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Socio-ecological Analysis of Artisanal Gold Mining in West Africa: A Case study of Ghana.

Socio-ecological analysis of artisanal gold mining in West Africa: A case study of Ghana

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Abstract

The surge in artisanal gold mining (AGM) activities and the associated environmental impact in Ghana have elicited several stakeholders' attempts to curb the problem. However, due to little understanding of the underlying issues, these efforts have been ineffective. This study aims to use a socio-ecological framework to analyze drivers of AGM activities, the environmental pressures, the state change, their impact on human welfare, and the management response as measures (DAPSI(W)R(M)) to the problem. Evaluate AGM's impact on Ghana's ability to achieve the United Nations Sustainable Development Goals (SDGs). Data were collected from relevant literature on the subject and analyzed with the DAPSI(W)R(M) framework. Esteem needs, food, acceptance and friendship, and self-actualization are the main drivers of AGM activities leading to environmental pressures, including abrasion, extraction of living and non-living resources, the introduction of non-synthetic compounds, among others. State changes of the environment resulting from the pressures generated by human activities were changes in the land and forest cover (1.13%), topography (hills turned into flatland and undulating), and biota. Due to the state in the environment, water quality and availability, agriculture food production, fish yield, food safety, spiritual and cultural loss, death, injury, and health of gold miners and other stakeholders have been affected.

Keywords: artisanal mining, environmental assessment, management, gold, Ghana

1. Introduction

Mining contributes significantly to the economic growth and development needs worldwide [1,2], making it the fifth-largest industry worldwide [3]. There are over 70 mineral commodities that are produced by about 168 countries worldwide [4]. Mining of these minerals is either on a large scale or small scale (artisanal). However, in most cases, artisanal gold mining (AGM) has been associated with many environmental and social impacts globally. Especially in poor resource-rich developing countries because of illegal and unsustainable mining methods [5,6].

The negative environmental impacts include land degradation, destruction of flora and fauna, air pollution, heavy metal contamination of sediments, surface and groundwater [7–9]. The social impacts include increased trafficking (human and drugs), prostitution, crime, breakdown in societal cohesion, decreased respect of culture and traditional rights [6,10]. The importance of mining to the economy of Ghana is well documented since it was known as the Gold Coast [3,11]. Recent figures indicate that gold production alone contributes about 40% of the country's gross foreign exchange earnings, making up to about 9.1% of Ghana's gross domestic product [12,13]. Ghana is ranked among the top 10 gold producers in the world [14]. Interestingly, AGM accounts for between 35 and 40% of total national gold production. Gold production from AGM has also increased in the last two decades from 567 kg in 1990 to 45,359 kg in 2016. Nominal revenues accrued in 2016 alone from AGM was US$ 2.0 billion [15]. The adverse impacts of mining activities are also on the increase, especially in the artisanal sector, even though mining contributes significantly towards the socio-economic development of Ghana in terms of

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revenue generation [12]. AGM activities, especially illegal ones, play a critical role in the degradation of the Ghanaian environment. For instance, the use of harmful chemicals and a large tract of land for mining activities represent the loss of fertile land. Furthermore, AGM can be described as a heterogeneous activity due to the different technologies, practices, and socio-ecological impacts [16] as such it is very complex and challenging to study.

This research aims to analyze AGM activities through a socio-ecological framework that assesses the drivers, activities, pressures introduced or exacerbated due to the activities, state change in the environment, impact of the change in the state of the environment on human welfare and the response instituted or needed (DAPSI(W)R(M)) [17]. This study also aims to understand the impact of AGM on Ghana's ability to achieve the United Nations Sustainable Development Goals (SDGs).

2. Materials and methods

2.1. Study area

Ghana (7.9465° N, 1.0232° W) is in Western Africa, bordered on the south by the Gulf of Guinea (Atlantic Ocean), to the east by Togo, to the west by Cote d'Ivoire, and the north by Burkina Faso (Fig. 1). It is a lower-middle-income country, has a population of about 29.6 million (2018) and a total area of 238,533 km^2, with water making up about 4.6% [18,19].

About 67.6% of the labor force of the approximately 13.7 million are in employment, of which an estimated 35.9% work in agriculture, fishery, and forestry, 18.2% work in industry, and 38.3% work in the service industry [20]. Hilson and McQuilken [21] estimated that over one million people are directly involved in artisanal mining (AGM) in Ghana, and about 4.4 million depend on it.

The AGM is widespread in Ghana but commonly found in nine of the 16 regions, namely: Ahafo, Ashanti, Bono, Central, Eastern, Savannah, Upper East, Western North, and Western Regions (Fig. 1) [22–28]. These include 19 districts and seven municipality.

2.2. Method

The DAPSI(W)R(M), a socio-ecological framework, stemmed from the work of Rapport and Friend (1979) and was known as DPSIR (Drivers-Pressure-State-Impact Responses). It was accepted as a conceptual framework by the European Environmental Agency in 1995 and proposed by the Organization of Economic Co-operation and Development as a means of structuring and establishing the cause-effect relationships between human activities and environmental components in a way that is meaningful to managers and policymakers [17,29,30]. The DAPSI(W)R(M) has been widely applied to various socio-ecological studies and works on the principle that basic human needs (drivers (D)) lead to activities (A) that brings about pressures (P). State (S) change on the natural system resulting from pressure leads to impacts (on human welfare), and these then require Responses (as Measures) [17].

2.2.1. Data collection

We sampled data from online peer-reviewed research papers, thesis, reports, conference proceedings, and news portals extensively with systematic methods adopted from Van Cauwenberghe et al. [31], Khamis et al. [32], and El Mahrad et al. [29]. Predefined keywords and phrases including 'Ghana', 'mining', 'gold mining', 'artisanal gold mining', 'chemicals used for artisanal gold mining', 'effects of artisanal gold mining', 'pollution from artisanal gold mining', 'physicochemical characteristics of water systems in artisanal gold mining areas', 'management measures for artisanal gold mining', and 'regulations for artisanal gold mining in Ghana' were used, as guidelines.

Based on the keywords and search phrases, 92 publications from 1989 to 2020 that were significant to the study were retrieved. The majority of data used were published in the last 20 decades. Thirty-eight were peer-reviewed articles with 54 of them being reports of government agencies, conference proceeding, thesis and online news items.

2.2.2. Data analysis

Data collected were organized into thematic areas including, importance of artisanal mining, methods employed in AGM, socio-economic factors, environmental and ecological health, socio-ecological and health impact, legal and institutional framework and enforcement, conservation efforts and training based the study area.

We synthesized the information in the publications gathered with the DAPSI(W)R(M) framework by identifying and highlighting all relevant information in relation to drivers of AGM activities, the pressures, state change, and impacts on different aspect of the socio-ecology in Ghana. The DAPSI(W)R(M) framework was used because it describes the linkages between human needs (as posited by Maslow), AGM activities, the pressure generated by the activities on the environment, the resultant change in the environment's state, and the effect of the change on human welfare in Ghana [17].

We developed a conceptual framework based on the synthesized information gathered to highlight

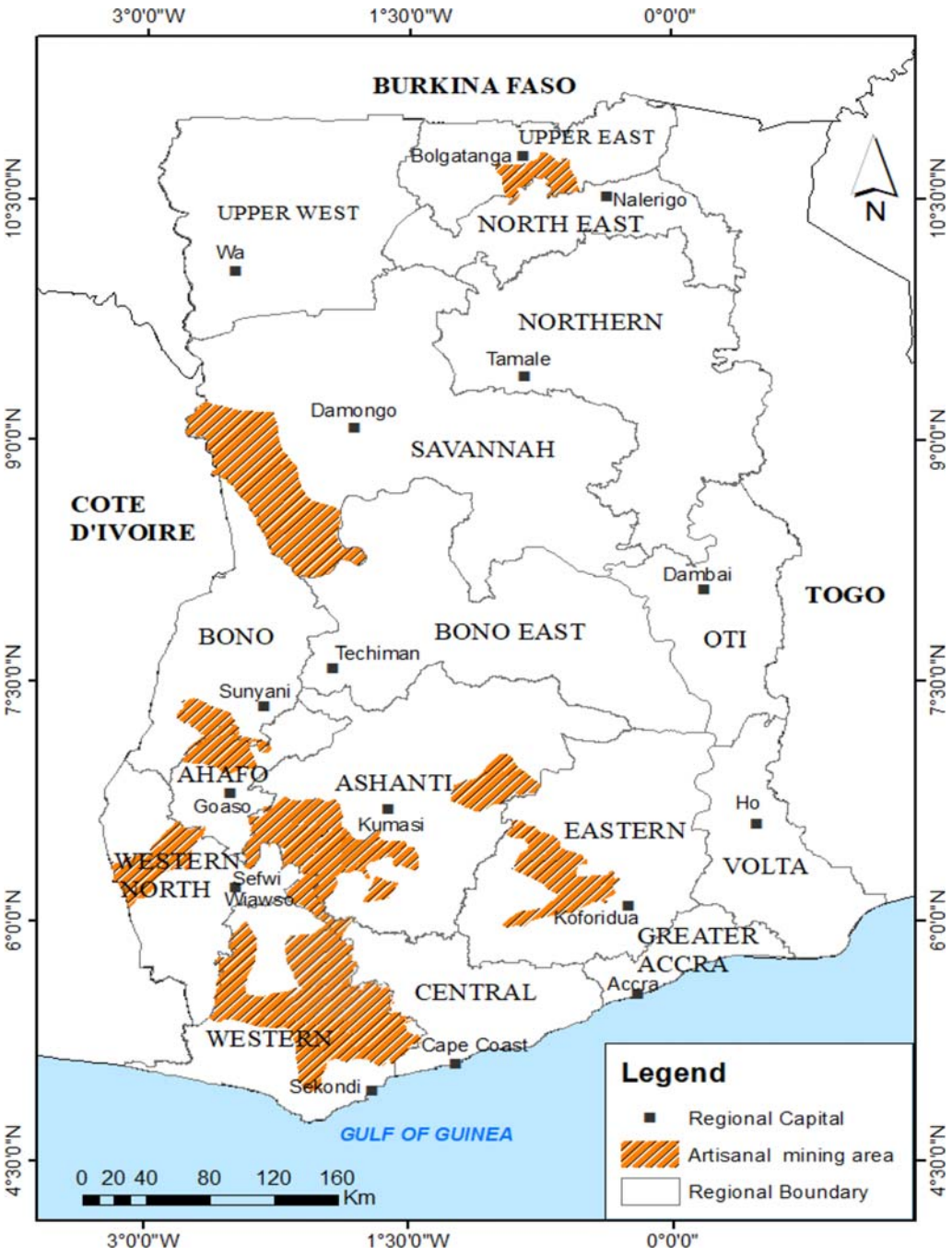

Fig. 1. Artisanal gold mining areas in Ghana.

AGM activities and their linkage with the SDGs (Figs. 2 and 3).

3. Results and discussion

3.1. Drivers

3.1.1. Esteem needs

The ability to be independent and self-reliant without living on the benevolence of others is a motivating factor. For instance, earning between US$ 2.6 and US$ 22.9 per day or US$ 100 to US$ 748 per month via illegal AGM in rural Ghana as compared to US$ 70 per month from farming [33–36] can give an individual especially the youth that independence and self-reliance they desire.

The desire for status, dominance, and respect by the individual from others within and outside the society. According to Hirschman [37], humans are continuously in competition for dignity and honor. The

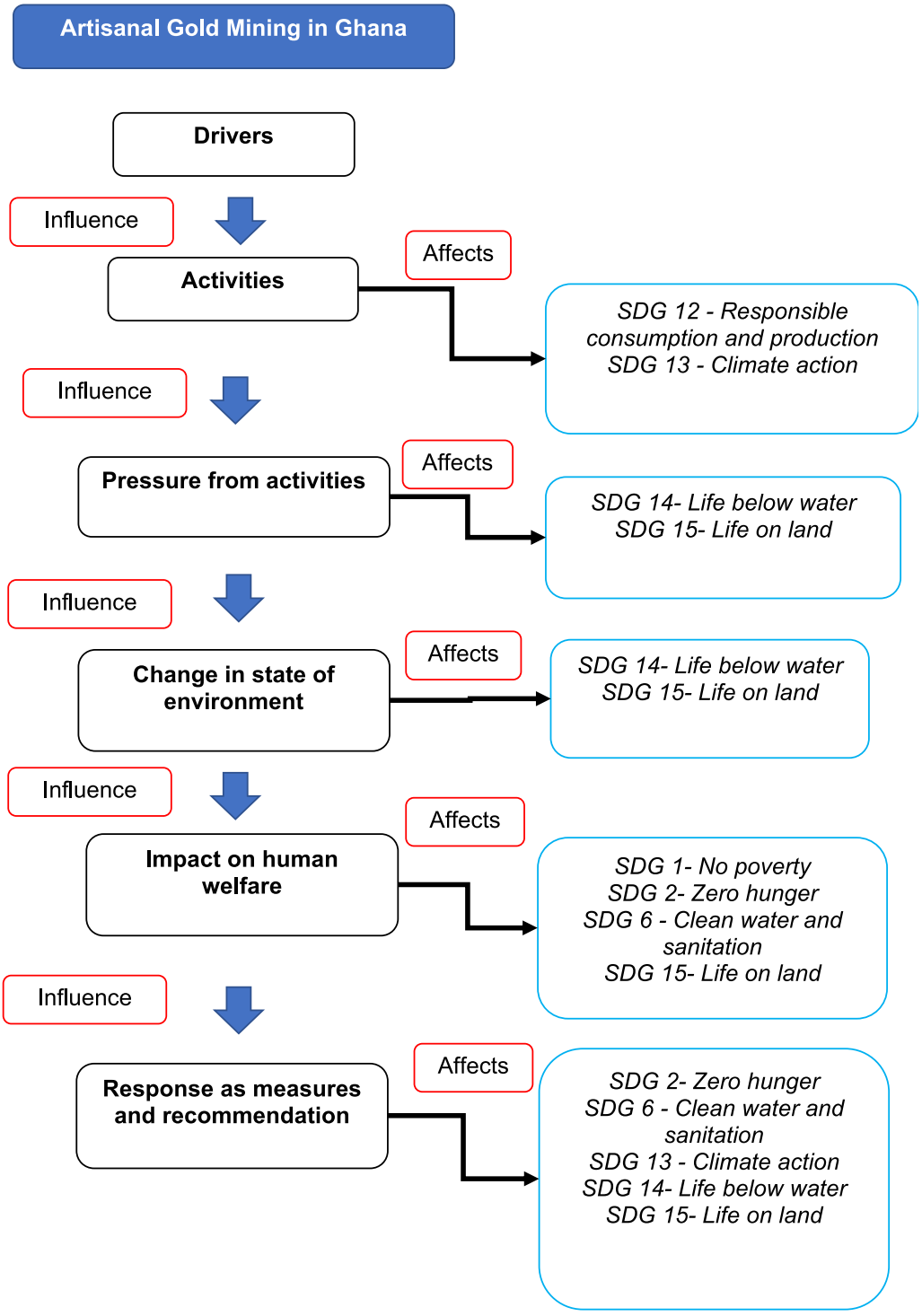

Fig. 2. Linkage between AGM, DAPSI(W)R(M) and SDGs.

majority of Ghanaian households (both nuclear and extended families) are male-dominated [34], and society expects them to maintain their status, be respected, and dominate in the decision-making processing, which is why AGM is male a dominant activity [38].

3.1.2. The need for food

Adequate nutrition is an essential biological and physiological need for continuous existence [39,40]. According to SDG 2 on zero hunger, although there has been extended progress to end hunger, the number of people suffering from starvation is still

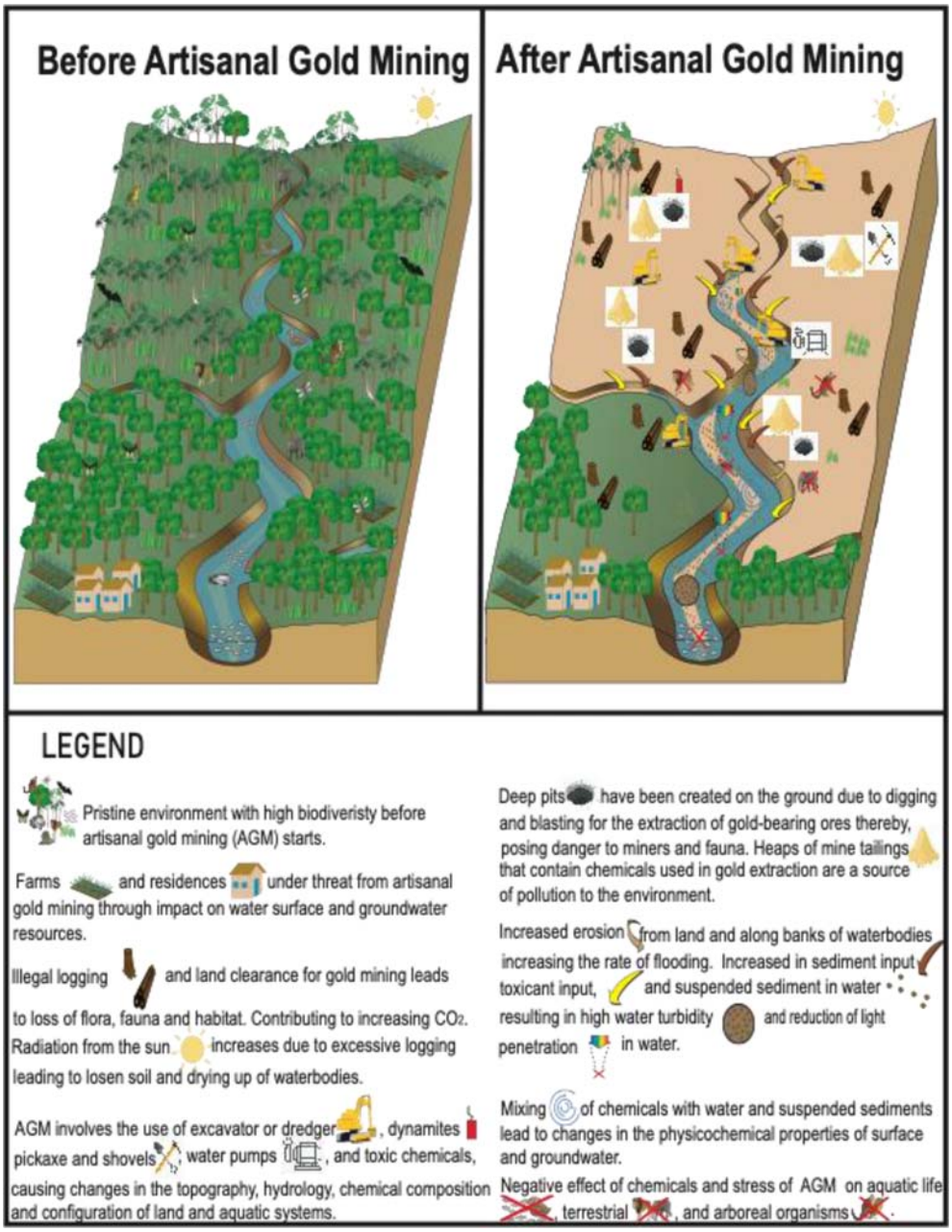

Fig. 3. A conceptual framework of AGM activities with resultant effects (illustrated with symbols for diagrams by courtesy of the Integration and Application Network) (ian.umces.edu/symbols).

surging [41]. The United Nations food agency estimates that there are over 820 million hungry people globally [42]. Sub-Saharan Africa experiences the highest prevalence rate of hunger globally with a rate of 23.2% (2017) [41]. For instance, in Ghana, approximately 1.2 million people are classified as food insecure [43]. Also, about 37% of the adult population have suffered growth retardation as children, 41% of all those engaged in manual labor experienced stunted growth as children, and 24% of all child mortality cases are associated with undernutrition [44].

3.1.3. *Acceptance and friendship*

Being accepted by peers and feeling belong influenced individuals, especially the youth, to venture into illegal AGM. For instance, Adu et al. [38] posited that peer influences are part of the reasons why individuals in Denkyira are involved in illegal AGM activities.

3.1.4. *Self-actualization*

The desire of individuals to seek person growth and potential. In Ghana, about 23.4% of the

population are poor, of which the majority (80%) of the affected live are in rural areas [45] where there are abundant gold deposits. Consequently, most people seek growth from poverty to riches for themselves and their families hence their involvement in AGM.

3.2. Activities

The AGM in Ghana involves the use of rudimentary and high mechanized tools (Fig. 3). It is labor-intensive, unmonitored, and uncontrolled [5,16,46]. The mining operations involve digging (e.g., with a pickaxe, shovel, wheel loaders, excavators), conveying (e.g., head pans, dump truck, etc.), and the use of reconfigured water pumps for the pumping of water. A Chinese-made diesel-powered rock crusher referred to as 'Changfan' (repurposed milling machine), the use of mercury (Hg) in separating gold ore-bearing rock (mercury amalgamation), and other rudimentary tools [5,16] are also employed. Other methods used include setting large fires to make fractions in rocks and then blasting them with dynamite [12].

In addition, the mining operations have a varied range of different sub-activities that makes management difficult because every area needs its criteria according to its features. The SDG 12 on responsible consumption and production encourages countries to ensure sustainable consumption and production patterns, however methods and materials used in AGM go contrary to this goal (Fig. 2).

3.3. Pressure

There are several pressures from AGM on the environment and the ecology of Ghana.

3.3.1. Abrasion

Physical and mechanical interaction with plants, animals, and substrate due to the frequency, magnitude, and duration of logging, land clearance, scooping, and driving of vehicles (e.g., excavators, dozers, dump trucks). For instance, in Upper Denkyira East, there are three excavators, one dump truck, several rudimentary tools, and between six to 26 miners work per site throughout the year [16].

3.3.2. Extraction of living and non-living resources

These involve the selective removal (at least 1 m depth) of sediments (e.g., Birimian and Tarkwaian rocks), gold deposits, flora, fauna and high abstraction of water from rivers, streams, lakes, and land in mineral extraction and processing [47,48]. For instance, an average of 0.3 and 1.4 tonnes of gold are extracted in areas with less and more than four artisanal mines, respectively [49]. The AGM activities such as logging, land clearance, and digging result in removal of 0.59% of forest per year and fauna, including endemic plants and endangered forest fauna [49]. Consequently, exacerbating the pressure of exposure of soil and fauna to negative effect of the weather [50].

3.3.3. Introduction of non-synthetic compounds

Pressure from the constant release of heavy metal (Hg, SO_2, N_2O, cyanide, etc.) into the air, water, and soil environment from gold extraction and processing. For instance, the release of 45,150 kg of Hg per year via mercury amalgamation techniques with 32,570 kg yr^{-1}, 6580 kg yr^{-1}, and 6000 kg yr^{-1} released into the air, water and land, respectively [15]. Also, the amount of mercury used in AGM per person ranged between 270 and 300 kg yr^{-1}, and for every 200 g (1 kg) gold produced, 210 g (2 kg) mercury is used [51].

3.3.4. Suspended sediment

There is pressure from sediment runoffs in rivers, streams, and lakes in the catchment area due to logging and stirring of soil. For instance, sediment discharged is between 27 tonnes day^{-1} at Brenase and 20,500 tonnes day^{-1} at Twifo Praso into the Pra River basin due to AGM [52].

3.3.5. Noise and air pollution

There is pressure from the generation of high decibels (noise) of sound (e.g., 82 dBA), the release of carbon monoxide, large quantities of soot and dust from the continuous operation of 'Changfan,' excavators, drillers, water pumps, blasting of dynamite and during pounding, grinding and sifting of gold-bearing materials for long hours daily [35,53–55].

Pressure on the environment from the release of mercury fumes during the amalgamation of gold, sulphur dioxide, and nitrous oxide during the blasting of dynamite [55]. The quantity and level of soot generated have so-far not been measured, although the problem continues unabated.

3.3.6. Litter

There is pressure on the environment from the indiscriminate disposal of untreated mine tailings with 901.5 mg kg^{-1} Hg [50] and domestic waste generated during mining activities into aquatic systems and on land. For instance, in and along the Sintim River (Asutifi North District, Ahafo Region), Prestea (Western Region), and Kokoteasua (Obuasi

Municipality, Ashanti Region) [56,57]. Quantities of tailings generated per day have so far not been quantified.

3.4. State changes in environment and ecosystem

Pressures from these activities have dire consequences for Ghana's ecosystem health.

3.4.1. Land and forest cover

It has been estimated that Ghana has lost about 1.13% (2018) of its forest cover, and about 6.03 km^2 of the forest has also been encroached on due to AGM activities [58,59]. For instance, in the Offin shelterbelt forest reserve, about 2.5 km^2 of the forest has been degraded by illegal AGM [36]. A recent documentary by JoyNews (a local news network) indicated that illegal AGM destroyed about 300 acres of Anhwiaso-East forest reserve [61]. Tom-Dery et al. [60] reported that the mean index of individual trees and shrubs density for 100 m^2 in mined areas was lower (2.4) compared to unmined areas in Nangodi (Talensi-Nabdam District, Upper East Region).

3.4.2. Topography

Hills have been turned into flatlands (e.g., Kyebi, Eastern region) [62], and lands are characterized by varying sizes of unrehabilitated deep pits and trenches (filled with water) and loose soils [63,64]. The landscapes in AGM areas have also become undulating due to the creation of ridges (e.g., Akim Oda, Eastern Region) by mine tailings [65].

3.4.3. Biota

The state of species diversity has been affected. For instance, mined areas in Nagodi, Upper East Region, have low species diversity of trees (8.3) compared to the unmined zone (10.8) [60].

Mercury concentrations between 0.001 and 0.975 $\mu g\, g^{-1}$ have been recorded in fish species, including *Sarotherodon melanotheron, Heterobranchus bidosalis, Synodontis* spp, *Hepestus odoe,* and *Tilapia zillii* [51]. Fish species from Apopre and Rora Rivers in Dumasi have 0.55–1.59 $\mu g\, g^{-1}$ Hg [66]. Similarly, mercury levels were found to be high in fish from AGM area in Columbia [67,68]. Tree species, including *Funtunmia elastica, Pycnanthus angloensis, Milicia exculsa,* and *Alstonia boonei*, have been lost in Atiwa District due to illegal AGM [69].

3.4.4. Substratum

By stripping the land bare of vegetation, top, and sub-soils, illegal AGM has impoverished lands and rendered soils erosion-prone [70]. For instance, soils in illegal AGM areas have become mostly sandy and less fertile, with a low level of organic matter, organic carbon, total nitrogen, and phosphorous compared to unmined areas [71]. The state of land around illegal AGM areas in Tarkwa Nsueam Municipality in the Western Region has been rendered bare, unstable, with important micro-organisms destroyed [2].

Soils from Bolgatanga, Badukrom, Wangarakrom, and T-Tamso in Tarkwa, where illegal AGM activities are in place, have been found to contain relatively high concentration of Arsenic (As) and Hg content [51,72]. Soils of farmlands in the Prestea/Huni Valley District around illegal AGM areas contain higher concentrations of arsenic, mercury, cadmium, copper, and lead above-recommended values of the Environmental Protection Agency, Ghana. Mercury concentrations of 0.64–330 $\mu g\, g^{-1}$ have been recorded in soils of illegal AGM areas (e.g., Upper East, Dumasi (Bogoso)) [51,66].

3.4.5. Hydrology

The hydrology of some rivers has been affected due to the diversion and intense pumping of water for illegal AGM activities [64]. Consequently, the Bosomase and Pra rivers in the Western Region are drying up due to AGM [73]. Modification of water flow and deterioration of riverbanks in the Dagua river due to AGM has also been reported by Gari et al. [68].

3.4.6. Water quality

Rivers, streams, and lakes in and around illegal AGM areas in Ghana have become turbid and have acquired new coloration due to increase sediment loads and contaminations [12,74]. For instance, the Offin, Pra, and Ankobra rivers have obtained yellowish and brownish coloration due to sediment and chemical contamination from illegal AGM [75]. The Bonsa River's color range has changed from between 80 and 300 to 300 and 900 due to AGM [76]. Similarly, the down streams of Sintim and Akantansu rivers in the Asutifi North District have obtained water color higher than standards of EPA Ghana [77].

Surface and groundwater systems (e.g., Pra Basin) in and around mining areas have become acidic or slightly acidic and are below the permissible WHO guideline limits for drinking water due to illegal AGM [56,78].

Major rivers in the Tarkwa Nsuaem Municipality have become polluted with arsenic, mercury and suspended solid due to AGM [2]. The Apopre and Rora rivers and groundwater in Bogoso have acquired mercury concentrations of 0.18–0.76 $\mu g\, L^{-1}$,

and 0.12–0.27 $\mu g\,L^{-1}$, respectively, due to illegal AGM [66].

3.5. Impact on human welfare

3.5.1. Protection

More than 90% of disasters worldwide are attributable to climate-related disasters. Therefore, countries have been encouraged to take urgent actions against climate change and climate-related disasters under the SDGs [79]. Clearing forested areas for illegal AGM increases the effects of extreme and unpredictable weather conditions, high temperature, and flooding, which are currently being experienced in some parts of Ghana [80,81]. Protection services (i.e., windbreaks) provided by trees are on the decline due to logging activities influenced by AGM. The vulnerability and resilience to windstorms in some rural communities have been affected [82].

3.5.2. Leisure and revenue

Ecotourism plays an essential role in the economic development of countries worldwide. The quality of the environment that provides this service also helps in promoting the physical and psychological wellbeing of visitors [83,84]. Regarding Ghana's tourism market, ecotourist sites can receive between 8000 and 159,000 visitors a year [85]. Therefore, the decline in biodiversity and air quality represents a decline in ecotourism and leisure activities with consequences for government revenue targets.

Birdwatchers and wildlife lovers will not have the opportunity to enjoy the scenery and recreation as habitats are destroyed [86], which can negatively impact on their wellbeing and quality of life. The US$ 1.6 billion generated annually from ecotourism for the Ghanaian economy is also likely to be affected [82].

The government of Ghana also loses a lot of revenue in reclaiming lands that have been devastated by AGM. It is estimated that the cost of reclaiming 0.404 ha of mined land excavated to 0.9 m is US$ 54,419.33, inclusive of 2–3% maintenance [87]. Due to illegal AGM in the forest concession of the Ghana Rubber Estate Limited, the company is to lose over US$ 3.5 million, which will derail the government of Ghana's one district one factory project [88]. These revenues could have been invested in the maintenance of other essential sectors of the economy.

3.5.3. Water quality and availability

According to SDG 6 on clean water and sanitation, freshwater is an essential resource for food security, health, energy, and poverty eradication. Globally, poor water quality and availability have been linked to the majority of diseases and death, with women and children being the most affected, especially in sub-Saharan [41]. About 25% of the Ghanaian population do not have access to potable water [89]. Therefore, the opaque brown or yellow coloration acquired by waterbodies through AGM has implications for water availability to rural, peri-urban, and urban communities. Studies have shown that the turbidity levels of rivers and streams in the catchment areas of AGM activities in Ghana are above WHO standards making them unsuitable for drinking. For instance, in recent times, the Ghana Water Company had to shut down one of its treatment plants (e.g., Kyebi, Eastern Region) because chemicals treatment has become expensive due to pollution of rivers (e.g., Birim River) [90]. The quantity of water for residents in Tarkwa Nsuaem Municipality has reduced from 1.2 million to 800 thousand gallons per day [76]. It is estimated that the capital of Ghana, Accra, is likely to lose 65% of its water supply due to pollution of the Densu River by illegal AGM in the Atiwa Forest [91].

Ghana's agriculture is dependent on rainfall, rivers, lakes, and streams. Therefore, the continual degradation of the environment by AGM will reduce the amount and quality of water available for farmers since agricultural water constitute 48% of total water use in the country [89,92].

3.5.4. Agriculture production

The role of agriculture in the reduction of hunger, poverty, and improving food insecurity cannot be overemphasized. Agriculture production is the most important activity for rural households in Ghana in terms of foods, jobs and income generations [93]. Some vegetables and crops (e.g., rice) production have ceased in AGM communities such as Saa in the Wassa Amenfi West District, contributing to food price hikes [94]. In the cocoa sector, an essential and major export earner for Ghana (19.7% gross domestic product), farmers in AGM areas have observed early dropping of immature pods, wilting, yellowing, and low yields [69,95].

The average availability of land per farmer in some communities (e.g., Saa, Manso Nkwanta), as well as the percentage of people in farming in Ghana, has reduced (e.g., from 90 to 76% in the Offin forest belt) [36,94] with implications for the growth of staple foods (e.g., corns, cassava, and maize) and jobs. Gari et al. [68] also reported a similar situation where about 73% of farmlands and 60 ha (in Zaragoza, Columbia) have been destroyed due to gold extraction with threats to food security.

3.5.5. Fish yield

Fish from freshwater and estuarine sources are essential in the Ghanaian diet, especially for non-coastal dwellers due to their affordability [89]. Therefore, continual destruction and pollution of aquatic habitats have implications for fish availability. For instance, due to pollution by illegal AGM in the Pra River, which drains into the estuary, fishers in Shama in the Western Region of Ghana, who depend on the coastal waters are already experiencing reduced catch [96].

3.5.6. Food safety

Food is meant to provide nourishment and energy but not to cause harm to our bodies [97]. The exposure of fish (*S. melanotheron*), crops (e.g., cassava, cocoyam, yam), free-range domestic animals (80%) (e.g., goats, cows, chickens, etc.) to polluted water and plants is evident with a resultant compromise on food safety [98].

3.5.7. Spiritual and cultural loss

Globally, indigenous or traditional people inhabit huge bio-diversified areas [99]. The natural environments provide the basis for cultural processes, activities, and belief systems for indigenes. Illegal AGM activities in Ghana are destroying the avenues for spiritual inspiration (e.g., spiritual guidance from ancestral spirits) and cultural identity. Similarly, the majority of Ghanaians depend on plants and animal products to cure disease through the mastery of traditional healers. Additionally, sacred water bodies and forests (with Mausoleums of traditional rulers) that are linked with the spiritual, mythical, and ethnic beliefs of indigenes (e.g., Atiwa) have been invaded and destroyed [69,100].

3.5.8. Death, injuries and ailment

Mining is known to be one of the most hazardous working environments. The situation is worse and poses more hazards in AGM activities than in the highly technologized, regulated, organized, and large-scale formal sectors [101]. In Ghana, high rates of accidental death resulting from drowning, pit collapse, and landslides are frequent among miners due to the weak configuration of soil formation and lack of proper safety measures. Many of those who die in the trade are breadwinners for their families resulting, in abject poverty and broken homes. Between 2009 and 2020, about 581 miners died (Fig. 4) from either collapsing pits due to loosening soil or drowning in pits [102–104].

The cases of diseases especially from malaria is on the increase due to an increase in puddles of water in mining communities. For instance, in Manso Nkwanta, AGM has contributed to an increase in malaria cases of about 6853 from 29,244 (2008) to 36,097 (2009) [34].

The number of people who were not involved in mining activities but died through falling into abandoned gold miners' pits has been three. At least twenty-six miners have been trapped in miners' pit between 2009 and 2017 [103–105]. In the Upper East Region, about 195 miners have suffered varying injuries [101]. Also, hunters and farmers have suffered injuries and death from falling into abandoned trenches and pits [53].

Finally, these impacts present huge threats to Ghana on all aspects of life, and the nation's goal to achieve the SDGs. The above situation shows the need to decrease the effect of AGM activities as much as possible by using appropriate management policy measures.

3.6. Previous management measures

3.6.1. Legislation and policy

The government of Ghana and its agencies enacted several legislations to tackle issues related to AGM. They include and are not limited to the Provisional National Defense Council Law 218 of 1989 and Law 217 for the regularization of AGM [106]. In recognition of evolution in the mining sector, the government of Ghana amended the mining law to become the Minerals and Mining Act, 2006 (Act 703) and later reamended in 2015 by Act 900. The Environmental Assessment Regulations 1999 L.I. 1652 [107], Minerals and Mining (Explosive) Regulations, 2012 L.I. 2177, a handbook on AGM, and a small-scale mining scheme have been developed and enacted for the management of AGM [108–110]. Similarly, a national policy and management plan on mercury in Ghana is also being implemented [15].

3.6.2. Law enforcement and ban

These include the 'Operation Vanguard team,' a combined team of personnel from Ghana Armed

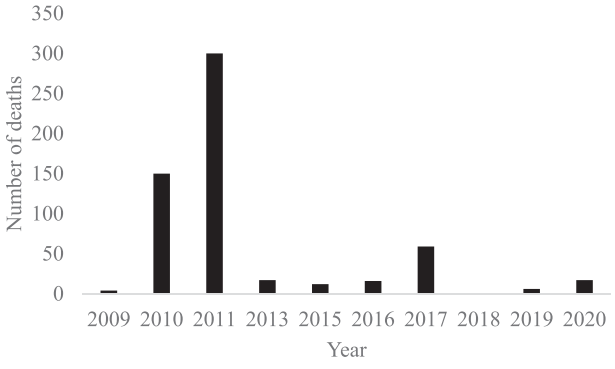

Fig. 4. Death toll from artisanal gold mining [102–104].

Forces, Ghana Police Service, Ghana Immigration Services, and National Security Operatives in 2017 under an Inter-Ministerial Committee on Illegal Mining (IMCM) [111]. Operation Vanguard led to the arrest of 1687 illegal AGM with a successful conviction of about 12% in 2018 [22,27,112]. Additionally, surveillance (by the Rapid Response team of the Forest Commission of Ghana), satellite imagery, fines (between US$ 134.54 to US$ 471.02) have also been imposed [22,64,112–114]. An almost two-year ban was also put in place by the government to curb their operations [115].

3.6.3. Provision of alternative livelihood

The government of Ghana (with the aid of both local and international stakeholders) is trying to provide miners with skills that would enable them to earn a living from alternative sources other than AGM. These include and are not limited to the vocational and technical training of about 1107 illegal miners by the Ministry of Local Government and Rural Development (MLGRD) [116,117]. Best mining practice training of artisanal miners under the auspices of a German non-governmental organization (NGO), Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), and the World Bank has also been implemented.

3.6.4. Land reclamation

Non-governmental organizations such as Partners of Nature Africa, donors (e.g., World Bank), and government agencies led by the Forestry Commission and District Assemblies have also initiated land reclamation and plantation programs [118] due to the environmental effects of AGM. For instance, the reclamation of Apramprama forest reserves in the Amansie Central District in the Ashanti Region [119].

3.6.5. Education and media-led campaign

The media (e.g., Joyfm, Citi FM, Graphic Communications Group, Asempa FM) in Ghana with, support from some non-governmental organizations, has also been at the forefront with the launch of a #*StopGalamseyNow* campaign in April 2017 and the establishment of Media Coalition Against Galamsey [120]. These initiatives have created awareness of the dangers of AGM and prompted government responses but have sustainability problems.

3.6.6. Community mining programs

The government of Ghana has introduced the community mining programs. This program is to formalize the activities of illegal miners in some selected communities [121]. However, pollution of water bodies in these areas are still taking place [122].

3.7. Stakeholder issues

These include complaints by the Operations Vanguard task force about the pittance of fines imposed by courts. The conflict between illegal AGM miners, community miners, landowners, and large mining corporations [123]. The partisan politicization of AGM activities and mining communities. The introduction of foreigners with ties to government officials, traditional rulers, and community leaders. The corruption of some government officials and media personnel.

3.8. Recommendations

Ghana holds a signatory to the United Nations SDGs and many other conventions. Therefore, the nation must adhere to the principles underlying these goals and international conventions in response to AGM activities. Given the challenges still facing the country concerning illegal AGM, we proposed the following recommendations.

Tackle extreme poverty: Since extreme poverty is prevalent in rural areas, the government and other stakeholders must implement policies to reduce rural poverty and unemployment rate, especially among the youth. Introduce meaningful social intervention policies and programs that is labor and socially inclusive such as community-based microfinancing and social security.

Define indicators for ecosystems: It is essential to define (scientifically) what healthy ecosystems are, and the indicators for assessing them in the Ghanaian context. Set standards with a routine monitoring regime for the status of ecological thresholds that should not be exceeded during mineral exploitation [48]. Culturally and aesthetically important areas should be protected from artisanal gold miners [17] through these indicators.

Bureaucratic inefficiencies and bottlenecks in the formalization of AGM should be reduced through stakeholder engagement under the relevant laws and policies.

Encourage sustainable mining methods: Mine site selection and exploitation intensity should be regulated to ensure ecological sustainability. Miners should be introduced to environmentally sustainable methods of mining through technical support, use of modern and efficient technologies. Controlled washing of gold-bearing ores and treatment of mine tailing should be implemented (legally binding) for AGM to reduce the release of contaminants into the environment.

Depoliticize AGM: Political parties, i.e., the two major political parties in Ghana, the New Patriotic

Party and the National Democratic Congress, must be encouraged to have an agreement and commitment for sustainable AGM practices.

Enforce laws, implement policies, plans (e.g., the National Biodiversity Strategy and Action Plan), and fines without biases and fear of electoral defeat.

4. Conclusions

In conclusion, we have highlighted with DAPSI(W)RM framework that AGM management requires multiple factors. It is evident that the drivers of AGM activities which involved the use of mercury, rudimentary and mechanized tools stemmed from the need for food, acceptance and friendship, and self-actualization.

The use of these tools and chemicals has introduced and worsened physical and mechanical pressure on fauna and flora. There is pressure from the selective extraction and removal of minerals (e.g., gold), sediment, and endemic plant and animal species. Land clearance and logging activities have led to the exposure of soils to harsh environmental conditions, increasing the rate of soil moisture evaporation. Pressure from the littering (e.g., tailings, domestic wastes), the release of non-synthetics materials and the increase in suspended sediments in waterbodies within AGM areas are evident.

We determined that due to the pressures emanating from AGM activities, about 6.03 km^2 of forest cover has been lost. Species diversity has declined in AGM areas, hills have been reduced to flatlands, and the hydrology of some waterbodies within the catchment areas of AGM has also been altered. Fertile lands have also been impoverished and the water quality of aquatic systems has declined compared to the EPA Ghana and WHO standards.

Food and crop productions have been impacted due to the scarcity of farmlands. The spiritual and cultural significance of some plants and forested areas have also been impacted. Loosening soils, pit collapses, and floods have led to the deaths and injuries of miners.

The previous measures at mitigating or eliminating the problem implemented include legislation and enforcement, provision of alternative livelihoods, reclamation, education and retraining and community mining program. However, there are stakeholder issues that needs to be resolved.

We recommended that issues of poverty must be taken seriously. Also, Ghana should have a defined ecosystem classification system and depoliticize the management of AGM activities. We also demonstrated that AGM has implications for Ghana's aim of complying with the UN-SDGs. Finally, we recommend the application of the DAPSI(W)R(M) framework in a local and specific area since it covers multiple elements. It could help to improve the socio-ecological systems concerning AGM in Ghana.

Conflicts of interest

None declared.

Ethical statement

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

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