Communications in Applied Sciences
ISSN 2201-7372
Volume 9, **2021**, 1

INFINITY PRESS
www.infinitypress.info

Influence of Illegal Small-Scale Gold Mining on the Black Volta Water Quality

Patrick Aaniamenga Bowan[1]*, Ellen Maala-an Tingan[2]

[1]Senior Lecturer, School of Engineering, Department of Civil Engineering, Wa Technical University, P. O. Box 553, Wa, Upper Region, Ghana

[2]Technician, Ghana Highways Authority, Wa, Upper Region, Ghana

*Corresponding author: bowanaania@yahoo.co.uk

Abstract

The discovery of gold in most parts of Ghana has resulted in the emergence of illegal small-scale gold mining activities alongside water bodies. This paper investigated illegal small-scale gold mining vis-à-vis the Black Volta River water quality in Ghana. Water samples were collected from three sites along the Block Volta River and some physicochemical parameters of the sampled water were analyzed. In addition, informal interviews were conducted using purposive and simple random sampling methods to understand the perspectives of the illegal small-scale miners on laws governing mining and the environment in Ghana. The results showed that some physicochemical parameters are high at the upstream of the Black Volta River. However, the illegal small-scale miners had poor knowledge of mining laws and the impact of their activities on the Black Volta River water quality. The study proposes the strict enforcement of environmental laws in Ghana to stop illegal small-scale mining activities on and near water bodies.

Keywords: Physicochemical Parameters; Galamsey; Water Sampling; Laboratory Analysis; Black Volta

1.0 Introduction

Water plays an important role in the maintenance of human health and wellbeing. Consequently, water is recognized as the most basic and essential of all natural resources globally, as it is obvious that neither social or economic development, nor environmental diversity can be sustained without water (Baudoin and Arenas, 2020). However, for many people the quality of water is poor. All-natural water contains substances derived from the environment; the amount of these constituents in the water determines its quality (Fu *et al.*, 2019).

Water quality can be defined in terms of the physical, chemical and biological characterization of water (Perrin *et al.*, 2019). Surface water comprises inputs from rainfall, runoff and base-flow. Each of these inputs to the surface-water system can contribute natural compounds of relevance to water quality. Rainfall in highly industrialized regions may consist of acidic precipitation, which is introduced to surface water (Grennfelt *et al.*, 2020). Similarly, runoff may carry natural organics and sediment, whereas, base-flow may have elevated levels of hardness from the flow of the water through flowing wells.

Notwithstanding these, anthropogenic activities, such as mining are the main causes of water pollution, as human activities increase the concentration of the existing compound in surface water or may cause additional compounds to enter surface water. Discharge of wastewater (treated or otherwise) greatly adds to the organic load of surface water (Tran *et al.*, 2019). Clearing of land for construction or farming, river course dredging, sand production for construction material, etc., equally result in increased erosion and sediment load in surface water.

The discovery of Gold in the Upper West Region of Ghana has resulted in the emergence of illegal small-scale gold mining popularly known as 'galamsey'. Its disorganized nature and siting close to and dependence on water have negative effects on water quality (Mujere and Isidro, 2015). Toxic chemicals such as mercury, cyanide, sulfuric acid, and arsenic are often used in various stages of gold mining. The improper discharge or release of these chemicals into the environment, especially into water bodies do not only pollute the immediate environment and water bodies but also have rippling effects on plant, animals and human populations.

The pollution of watercourses leads to rising levels of Biochemical Oxygen Demand (BOD) and the presence of microbial contaminants in drinking water sources. A small amount of toxic chemical is capable of contaminating a large volume of water, which in turn can contaminate and affect biodiversity and enter the food chains (Singh *et al.*, 2018). The Black Volta River serves as the main surface water source of drinking water for the Upper West Region of Ghana. A water treatment plant was recently built at Jambosi with a direct intake from the Black Volta River to provide portable water for the Wa Municipality. However, there is a potential increase in the pollution of the Black Block River due to 'galamsey' activities in some parts of the Upper West Region along the Black Volta River and its tributaries. According to the Water Resources Commission of Ghana, 60% of Ghana's water bodies are polluted (water.org, 2019). As a result, the Ghana Water Company Limited (GWCL), the company responsible for urban water supply in Ghana, has hinted of the possible increase in water tariffs due to the high cost of water treatment, because of high pollution of the Company's water sources.

Mining, especially surface mining results in adverse environmental impacts on water bodies (rivers and streams) in Ghana through the release of effluents such as mercury, arsenic and solid suspensions. The impact of gold mining in general on water resources can take the form of either or both physical and chemical impacts (Roy *et al.*, 2019). The chemical impacts include changes in acidity and alkalinity levels, and the release of arsenic, mercury, cyanide and other heavy metals into water bodies; whereas, the physical impacts include salinization, siltation, changed patterns of water use, and the diversion of rivers and streams from their original courses (Kortei *et al.*, 2020).

Although illegal small-scale gold mining provides indigenous and many poor people with employment and contributes to foreign exchange earnings for Ghana, the problems associated with this industry has far-reaching consequences, especially on water quality. For instance, the management of GWCL in the Eastern Region of Ghana has been struggling to produce water due to the pollution of the Birim River (the Company's water source) by the illegal small-scale gold miners because the company's Water Treatment Plant is intermittently shut down due to alarming levels of raw water turbidity of over 8000 NTU (Starr FM, 2020).

Therefore, the objective of this paper is to investigate the influence of illegal small-scale gold mining on the Black Volta River water quality. The analysis of the Black Volta River water quality concentrates on the physicochemical parameters: Turbidity, total dissolved solids (TDS), and total suspended solids (TSS). Turbidity is caused by particles suspended or dissolved in water that scatter light making the water appear cloudy or murky (Pradesh and Sarup, 2018). Measuring the turbidity of water is an important test of its quality, as it is one of the important methods of determining whether or not it is safe to drink; pathogens harmful to human health can be suspended in turbid water (Reed, Smith and Shaw, 2017). Accordingly, the World Health Organization (WHO) notes that managing turbidity is important because it affects the acceptability of water to consumers, and the selection and efficiency of treatment processes, particularly the efficiency of disinfection with chlorine (WHO, 2017).

Also, TDS affects the taste of the water and are one of the leading causes of turbidity and sediments in water (Ugbaja and Ephraim, 2019). Although, reliable data on possible health effects associated with the ingestion of TDS in drinking water are not available (Daramola *et al.*, 2019), the presence of high levels of TDS in water may be objectionable to consumers owing to the resulting taste and to excessive scaling in water pipes and household appliances (Stout *et al.*, 2019). Nonetheless, water with extremely low concentrations of TDS may also be unacceptable to consumers because of its flat, insipid taste. Besides, water with low concentrations of TDS is corrosive to water-supply systems. Similarly, high concentrations of TSS decrease the effectiveness of drinking water disinfection agents by allowing microorganisms to "hide" from disinfectants within solid aggregates (Gupta, Sati and Gupta, 2019). Levels of total solids that are too high or too low can also reduce the efficiency of water treatment plants, as well as the operation of industrial processes that use raw water (Song *et al.*, 2019).

2.0 Materials and Methods

2.1 The study area

The Black Volta River has its source in Burkina Faso and flows roughly north and east for about 200 miles (320 km) and then turns to flow south for 340 miles (550 km), forming a border between Ghana and Burkina Faso and then between Ghana and Côte d'Ivoire (see Figure 1). At Bamboi in Ghana, it turns again, first north and then east, and approximately 130 km farther east it empties into Lake Volta, after a course of about 1,160 km. Its gradient is relatively gentle (40 cm per km), and the rainfall in its river valley is likewise small (McKenna, 2020). The Black Volta River is the main surface water source for GWCL in the Upper West of Ghana, particularly the Wa Municipality, where GWCL only operates in the Upper West Region.

Figure 1: The Black Volta River

Source: Ghana Water Resources Commission, 2020

2.2 Sample Collection, Processing and Analysis

Water samples were collected from three different points purposively selected to capture the impacts of illegal small-scale gold mining on the Black Volta River water quality. Two of the samples were collected from two illegal small-scale gold mining sites along the Black Volta River, Tangesie and Duu; and one sample collected at Jambosi, where the GWCL's direct intake structure is located (see Figure 2). Both Tangesie and Duu are at upstream of Jambosi.

500 ml plastic bottles were used in collecting the samples. Before collecting the samplings, the bottles were cleaned and washed thoroughly, and rinsed with distilled water. Furthermore, five drops of Aqueous Sodium Thiosulphate Solution was added in each bottle to neutralize any residual chemical, which could affect the quality of the water to

be sampled. The sampled water from the three sites was stored in an ice-chest containing ice and transported to the GWCL laboratory in Wa in the Upper West Region of Ghana within 12 hours.

Figure 2: Sampled water from the three sites

The Laboratory Analysis of the sampled water involved purely testing of water samples and comparing the results to strike a balance with WHO's benchmark or standards for physiochemical properties of water. Turbidity, TDS, and TSS were the physicochemical parameters examined. The methods used for the turbidity, TDS, and TSS analysis were turbidity photometric method, TDS electrode method and TSS spectrophotometric method respectively.

For turbidity analysis of the three water samples, a turbid meter was used. The turbid meter was first calibrated by dipping the probe into a standard solution (formazine suspension), with turbidity values of 0.00 and 10.00 Nephelometric Turbidity Unit (NTU), and re-calibrated before taking the turbidity values of the three samples. The TDS was analysed by filtrating a well-mixed sample of each of the three samples through a standard glass fibre filter; the filtrate was evaporated to dryness in a weighed dish and dried to constant weight at 179 -181 degree Celsius. The increase in dish weight represented the TDS. Similarly, for TSS analysis, a well-mixed sample of each of the three samples was filtered through a weighed standard glass fibre filter and the residue retained on the filter was dried to a constant weight at 103 – 105 degree Celsius. The increase in weight of the filter represented the TSS.

In addition, informal interviews were conducted using purposive and simple random sampling methods. Sixty-five (65) illegal small-scale gold miners at both Tangasie and Duu illegal small-scale gold mining sites were sampled for the study. The objective of the informal interviews was to obtain indebt information on the knowledge of the illegal small-scale gold miners on gold mining laws in general and small-scale gold mining in particular. The informal interviews were recorded, transcribed and analyzed using percentages.

3.0 Results and Discussion

3.1 Physicochemical Parameters of the Black Volta River

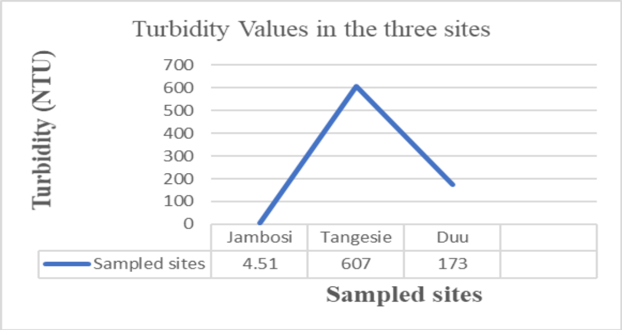
The physicochemical parameters of water quality assessment provide a proper indication of the status, productivity and sustainability of a water body (Tyagi and Malik, 2018). The changes in the physicochemical characteristics like transparency and chemical elements of water such as dissolved oxygen, turbidity, TSS and TDS give important information on the quality of the water, the source of the variations and their impacts on the effective functioning of water treatment plants. Considering the importance of understanding physicochemical properties of water in drinking water treatment, a study was carried out on the physicochemical status of the Black Volta River, which is the main surface water source for the GWCL in the Upper West Region of Ghana. The following parameters were analyzed:

3.1.1 Turbidity

Raw water was sampled from three sites (Jambusi, Tangasei, and Duu) and analyzed using a turbid meter. The results as indicated in Figure 3 revealed that the turbidity level for the Jambosi sampled water, the location of the GWCL intake structure and Water Treatment Plant, was satisfactory per the GWCL standard and WHO guidelines of $\leq$

5 NTU, as the water sampled from Jambusi turbidity value was 4.51 NTU. This can be attributed to the downstream location of Jambusi as compared to the other two sites that are at the upstream of Jambusi along the Black Volta River; water usually has a self-cleansing ability as it flows. However, the water sampled at Tangesie and Duu, both of which are illegal small-scale mining communities, produced 607 NTU and 173 NTU turbidities respectively, indicating very high turbidity levels. Meanwhile, high turbidity levels of water leads to an increase in the cost of water treatment for drinking and food processing (Laghari *et al.*, 2018).

Figure 3: Turbidity Values for the Three Sampled Sites



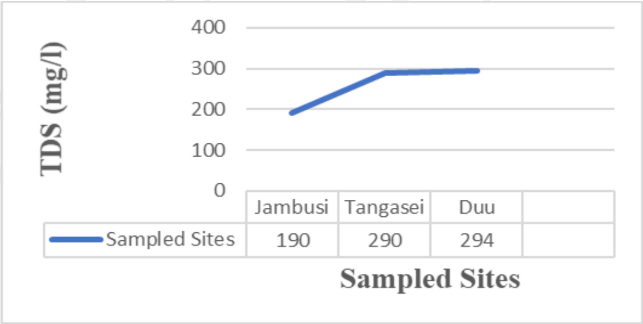
Particulate matter that causes turbidity usually include sediment - especially clay and silt, fine organic and inorganic matter, soluble colored organic compounds, algae, and other microscopic organisms. However, Lisi and Hein (2019) indicate that any watershed has multiple sources of the pollutants or physical features that can affect water clarity, which can be divided into natural or background, and human-induced sources. Natural sources can include erosion from upland, riparian, stream bank, and stream channel areas (Manning, Julian and Doyle, 2020). On the other hand, the human-induced sources include mining of all forms, particularly illegal small-scale gold mining, which was the focus of this study.

Furthermore, noticeable turbidity decreases the aesthetic acceptability of drinking water among consumers. According to WHO (2017), turbidity can vary in colour and appearance, ranging from milky-white clay-based particles to muddiness from sediments and soils, red-brown iron-based particles and mercury-based particles. Aesthetic impacts can lead to indirect health impacts if consumers lose confidence in a drinking-water supply and drink less water, or choose to use lower turbidity alternatives that may not be safe.

3.1.2 *Total Dissolved Solids* (TDS)

Total dissolved solids (TDS) is the term used to describe the inorganic salts and small amounts of organic matter present in solution in water. The analysis of TDS for the three-sampled water from Jambusi, Tangasie, and Duu sites was satisfactory and below WHO's recommended guidelines of $\leq 500\, mg/l$, as indicated in Figure 4. Panels of tasters concerning TDS levels have rated the palatability of drinking water as follows: excellent, less than 300 mg/l; good, between 300 and 600 mg/l; fair, between 600 and 900 mg/l; poor, between 900 and 1200 mg/l; and unacceptable, greater than 1200 mg/l (Idris, Darma and Koki, 2019; Muleya *et al.*, 2020). However, water with extremely low concentrations of TDS may also be unacceptable because of its flat, insipid taste.

Figure 4: TDS Values from the three sites

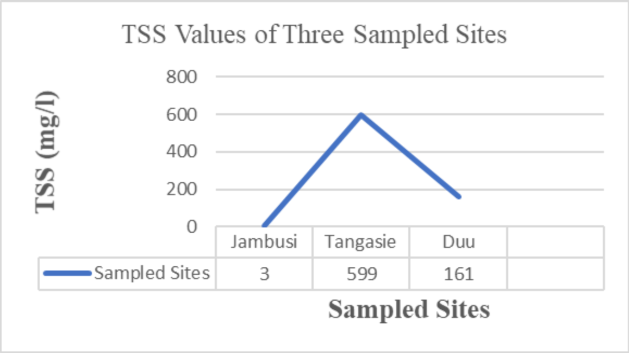


The principal constituents of TDS in water are usually calcium, magnesium, sodium, and potassium cations and carbonate, hydrogen carbonate, chloride, sulfate, and nitrate anions (Selvakumar *et al.*, 2017; Roy *et al.*, 2019). These chemicals were not used by the illegal small-scale gold miners in their operations and was the possible reason for the low TDS values in all the three sites. However, the researchers observed that mercury was the main metal used by the illegal small-scale gold miners in their operations.

3.1.3 Total Suspended Solids (TSS)

Surface waters often contain a variety of solid or dissolved impurities. The TSS analysis of the three samples produced results that were not satisfactory for all the three sites, as TSS level for all the three sites were larger than 2 *microns*, as indicated in Figure 5. High concentrations of TSS decrease the effectiveness of water disinfection agents by allowing microorganisms to "hide" from disinfectants within solid aggregates (Teh *et al.*, 2016; Gupta, Sati and Gupta, 2019), and it is one of the reasons for the removal of TSS of water treatment facilities. Also, flocculation and coagulation may be slow in raw water with high TSS concentration during drinking water treatment.

Figure 5: TSS Values for Three Sampled Sites



3.2 Illegal Small-scale Gold Mining Operatives Perspectives

The researchers further interacted with some illegal small-scale gold miners through informal interviews to understand the illegal miners' perspectives on their operations. Sixty-five (65) illegal small-scale miners were sampled for this study. The demographic characteristics of 65 illegal small-scale gold miners sampled in this study showed that 85% were males and the remaining 15% being female. Illegal small-scale mining involves manual digging and the use of strength; thus, the males were undertaking the digging in all the sites visited, whereas, the few females were fetching water for the washing of the soils in search of gold.

Notwithstanding that, the analysis of the physiochemical parameters indicates the potential pollution of the Back Volta River by illegal small-scale mining activities, majority of the operatives of the small-scale mining did not agree that their operations could affect the Black Volta River quality in any way. Through informal interviews with 65 small-scale miners in Tangasie and Duu, 80% of the small-scale miners interviewed responded that their operations did not have any impact on the Black Volta River water quality.

However, on the knowledge of the small-scale miners on gold mining laws in general and laws governing small-scale mining in particular in Ghana, 90% of the small-scale miners claimed that they had good knowledge of the laws governing small-scale mining, with some of the small-scale miners admitting that their activities were illegal. Nonetheless, some illegal small-scale miners claimed that the central government was not fair to them by disallowing their activities, with a leader at Tangasie explaining that:

> "*We were hear when all of a sudden Asumah Resources Ghana Limited invaded our community without our knowledge and took over our farmlands without compensation but we know we are sitting on gold. Should we sit aloof and allow them to destroy our land, take away our gold and allow us to still wallow in our poverty*?"

Asumah Resources Ghana Limited is a subsidiary of Asumah Resources Limited; an Australia based mining company that has been licensed to mine gold in parts of the Nadowli-Kaleo District, including the Tangasie enclave. Thus, the opinion of the small-scale miners' leader at Tangasie supports other researchers and institutions who found out that small-scale mining has been a support for many rural folks who are usually coerced to sacrifice their farmlands and sources of livelihoods to multilateral mining companies in Ghana (Ladu, Athiba and Demetry, 2019; Pokorny *et al.*, 2019).

Whiles laws have been enacted in Ghana to safeguard the environment against illegal small-scale gold mining, including water bodies; many unemployed youth see small-scale gold mining as their only source of income and usually defy all the odds to engage in it. Worst of all, the lack of proper enforcement of laws on illegal small-scale gold mining has led to non-compliance with the laws by illegal small-scale gold miners. For instance, bulldozers and other earth moving equipment that were seized by a tasked force established by the Government of Ghana to stop illegal small-scale gold mining, cannot be traced. Meanwhile, it is speculated that the seized equipment have been re-distributed to some members of the ruling party to engaged in the same illegal small-scale gold mining activities for which the equipment were seized. Thus, the lack of political will to effectively enforce mining laws and the non-compliance with these laws lead to the pollution of water bodies in Ghana.

4.0 Conclusion

The study revealed that, turbidity was very high in water sampled at two illegal small-scale mining sites (Tangesie: 607 NTU and Duu: 173 NTU) and far above the 5 NTU turbidity prescribed by WHO. However, the turbidity for the water sampled at the Jambosi site (the location of GWCL's Water Treatment Plant) was 4.51 NTU, and was acceptable per WHO's guidelines for drinking water quality. The results on TDS were satisfactory for all water sampled from the three sites. Whereas, the results for TSS test showed the sampled water from the three sites were not satisfactory per the WHO's drink water quality guidelines. The study findings indicate that illegal small-scale gold mining activities in the Upper West Region have the potential of negatively influencing the Black Volta River water quality. However, an assessment of the illegal small-scale gold miners' perspectives on gold mining in Ghana showed that the illegal small-scale gold miners' had poor knowledge of mining laws and the impact of their activities on the Black Volta River water quality. The study, therefore, proposes the strict enforcement of environmental laws in Ghana to stop illegal small-scale mining on and near the tributaries to Black Volta River and other water bodies.

Competing Interests

The authors declare no competing financial interests.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Reference

Baudoin, L. and Arenas, D. (2020) 'From Raindrops to a Common Stream: Using the Social-Ecological Systems Framework for Research on Sustainable Water Management', *Organization and Environment*. SAGE Publications Inc., 33(1), 126–148. doi: 10.1177/1086026618794376.

Daramola, J., Ekhwan, T.M., Adepehin, E.J., Mokhtar, J., Lam, K.C. and Er, A.C., (2019) 'Seasonal quality variation and environmental risks associated with the consumption of surface water: implication from the Landzun Stream, Bida Nigeria', *Heliyon*. Elsevier Ltd, 5(7), e02121. doi: 10.1016/j.heliyon.2019.e02121.

Fu, B., Merritt, W.S., Croke, B.F., Weber, T.R. and Jakeman, A.J., (2019) 'A review of catchment-scale water quality and erosion models and a synthesis of future prospects', *Environmental Modelling and Software*. Elsevier Ltd, 75–97. doi: 10.1016/j.envsoft.2018.12.008.

Grennfelt, P., Engleryd, A., Forsius, M., Hov, Ø., Rodhe, H. and Cowling, E., (2020) 'Acid rain and air pollution: 50 years of progress in environmental science and policy', *Ambio*. Springer, 849–864. doi: 10.1007/s13280-019-01244-4.

Gupta, R., Sati, B. and Gupta, A. (2019) 'Treatment and Recycling of Wastewater from Pharmaceutical Industry', in Garg, M. (ed.) *Advances in Biological Treatment of Industrial Waste Water and their Recycling for a Sustainable Future*. Springer, Singapore, 267–302. doi: 10.1007/978-981-13-1468-1_9.

Idris, M., Darma, T. H. and Koki, F. S. (2019) 'Investigation on tranport and mixing processes of water pollutants: an assessment of effluents from some industries in Kano - Nigeria', *Bayero Journal of Pure and Applied Sciences*, 11(1), 368. doi:

10.4314/bajopas.v11i1.59s.

Kortei, N.K., Heymann, M.E., Essuman, E.K., Kpodo, F.M., Akonor, P.T., Lokpo, S.Y., Boadi, N.O., Ayim-Akonor, M. and Tettey, C., (2020) 'Health risk assessment and levels of toxic metals in fishes (Oreochromis noliticus and Clarias anguillaris) from Ankobrah and Pra basins: Impact of illegal mining activities on food safety', *Toxicology Reports*. Elsevier Inc., 7, 360–369. doi: 10.1016/j.toxrep.2020.02.011.

Ladu, J. L. C., Athiba, A. L. and Demetry, P. L. (2019) 'Environmental Impacts of Gold Mining : A Study of Mining Communities in Environmental Impacts of Gold Mining : A Study of Mining Communities in Gorom Village , Rejaf County , Central Equatoria State , Republic of South Sudan', *Science and Education*, 7(February), 1–10. doi: 10.12691/aees-7-1-1.

Laghari, A.N., Walasai, G.D., Jatoi, A.R., Shaikh, F.A. and Siyal, Z.A., (2018) *Performance Analysis of Water Filtration Units for Reduction of pH, Turbidity, Solids and Electricity Conductivity*, *Engineering, Technology & Applied Science Research*. Turbidity.

Lisi, P. J. and Hein, C. L. (2019) 'Eutrophication drives divergent water clarity responses to decadal variation in lake level', *Limnology and Oceanography*. Wiley Blackwell, 64(S1), S49–S59. doi: 10.1002/lno.11095.

Manning, A., Julian, J. P. and Doyle, M. W. (2020) 'Riparian vegetation as an indicator of stream channel presence and connectivity in arid environments', *Journal of Arid Environments*. Academic Press, 104167. doi: 10.1016/j.jaridenv.2020.104167.

McKenna, A. (2020) *Black Volta River*. Available at: https://www.britannica.com/place/Black-Volta-River (Accessed: 10 April 2020).

Mujere, N. and Isidro, M. (2015) 'Impacts of artisanal and small-scale gold mining on water quality in Mozambique and Zimbabwe', in *Impact of Water Pollution on Human Health and Environmental Sustainability*, 101–119. doi: 10.4018/978-1-4666-9559-7.ch005.

Muleya, E., Nyomombe, T., Maphosa, N.S. and Matunhu, V., (2020) 'Assessing water quality and its relationship to selected disease patterns in Zvishavane Town, Zimbabwe', *Journal of Applied Sciences and Environmental Management*. African Journals Online (AJOL), 23(11), 2029. doi: 10.4314/jasem.v23i11.21.

Perrin, Y., Bouchon, D., Delafont, V., Moulin, L. and Héchard, Y., (2019) 'Microbiome of drinking water: A full-scale spatio-temporal study to monitor water quality in the Paris distribution system', *Water Research*. Elsevier Ltd, 149, 375–385. doi: 10.1016/j.watres.2018.11.013.

Pokorny, B., von Lübke, C., Dayamba, S.D. and Dickow, H., (2019) 'All the gold for nothing? Impacts of mining on rural livelihoods in Northern Burkina Faso', *World Development*, 119, 23–39.

Pradesh, M. and Sarup, J. (2018) 'Water Quality mapping using Remote Sensing and GIS- a case study of Pampawa Watershed in Jhabua Dist ', *International Journal of Scientific Research & Engineering Trends*, 4(5), 999–1006.

Reed, B., Smith, M. D. and Shaw, R. (2017) *G031: Measuring the turbidity of water supplies.*, *Water Quality Analysis*. Available at: https://repository.lboro.ac.uk/articles/G031_Measuring_the_turbidity_of_water_supplies/9582362 (Accessed: 21 April 2020).

Roy, M.K., Roy, P.C., Reza, A.S., Ahmed, N., Moniruzzaman, M. and Hossain, S., (2019) 'Water Quality Studies of the Kapadak River Basin, South-Western Bangladesh with Special Emphasis on Environmental Degradation', *Journal of the Geological Society of India*. Springer, 94(6), 624–634. doi: 10.1007/s12594-019-1369-4.

Selvakumar, S., Ramkumar, K., Chandrasekar, N., Magesh, N.S. and Kaliraj, S., (2017) 'Groundwater quality and its suitability for drinking and irrigational use in the Southern Tiruchirappalli district, Tamil Nadu, India', *Applied Water Science*. Springer Nature, 7(1), 411–420. doi: 10.1007/s13201-014-0256-9.

Singh, N.S., Sharma, R., Parween, T. and Patanjali, P.K., (2018) 'Pesticide contamination and human health risk factor', in *Modern Age Environmental Problems and their Remediation*. Springer International Publishing, 49–68. doi: 10.1007/978-3-319-64501-8_3.

Song, Z., Zhang, X., Ngo, H.H., Guo, W., Wen, H. and Li, C., (2019) 'Occurrence, fate and health risk assessment of 10 common antibiotics in two drinking water plants with different treatment processes', *Science of the Total Environment*. Elsevier B.V., 674, 316–326. doi: 10.1016/j.scitotenv.2019.04.093.

Starr FM (2020) *Covid-19: Bunso Water Treatment Plant shut down again over galamsey*. Available at: https://starrfm.com.gh/2020/04/covid-19-bunso-water-treatment-plant-shut-down-again-over-galamsey/ (Accessed: 10 April 2020).

Stout, J., Tellinghuisen, D.J., Wunder, D.B., Tatko, C.D. and Rydbeck, B.V., (2019) 'Variations in sensitivity to chlorine in Ecuador and US consumers: Implications for community water systems', *Journal of Water and Health*. IWA Publishing, 17(3), 428–441. doi: 10.2166/wh.2019.297.

Teh, C.Y., Budiman, P.M., Shak, K.P.Y. and Wu, T.Y., (2016) 'Recent Advancement of Coagulation-Flocculation and Its Application in Wastewater Treatment', *Industrial and Engineering Chemistry Research*. American Chemical Society, 4363–4389. doi: 10.1021/acs.iecr.5b04703.

Tran, N.H., Reinhard, M., Khan, E., Chen, H., Nguyen, V.T., Li, Y., Goh, S.G., Nguyen, Q.B., Saeidi, N. and Gin, K.Y.H., (2019) 'Emerging contaminants in wastewater, stormwater runoff, and surface water: Application as chemical markers for diffuse sources', *Science of the Total Environment*. Elsevier B.V., 676, 252–267. doi: 10.1016/j.scitotenv.2019.04.160.

Tyagi, D. and Malik, D. S. (2018) 'Assessment of Physico-chemical parameters and water quality index of Ram-Ganga reservoir at Kalagarh (Uttarakhand)', *International Journal of Current Research in Life Sciences*, 07(03), 1234–1239.

Ugbaja, A. N. and Ephraim, B. E. (2019) 'Physicochemical and bacteriological parameters of surface water quality in part of Oban Massif, Nigeria', *Global Journal of Geological Sciences*. African Journals Online (AJOL), 17(1), 13. doi: 10.4314/gjgs.v17i1.2.

water.org (2019) *Ghana's Water Crisis - Ghana's Water In 2019*. Available at:

https://water.org/our-impact/ghana/ (Accessed: 9 April 2020).

World Health Organization (2017) *Water quality and health-review of turbidity: Information for regulators and water suppliers, Who/Fwc/Wsh/17.01*.