

Review

Typology of Environmental Impacts of Artisanal and Small-Scale Mining in African Great Lakes Region

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Abstract: Artisanal and small-scale mining is a widespread economic sector in the African Great Lakes Region, where it has an adverse impact on the population's environment. The purpose of this paper is to summarize and consider the typology of the environmental impacts of artisanal and small-scale mining, in particular, the anthropogenic influences on topography with regard to the methods used in raw material mining. Among the most significant environmental aspects related to artisanal and small-scale mining are deforestation, changes in landscape structure, influence over geomorphological processes and hydrological river regime, chemical pollution of soil and watercourses, influencing soil production capacity. The aforementioned factors can cause health problems such as silicosis, poisoning by methyl orthophosphate, or injury during the mining activity itself. Artisanal and small-scale mining could initiate new geomorphological processes or modify naturally occurring geomorphological processes. These dynamic processes are influenced by the topography of the relief, soil properties, and rock composition. Anthropogenic activity in these cases may lead to faster reshaping (degradation or abrasion) of soil shapes. This study covers a broad understanding of environmental impacts of artisanal and small-scale mining with a focus on anthropogenic influencing.

Keywords: artisanal and small-scale mining; change of landscape; environment; anthropogenic activities; Great Lakes Region

1. Introduction

Mineral resources represent the wealth of individual states, and their extraction constitutes one of the basic elements of the associated economies. In developing countries, the impact of the mining industry on the state economy may be even more striking [1]. A specific issue in developing countries is that relatively small consideration is paid to the environmental consequences of mining, including for frequently used methods of chemical mining. A separate issue typical for the countries of the East African Lakes region is the use of artisanal and small-scale mining (ASM). Although ASM is highly inefficient compared to industrial mining, it represents a very important element of the economy both at the local and regional level, especially for low-income population groups.

Like any other mineral resource extraction, the artisanal mining method is associated with human intervention in the environment. Anthropogenic influence on topography is an integral part of raw material extraction. However, in developing countries, where there is less adherence to mandated practices and rules, the impact of mining on the landscape structure is even more significant. As claimed by the International Labour Office (ILO) report on artisanal mining, unlike conventional industrial mining, ASM is illegal in many cases, and thus degrades the environment [2]. The aim of this paper is to analyze the environmental impacts of artisanal mining of 3TG (tin, tungsten,

tantalum, gold) minerals with respect to the methods used for the artisanal mining of minerals in the African Great Lakes Region (GLR).

2. Materials and Methods

The paper deals with the African Great Lakes Region, which can be defined as an area surrounding seven large lakes and in the basin of two large rivers—the Congo and the Nile. The author chose an area of interest similar to Schütte et al. [3] or Mpangala [4], who include Uganda, Kenya, Tanzania, Burundi, Rwanda, and the eastern part of the Democratic Republic of Congo (DRC), or the province of North Kivu, South Kivu, and Katanga in the Great Lakes Region (Figure 1).



Figure 1. African Great Lakes Region. Author's own format [5].

The basic methods include quantitative and qualitative research. Qualitative research was, as defined by Disman [6], carried out with the aim of creating a new hypothesis and understanding. At the beginning of the research process, a literature search and data collection were performed, followed by analysis of data sources and formulation of preliminary conclusions. The primary objective is to compile a basic typology of environmental impacts of the artisanal method of mineral material extraction, in particular, of 3TG minerals (tin, tantalum, tungsten, gold) in the GLR. The methodology is based on the collection and analysis of information provided by contemporary authors, research institutions, institutes, and mining companies based on field research. Field research was carried out from June through November 2012 and 2013 in Rwanda

(Rutsiro district and Ngororero district). An important factor that made communication and interviews with the local population more difficult was cultural differences, some distrust toward a foreigner (author cooperated with local translator), as well as the security situation in Rwanda in 2013, which did not allow visiting mining sites near the border with Burundi, where further interviews with participants were supposed to be conducted. Another part of the research took place in the months of March through June 2014 in Tanzania (Geita district and Tarime district). Between August and November 2015, field research was again conducted in Rwanda (Rutsiro district, Ngororero district and Bugesera district). Within the primary objective, some of the mining sites in the different GLR states are listed in the paper for illustration. As part of the field research, expert interviews—as one of the qualitative research methods—were conducted in Rwanda and Tanzania [7]. Expert interviews were carried out in cooperation with a mining company operating in the Great Lakes Region. The company provided referrals and contacts to stakeholders involved in ASM. Expert interviews were conducted at the same time as field research, and served as a supplementary source of information which was obtained through intensive study of the available literature sources. The respondent sampling method was aimed at maximum opinion diversity and representation of key participants. Representatives of mining companies, academia, government sector, geologists, miners, and mineral traders were all interviewed. During the interviews, respondents were asked questions about the environmental impacts of ASM in the GLR (in which way the environment is being damaged; what type of mining causes the greatest damage; which environmental impacts are most significant; what are the informal mining problems, etc.). These topic categories were then expanded to include additional subquestions and interviews. Given that the respondents' responses matched to a large degree, these answers are presented collectively in Section 3.2. The interviews aimed to interpret the subjects' views on the issue of the artisanal method of mining, and to understand the issue in its social context. Researcher used open, unstructured research questions in their interviews with different stakeholders engaged in ASM. The remit was to create a holistic image of the issue, to capture how participants in the process interpret situations, and to capture impressions of these interpretations. The chosen form was unstructured interviews covering key topics from the area of mineral extraction with a focus on artisanal mining methods. A total of eleven experts were selected for qualitative research. The method of their selection was targeted at obtaining the maximum possible opinion diversity and representation of key participants. Another method was non-participant observation in mining sites in the region of interest [8]. Ethical approval was obtained from the Palacky University and Rwanda National Resources Authority. All procedures in the study involving human participation were in accordance with the ethical standards of Palacky University.

3. Results

The issue of ASM is a broad topic dealt with by a number of authors and institutions. The actual definition of ASM is provided by the Noetstaller [9], Barry [10], Peiter, Boas, and Shinya [11], Jennings [12], Hilson [13], Hentschel, Priester, and Hruschka [14], Perks [15], International Labour Office [2], and many others. The ASM topic overlaps several areas (socioeconomic, transport, political, etc.) and intersects with geopolitics of the country itself. However, this study only deals with the specific issue of the environmental impacts of ASM. The key topics of the ASM issue in GLR include socioeconomic impacts [13,16–21], health aspects [19,22,23], women's labor [24–29], child labor [30,31], and the role of minerals in armed conflicts [32,33]. Conversely, in ASM, much less interest is devoted to the actual environmental impacts and their typology. The impacts of mining on the environment are mentioned in research and specialized literature less frequently or only as a supplement to the research topic. One of the first publications that broadly describes ASM and, among other things, environmental impact issues is *Mining on a Small and Medium Scale: A Global Perspective* by Ghose [34]. This publication aims to summarize all the problems encountered in the given sector and to evaluate the impacts of ASM on developing countries. A significant author is Gavin Hilson [13,16,35–37], who deals in particular with socioeconomic impact, but he also notes

that soil degradation and contamination is one of the biggest environmental problems. Hentschel, Hruschka, and Priester in their joint publications: *Global Report on Artisanal & Small-Scale Mining* [14] and *Artisanal and Small-Scale Mining—Challenges and Opportunities* [38] focus on socioeconomic aspects that accompany the environmental aspects of ASM. ASM is often mentioned in connection with gold mining, where environmental degradation occurs as a result of mercury usage [31,39–45]. Mercury can then contaminate water resources, soil, air, and can also enter the human body, as confirmed by research in mining sites around the world. Mercury enters the environment during gold mining from ores, via a process known as amalgamation. The impact of heavy metals (besides mercury) on the environment in GLR is addressed by Pourret et al. [46] and Diogo et al. [47]. ASM-related geomorphological processes are defined by Byizigiro et al. [48], who describe geomorphological phenomena typical of artisanal and small-scale mining. Byizigiro's findings are based on the division of relief by Jones [49]. Hilson [13], dealing with positive and negative aspects as well as the approaches of individual governments to this issue, notes that the biggest environmental problems include soil degradation and mercury soil contamination [14,16,19,50]. The influence of heavy metals on the natural riverbed can also be associated with sedimentation. Pollutants that are part of the sediment are transported downstream to water reservoirs, which is a major problem in GLR, with a significant percentage of the population dependent on fishing [51]. A large number of international organizations, such as The World Bank (WB) [52], ILO [2], USAID [53], the International Institute for Environment and Development [54], and others, are addressing this topic.

The extent to which the landscape is affected depends on the type of ASM and the extent of mining activity. Individual types of ASM can be defined by technological procedures and their effect on geomorphological processes. Technological procedures involved in ASM are especially associated with surface and subsurface mining, which take place in rock masses on surfaces with a different incline or in alluvial areas [55]. The methods used to extract material can be divided into three categories.

Shallow alluvial mining—the mining from alluvial sediments, where material is extracted followed by the “dig and wash” technique. Rich deposits are found in sediment loads of alluvial deposits in valleys, or in low situated areas with little or no rock cover. These sites are of a maximum thickness of up to 3 m [41]. The material is first extracted and then washed. Washing can be done in two ways, either with a shovel (coarse wash) or with a prospector's pan (gentle wash). When it comes to the mining from alluvial sediments, the actual method of physical work the miners use is very important. As noted by Juez et al. (2018), the sediment concentration–discharge patterns are a result of the contribution of distal and proximal sediment sources. Mining activities strongly impact the sediment dynamics: the different techniques used to extract minerals from the alluvial channels increased the natural sediment supply to the rivers. The resulting erosional and depositional processes were thus affected [56].

Deep alluvial mining—mining involving extraction from deep alluvial deposits on the banks of big rivers. Deep alluvial deposits include excavation of the pit and digging until the mineral-bearing horizon is reached. In this case, the horizon was located at a depth of 7–12 m [41]. During mining activities, the mined material is stored in the form of benches or banks to prevent the collapse of mining pits.

Hard rock—sometimes also referred to as primary mining, is characterized by the extraction of material from mineral veins. This type of mining is used both in shallow and deep mineral mining. Miners access the vein through tunnels, and then follow the mineral vein. Hammers and chisels are used to extract the mineral. In the case of richer deposits with larger veins, or in the case of hard subsoil, an explosive is used to blast the deposit. Then, the rock is transported to the surface where it is further processed. Despite all the efforts of miners, however, these methods of mining do not allow mining at greater depths. Access to mineral veins are through shafts that are not safe enough. The actual rock disintegration is done using simple tools (shovels, pickaxes, hammers, chisels, etc.). The light source is kerosene lamps, preferably flashlights or headlamps.

In the context of the development of mineral resource extraction on the African continent, where minerals have been mined for thousands of years, the region of East African countries has a specific position in the area of rare minerals belonging to the 3T mineral group (tin, tantalum, tungsten), sometimes referred to as 3TG (tin, tantalum, tungsten, gold). 3T minerals are a group of minerals that has gained in importance over recent years, especially in the field of transport engineering. Furthermore, 3T minerals are very important for the production of electrical appliances, computers, cables, and other components.

3.1. Basic Typology of Environmental Impacts Associated with ASM

The concept of the environmental impacts of artisanal mining includes all consequences—especially threats and processes—with potentially negative impacts on the environment. Environmental risks can be divided into two basic groups, the first group being the risks to the natural environment, and the second the risks to the human environment, i.e., changes in the natural environment with a negative impact on humans. The risks to the natural environment include, in particular, human activities negatively affecting and degrading the environment. This category typically includes raw material mining. Obviously, both groups are closely interrelated, and one negatively affects the other.

The environmental impacts and risks of ASM mean all the consequences that negatively affect the natural environment and, consequently, the human environment. In developing countries, where the population is directly dependent on soil and its quality, environmental impacts are often limiting regarding the living conditions of the locals and their farming activities.

3.1.1. Changes to Landscape Structure Due to ASM in GLR

Mining activities are one of many anthropogenic activities that shape the Earth's surface. Hooke [57] states that no other anthropogenic process affects the Earth's surface as much as (raw material) mining. His claim is based on the quantitative expression of erosion processes; he states that the human species is involved in the transfer of 35 metric gigatons (Gt) of soil every year. Of this amount, 24 Gt will end in the oceans, with 10 Gt of relocated soil being a direct result of agricultural activities. Although the proportion of ASM in the total amount of material transferred cannot be accurately quantified, these activities are a significant creator of geomorphological processes. ASM is not a very widespread method of mining in developed countries, however, in developing countries, it accounts for up to 90% of total mining output [58,59]. Ghose [58] summarizes the impact of ASM, or of anthropogenic activity, to be a fundamental component of landscape formation which, due to its dynamism and migratory nature, affects large areas and is often characterized by poor organization and negative environmental impact. The actual geomorphological processes are also happening on dumps, in waste rocks, or at the sites where wastewater is stored. According to Li [60], mining waste consists of waste rock, slag, and other depreciated soil. The liquid waste is then stored in setting pits. Deforestation is one of the most visible factors.

Changes to Landscape Structure Due to ASM in Migori (Kenya)

The Migori district is one of the most important gold mining areas in Kenya. During the drought period, when conditions for farming are unsuitable, there is a lack of food crops and income in the Migori area, resulting in the local population from surrounding regions moving to mining sites. At the time of the highest mining activity, as many as 20,000 people temporarily relocate into the area, and were either directly involved in actual mining or working in associated employment (vendors, motorcycle riders, truck drivers, traffickers, etc.) [61]. It is already this high number of people temporarily migrating for work that is a major problem for both the local population and the environment. These aspects then give rise to primary and secondary deforestation. Primary deforestation occurs when there is a need to expand the mining area or the shaft itself. Secondary deforestation is caused by the fact that a large quantity of miners temporarily moves to a mineral-rich area, increasing the demand for wood and charcoal. The Migori mining is occasional, since it is—similarly to most other cases—an

illegal activity. There are both surface and subsurface mines in the area. The ore is crushed and then washed, while the remaining waste rock is deposited in dumps. Many years of mining have left behind polluted watercourses, disturbed vegetation areas, and ruined landscapes. In the area, one can find remnants of large-scale mining that took place here until the late 1970s. There are dozens of dumps in the mining locality, which are partly re-washed by miners. The remaining buildings and old machines used in large-scale mining are not used to their full extent. One big problem is the state of vegetation when the soil has been saturated with the chemicals used in metal processing. In periods of heavy rain, toxic compounds and heavy metals are washed out of the soil, which then return to the soil in other parts of the locality. Some of the heavy metals that are washed out reach the rivers and are carried downstream. Many people use a large amount of wood, which is used here to cook food, but also as a material used to build supports in deep shafts. Thus, artisanal mining has its highest impact on deforestation in the Migori area where, in addition to forest loss, there is also a decline in soil quality, with the damage proving irreversible [62]. There is also great pollution of watercourses in Migori. During gold panning, river profiles are disturbed, leading to lateral and deep erosion. Suspended sediments and floating solids are carried downstream, where they settle and disrupt the river profile. The most affected are the Kuja, Migori, and Mickey rivers [61]. A major problem is also the waste rocks, as the water which flows into the watercourses is also contaminated by this waste rock. Another major problem is “acid mine drainage”, which is water of a low pH caused by the oxidation of sulfides [63]. The production of acid mine drainage usually lasts several decades after the start of sulfide oxidation, and is a phenomenon caused by large-scale mining.

Deforestation Due to ASM in GLR (Rwanda)

Deforestation is one of the most significant environmental impacts of mineral material extraction, including ASM. In most cases, it is the first major intervention in the natural environment after the start of mining, when deforestation of the area intended for surface mining occurs [64]. In the case of ASM, the risk is not only the increased erosion in the locality which is intended for mining, but also the wider surroundings which are affected by this type of mining. Due to the population growth that follows the mining, there is a greater demand for timber and charcoal in the locality, resulting in secondary deforestation. A change in the soil cover or loss of vegetation occurs very frequently at ASM sites, and deforestation is thus an important element that is characteristic of ASM. Maponga et al. [65] note that in Zimbabwe, for example, the deforestation of up to one hundred thousand hectares of land which was subsequently converted into mining localities where gold is extracted.

A good example of an area with mining activities and related population changes is Rwanda, which is heavily dependent on areas of forest for timber resources for use as an energy source (fuel). According to the available data, the majority of the population is dependent on wood heating, and up to 90% of the power produced uses wood and charcoal as its fuel source [66]. Long-term deforestation in Rwanda, in addition to mining activities, is also another factor linked to population pressures on land, and results in soil degradation, erosion, landslides, reduced water quality, and loss of biodiversity (mammals, birds, insects) [66–69].

Research shows that over the last 50 years, the land use structure has changed significantly in the entire Rwanda area, with the original forest area being reduced by 64% between 1960 and 2007. Anthropogenic mining activities, predominantly ASM and resettlement of refugees, had the biggest impact on this rapid decline. On the other hand, reforestation is presently taking place as part of a government initiative, but is still rather insufficient for replacement of original forest stands. Over the past 20 years (more accurate data is from 1990), an average of 2600 hectares of forest per year have been planted in Rwanda [70]. The forest area loss in a total of 18 areas between 1984 and 2015 is documented in Table 1. The data show a reduction of forested areas in Rwanda’s old growth forest areas during the above listed years.

Table 1. Rwanda forest area loss between 1984 and 2015. Adapted from Ministry of Land and Forestry 2017.

Location (Forest Area)	Total Area of Forested Areas (in ha) in		Forest Area Loss 1984–2015 (in %)
	1984	2015	
Buhanda Natural Forest	1116	18	98.4
Gishwati Natural Forest	21,213	1440	93.2
Mashyuza Natural Forest	85	6	92.9
Ibanda-Makera Natural Forest	1425	169	88.1
Karama Natural Forest	3235	1061	67.2
Dutake Natural Forest	31	11	64.5
Karehe-Gatuntu Natural Forest Complex	48	19	60.4
Nyagасыnyi Natural Forest	45	19	57.8
Akagera National Park	267,741	112,185	58.1
Mukura Natural Forest	4376	1988	54.6
Sanza Natural Forest	49	24	51.0
Mashoza Natural Forest	36	18	50.0
Muvumba Natural Forest	1286	688	46.5
Ndoha Natural Forest	39	29	25.6
Kibirizi-Muyira Natural Forest	454	352	22.5
Busaga Natural Forest	191	159	16.8
Nyungwe National Park	112,230	101,005	10.0
Volcanoes National Park	16,128	16,004	0.8
Total	429,728	235,195	54.7

In some of the listed areas, illegal gold mining is carried out using the ASM method. According to the Rwandan government, ASM affects deforestation, in particular, by illegal mining in protected forest areas. There are three protected national parks in Rwanda that serve, among other things, to protect the old growth forest. In the case of illegal ASM, large areas of the original forest and quality land are degraded by rough mining. With a legal ASM, deforestation can happen to a lesser extent. Mostly, it is the tree logging at the boundaries of a mining area, or secondarily as a result of illegal tree logging for fuel use (Figure 2).

**Figure 2.** Deforestation in a mining site (Rwanda). Photo taken by author.

Thus, mining activities are followed by illegal deforestation, river pollution (mercury, cadmium, chromium, lead, and zinc) [71], and soil contamination [70]. During ASM, a smaller area is generally affected when compared to large-scale mining, and the same extent of deforestation common for

surface mining is therefore not observed. However, other risky natural processes, such as erosion and/or landslide, are associated with deforestation.

3.1.2. Impact on Geomorphological Processes as a Consequence of ASM in GLR

Relief is the result of the interaction of endogenous and exogenous forces of geomorphological processes over time. However, during the last centuries, this original relief has been increasingly transformed by people, with anthropogenic activities thus becoming an important relief formation factor, the influence of which continues to grow. Anthropogenic activities are often more important in disturbance of the rock environment than a natural factor [72]. The impact of ASM on geomorphological processes and anthropogenic relief transformation can be divided into three basic categories:

- Direct or indirect influence on natural geomorphological processes (acceleration and deceleration);
- Unplanned (unintended) formation of surface formations;
- Planned (intentional) formation of new anthropogenic formations.

Impact on geomorphological processes through anthropogenic activities is manifested by both acceleration and deceleration of some processes. The acceleration of natural exogenous geomorphological processes is manifested at a greater rate and intensity of geomorphological processes as a result of the artisanal mining. According to the types of exogenous processes, we can define five basic groups of anthropogenically affected geomorphological processes. Artisanal mining can lead to the following processes:

Rock breaking, weathering—the process of rock disintegration and the formation of so-called weathering crust, the weathering process is a response of the material that was in equilibrium and in the Earth's crust to the landscape conditions of the contact of rock with the atmosphere, cryosphere, and biosphere [73]. Weathering depends on the climate and the intensity of weathering processes is conditioned by the laws of latitude and altitude [72].

Mass movements—all movements of rock particles down the slope (gravitation movements, movements that are part of surface and subsurface water), resulting in slope deformation. The main mass movement factors include slope incline (critical slope incline is 25° +), slope load, increased water content, and cohesion disruption (by weathering, vegetation cover changes). According to Rybář et al. [74], we also distinguish four categories of mass movements: creeping, sliding, running-down, and collapsing.

Fluvial processes—are associated with running water, where water is the main removal carrier, and, therefore, the development of landscape and river network is dependent on fluvial processes. The anthropogenically increased sediment supply to the rivers due to mining activity causes a fining of the riverbed surface. As a result, bed roughness is modified, and this has implications in sediment transport and the velocity/shear stress flow patterns. This has been studied in the field [75], and accordingly modeled in the laboratory and numerically in Juez et al. [76]. As stated by Kirchner and Smolová [72], a fundamental factor in influencing the fluvial processes is the disruption of vegetation cover near river springs. Mineral extraction on flood plains tends to lower the alluvial water table, disrupting fluvial flow paths [77]. The collapse of banks in alluvials is caused by a combination of fluvial erosion, geotechnical failure, and mining [51]. Mining of minerals on flood plains tends to lower groundwater levels and disrupt the fluvial flow path. Deforestation can occur as a result of fires, tree cutting intended to expand arable land, and/or as a result of mining. A combination of the above phenomena is a common cause influencing fluvial processes in developing countries. The vegetation cover, especially forest stands, serve as an important regulatory function, retaining residual rainfall and thus slowing down the area's water drainage. Soil erosion also involves soil degradation, and this leads to a reduction in soil fertility. In addition to fluvial erosion, loss of organic matter, salinization, and chemical contamination contribute to soil degradation. The intensity of fluvial processes can be numerically expressed by the volume of eroded and transported material by

watercourses. This material is in the form of suspended sediment which, however, demonstrates the speed of natural and anthropogenic processes together [72].

Aeolian processes—are processes with the wind being a main modeling factor. The modeling activity of the wind plays a more significant role in the case of the soil surface not being reinforced by vegetation cover (deforestation leads to extensively deforested areas), the geological subsoil is formed by loose fine-grained materials with a dry soil surface. The anthropogenic influencing of aeolian (also known as windborne) processes is manifested by the acceleration of aeolian erosion, transport, and material accumulation [72].

ASM significantly affects geomorphological processes and participates in anthropogenic relief transformation. As noted by Dentoni and Massaci [78], ASM has the biggest impact on soil profile changes and acceleration of erosion processes. Szabó [79] includes ASM in anthropogenic geomorphology, which deals with a wide and increasingly expanding area of newly created relief formations of very diverse origins and purposes. Goudie [80] distinguishes two types of processes associated with anthropogenic intervention—direct and indirect. Direct interventions or impacts that are damaging to the landscape are usually conscious, leading to clearly noticeable consequences. These consequences include, for example, mining pits and disintegrated slopes damaged by mining activities. However, less recognizable results of anthropogenic activities are attributed to natural processes that are modified or intensified. These factors are indirect consequences of an anthropogenic intervention. It is, for example, sediment displacement and high sediment ingress into rivers.

In the context of the above, we can observe a number of processes taking place in ASM areas. The transport of rock material to processing areas is, in many cases, assisted by human capital. It is, in particular, manual activities where workers carry rock to a processing site in bags. This type of movement leads to rapid changes in the landscape, depending on the intensity of raw material mining and also depending on climatic processes such as a high rainfall activity, which is typical in a tropical zone. Average annual rainfall amounts to 880 mm in Kenya, 952 mm in Uganda, 970 mm in Tanzania, and 1286 mm in Rwanda [81]. As a result of the listed processes, there are increased erosion activities, a greater volume of removed material, and thus degradation of the soil profile; fluvial activity and fluvial processes are, therefore, the most affected.

Direct Impact on ASM Geomorphological Processes

Material extraction and displacement methods commonly used in ASM are the most fundamental factors affecting geomorphological processes. Waste material and waste rock, which are one of the most important factors in these anthropogenic activities, are also produced during the extraction itself. By combining the relative timeline of mining and the extent of affected area, which is disrupted by mining, a starting point for the possible exploration of anthropogenic impact on the landscape arises. The intensity of landscape disruption in sites with ongoing mining depends on the used technologies and the mechanisms used to mitigate the impacts of mining. The extent to which the landscape is affected depends on the type of ASM and the extent of mining activities. Graphically, we can define individual types of ASM according to technological levels and their effect on geomorphological processes.

Technological processes used in ASM are mostly associated with surface and subsurface mining, which take place in rock masses of areas with different inclines or in alluvial areas. Most mining activities are not based on initial geological surveys but based only on several randomly collected samples or excavated mining pits. Mining thus begins with little or no survey or planning in the mining area at all. This aspect thus results in very scattered areas of mining activities, thus significantly worsening the impact and resulting damage to the local landscape [41].

In the case of the discovery of a deposit location, several methods are used for its extraction. A mining pit is excavated for both the deposit located in a slope and the alluvial deposit, using simple tools (shovels and pickaxes). Once rock material that contains the mined mineral is revealed, it is transported up from the pit and accumulated on the surface. Subsequently, this material is scrutinized or sluiced with water. Only simple tools are used during this process. In some cases,

light mechanization is used. The methods which are used to extract material can be divided into three categories. These categories are partly related to geomorphological processes that are influenced by anthropogenic activities. Extraction methods used in ASM for mineral processing are based on relatively simple surface mining methods. These techniques have been in use since the 19th century and are mostly based on rock sluicing and capturing of extracted material which is heavier than the original rock [82]. In developing countries, the three most common approaches to extraction are simple sluicing, ground sluicing, and hydraulic mining. The output of 3T mineral mining is the concentrate, which is obtained using the two most widely used techniques in ASM: gravity concentration and comminution. Table 2 illustrates the influence of geomorphological processes by individual material mining and extraction methods.

Table 2. Influence of geomorphological processes based on the chosen mining method and material extraction. Author's own format.

Process Characteristics	Process Influenced (x = yes, 0 = no)					Form Influenced
	Rock Breaking, Weathering	Mass Movements	Fluvial Processes	Cryogenic Processes	Aeolian Processes	
Mining method						
Shallow alluvial mining	x	0	x	0	x	alluvial plain, levee
Deep alluvial mining	x	0	x	0	x	alluvial plain, levee
Hard rock	x	x	x	0	x	cret, fork, back, influencing entire solid rock mass
Extraction method						
Simple sluicing	x	0	x	0	x	alluvial plain, levee
Ground sluicing	x	0	x	0	0	cret, fork, back, alluvial plain, levee
Hydraulic mining	x	x	x	0	x	cret, fork, back, alluvial plain, levee
Gravity concentration	x	x	x	0	x	cret, fork, back
Comminution	x	x	x	0	x	cret, fork, back

In the artisanal mining process, the mineral extraction takes place on the slopes of the mining area, and in the spring sections of watercourses and their tributaries, where high river energy is naturally used due to gravity. Workers excavate red-bearing rock in narrow shafts and tunnels, reaching a depth of up to 100 m, transport it to a watercourse, and then wash it using a panning technique. As the mined minerals are heavier than regular rocks, they sink to the bottom where they are retained. After the worker has washed all the rock that was brought in, the watercourse is dammed upstream, and the water flow is diverted elsewhere. The minerals are collected at a sluicing site and the whole process continues. This method of extraction is quite unprofitable, and enables the extraction of larger-sized minerals. As a result of the necessity of using flowing water, many artificial channels with a system of little dams are created in the quarry area, which are constantly disturbed both by this mining technology, as well as by natural depth (gully) erosion during intense rainfall. The second level is mining in a wide riverbed and in an alluvial plain (in fluvial sediments). The lighter and smaller metal minerals that have not been collected upstream are transported as floating solids and accumulate downstream. Where the riverbed is wide and the river is not so deep, there is a secondary extraction of minerals from deposited sediments [83]. The miners collect the coarse sediments from the riverbed and the banks, which are then washed using a pan. The unconsolidated banks are then more prone to lateral erosion, which manifests along the entire length of the stream with the formation of bank disintegration and landslides [84]. In particular, fluvial processes are those significantly affected [85].

Mining processes may lead to mass movements such as creeping, sliding, running down, or collapsing (Figure 3). In addition, there may be terrain subsidence in undermined areas. Significant movements include landslides along cylindrical shear surfaces, which take place mainly in unconsolidated or partially consolidated rocks (in clays and marl, claystone, and clay slates). The landslide separation area then typically has a concave shape, and the collapsed mass accumulates at the foot of the slope. In addition, transverse cracks are formed on the landslide where water accumulates, which then aggravates the equilibrium conditions of the slope. The collapsed rock is often saturated with water so that the tongue has the character of a ground stream.



Figure 3. Slope damage by mass movements. Photo taken by the author.

The Emergence of New Anthropogenic Formations

Anthropogenic mining processes are caused by the mining of raw material from the Earth's crust. Kirchner and Smolová [72] report that anthropogenic formations during mining activities can be created both intentionally or unintentionally. Mining forms can also be distinguished by the custom mining forms and accompanying mining forms (anthropogenically conditioned forms). The forms themselves are then defined as the forms created by surface and subsurface mining.

Dávid [86] classified three main groups of landscape damage during mining activities by actually setting apart three basic groups of anthropogenic formations:

- Dug (also called negative) forms—with shafts and trenches being the most prominent;
- Accumulated (also called positive) forms—represented by mine dumps, whose form is determined by several factors, including the ground surface, the accumulation mode, and the physical properties of the material discharged;
- Areas destroyed by mining leading to surface levelling.

In other words, they could be defined as concave, convex, and flat anthropogenic formations. The emergence of new anthropogenic formations in connection with an artisanal mining method is related to the considerable volumes of raw materials that are extracted and transferred, and the waste material that is deposited. In the ASM areas, new formations are emerging, with most of them being due to anthropogenic activities. The most frequently represented formations are mines, pits, adits, hollows, fluvial placers, and fluvial placer fields (Figure 4).



Figure 4. Fluvial placers and fluvial placer fields. Photo taken by the author.

All forms create new morphologically important forms of relief, which fundamentally change the morphology of the area, creating destructive or accumulative forms. The largest forms, such as an underground mine or a quarry, include a whole set of subforms. In the case of an underground mine, there are, for example, shafts, adits, and chambers. Accompanying mapped mining forms are unintentionally created as a consequence of subsurface mining. Typical examples are hollows, which are caused by a surface depression in undermined areas, i.e., in the area under which the subsurface mining is carried out. Another example is the hollows resulting from the rapid sinking, fall, and collapse of subsurface mines called surface depressions.

Surface depressions are an example of terrain hollows caused by the rapid sinking, fall, and collapse of mines. The ground plan of surface depressions is most often circular (above intersections of mine tunnels) or elliptical (formed by the merging of two circular surface depressions) in the area. Circular surface depressions usually have a diameter of up to 10 m and a depth of 3–5 m. They are sometimes filled with water, but unlike hollows, they usually do not contain a permanent year-round water surface.

The basic form created by the artisanal mining method is an underground mine, which is formed by a vertical conduit—a shaft that runs from the surface to the seam. The primary function of the shaft is as a transport connection designed to transport people and material. Tunnels required to mine deposits are then excavated from the shaft. The tunnels are only reinforced to a limited extent, to withstand the stresses of upper beds. Provided that the reinforcement is present on the mining site, it is only made of wood located at the beginning of the shaft. The mined space behind the progressing reinforcement is usually filled with rock material, or is intentionally caved in with rocks from the ceiling. In order to prevent mine collapse, the protective pillars—i.e., blocks that support the upper beds—are left in place.

Shafts and adits reach depths of 20–30 m and, in extreme cases, up to 100 m. In the actual geological survey, it was found that the adits often branch, thus creating an interconnected network which is very hazardous due to insufficient securing of subsurface works. This unintentional activity then often causes hollows and surface depressions. Hollows are in the form of flat depressions, often with no drainage, and flooded or muddy. They are caused by the fact that the stress exerted during the excavation of the deposit in the upper bed rocks is equalized after the breaking or elastic deformation of an upper bed and cave in the excavated space.

3.1.3. Influence of Hydrological Regime Due to ASM in GLR

The change in the hydrological balance is, in particular, influenced by the large amount of extracted material, which further erodes and can enter watercourses. In the watercourse, the material in the form of suspended sediments moves further down the stream, where it is deposited in the form of alluvial silt. The influencing of the hydrological regime is demonstrated by a change in the natural state of the watercourse and, in particular, by water contamination and deterioration in the quality of water resources. Another factor is the expansion of riverbeds, not only at the expense of agricultural land in alluvial mining activities. Mining in alluvial sediments leads to the removal of large coarse-grained materials, rocks, and other material that is carried down from the upper parts of the stream (parts of trees, branches, etc.). In lower parts of the stream, one can observe the accumulation of sediments and depositing of chemical substances used in mineral processing. In addition to the movement and depositing of sediments, mining in riverbeds has an impact on the flow and direction of the river stream which, in turn, affects flora and fauna reliant on the watercourse. ASM intensifies lateral and vertical erosion. Mineral sluicing and mining itself, where miners damage slopes and river banks, lead to erosion. In particular, in the case of mineral sluicing, vertical erosion as well as deepening and widening of artificial channels occur. Vertical erosion continues until it encounters hard subsoil which is formed, for example, by rock. Lateral erosion is mainly related to alluvial mining. In the case of widening of a riverbed in alluvial mining at the expense of agricultural land, eutrophication and chemical pollution of the areas downstream may occur. Examples include research carried out in the largest mining sites in Tanzania and Uganda [19,54,86–94].

ASM fundamentally influences the hydrological regime, while the use of chemical mining methods leads to contamination of both the surface and subsurface waters. In particular, contamination of water resources by mercury, which is used for amalgamation in gold treatment, represents a risk. Mercury is the most common toxic element. Mercury enters the atmosphere, soil, and water streams during gold processing, where it is then transformed into toxic methyl mercury (MeHg) through reducing bacteria. Given the lack of security standards, and in particular, a lack of information and thus ignorance by ASM workers, mercury is a widely used substance across the African continent [16]. Lacerda [95] reports that 6 tons of gold have been produced in Lake Victoria Goldfields in Tanzania since 1991, while some 24 tons of mercury have been released into the atmosphere over the same amount of time. In the mid-1990s, a field survey was carried out in the area of Lake Victoria Goldfields in Tanzania [96], in order to detect mercury concentrations in mining localities. Water and soil samples, river sediments, and waste rock samples were analyzed with one of the conclusions being that mercury was strongly bioaccumulated in the natural environment. The concentration of mercury in the mine water ranged from 0.01 to 6.78 µg/L, while the concentration of mercury in watercourses, draining the mining areas, was even between 0.04 and 19.8 µg/L; [96]. The negative effects of mercury on the health of miners are documented in numerous studies [94,96–100]. The report *Monitoring of Mercury Pollution in Tanzania: Relation between Head Hair Mercury and Health* [101] deals with the health status of miners digging gold in Tanzania using this method. The study included a health assessment of 150 workers, 103 fishermen and their families, and 19 residents of Mwanza City in northern Tanzania. The risk of having mercury in the body also lies in reduced immunity, and some studies [11] show a link with the spread of malaria, where a high degree of mercury concentration in the body can weaken the immune system, and an individual can be infected with malaria more easily than would normally be the case [11]. Another example worth noting is the study from 1995 carried out in Ghana by the World Bank, which reports that 4–5 tons of mercury enters the environment annually in connection with the ASM method, thus contaminating a large number of areas neighboring to the mining sites. As part of this study, soil, grass, and crop samples that serve as a fodder crop for livestock or for the livelihood of the local population were collected. All analyzed vegetation samples (azolla, green banana, cassava, or also elephant grass known as cane plant) contained high concentrations of mercury [102]. The plants that can hold mercury in large quantities include sugar cane and sugar beet [103,104].

The Minamata Convention on Mercury is supposed to limit the use of mercury in ASM, which aims to protect human health and environment from anthropogenic emissions, as well as leakage of mercury and its compounds. The Convention entered into force on 16 August 2017, and has reached 105 ratifications as of March 2019. The Convention measures include the control of trade and mercury supply networks, including the setting of limits for the use of mercury in raw material mining and their processing. Article 7 of the Convention covers ASM; it notes that the countries using mercury for artisanal gold mining take steps to reduce the use of mercury in mining and processing processes. These countries must develop and follow a national action plan (NAP) three years after ratification of the Convention at the latest. NAP must be prepared in compliance with the annexes to the Convention, with the list of steps taken to gradually eliminate the use of mercury. The states that ratify the Convention cooperate, in particular, in the training and support of research on mercury alternatives, technological and financial aid, exchange of information, and partnerships that could help in the implementation of these objectives. The Convention objectives, however, will only be fulfilled provided that there is compliance with the set rules and their follow-up inspection [43,98,105].

The largest mining localities in Uganda include the Kilembe site, which was shut down in the 1980s, but is currently being re-opened. Between 1956 and 1979, 15 million metric tons of ore were extracted here [91]. The remaining rock was then stored in the form of dumps in the vicinity of the mining site, and the water used for rock sluicing was pumped into the sump tanks. The largest sump tanks are still located near the town of Kasese, which is less than 10 km away from the mining site. Other smaller tanks are located in Kilembe. Although mining in Kilembe was stopped in 1979, the area near the sump tanks is still contaminated. Studies from nearby sites show that even if the source of pollution is removed, heavy metal contamination deposited in waste rock is still present [76]. As described by Mwongyera et al. [76] in their research in the locality of Kilembe, in the vicinity of Kasese, groundwater was contaminated with toxic heavy metals used in copper mining. Another pollution factor is sump tanks that leak acidic water saturated with heavy metals into the environment.

3.1.4. Influence on Soil Fertility Due to ASM in GLR

Compared to other African countries, agricultural land in GLR is valued much more in terms of the population size and density. The share of arable land in the region is shown in Figure 5. Rwanda and Burundi, the two most densely populated countries in Africa and where the land pressures are the highest in the region, have the largest share of arable land (40 to 50%) in the long term. Tanzania, Kenya, and the DRC have the lowest share of arable land.

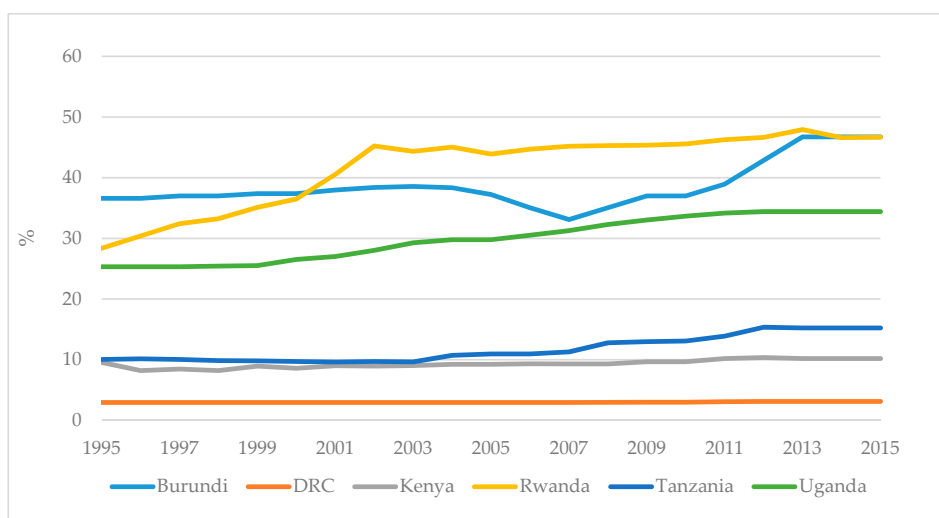


Figure 5. Development of the share (in %) of cultivated land in the total area of the state in Great Lakes Region (GLR) during the period 1995–2015. DRC—Democratic Republic of Congo. Source: Chart compiled by the author based on data from World Bank Group [106].

Throughout the entire GLR, agriculture employs more than 80% of the local population, with other options for making a living being rather scarce [107]. As a result, competition among farmers is becoming increasingly fierce, while the opportunities for a decent livelihood are getting worse, thus leading to a profound social crisis. This fact is closely linked to the debate on land ownership and its use, which can become a source of civil disputes that can lead to the renewal of conflicts and former disputes [107].

The expansion of areas for ASM considerably reduces the production capacity of soils in the areas affected by mining, where there actually exists great potential for further development of agriculture in GLR due to the high soil quality combined with favorable climatic conditions [96]. Agricultural activities have been a dominant source of income in GLR before the expansion of mining activities applied ASM, and agriculture continues to employ 80%–90% of the population. However, in some areas, it gives way mining activities [108]. An example of this is the rise in mining activities at the expense of agriculture linked to a global tantalum shortage in 2000, which has led to increased coltan prices and a coltan boom in the GLR region of interest.

The effect of 3TG minerals mining on agriculture in the GLR has primary and secondary consequences. The primary consequences result from a sudden influx of labor force into mining centers, with a marked increase in stakeholder wealth. ASM attracts many GLR farmers who tend to move away from agriculture and pastoral farming to the mining industry that they consider to be an essential factor to break out of poverty [109,110]. As a result, there was a shortage of labor in agriculture. In addition, some farmers have turned their farms into mining sites because their fields were located in mineral-rich areas. This step has led to the loss of existing agricultural land, to soil degradation and, ultimately, to the disintegration of rural economies [111]. This situation has significantly reduced the export of crops to neighboring countries [112]. As already mentioned, unregulated and often illegal mining often leads to environmental degradation, landslides, and excessive erosion, thus resulting in irreversible land damage and biodiversity loss.

The secondary consequences of mineral mining on agriculture, and hence on the GLR economy, are a combination of other negative effects associated with ASM. There is a strong link between land access and food security in many rural areas. Given that rural populations make their living from subsistence farming, some situations, such as poor crop or population growth (caused by moving of the population to mineral-rich areas) can be reflected in the access to food. Lecoutere et al. [112] state that in some areas of GLR, ASM has led to food shortages in former food production areas that have changed to mining sites. At the same time, there has been an increase in population and an increase in demand for basic agricultural raw materials and a lack of supply of these raw materials. This situation exacerbated the current food insecurity and increased the percentage of malnourished people. Food shortages in rural areas have even led to increased food prices in urban centers [112]. Geenen [109] describes ASM as “easy money” that can be earned by mining activity. However, together with ASM, other economic sectors and services in the area are also growing. Small business is emerging and agricultural activity can be made more efficient by increasing fertilizer yields [109].

The ASM-related technological processes bring about many problems, such as insufficient security of waste rock and sludge and their uncontrolled discharge into the environment, resulting in a number of environmental problems. The issue of waste rock is also addressed by Kainthola et al. [113], who mention problems with waste rock storage and subsequent slope instability as well as acceleration of mass movements. The mined material can then enter watercourses and lead to an increase of sludge in the landscape, as well as facilitating the waterborne distribution of toxic materials resulting in them being deposited further downstream [100]. The environmental problems caused by anthropogenic activities—that may arise during mining and consequently manifest themselves long after mining has ceased—are dealt with by Harris et al. [114]. In addition, soil degradation is influenced not only by specific mining techniques, but also by various natural factors that cause subsequent geomorphological processes in the landscape, such as slope stability, soil erodibility, and vegetation cover.

In the event of ASM using explosives to blast large rock formations, artificially induced earthquakes and/or vibrations may occur which, in turn, may lead to the collapse of shafts and mining spaces [38,115,116]. This activity not only leads to other negative environmental impacts but can also be a cause of the loss of human lives. Blasting of the rock, as well as mining itself, are associated with increased dust and air pollution [110,116]. For miners and locals living close to the mining site, this means deterioration of air quality in their homes and also dust settling on agricultural crops. In the case of large amounts of dust in the air or in the mining site, miners may suffer from silicosis [44,117,118].

Airborne dust is associated with significantly reduced air quality during ASM and subsequent mineral processing. In the treatment of minerals, chemicals that vaporize into the air are used, thus damaging not only the environment but also human health. Gold mining and the amalgamation process, during which large quantities of mercury enter the air, both have the worst environmental impact. Mercury can enter the soil and human body, not only from the air but also from the water. Wastewater is retained in sump tanks, which can leak, allowing mercury to enter the soil and, subsequently, the groundwater. In the case of rainfall, mercury is washed from the soil and goes straight into watercourses. From these water resources, mercury can transform into toxic methyl mercury and, through flora and fauna, get into the human body. Understanding these factors and the assessment processes of soil degradation due to mining is an essential step for the introduction of appropriate management techniques as well as for developing appropriate mitigation measures [119]. Lack of knowledge about how to solve specific environmental problems associated with ASM is, according to Zhang et al. [120], also in the mindset of individual participants in the ASM sector. Zhang et al. argue that in developing countries, people's 'grow first, clean up later' mentality is widespread. Freak [121] states that, in recent years, several environmental awareness projects have been launched, especially in developing countries. For example, the *China Australia Research Institute for Mine Waste Management* (CARIM, 1994–1997) has developed many guidelines that allow industry administration authorities to implement good environmental management practices. The next step toward environmental protection based on knowledge of geomorphological processes was the launch of the German *Coltan Environmental Management* (CEM) project in Central Africa in 2007. The project was designed to develop scientifically based but tangible strategies to prevent environmental problems caused by 3TG mining. In both cases, projects try to address the same problem of how quality arable land in densely populated areas of Africa [122] and Asia [121] is becoming scarcer and what proactive steps are needed to mitigate anthropogenic effects. Mitigation of the adverse effects of mining is also possible through environmental development aid [123]. Mitigation of soil degradation and proper recultivation connected with the cessation of mining constitute a primary factor for sustainable ASM. Lóczy has a similar view [124], where he emphasizes that human activities and geomorphological processes are an integral part of environmental management, involving both the use of environmental resources and environmental protection. As stated by Lawford [125], many studies and international scientific discussions have addressed the best approaches for the sustainable management of natural resources, in particular, to avoid soil degradation and loss of arable land. According to Lawford, the scientific community has agreed that natural resources such as water and soil, but also waste produced by anthropogenic activities, are interconnected systems. Soil is one of the non-renewable natural resources that is often severely damaged by ASM. Lawford also emphasizes that geomorphologists need to study this problem comprehensively because environmental impacts are exponentially increased by anthropogenic influences. Therefore, a better understanding of all related processes will lead to a sustainable mining industry and mitigation of environmental impacts [125].

3.2. Key Participants' Perspectives on the Environmental Implications of ASM

According to the experts who participated in the interviews, the extraction of raw materials in GLR is gaining importance, and governments are hoping for a great deal of diversification of the economy. Mining activities are viewed as a tool for obtaining funds for the development of the region. According to the interviewees, governments are trying to combine two approaches for environmental

management. The first approach is to use natural resources as effectively as possible for economic growth while, contrarily, the second approach is about preserving the country's natural wealth while not irrevocably harming the environment. In the example of Rwanda, experts show that the country is more dependent on arable land than other countries in the region, namely, on its natural resources. The funds provided by world states for development aid are used to invest in the education and technology of universities, and to acquire modern scientific instruments. One big issue is the lack of experts in various professions in the mining area. Professional institutions are trying to educate geologists, mining engineers, technicians, and other professionals involved in mining practices that could minimize the negative environmental impact of mining. This process is slow though, and the interest in the experts—given the developing mining industry—is high. The interviews revealed that illegal mining activities, which take place in remote areas, are a major problem. While there is local government in these areas, this has often not been effective in stopping illegal activities. However, the interviewed experts appreciate the efforts of governments in the region to bring ASM closer to smaller groups of people, thus legalizing their activities. Governments want to achieve this by strengthening mining cooperatives through further support. This is why state institutions organize workshops and seminars for cooperatives, where they learn appropriate mining methods and techniques, particularly in terms of safety, and the basics of economics and business. A large number of people, including miners and their families, smugglers, mineral carriers, traffickers, traders, and others, are connected to ASM activities. For miners, ASM is a dangerous job, but they can earn much more than from agricultural activities, and therefore take this risk. If a miner works for a mining company as a subcontractor, he is provided with occupational and protective equipment. If a miner works illegally in another place or under a mining company's concession, he can receive 25% more money from smugglers per kilogram of mineral than in the case of legal mining. This money is then a motivating factor for some miners to mine illegally.

ASM has been found in some areas in GLR for several centuries, and is thus an integral part of the region. Therefore, the local population views environmental problems associated with ASM as part of their natural environment. The advantage of mineral mining is that the work is permanent and in the case of a poor crop, it is the only source of income for the local population. The interviewees claim that because of ASM, there is sometimes a need to cut down trees (even illegally), where miners believe the mineral vein continues. The tree root system then no longer reinforces the slopes, causing landslides or land sinks. Wood that is obtained in this way is then used as fuel for food preparation and cooking.

4. Discussion

The main output and contribution of this paper is a complete typology of the environmental impacts of artisanal mining. The typology was based on primary research, comparison with foreign approaches, and expert interviews within qualitative research. The environmental impacts of artisanal mining are grouped into four basic categories:

- Changes in landscape structure
 - Deforestation
 - Primary
 - Secondary
 - Land cover change
- Influence of geomorphological processes
 - Weathering
 - Mass movements
 - Fluvial processes
 - Aeolian processes

- Creation of new anthropogenic forms
- Influence of hydrological regime
 - Water contamination
 - Sedimentation of water stream
- Influence on fertility of soil
 - Soil contamination
 - High dustiness
 - Land use change

The aforementioned results may help in the creation of new mining sites and their proper management, as well as preventing or at least minimizing the environmental problems associated with mining.

It is important for the sustainability of ASM:

- To introduce and enforce environmental laws, mining process regulations and standards;
- To monitor and control mining areas to ensure that mining companies comply with all standards, regulations, and laws;
- To support mining companies in the implementation of cleaner technologies and minimization of adverse aspects of mining. Mining companies need to know and comply with environmental regulations, invest in clean technologies, and protect the environment from the potential impacts of their mining processes.

The interviews with the ASM experts have revealed several facts that all respondents agree with:

- The currently introduced certification system in GLR countries designed to label legal minerals could have a positive impact on the environment;
- Workshops and seminars for miners organized by governmental or non-profit organizations can advise miners on how to approach mining with less undesirable impact;
- In spite of adverse environmental aspects, ASM is the key to the region's economic development;
- A major problem in environmental protection is non-compliance with the legislation, or inconsistent control by state institutions;
- Environmental and economic legislation often conflicts with the GLR countries;
- In some countries, there is a shortage of mineral mining experts (geologists, mining engineers, technicians), which in some cases leads to unprofessional practices that negatively affect the environment.

Environmental risks can be divided into two basic groups; the first group is the natural environment risks and the second one is the risks to the human environment, i.e., changes in the natural environment with adverse impacts on man. The risks to the natural environment especially include human activities that negatively affect and degrade the environment. This category typically includes mining. Obviously, both groups are closely interrelated, and one adversely affects the other.

Given that the environmental aspects of ASM are addressed by a number of authors, this paper creates a missing typology of ASM effects on the landscape, contributing to a better understanding of ASM in the Great Lakes Region. The author agrees with Nelson and Church [82], and Byizigiro [48], who, in the typology of environmental impacts, place emphasis on taking into account the different types of ASM and their specifics.

This study provides readers with an introduction to the environmental impacts of ASM in the Great Lakes Region. Given the above findings, this research will help better understand the sustainability of mining operations and can contribute to better environmental protection by improving

the wellbeing of local communities. This study may also be interesting for an international readership of the journal.

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