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Beyond the doom: Sustainable water management practices of small-scale mining operations

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ABSTRACT

Artisanal and Small-scale Mining (ASM) is often implicated as a source of pollution to water systems. In this paper, we explore the water management systems of a formalised small-scale mining operator in Ghana to explicate how its operational activities and organising routines contribute to sustainable water management in practice. Emphasizing how sustainable management of water bodies play out in organising, our study highlights the underpinning mechanisms shaping the shift to environmentally sustainable operations. By unpacking the complex practices of water management in ASM operations, the study extends understanding of how sustainability driven practices emerge and comes to be identified and labelled in the context of an industry historically tagged as an 'enemy of the environment', and the consequences that follow. Thus, contrary to the dominant logic of stigmatizing ASM as water polluting champions, our study suggests that ASM operators could be caretakers of water bodies and the environment. We conclude by highlighting implications for policy on sustainable water management.

1. Introduction

'Small-scale mining is mostly known for its faults. It's time to see what it gets right' (Zavala, 2017).

Good quality water is important for the existence of man and all forms of life (WHO, 2011). Hence water pollution may have serious consequences on the health of living organisms. However, access to good and quality water can be challenging and a problem (Murhekar Gopalkrushna, 2011). This precious resource is increasingly being threatened as populations increase, leading to the demand of more water of high quality for domestic purposes and industrial activities (Ackah et al., 2011; Sayyed and Wagh, 2011). In Ghana, for example, even though the country is well endowed with water resources, its availability is rapidly decreasing due to climate variability and change, rapid population growth, increase in environmental degradation and pollution of rivers and draining of wetlands (Dorleku et al., 2018; Ackah et al., 2011).

Artisanal and small-scale mining (ASM) is often described as a low-tech, labour-intensive type of mining (Hilson, 2017). According to IGF however, ASM is a complex and diversified sector that includes poor informal individual miners seeking to eke out or supplement a subsistence livelihood, to small-scale formal commercial mining activities that can produce minerals in a responsible way respecting local laws[1] (IGF, 2017a; 2017b). Worryingly, however, the increase in ASM activities continues to have major negative impacts on water and land quality in many mining communities (Ofosu et al., 2020; Worlanyo and Jiangfeng, 2020). ASM operations have been known to be a major contributor of metals in surface and groundwater within water basins because of indiscriminate use of, for example, mercury (Hg) and other chemicals, which are detrimental to human health (Donkor et al., 2006; Ramírez et al., 2021). Small-scale gold mining all over the world is noted for its effects on water bodies through pollution of both ground and surface waters, because its activities by nature make use of a lot of water thereby seriously polluting water resources (Owens et al., 2005; Mensah et al., 2015). Rivers, streams, and other water bodies have been found to be contaminated by trace elements such as mercury (Hg) from artisanal mining operations, and their values have also been found to exceed standard safety levels (Nartey et al., 2011; Agyarko et al., 2014). However, it is still worth remarking that these problematic water management issues are usually associated with the operations of illegal (unregistered) small-scale miners, popularly known as *galamseyers* in Ghana (Ofosu et al., 2020), who constitute a vast majority of small-scale mining operators. According to studies, over 90 percent of ASM operations are found – many of them embedded – in the informal economy, carried out by individuals and groups who are not in possession of a license (Hilson, 2017; Hilson and Hilson, 2015; Wagner, 2016).

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[1] This study focuses on the latter definition (formal mining operations). However, since the majority of the operators are found in the former, coupled with the fact that the burgeoning literature also focuses on the former, the study highlights both definitions throughout.

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It is however worthy to remark that efforts to minimise the environmental quagmire associated with the expansion of the ASM sector have lead many governments to look for efficient ways to regulate the operations of the sector through formalisation (Hilson et al., 2018). The formalisation process has been aimed at advancing the sector from its transient, inefficient, and ecologically harmful ways to a settled, sustainable business path (Siegel and Veiga, 2009). To effectively regulate ASM activities, a host of countries have legalised ASM by providing a regulatory framework through which mining entrepreneurs can secure a license and operating permits to operate legally (Hilson et al., 2018). Generally, formalisation entails the legalisation of ASM, the observance of all the provisions and requirements set forth in the mining code. Although formalisation has proved challenging with its bureaucratic and high costs spawning illegal mining activities, recent reports are beginning to show that a number of individuals and companies do overcome the formalisation barriers and have secured titles to mine using more advanced technology (Hilson and Maconachie, 2020). The formalisation principles and legal recognition are imposing obligations on mining entrepreneurs to conform to environmental standards (Siegel and Veiga, 2009).

In recent years, our understanding of the different environmental management practices in ASM has improved immensely (Zavala, 2017). Our knowledge of the dynamics of ASM, specifically information on the type of equipment now found at mining sites and the organising practices has been enhanced tremendously (Siegel and Veiga, 2009; Verbrugge, 2015). In addition, studies in countries such as Ghana (Crawford and Botchwey, 2017) and the Philippines (Verbrugge, 2015) have revealed a prominent role for external financiers. The injection of capital has led to a growing differentiation among ASM operations in terms of their level of professionalization (Verbrugge, 2015). Moreover reports are beginning to show that there exists small-scale formal commercial mining activities that can produce minerals in a responsible way respecting local laws (IGF, 2017b; Zavala, 2017).

This present study contributes to these efforts to highlight the operations of the 'responsible' miners by examining the sustainable water management practices of a formalised small-scale mining operator in Ghana. The findings demonstrate that legal obligations, especially on the part of concessioners and mining entrepreneurs, to conform to environmental standards regarding small-scale mining activities can engender different results on water quality. In this regard, the findings show that the organising practices of this small-scale mining operator, with regards to sustainable water management mechanisms have largely lead to the non-pollution of the main river that runs its course through the operational site. This has largely been achieved through the establishment of ponds to recycle water for mineral processing purposes. Hence the river that runs its course through the concession has virtually remained non-polluted at least at the *compliance stage* – where the water is within the catchment area/concession site of the mining operations, and the *surveillance stage* – where the water leaves the catchment area/concession site of the mining operations. In addition, the absence of mercury for processing at the mine site has been very beneficial to the river, and in effect to the members of the community who depend on the river for domestic and agricultural purposes. On the basis of different water quality indices, the quality of the water of the study area is deemed good. We will provide the fine details of the organising practices of our case organisation in a later section. Before that however, we deem it fit to contextualise this study and its findings in the mining-related water pollution quagmire currently being witnessed in Ghana's mining landscape.

1.1. ASM in Ghana: the water degradation quagmire

River bodies serve as sources of water for domestic purposes in most rural communities. They also serve as sources for farmland irrigation and food cropping. Following the intensification of reports by the Ghanaian media on the deleterious effects of illegal mining on some major water bodies in the country, there have been revelations to the effect that illegal mining operations have negatively impacted the hydrosphere in most mining communities nationwide (Eshun, 2017; Mensah et al., 2015). The sluicing and amalgamation processes which are commonly associated with illegal mining have released solid metal waste and mercury into water bodies and streams (Mensah et al., 2015). The water pollution situation is not dire but frightening because high volumes of harmful chemicals used in the mining process by illegal miners have been dumped into water bodies across the country (Eshun, 2017). This is corroborated by Mensah et al. (2016) in Prestea in the Western Region. The study found that illegal mining operations were carried out in the open air without appropriate safeguards and environmental standards, and in the process released contaminated water into the surrounding environment thus polluting nearby rivers. Bansah and Bekui (2015) reveal that the Bonsa river, also in the Western Region has been dredged and polluted by *galamsey* operators increasing the cost of water treatment by over 90 percent.

The Ghana Water Company (GWC) in a report on the activities of illegal miners and their impact on the country's water bodies, lamented that the River Pra, Daboase and River Ankobra in the Western Region have been polluted. In the Eastern Region, the course of one of the main water bodies, River Birim, has been diverted, and the river heavily polluted, leading to the shutdown of water treatment plants in Kyebi. Also due to illegal mining activities, the Enu River, which serves the residents of Konongo in the Ashanti Region has been polluted. Further, the Black Volta in the Upper West Region has not been spared its share of contamination by the activities of illegal miners. The GWC report also revealed that several other rivers in the Brong Ahafo Region and the Central Region have faced similar issues of pollution (Citifmonline.com, 2017b, 2017a). The following excerpt from a farmer in the Manso Abore town of the Amansie West district represents a good illustration of the water problems residents have had to endure due to the negative effects of *galamsey*:

Before the galamsey, when the farmer was going to his farm, he brought an empty bottle, because he knows that he could fetch water from the river on the way. But now the people of the community are crying for water, because the galamsey have destroyed it (Farmer 1, MansoAbore, 16.01.2014). (Bach, 2014, p.51).

Prior to the total ban on small-scale mining activities in Ghana in 2017 (Eduful et al., 2020; Osei et al., 2021), the GWC officials had warned that the country risked importing water from neighbouring countries with local residents in mining communities facing severe potable water shortages.

2. Methods

The study employed a qualitative research approach involving semi-structured interviews with 20 employees of the case organisation. In addition, the purposive sampling technique was employed to interview the project manager of the case organisation, 2 officers of the Minerals Commission (MC) and 2 employees of the Environmental Protection Agency (EPA). In view of the fact that the main communities surrounding the ASM area of this study are mainly farming communities, the snowballing technique was used to interview 15 local residents (10 males, 5 females) who are predominantly farmers. Their responses were deemed very essential also because their economic activities surround the main mine sites and are thus directly affected by the environmental and water management practices of the mining company In addition, the environmental and safety officer of the case organisation was a prime respondent because of his in-depth knowledge in the environmental and water management systems in operation at the mine site.

In line with the logics of the case study approach (Siggelkow, 2007), we selected a formalised small-scale mining firm to help us in-depth knowledge on sustainable water quality management mechanisms at the mine site. We develop our contribution based on the operations and work practices of a mining company under the pseudonym of Mabodia

Mines (MM), a mining firm which has been in the extractive business for close to a decade, and has secured large concessions in Ghana - the epicentre of artisanal gold mine production for many centuries (Hilson, 2002). However, since MM has been unable to exploit the mineral resources, a section of the concession in the eastern part of Ghana has been given to a small-scale mining company under the pseudonym Mpaem Akwa Mines (hereafter MAM). This mining company was selected for this study because initial interviews with the officers of the MC revealed that the company is a 'model' in the mining industry in terms of good environmental and water management practices.

The concessions allocated to MAM are divided into not more than 25 acres. MAM is tasked to provide small-scale mining support services on the concession. This comprises the exclusive right to extract, process and sell the mineral wealth of the concession. The two companies have sharing arrangements in relation to the funds that accrue from the sale of gold from the concession. While MAM takes responsibility for the recruitment of their own employees, MM is answerable to the Minerals Commission (MC) and takes the ultimate responsibility in the environment management processes. A critical component of this environmental management process is the management of the quality of the river that runs through the concession.

The field research was conducted in December 2020 to June 2021 inside the mining compound of OMCL. During the research period, the first author visited the mining site to observe the day-to-day work and mining activities in the compound. Specifically related to water management mechanisms, an extensive interview was conducted with the safety and environmental officer and project manager of MAM at the mining site. The first author observed all the water ponds under the supervision and guidance of the safety and environmental officer. The interviews which typically lasted 30–40 min each were tape recorded and transcribed within 24 hours of collection. The interviews data together with data collected through observations from the work site were triangulated into a whole.

3. Data analysis

The recorded interviews were transcribed and checked against the recorded audio files and field notes separately by both authors to ensure the accuracy of the data. Then the transcribed data by each author was exchanged and re-checked. Once satisfied that the recorded audios reflected what had been transcribed, the interviews were then coded into main themes, sub themes, and common themes. Importantly also at this stage, judgements about meanings of contextual statements were made so that the relevance and importance of issues and implicit connections between them could be made (Hardy and Bryman, 2009). Here, we also made cross-references between the transcribed data, mental and field notes and in some cases, the original audio file to get a better understanding of the relevant themes. These processes were also undertaken separately by each author and was later verified and re-checked in turns.

As part of the analysis, three main themes i.e the water management practices, 'motivations' for these practices, and 'perceptions' and 'realities' were developed and coded. The coding process was recursive in nature and involved movements back and forth with the data and the emerging themes. Here it is worth mentioning that the issue of confidentiality and anonymity was very important to the mining company especially. Therefore the name of the company, and other names in general were anonymised in the final stages. To ensure the validity and credibility of data documents that were provided to the researchers, see for example Tables 1 and 2, the documents were checked with multiple sources of evidence from officers of the MC, EPA and the Ghana Standards Authority water quality reports, see (Ministry of Water Resources, Works and Housing, Ghana, 2015).

Finally, the thematic frameworks identified were then applied to the entire dataset by annotating them with numerical codes which were also supported with short descriptors that elaborate the headings (Ridder, 2014; Ritchie and Spencer, 1993). This helped us to develop a meaningful and more robust understanding of the data that enabled subsequent interpretation and the verification of meanings (Miles and Huberman, 1994). Following this, we engaged in what we refer to as a systematic and rigorous comparison of our indexed themes with the existing literature to build up understanding of the organising practices of MAM to develop greater insight into how they contribute to quality water management in practice. We present the fine details of our research findings in the paragraphs that follow.

Table 1
Water quality analysis for Buxux resource block site 1.

Parameters	Unit	Buxux control	Buxux compliance	Buxux surveillance	Ghana Standards
pH		7.52	7.47	7.50	6.5–8.5
Conductivity	μS/cm	56.1	53.8	64.5	2000
Turbidity	NTU	24.8	23.2	26.2	0.1–5.0
TDS	mg/L	28.1	26.8	32.2	1000
Nitrate	mg/L	0.62	0.78	0.96	50
Sulphates	mg/L	23	26	34	250
Fluoride	mg/L	0.251	0.282	0.419	1.5
Total alkalinity	mg/L	160	300	295	500
Chloride	mg/L	56	62	77	250

Source of water: Buxux stream: Date of water sampling: 07/08/20
Date of analysis: 10/08/20–19/08/20.
Physical/chemical water analysis report.

Table 2
Water quality analysis for Buxux resource block site 1.

Parameters	Unit	Buxux control	Buxux compliance	Buxux surveillance	Ghana Standards
pH		6.98	7.03	6.99	6.5–8.5
Conductivity	μS/cm	57.7	57.8	66.0	2000
Turbidity	NTU	18.7	20.0	18.9	0.1–5.0
TDS	mg/L	28.8	29.1	32.8	1000
Nitrate	mg/L	0.38	0.44	0.35	50
Sulphates	mg/L	8	17	13	250
Fluoride	mg/L	0.102	0.100	0.087	1.5
Total alkalinity	mg/L	345	210	220	500
Chloride	mg/L	24	14	13	250

Source of water: Buxux stream: Date of water sampling: 12/05/20
Date of analysis: 13/05/20 – 22/05/20.
Physical/chemical water analysis report.

4. Research findings

4.1. Water management systems at MAM

At the concession site where MAM currently operates, a river we refer to here as Buxux runs its course through the area. To protect this river from being polluted, water ponds have been created to store water that is recycled and deployed for processing of the mineral ores. The safety and environmental officer took the researcher round the site to show him the water ponds, and how they operate. The officer explains it as follows:

At the start of our operations, we take the water from the Buxux river. We first store the water in a freshwater pond. Then the water comes to the plant where it is employed for washing the gravels and the ores. After this the water runs through the ponds to be recycled and reused. In all we have nine ponds. The first pond is strategically located after the processing plant. The processed water from the plant settles in the sand pit 1. From this first sand pit, it goes to the second sand pit. We remove the sediment from the water from these first two pits. After this stage, the sediment is so fine that you cannot use the excavator to remove the sediment. You must leave it to harden before the excavator can be used. So, we use slurry pumps. Others refer to these pumps as *Changfa* pumps. These machines pump the water to the tailings storage facility (TSF). Once we pump the water into the TFS we wait for the sediment to dry. Then some of the water will evaporate leaving the sand. Some of the water will also sink. After this stage, the water goes to the first settling pond. We have slurry machines in the first and second settling ponds. From there it goes to the third settling pond. Throughout this process, the water settles until it gets to the final pond. The ninth pond is the freshwater pond where the water becomes clear. Sometimes the water here is very clear. Sometimes also, depending on the material we wash, the water is not so clear. But it is better. We can use it for further washing then we pump it to the plant. We don't have to take water from the Buxux river again. We can also get water from the rain. The rainwater enters the second sand pit, and we reuse it in the system. We don't do pumping during the rainy season; we only do it in the dry season - January, February, March. I must also explain that the water flows by gravity. Our dams are created by digging pits. So once the water rises to a level, it flows into the next pond, and this helps avoid spillage.

According to management of MAM, the water management systems outlined above are encapsulated in their obligatory functions. Specifically, MAM is required by the mining regulator i.e., the MC and EPA to undertake physical/chemical water analysis to ensure environmental and water safety. Hence the water at the site is periodically subjected to checks to ensure that it meets the required physico-chemical standard for use. This process and procedure are examined below.

4.2. Water quality analysis by MAM and the relevant authorities

As indicated above, as part of the requirements in ensuring water safety, the EPA lists the requirements for water quality and its management together with the mining permit conditions. To meet this requirement, management of MAM is required to send samples of the water from the Buxux river and the water from the ponds to a private laboratory for physico-chemical analysis and testing. To ensure proof of quality, the Ghana Standards Authority (GSA) also checks the water quality from the site of MAM. The water analysis check by the GSA is done quarterly while that of the private company is undertaken monthly. The GSA checks the water quality quarterly to compare results with that of the private company. According to the project manager, when there are issues e.g. legal suits, the water quality checks by the private company is supposed to be compared with that of the GSA.

4.3. Parameters

The water samples are checked with regards to parameters such as pH, conductivity, turbidity, total dissolved substances (TDS) and sulphates. Other parameters include fluoride, nitrate, total alkalinity and chloride. The researcher was provided with documents indicating the physical/chemical water analysis report by the private laboratory for a quarterly period in 2020. The analysis reports indicate that samples of the water are taken at three main points: the *Buxux control* i.e., the area just before the river enters the concession site; *Buxux compliance*- at this stage, the water is within the catchment area/concession site of the mining operations of MAM; *Buxux surveillance* i.e., the area just before the water leaves the catchment area/concession site of the mining operations of MAM. Details of these reports are indicated in the tables below.

4.4. Water quality analysis and discussion

The water analysis showed that generally almost all the parameters are within the acceptable standards set by the GSA. We provide highlights of the analysis as follows.

pH (power of Hydrogen) is one of the most essential parameters for the assessment of water quality and this is due to its influence on the chemical, biological and geological processes that take place in the environment (Nukpezah et al., 2017; Robinson, 2012). pH generally shows the alkaline or acidic levels of water (Robinson, 2012; Bauder et al., 2011). Water with a pH below 7 is generally considered acidic while water with a pH above 7 is usually considered alkali (Robinson, 2012; Bauder et al., 2011). According to studies, one of the greatest threats associated with an abnormal pH in water for irrigation purposes is its impact on the equipment used for irrigation (Jeong et al., 2016). Very low pH in water – implying the water is highly acidic - can hasten the corrosion of irrigation equipment (Jeong et al., 2016; Nukpezah et al., 2017). In addition, irrigation water with a pH outside the acceptable limits may affect the availability of some plant nutrients (Hussain et al., 2010).

In Ghana, the GSA recommends keeping the pH between 6.5 and 8.5 in drinking water and water for other agricultural purposes, see (Ministry of Water Resources, Works and Housing, Ghana, 2015). From the tables above, it could be seen that all the sampling sites at the MAM catchment area recorded pH levels that are within the Ghana Standards permissible limits.

Conductivity of water is a very important parameter in determining the suitability of water for domestic and agricultural purposes as it affects the salinity of the water which subsequently affects the productive levels and crop yield (Bauder and Brock, 2001; Sundaray et al., 2009). From the tables above, the conductivity levels obtained at the MAM site are all below the 2000 μS/cm (microSiemens per centimetre) permissible limits set by the GSA.

Turbidity is the measure of the presence of particulate matter such as clay/silt, decomposed organic matter and other forms of pollutants that reduce the transparency of water (Murhekar Gopalkrushna, 2011; Gyamfi et al., 2012). Problematically, irrigating crops with turbid water could affect the quality levels of the crops produced, since bacteria and viruses could attach and migrate to the crops through solid particles in the water (Jeong et al., 2016). Also, high turbidity levels in irrigation water affects the aesthetic quality of farm yield (Jeong et al., 2016). As can be seen from the tables, the turbidity levels of the Buxux river at the mining site of MAM are above the GSA standard of 0.1–5.0 Nephelometric Turbidity Units (NTU). Worth noting however is the fact that at the control point (i.e before the water entered the concession of MAM), the turbidity levels were well above the GSA standard. When asked about the turbid nature of the river, the geologist employed by MAM explained that although the area had been rid of illegal miners, there were still tiny pockets of illegal mining activities upstream. This was confirmed by one resident farmer. In his words:

> There were very many illegal mining operations in this area before this mining company (MAM) took over. The *galamseyers* even used to mine directly in the river. Now the *galamseyers* have left this area but they still come back once in a while. A few months ago when I visited my farm, these operators had come in the night to excavate a section of the land. But their operations are not as rampant as before. The police and the military have helped to push them away almost entirely from this area

In relation to the operations of MAM, it is critical to note that at the compliance point (i.e when the river was in the concession of MAM) there was no significant difference in the turbidity levels. This is because although MAM employs heavy earth moving equipment such as excavators in the mining operations, the extractive activities are strategically undertaken far away from the river. This helps to prevent the dissolution and washing of silt into the river. In addition, the operations do not discharge tailings into the river.

Total dissolved solids (TDS) is the measure of the total organic and inorganic substances dissolved in the water (Nukpezah et al., 2017). The GSA standard for TDS in water is 1000 mg/L (milligrams per litre) (Ministry of Water Resources, Works and Housing, Ghana, 2015, p.125). The total dissolved solid concentrations observed at the MAM site in this study are far below the GSA limits. This means the water (Buxux) is suitable, TDS-wise, for agricultural use.

Nitrate in irrigation water is often considered as beneficial to crop production (Nukpezah et al., 2017). From the tables, the concentrations of nitrate in the Buxux river recorded at the MAM concession site fell within the GSA permissible limit of 50 mg/L. This is a favourable result since high concentration of nitrate in irrigation water can cause excessive vegetative growth, poor crop quality and delay maturity in crops (Bauder and Brock, 2001; Bauder et al., 2011).

The presence of **fluoride** in water is usually occasioned during weathering and circulation of water in rocks and soils; fluorine usually leaches out and dissolves in ground water (Murhekar Gopalkrushna, 2011). In the water quality analysis at the MAM site, fluoride concentrations were found to be within the GSA acceptable limits.

Alkalinity of water is its capacity to neutralize a strong acid (Murhekar Gopalkrushna, 2011). Alkalinity of water is normally due to the presence of bicarbonate, carbonate and hydroxide compound of calcium, sodium and potassium (Murhekar Gopalkrushna, 2011). Total alkalinity values for all the investigated samples at the MAM mining site were found to be in the permissible limits of the GSA.

In sum, and as can be gleaned from the tables, it is worth reiterating that all the parameters, with the exception of for example *turbidity*, at the MAM site (i.e. the compliance) recorded concentrations that were within the GSA permissible limits. As indicated earlier however, the high turbidity levels were due to some activities of illegal mining operators upstream. Thus, generally, the sustainable water management systems engineered by MAM have been very beneficial to the river. Hence the researcher sought to find out from the residents their perceptions on the water management systems by MAM and the impact on the use and the potable nature of the water. These findings are presented below. Before that however, management of the company explained to the researcher the motivations behind the sustainable water management practices.

4.5. The underpinning (manifest) reasons

At this stage, the researcher sought to find out from management of MAM the underpinning reasons behind the water management systems in operation at the mining site. The project manager explained that obviously it was because of their obligation to conform to environmental standards which is enshrined in the mining laws. Management of MAM also consider that, just like land reclamation mechanisms, they have an obligation towards the safety of the people living in the communities in which they mine. Management of MAM consider the protection of the water bodies as a form of corporate social responsibility (CSR). In the words of the project manager:

> We undertake these water management projects because we are required to do so. We stand the risk of losing or failing to renew our mining permits if we fail to adhere to the environmental standards. However, we also consider that we have an obligation towards the safety of the people in these mining communities. We have been in this mining business for a long time, and we know what it is like to leave the mining communities polluted. The residents never forgive you; and you leave them bitter. Although we met the Buxux river very polluted by the activities of previous miners, we can't continue in the same vein. We need to show that we are responsible and law-abiding miners. If we cannot make the physical environment better, we cannot leave it worse. This has always been our guiding principle.

4.6. The underpinning (latent) reasons

Here, interviews with the project manager revealed a second and interesting reason why MAM undertakes the good water management activities. Here, it is very important to state that the company undertakes extensive land reclamation activities on the concession after extraction activities are over. After covering the pits with the rocks, subsoil, and the topsoil (primary reclamation), crops such as cassava and plantain are cultivated on the reclaimed lands. While the plantain provide shade for the cassava, they also help restore the lost nutrients, and their leaves are employed for mulching. Leguminous plants are also planted at various sections of the land to restore lost nitrogen to the soil. Inorganic fertilisers are however not applied to the land and the plants. This is because, as indicated earlier, the Buxux river runs its course through the concession and the company does not want to get it polluted by the chemicals of inorganic fertilisers.

During the cultivation phase, the workers volunteer to cultivate the cassava for consumption. However, as a way of restoring the lost nutrients, the first cassava plants to be cultivated on any plot of the land are not harvested during the first maturity period. The tubers are left to rot beneath the soil to restore nutrients. In the second harvest season however, the cultivated crops are usually given to the employees as a way of motivation. To ensure that the land is environmentally safe for crop cultivation, and to prevent the transfer of mining-related heavy metals and pollutants to the food chain, interviews with the project manager of MAM and officers of the EPA revealed that samples of the harvested food are regularly taken to the laboratory of the Ghana Standards Authority (GSA) for checks. The tests usually comprise the determination of the presence of heavy metals and other substances – lead, mercury, cadmium, acinic etc. Since operations started, all the food harvested on the reclaimed sites have been deemed fit for consumption by the officers of the GSA, partly because MAM does not employ the use of mercury or other chemicals in the mining and mineral processing stage.

Hence, according to the project manager, a latent reason behind the water management systems in place at the mine site is to find good quality water to irrigate the crops that are cultivated on the reclaimed lands. The manager explained it as follows:

> As we've already indicated, we provide food for the workers as a way of motivating them to work for us. Some of these crops are usually cultivated on the reclaimed lands. However, we need to irrigate these crops, especially the vegetables. Good quality water is essential in this case. So, we employ the water from our ponds for this purpose. In this case, we cannot have the river polluted since we sometimes source water from it. The quality of the food we harvest is a function of the quality of the water we use to irrigate the crops. So, it's a win-win situation for us and the community to make sure the water is devoid of pollutants.

The quote above suggests that mining operators themselves stand to benefit economically by adhering to environmental standards regarding mining. By employing good quality water, which has been realised through prudent efforts to maintain the water sources - i.e the river and the ponds - non-polluted, irrigation of crops has become possible. This has ensured good crop yield which has had beneficial consequences for both the company and the employees. Notwithstanding the massive beneficial consequences of the water management systems, however, it is worthy to note that the water quality analysis processes are not cost-free. The processes can come at huge financial costs to operating companies. This is also the case with MM and MAM which we focus on below.

4.7. Cost of water quality analysis

To ascertain the costs associated with the water quality analysis, the following interview excerpt between the researcher and the project manager is worth looking at.

Researcher (R): What is the estimation of the cost of the water quality analysis by the private laboratory and the GSA?

Project manager (PM): it should be around Ghc 25,000[2] - 30,000

R: but that is on the high side or?

PM: yea, but it includes the water testing and everything. The charges by the private laboratory are not different from that of the GSA.

R: but exactly is meant by you when you say the charges and *everything?*

PM: everything including the testing, verification and the preparation of reports. With the GSA, the last time they tested our water the cost was around Ghc 20,000.

R: Ghc 20,000 for one month?

PM: No quarterly, but the samples are taken for a particular month. And it also depends on the number of samples they take at a particular time. For every parameter, they have how much they charge. For the physico-chemical test, the last time we checked it cost us Ghc 990 per bottle of water. And sometimes we take as much as 28 bottles. We also test for the quality of the water in our boreholes and ponds which provide water for the employees for sanitation purposes, and for irrigation.

4.8. Supervision and assessment by regulatory institutions

Mining authorities have so often been found or accused of failing to undertake their obligatory functions such as, for example, the monitoring of the operations of small-scale miners. However, this was not the case during the course of this research work. Here, to confirm the water quality analysis from the regulatory institutions, the researcher consulted officials of the MC and the EPA for their assessment of the water operations of MAM. Here, an official of the MC revealed to the researcher that they regularly monitor the activities of the company to make sure that their management systems are up to standard. Indeed, during the research period, the researcher witnessed that officials of the MC visited the mine site on three different occasions. The MC official gave his assessment of the water quality systems at the mine site as follows:

We come here regularly to check the operations of the company. We know they are doing a good job, but we must also do our job and monitor their operations very well. We've looked at their report on water quality and it is really good. Their operations are very different from those of the illegal miners who continue to cause environmental damage nationwide. If I may not be seen to be praising this company (MAM) too much, I can confidently say that this particular company is a model in this small-scale mining industry in terms of water quality assessment and reclamation projects.

An official of the EPA also gave his assessment of the operations of MAM in the following words:

We at the EPA can confirm that the operations of MAM are very good and exemplary. We regularly request and monitor documents from their side. Their water quality systems are very good. Since they started operations at this site, we've not had any cause to complain about their environmental performance. We'll continue to monitor their operations, but we are very much rest assured that they would continue to do the good job – environmental wise.

4.9. Effects on the community

Interviews with some of the local residents and the farmers in the catchment area showed that they have high regards for the water management operations of MAM. According to some of them, the area used to be a hub for illegal small-scale mining operators who showed blatant disregard for the safety of the Buxux river. Before MAM officially began operations, the activities of *galamsey* operators had lead to massive pollution of the river. Residents were unable to use the water for domestic purposes as was the case before the *galamsey* operators populated the area. A local farmer described the situation thus:

The river has served the community very well. It is not the only river in the area though; yet it has served as a source of drinking water and for domestic purposes, even for irrigation purposes. I used it to water my cabbage farm. However, illegal mining operators came to the area and suddenly the river began to 'die' slowly. We couldn't drink from it, neither could we use it for other purposes. However, we got to know later that a legal mining operator had taken over the concession, but we still thought their operations would not be any different from that of the illegal miners. We were wrong. The river began to bounce back. There have been vast improvements in the quality of the water. We don't exactly understand how this legal small-scale operator is treating the water. But we know and appreciate the fact the water at least flows very well now

A local resident also described the situation this way:

I have lived in this community since I was born (about 40 years now). This river (Buxux) has been one of the major sources of water for domestic purposes. However, we suddenly found out about 10 years ago that the water had become very muddy, and the quality was very bad. We could not use it for anything. Now the situation has changed dramatically though. When we enquired, we were informed that a different mining operator (MAM) is operating in the area and that their activities are friendly to the water. If you have time to check (referring to the researcher) you would be aware that the water flows very well now.

These findings confirm previous findings, see for example (Bansah and Bekui, 2015; Bach, 2014; Bansah et al., 2018) that the operations of illegal mining operators has detrimental effects on the quality of water bodies in most mineral-rich mining communities. The findings further suggest that local residents usually consider mining operations as unfriendly to the local environment and water bodies. However, when formalisation mechanisms and the obligation to conform to environmental standards are applied thoroughly, small-scale mining operations can have little to no negative influence on water bodies.

5. Discussion and conclusion

This present study notes that in many countries in the mineral-rich world, the artisanal and small-scale mining sector has been well developed, providing direct employment to millions of people (Hilson, 2017; Hilson et al., 2021). Millions of farm-dependent families in sub-Saharan Africa, for example, regularly turn to ASM during times of difficulty to help buffer against economic shocks and stresses (Hilson et al., 2021). However, many resource-rich countries have always been challenged with the difficult choice of environmental protection and ASM-focused economic development. This is because while the operations of ASM, on the one hand, contribute significantly to economic progress, on the other hand, the activities of the sector have negative impacts on the environment. For example, the small-scale mining sector has often been implicated as a source of pollution to land and water systems. There is no doubt that ASM activities, irrespective of the mode of operation, and legal status, can have major negative impacts on water quality. ASM operations have been known to be a major contributor of metals in surface and groundwater within mining regions because of indiscriminate use of, for example, mercury (Hg) and other chemicals. This is because its activities by nature make use of a lot of water thereby seriously polluting water resources.

However, moving beyond the environmental 'doom', this present study sought to highlight the fact that it is time to see what small-scale mining gets right in relation to sustainable environmental practices. Hence, the study examined the water management performance of a formalised (legalised) small-scale mining operation in Ghana. As indicated in this study, formalisation of mining operations requires the conformity of their operations to the relevant minerals and mining

[2] US Dollar 1 was equivalent to about Ghc 6 at the time of the research.

regulations of Ghana. In this regard, the study aimed to shed some light on the extent to which small-scale mining companies respond to the mining governance system in terms of abiding by the mining regulatory framework, and the extent to which such responses bring about improvements in water quality and local livelihoods. In our case study, management of MAM, aware of their legal obligations towards the protection of water bodies have put in place systems to ensure that the river that passes through their concession is protected to the optimum.

Our findings indicate that legal recognition and obligation to conform to environmental standards regarding ASM activities can, contrary to the popular phenomenon, engender positive results on water quality. In this regard, this study has demonstrated that the organising practices of MAM with regards to sustainable water management systems have largely lead to the non-pollution of the river that runs its course through the concession. By establishing ponds to recycle water for processing purposes, river pollution has been almost non-existent. In addition, the non-use of mercury for processing at the site has been very beneficial to the river, and in effect to the larger community. These organising practices which have largely served the community and the water well can serve as a model for other small-scale mining operators. Combined with reclamation efforts, see for example (Worlanyo and Jiangfeng, 2020; Damptey et al., 2020) it is abundantly clear that mining entrepreneurs, their companies and local communities stand to benefit, socio-economically and environmentally, by adhering to environmental standards regarding mining operations.

Nevertheless, the cost associated with the water quality analysis, as highlighted above, brings to the fore the cost associated with formalisation. As has been noted elsewhere, see for example (Hilson, 2017; Siwale and Siwale, 2017), high cost of formalisation of mining businesses, including obligations to conform to environmental standards, usually discourage most mining entrepreneurs from formalising their business operations with the relevant governmental authorities. Here, governmental support is required. It is appropriate to suggest that the initial cost of registration of mining operations could be reduced so that mining operators can muster the financial capacity to undertake sustainable environmental management practices including water management projects. In addition, considering the expensive nature of water quality analyses, mining governance regimes would need to take a relook and consider whether they are all necessary. Would it be possible, for example, for artisanal miners to simply measure turbidity using a field metre as a surrogate for many other parameters of concern? Also learning from the practices of our case organisation, mining governance regimes can help establish water ponds in the numerous mining zones that can be employed for mineral processing purposes. This would help spare the natural water bodies of pollution and could act as a catalyst for ensuring small-scale mining-related win-win situation for mining companies, local communities and the environment.

Declaration of competing interest

That each Author has seen and approved the content of the submitted manuscript.

That the paper presents original work not previously published in similar form and not currently under consideration by another Journal.

That if the paper contains material (data or information in any other form) that is the intellectual property and copyright of any person(s) other than the Author(s), then permission of the copyright owner(s) to publish that material has been obtained, and is clearly identified and acknowledged in the text of the paper.

That any affiliations with a direct financial interest in the subject matter or materials discussed in this manuscript are disclosed and all financial research or project support is identified in an acknowledgment of the manuscript.

That authors followed ethics guideline.

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