water quality of the Konongo WTP. The importance and originality of this study stem from the fact that it evaluates a governmental policy against illegal mining activities by exploring 13 years of water quality data of the raw water source (Anuru River). The results obtained from this study could be used to guide the adoption of policy related to the ban on illegal mining activities by other countries facing challenges of illegal mining operations.

2. Materials and methods

2.1. Description of the study area

The research was conducted in Konongo-Odumasi in the Asante Akim Central District of Ashanti Region, Ghana. About 50% of the municipality's population works in the agriculture sector. With an average annual precipitation range of 125–175 mm, the region experiences double rainfall maximums. Several rivers flow through the municipality, including the Owerri, Anuru, Abosomtwe, and Bomire [22].

Konongo-Odumasi, a mining community, was selected for this study because it is where the GWCL water treatment plant is located; 7 km to the North-East of Odumasi, from the main Odumasi

junction off the Kumasi-Accra highway. The Konongo water treatment plant is the main source of potable water supply for the Asante Akim Central and North Districts.

The principal reason for selecting this area is the heavy presence of small-scale mining activities dominated by illegal miners. The river has been a receptacle for tailings from “galamsey” operations and a source of raw water for treatment operations at the Konongo WTP. Mining on the river bed has periodically threatened the drying up of the river. The pollution of the raw water source has led to the intermittent shut down of the treatment plant [23].

The Anuru River is the main source of raw water for the Konongo Water Treatment Plant with immediate tributaries being the Atunso and Peni streams. The river takes its source from the forests of Okaikrom in the Sekyere East District of the Ashanti Region. It supplies some communities with drinking water; as a result, any decline in the water quality becomes an issue of concern to the local indigenes. Fig. 1 shows the Ashanti Akim district map and the Anuru River.

2.2. Study design and data source

Secondary data on physicochemical water quality tests performed by the staff of the Konongo WTP and the Ashanti Regional Water Quality Assurance Department within the last 13 years (2006–2019) was sourced from the Ghana Water Company Limited (GWCL). A total of 12 water quality parameters were analysed (Table 1), including the following: temperature, pH, electrical conductivity (EC), turbidity, total dissolved solids (TDS), suspended solids (SS), calcium hardness, chloride, total iron, sulphate, total alkalinity, and total hardness.

To aid in analysis, the data were grouped into two to cover the two phases – before and after the ban on illegal mining activities.

“Before” the ban on “galamsey”/illegal mining refers to the period during which “galamsey” operations were active within the study area; before the Government of Ghana sanctioned “galamsey” activities (2006–2016), while “after” the ban on “galamsey”/illegal mining refers to the period during which “galamsey” was not active in the study area because of the ban on “galamsey” by the Government of Ghana (2017–2019).

2.3. Data management and analysis

The water quality data were entered into Microsoft Excel and imported into SPSS 20 and XLSTAT (version 2018.1.49310) software for analysis. Data

were checked for outliers, accuracy, and completeness.

The data were analysed using the SPSS 20, R 3.6.3 software, and XLSTAT version 2018.1.49310. Descriptive summary statistics were performed for the different water quality parameters to be investigated.

The data were subjected to Levene's homogeneity test of variance using SPSS 20. The outcome indicated an unequal variance (violation of the homogeneity assumption) in the data. Welch's W-ANOVA or W-test addressed homogeneity violation [24]. W-ANOVA was used to determine whether there were significant variations among the yearly average of the water quality parameters. It was also used to assess whether there was any significant difference in raw water quality before and after the ban on illegal mining (i.e., at a 5% level of significance).

Mann-Kendall seasonality test was used to determine statistically significant trends in the water quality data. Using Veusz 3.3.1 software, a time series plot was used to visualise the water quality trend before and after the ban on illegal mining.

The major limitation of this study is that secondary data collected did not include heavy metal concentrations of the raw water. Analysis of data on heavy heavy metal concentrations would have strongly related the impact of the “galamsey” activities, such as the use of mercury for gold processing, to water quality deterioration.

3. Results and discussion

3.1. Water quality analysis

A total of 12 water quality parameters data from 2006 to 2019 were analysed. Descriptive statistics for water quality parameters and yearly averages are summarised in Tables 2 and 3, respectively. Results of Welch's ANOVA analysis of the yearly averages of water quality parameters, as well as before and after the ban on illegal mining are shown in (Tables 4 and 5).

The pH values ranged from 5.0 to 7.85, indicating that the raw water is almost acidic to sub-alkaline. Welch's ANOVA showed a statistically significant variation among the yearly means of pH (p -value < 0.001) (Table 3). Also, a statistically significant difference (p -value < 0.001) was observed for the mean pH values before and after the ban on illegal mining (Table 4); at p -value < 0.001. The minimum value of the pH range recorded was lower than the WHO thresholds of 6.5–8.5. Asante et al. observed a similar pH value for surface water (6.40; stream

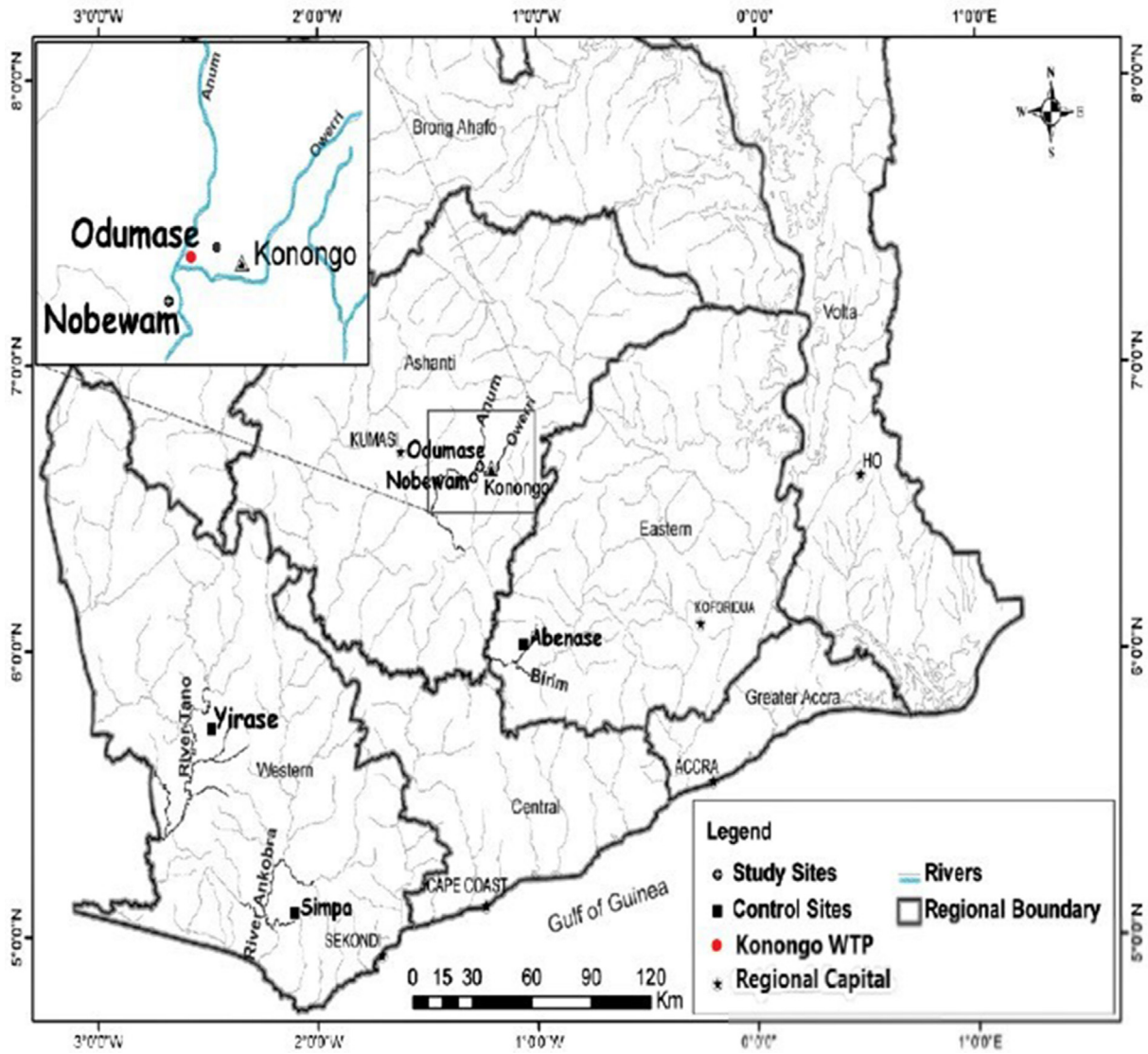


Fig. 1. Map of the study area.

water) in small-scale mining areas in Tarkwa, Ghana [25]. Nukpezah, Rahman, and Koranteng stated that the irrigation water in the Ashanti Akim Central affected by small-scale mining activities was

moderately acidic for the control and midstream samples analysed; a pH value of 5.4 and 6.4, respectively, was reported [26]. According to Dorleku, rivers or water bodies polluted by mining

Table 1. Water quality parameters.

| Water quality parameter | Significance of parameter |
|---------------------------------|---|
| Temperature | Affects the taste of water. |
| pH | Affects coagulation and disinfection with chlorine. |
| Electrical conductivity and TDS | Indicate the presence of dissolved substances. |
| Colour | Indicates pollution with solids waste and sludge from mining activities. |
| Turbidity | Indicates the dissolution and or washing of silt into the water source. |
| Total hardness | Affects the taste and indicates the hardness of the water. |
| Total alkalinity | Required for effective coagulation. |
| Chloride | Causes a detectable taste in water and increase corrosion of metal pipes. |
| Total iron | Causes an unpleasant taste of water and affects the colour of the water. |
| Sulphate | Indicates anthropogenic pollution (municipal or industrial discharges). |

Table 2. Descriptive statistics for the physicochemical water quality (2006–2019).

| | Descriptive statistics | | | |
|-------------------------------|------------------------|------------|-------|----------------|
| | N | Range | Mean | Std. deviation |
| pH | 168 | 5.0–7.9 | 6.8 | 0.5 |
| Colour (HZ units) | 168 | 4.0–2068.0 | 261.2 | 278.9 |
| Turbidity (NTU) | 168 | 2.0–325.0 | 41.9 | 49.2 |
| Electrical conductivity (S/m) | 168 | 15.6–783.0 | 133.9 | 111.2 |
| TDS (mg/L) | 168 | 9.3–625.0 | 76.2 | 74.8 |
| Temperature (°C) | 168 | 20.3–32.2 | 26.4 | 1.7 |
| SS (Suspended solids mg/L) | 168 | 1.0–159.0 | 25.3 | 23.4 |
| Total Hardness (mg/L) | 168 | 20.0–160.0 | 56.4 | 26.5 |
| Calcium hardness (mg/L) | 168 | 6.0–134.0 | 32.9 | 20.4 |
| Total alkalinity (mg/L) | 168 | 6.0–128.0 | 56.7 | 23.4 |
| Chloride (mg/L) | 168 | 7.0–102.0 | 23.8 | 13.9 |
| Total iron (mg/L) | 168 | 0.2–29.0 | 2.8 | 3.1 |
| Sulphate (mg/L) | 168 | 2.0–95.0 | 20.5 | 16.4 |

activities tend to have low pH as a result of reactions between rock minerals, water, and atmospheric oxygen [27]. The pH value significantly affects neutralization, coagulation, sedimentation, and

other phases of water treatment and water supply; for example, it is required for effective coagulation and disinfection with chlorine [28].

The mean temperature was 26.42 ± 1.67 °C; 25 °C is generally preferred for surface water, according to the WHO guideline. The observed temperature value in this study was consistent with the study of Agyapong, Besseah, and Fei-Baffoe [29]. Slight temperature changes can adversely affect the aquatic environment, such as algae and fish, because of their narrow temperature tolerance [28]. In water treatment and supply services, taste and odour are the major factors in customer acceptability, with the intensity of taste being significantly affected by temperature changes. Generally, the diffusion rate of gases and the amount of oxygen dissolution, known to improve water taste and odour, is temperature-dependent [30,31]. Pollution of water bodies as a result of mining activities elevates water temperatures [12]. Water turbidity affects water temperature, as suspended particles in

Table 3. Yearly means of physicochemical water quality (2006–2019).

| Means | | | | | | | | | | | | | | |
|-------------------------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|-------|--------|--------|-------|--------|
| Parameters | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
| pH | 6.77 | 6.70 | 6.92 | 6.80 | 6.99 | 6.74 | 6.53 | 6.09 | 6.78 | 6.80 | 6.62 | 6.96 | 7.04 | 6.90 |
| Colour (HZU) | 281.67 | 283.08 | 322.78 | 296.11 | 321.92 | 511.77 | 568.33 | 325.50 | 334.17 | 76.92 | 170.27 | 59.68 | 49.08 | 56.02 |
| Turbidity (NTU) | 34.87 | 22.92 | 43.59 | 53.75 | 41.54 | 50.47 | 63.40 | 53.13 | 35.98 | 35.48 | 81.07 | 34.58 | 14.86 | 22.18 |
| Electrical conductivity (S/m) | 382.85 | 91.44 | 183.68 | 94.45 | 114.02 | 78.33 | 131.33 | 114.20 | 101.40 | 86.56 | 124.48 | 122.75 | 90.83 | 157.79 |
| TDS (mg/L) | 248.75 | 41.28 | 88.50 | 50.30 | 58.84 | 44.70 | 74.91 | 80.40 | 60.87 | 51.63 | 73.94 | 63.15 | 44.50 | 84.55 |
| Temperature (°C) | 26.43 | 26.43 | 26.53 | 26.81 | 26.44 | 26.43 | 25.85 | 26.38 | 27.53 | 27.17 | 26.13 | 25.68 | 25.07 | 27.06 |
| SS (mg/L) | 22.08 | 19.08 | 17.67 | 28.75 | 24.42 | 34.25 | 29.67 | 35.42 | 17.33 | 18.67 | 29.92 | 23.08 | 24.00 | 22.17 |
| Total hardness (mg/L) | 43.92 | 51.50 | 75.25 | 53.83 | 56.33 | 48.33 | 36.67 | 45.67 | 48.50 | 49.22 | 67.95 | 99.40 | 66.28 | 46.67 |
| Calcium (mg/L) | 22.33 | 28.17 | 47.67 | 29.67 | 33.00 | 25.25 | 22.67 | 26.17 | 25.83 | 32.27 | 40.17 | 61.67 | 42.72 | 23.50 |
| Total alkalinity (mg/L) | 56.00 | 53.25 | 71.33 | 57.17 | 47.83 | 59.83 | 52.50 | 47.17 | 44.67 | 68.83 | 62.33 | 71.00 | 57.33 | 44.17 |
| Chloride (mg/L) | 23.42 | 23.67 | 33.17 | 24.67 | 22.50 | 36.17 | 19.83 | 19.75 | 24.33 | 18.33 | 24.58 | 29.08 | 21.50 | 12.25 |
| Total iron (mg/L) | 3.37 | 2.63 | 3.15 | 4.65 | 5.01 | 4.74 | 3.07 | 2.39 | 2.70 | 2.09 | 1.95 | 1.53 | 0.83 | 1.57 |
| Sulphate (mg/L) | 13.25 | 10.08 | 12.25 | 13.17 | 16.08 | 26.83 | 26.83 | 31.17 | 31.42 | 17.42 | 30.58 | 24.42 | 15.42 | 18.58 |

Table 4. Welch's ANOVA of the yearly means of water quality parameters (2006–2019).

| | Robust Tests of equality of means | | | | |
|-------------------------------|-----------------------------------|------------------------|-----|--------|---------|
| | | Statistic ^a | df1 | df2 | Sig. |
| pH | Welch | 3.820 | 13 | 59.180 | < 0.001 |
| Colour (HZ units) | Welch | 10.619 | 13 | 58.660 | < 0.001 |
| Turbidity (NTU) | Welch | 3.362 | 13 | 57.948 | 0.001 |
| Electrical conductivity (S/m) | Welch | 5.831 | 13 | 57.825 | < 0.001 |
| TDS (mg/L) | Welch | 4.975 | 13 | 58.179 | < 0.001 |
| Temperature (°C) | Welch | 4.187 | 13 | 58.957 | < 0.001 |
| SS (Suspended solids, mg/L) | Welch | 0.846 | 13 | 58.985 | 0.611 |
| Total hardness (mg/L) | Welch | 5.489 | 13 | 58.850 | < 0.001 |
| Calcium hardness (mg/L) | Welch | 3.644 | 13 | 59.005 | < 0.001 |
| Total alkalinity (mg/L) | Welch | 1.855 | 13 | 59.135 | 0.055 |
| chloride (mg/L) | Welch | 5.820 | 13 | 58.643 | < 0.001 |
| Total iron (mg/L) | Welch | 6.843 | 13 | 58.555 | < 0.001 |
| Sulphate (mg/L) | Welch | 3.112 | 13 | 58.964 | 0.001 |

^a“Statistic ^a” refers to asymptotically F distributed statistic.

Table 5. Welch's ANOVA of means of water quality parameters before and after the ban on illegal mining (2006–2019).

| | | Robust Tests of equality of means | | | |
|-------------------------------|-------|-----------------------------------|-----|---------|---------|
| | | Statistic ^a | df1 | df2 | Sig. |
| pH | Welch | 13.453 | 1 | 70.598 | < 0.001 |
| Colour (HZ units) | Welch | 97.448 | 1 | 155.506 | < 0.001 |
| Turbidity (NTU) | Welch | 13.048 | 1 | 114.678 | < 0.001 |
| Electrical conductivity (S/m) | Welch | 0.972 | 1 | 155.261 | 0.326 |
| TDS (mg/L) | Welch | 3.422 | 1 | 164.877 | 0.066 |
| Temperature (°C) | Welch | 2.852 | 1 | 45.923 | 0.098 |
| SS (Suspended solids, mg/L) | Welch | 0.618 | 1 | 134.591 | 0.433 |
| Total hardness (mg/L) | Welch | 10.26 | 1 | 45.691 | 0.002 |
| Calcium hardness (mg/L) | Welch | 7.941 | 1 | 46.368 | 0.007 |
| Total alkalinity (mg/L) | Welch | 0.064 | 1 | 60.311 | 0.801 |
| Chloride (mg/L) | Welch | 2.785 | 1 | 75.033 | 0.099 |
| Total iron (mg/L) | Welch | 32.223 | 1 | 164.202 | < 0.001 |
| Sulphate (mg/L) | Welch | 0.383 | 1 | 112.592 | 0.537 |

^aStatistic^a refers to asymptotically F distributed statistic.

a water column absorb and scatter sunlight and determine solar radiation's extinction [32]. The Welch's ANOVA showed a statistically significant difference in the means of temperature amongst the different years at a p -value < 0.001.

The mean colour was 261.23 ± 278.95 . Welch's ANOVA indicated that there was a significant difference (p -value < 0.001) between the yearly means of the colour of raw water (Table 3). Also, a statistically significant variation between the means of colour, before and after the ban on illegal mining was observed; (p -value < 0.001). According to Bansah et al., water quality analysis of the Bonsa River recorded an apparent colour range of 208–3239 Hz for the samples collected during illegal mining activities in the river [33]. The study by Bansah et al. indicated that the introduction of solid waste and sludge during mining operations into the river is responsible for the high colouration. These colour values recorded are above the 4.0–2068 Hz observed for the Anuru River in this study. The high level of colouration could be associated with the formation of acid mine drainage, which has been accelerated as a result of excavations made by mining operators along the river. Colour makes water aesthetically objectionable, and treating it to an acceptable limit of 5 Hz can be costly [34].

Turbidity is an essential parameter for surface water quality because it is easily noticeable to the average person [35]. The observed values varied from 2.01 to 325 NTU (Table 2); the mean turbidity was 41.99 ± 49.16 . Turbidity ranges of 103–445 NTU recorded within the “galamsey” polluted the Fena River in the Ashanti Region by Duncan [36] were higher than the observed range in this study. The higher levels of turbidity reported could largely be due to the activities of small-scale miners. High

turbidity in mining areas is an indication of land disturbances. “Activities such as the use of excavators, earth moving equipment, shovels and pick axe in the excavation of ores could enhance the dissolution and or washing of silt into the river” [36]. High turbidity usually has more pathogens and an excess of 5 NTU may be objectionable to consumers. Welch's ANOVA indicated that the difference in the yearly turbidity averages was statistically significant at a p -value = 0.001. The W-ANOVA test also revealed a significant difference in the means of turbidity before and after the implementation of the ban on illegal mining at a p -value < 0.001.

The observed means of Electrical Conductivity (EC) and TDS were 133.87 ± 111.24 and 76.17 ± 74.75 , respectively. There was a significant statistical difference in the yearly means of EC and TDS (p -value < 0.001). These values were within the WHO threshold limits for conductivity and TDS, which are 1500 μ S/cm and 500 mg/L, respectively. The low values indicate that contaminations due to dissolved ions were low. Several factors influence the conductivity and TDS of water. Activities that lead to the release of rock minerals into water, such as intensive mining or agricultural activities, have been reported to influence TDS and conductivity [37,38]. Such low conductivity and TDS values have been reported in previous studies in mining areas by Refs. [29,39].

The computed mean of alkalinity was 56.67 ± 23.36 . There was an indication of a significant difference in the average alkalinity concentrations among the years at a p -value < 0.001. In a study by Agyapong, Besseah, and Fei-Baffoe, values for the alkalinity of surface water samples were high at mining sites but were below the WHO permissible limits of 500 mg/L

[29]. Dharmappa et al. reported that high alkalinity usually indicated the presence of natural salts such as bicarbonates, phosphates or hydroxide ions in the water [40].

A high level of iron concentration (Fe; 16.43 to 11.0 mg/L and 314.09 to 11.63 mg/L) recorded for the Fena River indicated a possibility of an association with illegal mining activities that took place in and around the river at the time of the study [33]. The findings presented in the study of Bansah et al. [33] were similar to the 0.17–29.00 mg/L of iron (Fe) observed for the Anuru River in this study. These values are all above the WHO guideline limit of 0.3 mg/L. Ranjeeta, Rawtani, and Vishwakarma also reported a concentration of iron ranging from 1.60 to 3.30 mg/L; the study attributed the levels to the possibility of small-scale mining activities in the area [28]. Agyapong, Besseah, and Fei-Baffoe recorded similar iron concentrations at sites that were close to mining areas [29]. Study areas rich in arsenopyrite or pyrite rocks could contribute to high iron levels in the water. Ores processing, as observed in ASM activities, could release high iron concentrations into the surface waters [41]. The high levels of iron in water bodies could cause an unpleasant taste of water. The Welch's ANOVA indicated a significant difference in the yearly averages of the iron concentration at a p -value < 0.001 . Total iron showed statistically significant ($p < 0.001$) variation in mean concentrations before and after the ban on illegal mining.

A calcium (Ca) mean of 32.93 ± 20.42 was recorded. The Welch's ANOVA indicated a significant difference ($p < 0.001$) in the yearly averages of calcium concentration. In large concentrations, calcium “may affect the taste of the water by contributing to high TDS, which will also affect practical water usage (washing with soap)” [42]. Calcium hardness showed statistically significant variation in mean

concentrations before and after the ban on illegal mining (p -value = 0.007).

3.2. Trend analysis of water quality before and after the ban against “galamsey”

Tables 6 and 7 below show the results of the seasonal Mann-Kendall test for trends in the water quality data. The results showed a statistically significant upward trend in colour, turbidity, temperature, total iron, and sulphate before the ban on illegal mining activities (Table 6).

The Sen's slope of 8.03 for colour indicates that colour increased by an average of 8.03 Hz units annually before the ban. Similarly, turbidity, temperature, total iron, and sulphate indicated a yearly increase of 1.73 NTU, 0.08 °C, 1.07 mg/L, and 1.49 mg/L, respectively.

Contrary to the upward trend in water quality before the ban, there was statistically significant evidence of a downward trend in five water quality parameters, including turbidity, total hardness, calcium hardness, total alkalinity, and chloride, after the ban on illegal mining activities (Table 7). Although pH, colour, suspended solids (SS), total iron, and sulphate did not show a statistically significant trend, there was an indication of a downward trend after the ban.

The Sen's slope indicated an annual unit decrease in total hardness, calcium hardness, turbidity, total alkalinity, and chloride at 3.30 NTU, 25.50 mg/L, 20.00 mg/L, 10.00 mg/L, and 6.50 mg/L, respectively.

Comparing the trend analysis before and after the ban on illegal mining (Table 8); there was an increasing trend as a result of the annual unit increase in the concentrations of turbidity, temperature, total iron, sulphate, and colour before the ban on illegal mining. This observation could result from “galamsey” operations around the raw water source

Table 6. Seasonal Mann-Kendall trend analysis of physicochemical quality of surface water before the ban on “galamsey” (2006–2016).

| Series \ Test | Kendall's tau | p-value | Sen's slope | Trend |
|-------------------------------|---------------|---------|-------------|-------|
| pH | -0.110 | 0.090 | -0.020 | down |
| Colour (HZ units) | 0.170 | 0.010 | 8.030 | up |
| Turbidity (NTU) | 0.130 | 0.040 | 1.730 | up |
| Electrical conductivity (S/m) | -0.130 | 0.050 | -4.530 | down |
| TDS (mg/L) | -0.110 | 0.090 | -1.200 | down |
| Temperature (°C) | 0.160 | 0.020 | 0.080 | up |
| SS (Suspended solids, mg/L) | 0.070 | 0.280 | 0.070 | up |
| Total hardness (mg/L) | 0.050 | 0.480 | 0.140 | up |
| Calcium hardness (mg/L) | 0.060 | 0.390 | 0.670 | up |
| Total alkalinity (mg/L) | -0.020 | 0.750 | -1.300 | down |
| Chloride (mg/L) | -0.070 | 0.320 | -0.170 | down |
| Total iron (mg/L) | 0.140 | 0.040 | 1.070 | up |
| Sulphate (mg/L) | 0.260 | <0.001 | 1.490 | up |

Table 7. Seasonal Mann-Kendall trend analysis of physicochemical quality of surface after the ban on “galamsey” (2017–2019).

| Series \ Test | Kendall's tau | p-value | Sen's slope | Trend |
|-------------------------------|---------------|----------|-------------|-------|
| pH | -0.278 | 0.132 | -0.153 | down |
| Colour (HZ units) | -0.167 | 0.366 | -1.452 | down |
| Turbidity (NTU) | -0.333 | 0.048 | -3.300 | down |
| Electrical conductivity (S/m) | 0.111 | 0.546 | 7.600 | up |
| TDS (mg/L) | 0.167 | 0.366 | 2.150 | up |
| Temperature (°C) | 0.141 | 0.446 | 1.125 | up |
| SS (Suspended solids, mg/L) | -0.111 | 0.546 | -3.000 | down |
| Total hardness (mg/L) | -0.480 | 0.010 | -25.500 | down |
| Calcium hardness (mg/L) | -0.649 | 0.001 | -20.000 | down |
| Total alkalinity (mg/L) | -0.423 | 0.022 | -10.000 | down |
| Chloride (mg/L) | -0.833 | < 0.0001 | -6.500 | down |
| T. iron (mg/L) | -0.056 | 0.763 | -0.045 | down |
| Sulphate (mg/L) | -0.167 | 0.366 | -1.250 | down |

Table 8. Comparing trends of water quality data before and after the ban on “galamsey”.

| Parameters | Before the ban (2006–2016) | | After the ban (2017–2019) | |
|-------------------------------|----------------------------|-------|---------------------------|-------|
| | p-value | Trend | p-value | Trend |
| pH | 0.090 | down | 0.132 | down |
| Colour (HZ units) | 0.010 | up | 0.366 | down |
| Turbidity (NTU) | 0.040 | up | 0.048 | down |
| Electrical conductivity (S/m) | 0.050 | down | 0.546 | up |
| TDS (mg/L) | 0.090 | down | 0.366 | up |
| Temperature (°C) | 0.020 | up | 0.446 | up |
| SS (Suspended solids, mg/L) | 0.280 | up | 0.546 | down |
| Total hardness (mg/L) | 0.480 | up | 0.01 | down |
| Calcium hardness (mg/L) | 0.390 | up | 0.001 | down |
| Total alkalinity (mg/L) | 0.750 | down | 0.022 | down |
| Chloride (mg/L) | 0.320 | down | < 0.0001 | down |
| Total iron (mg/L) | 0.040 | up | 0.763 | down |
| Sulphate (mg/L) | < 0.001 | up | 0.366 | down |

Significant at < 0.05.

in the study area. However, after implementing of the ban, a reverse trend was observed; there was a decline in the annual unit concentrations, leading to a downward trend of the water quality parameters such as turbidity, pH, colour, suspended solids (SS), alkalinity, chloride, total hardness, and sulphate.

3.3. Time-series plots of water quality parameters

Fig. 2a–c show the plot of pH, turbidity, colour, alkalinity, and total iron, which are the major water quality indicators of the raw water source used by the Konongo WTP. From March 2011 to December 2013, declining pH values were observed, with a minimum value of 5.0 in December 2013. There was a steady rise in colour from January to November 2010. The highest colour concentration was observed in November 2010, and as shown on the monthly graph, it peaked from January to July 2011. From January to April 2012, a steady rise was

observed with the highest peak in April 2012 for colour, followed by an improvement over time in the subsequent years. A steady increase was again observed in the 2016 period, before the ban on illegal mining; a similar trend was observed for turbidity. Nevertheless, iron also showed a similar trend; the highest peak of the iron level was observed from March to May 2011; a steady rise was observed from January to February 2012, which was followed by a high peak in April 2012. A decline in alkalinity concentration was observed from January to November 2010; a fall in alkalinity concentration was again observed from January to July 2012.

It could be attested from the study findings that the colour pattern increased steadily from 2009 to 2012, when it peaked. A declining pattern followed it until 2016 (Fig. 3). A similar pattern was exhibited by total iron and turbidity concentrations in the raw water. This trend in total iron and turbidity concentrations could be attributed to the fact that colour is due to

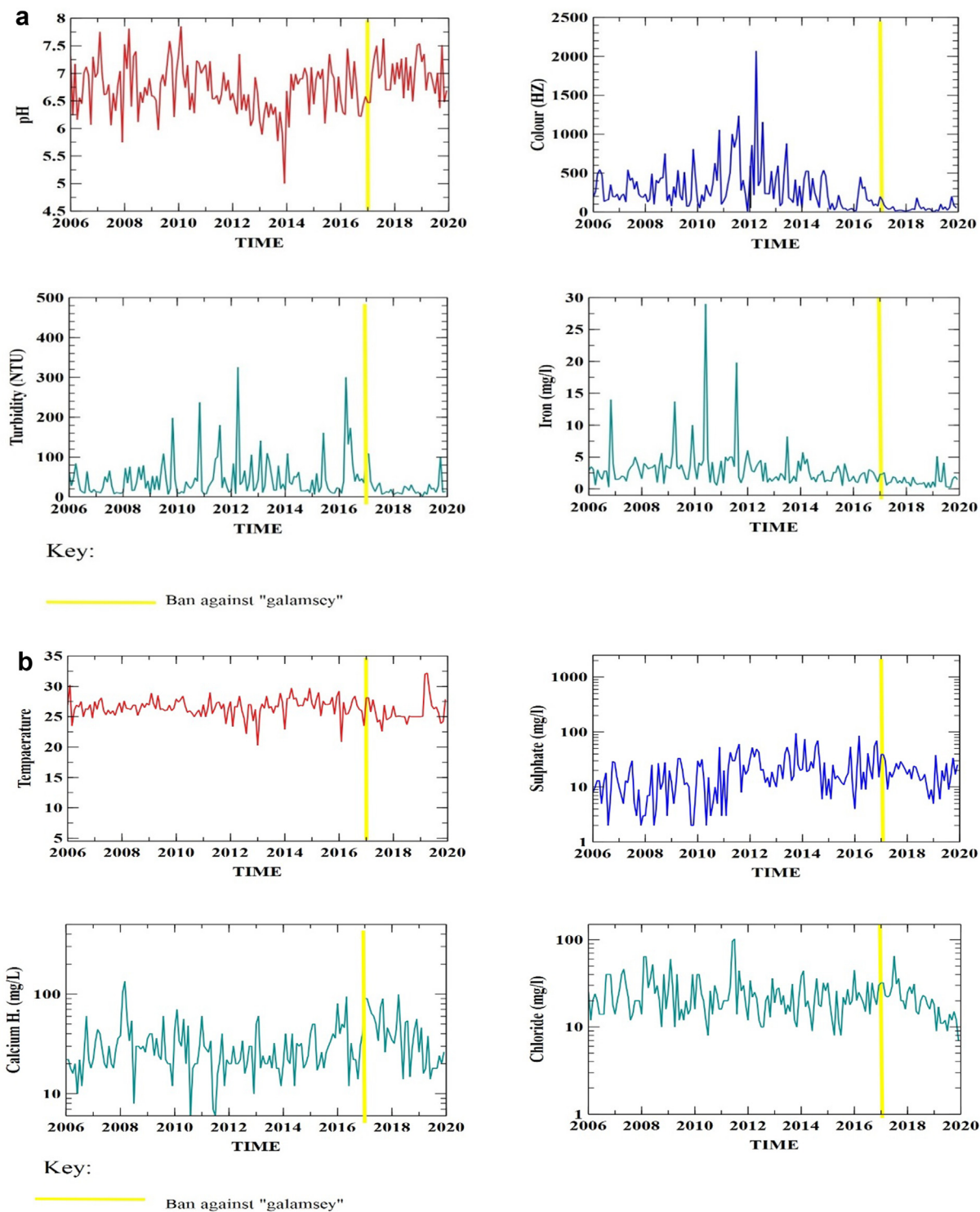


Fig. 2. (a, b and c). Time series plot of concentrations of the water quality parameters.

dissolved and suspended particles in water. Also, colour is strongly influenced by metals such as iron present in water as a result of natural or anthropogenic phenomena such as “galamsey”. This influence could be the reason why iron levels fluctuated with

colour levels. The pH level fell within the 2010–2013 period; a similar pattern was exhibited by alkalinity. This could be attributed to the strong correlation between pH and alkalinity, such that higher alkalinity informed the rise in pH in water [43]. The decline in

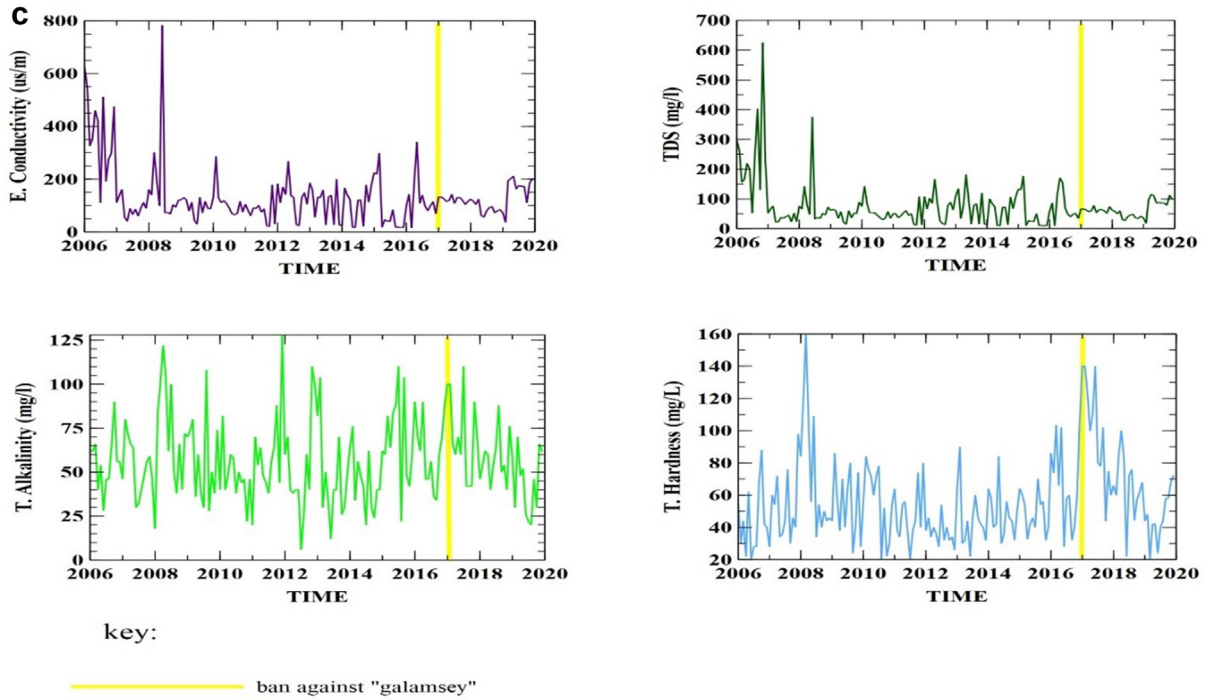


Fig. 2. (Continued).

the pH and alkalinity could be attributed to the mining activities in the study area.

A general steady decreasing trend in the concentrations of the water quality parameters was observed throughout the 2017 to 2019 after the ban on “galamsey”.

The result also showed that the deterioration of the water quality parameters (pH, turbidity, colour, iron, and alkalinity) occurred within the 2010–2013 and 2016 period (Fig. 3); this could be the period in which “galamsey” activities intensified in the study area.

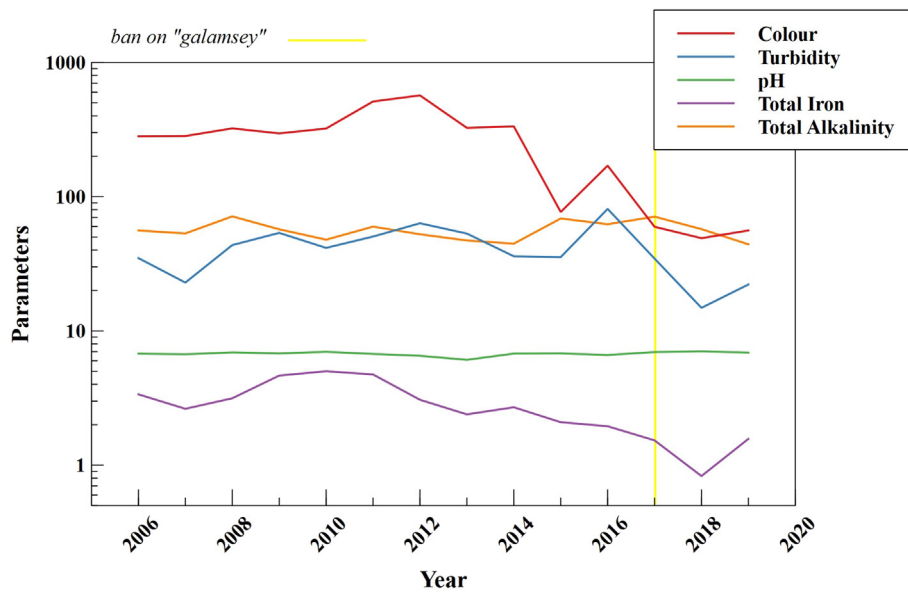


Fig. 3. Plot of the annual averages of pH, colour, turbidity, alkalinity, and iron.

3.4. Impact and implications of the ban on illegal mining on water quality

GWCL is very particular about turbidity, pH, colour, alkalinity, and iron. In evaluating raw water content, the most critical parameters are pH and turbidity. The effectiveness of chemicals applied during the treatment phase, as well as the effectiveness of chlorine disinfection, are affected by these parameters [44]. The most relevant parameters that affect the chlorination, coagulation, and flocculation process are pH, turbidity, and colour [45].

The Water Resources Commission published in 2018 an annual report which included water quality assessment of water resources [46]; the water quality monitoring covered 41 stations, including rivers and reservoirs. Their submission concluded that there had been a considerable downward trend in turbidity levels after the ban implementation on “galamsey” activities. Turbidity of 1508 NTU and 4150 NTU in 2016 were recorded for the Offin River. These results on turbidity indicated an increasing trend in turbidity before implementing the ban on “galamsey”. In 2018, the turbidity trend had reduced significantly to 11 NTU after the ban on “galamsey”.

The Pra River, one of the Anuru River tributaries, recorded a steady rise in turbidity; the turbidity of 1824 NTU and 3822 NTU were recorded in February and July 2016, respectively. After the ban on “galamsey” operations, a negative trend was observed with turbidity recording 2061 NTU and 109 NTU in February and July 2018, respectively. A further decline in turbidity was observed in February 2019 at 104 NTU. However, in July 2019, there was a steady rise in turbidity from 184 NTU to 1519 NTU in February 2020 [47]. A similar trend was observed for turbidity in this study. The Mann-Kendall analysis revealed a statistically significant upward trend in turbidity before implementing the ban on “galamsey”. A significant downward trend was observed for turbidity after implementing the ban. A time series plot (Fig. 2a) revealed a steady rise in turbidity in 2019. This may result from a diminished government's effort in tackling the menace of “galamsey” activities as stated by the [47].

In mining areas, elevated iron concentrations (Fe) have been found in water sources. “Despite not being a health concern, high concentrations of iron affect the quality of water, leading to bad taste and colouration” [42]. Our study showed a significant upward trend in iron (Fe) concentration before the “galamsey” ban. A downward trend of iron and colour was identified after the ban implementation; this could result in reducing or eliminating land

disturbances vis-à-vis the excavation of ores during “galamsey”, which leads to the dissolution of iron into the river. The time series plot of iron and colour in Fig. (3)a showed a peak in concentration in the 2019. This could indicate a surge in the “galamsey” activities around the catchment area.

Eduful et al. investigated three illegal mining towns, namely, Akwadum, Apapem, and Odumase, within the Eastern Region of Ghana, to determine whether the military-style approach of enforcing the ban was effective against the “galamsey” menace [48]. Their study revealed that residents perceived that the introduction of the anti-illegal mining task force led to an improvement in the turbidity of the Densu River. The GWCL, according to the study, attributed the improved turbidity of both the Birim and the Densu rivers to the ban on illegal mining operations [48]. The result from this study is following these findings; the improvement in the raw water quality was observed after implementing the ban in 2017. Agbozo and Spassov also observed similar findings and reported improved quality of the Pra River after the ban on “galamsey” and the introduction of the anti-illegal mining task force [49].

In terms of policy impacts, the findings of this study are crucial and further re-enforces the government's newly introduced policy on the Community Mining Scheme (CMS) which seeks to legitimise the involvement of residents of mining communities in small-scale mining activities. Under this program, small-scale miners are expected to be trained at the University of Mines and Technology (UMaT) before issuing a license and permit to commence mining activities. This initiative aims to address environmental degradation associated with illegal mining activities as well as formalize and regulate small-scale mining activities. Also, in our drive towards ensuring universal access to safe drinking water by all by 2030, countries where illegal mining activities are predominant with its associated water quality deterioration will need to prioritise initiatives that may include a ban on “galamsey” activities to meet the set SDG target on access to safe water.

4. Conclusions

The research study looked into the ban's impact on illegal mining activities on the raw water quality of the Konongo Water Treatment Plant. The results from the study indicated a statistically significant upward trend in colour, turbidity, temperature, total iron, and sulphate before the ban on “galamsey” activities; this indicated a deterioration of the water quality with time. There was statistically significant

evidence of downward trends in five water quality parameters after the ban against “galamsey” including total hardness, calcium hardness, turbidity, total alkalinity, and chloride. Even though pH, colour, suspended solids, total iron, and sulphate did not have enough evidence to show a statistically significant trend, there was an indication of a downward trend over time after the ban. It is expected that the water quality of most polluted water bodies will improve after implementing of the ban on illegal mining by the government. The observed trend of the water quality parameters after implementing the ban indicates an overall improvement of the raw water source the Konongo WTP abstracts for treatment (i.e. the Anuru River). To sustain these gains in water quality improvement, cost-effective strategies are to be developed to monitor raw water resources in addition to the strict enforcement of the law on “galamsey” to protect water resources and the environment as a whole. This may include the cooperation between institutions such as the security and traditional leaders to allow for effective information sharing and decision-making concerning the protection of drinking water sources. Also, the public needs to be educated and informed about the impact of “galamsey” operations on water bodies and water supply. For this to be effective, traditional leaders and local authorities must be used in maintaining constant communication with members of the communities.

Ethical statement

The authors state that the research was conducted according to ethical standards.

Funding body

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Conflicts of interest

The authors declare no conflict of interest.

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