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Artisanal and Small-Scale Gold Mining in Syanyonja, Busia Gold District, South Eastern Uganda: Impacts on the Mining Population and the Environment

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Abstract: Syanyonja village in the gold district of Busia, South East of the Republic of Uganda contain geologically epigenetic gold quartz vein deposits in carbonate-altered mafic metavolcanic rocks, deposited as quartz reefs in mineralized shear zones. In supracrustal rocks, alluvial gold is obtained from weathered auriferous quartz veins, which are of late orogenic granitic activity. The Syanyonja gold deposits have long been subjected to artisanal and small-scale gold mining (ASGM) by the locals for livelihood. This study determined the amount of mercury discharged with tailings into Namukombe stream, a major water body in Syanyonja village and investigated the impacts of ASGM on the mining population and the environment. Quantitation of mercury discharged with tailings was done by mass balance method. Field survey at the mining sites was done followed by administration of questionnaires to 50 stamperders in the village. The study indicates that about 8% of mercury mixed with auriferous materials are lost in tailings, accounting for an annual mercury release of about 1.757 kg into the environment. Socio-demographic results indicate that the majority of the mining population (64%) are male and ASGM have left health and environmental footprints, which directly or indirectly affects the population. The most common health problems among miners are malaria (36%) and abdominal pain (20%). The standard of living of the miners are evidently low, and most mines are characterized by school dropouts, prostitutes and thieves. Mining sites have deplorably poor hygiene, with evident burning of amalgams to recover gold. ASGM have been accompanied by wanton mowing down of vegetation, land degradation as well as mercuric pollution of water, air, land and aquatic ecosystems. It is suggested that the Ugandan government should re-enforce committees to follow up on ASGM activities, train artisans on sustainable gold mining using borax, magnets, sluice boxes as well as take up farming actively as an alternative.

Keywords: artisanal gold mining; Busia; environmental impacts; mercury pollution; Namukombe stream; panning; Syanyonja; Uganda.

1. Introduction

Uganda is a low income landlocked African country with an averagely solid economic growth and demonstrated ambitions to attain a middle income status by 2020 [1]. The country is at a juncture in its history of economic transformation preceding a decade of an apogee of gross domestic product (GDP) growth that calamitously dwindled from 7% in 2009 to 3.9% in the fiscal year 2016/2017 [2, 3]. Accordingly, the fiscal policy is badly advocating for capital investment to revitalize this GDP. The minerals sector, which used to be informal and largely illegal, is poised to contribute a pivotal part in this economic move, as evidenced by its position of citation in the second National Development Plan for 2015 to 2020 [1].

Uganda lies in the African plate, a continental crust rich in Precambrian rocks of Achaean and Lower Proterozoic to Middle Proterozoic geology [4]. Thus, it has a substantial geological potential for precious minerals including copper, cobalt, tungsten, beryllium, bismuth, uranium, limestone, phosphate, vermiculite, kaolin, bentonite, diatomite, gypsum, glass sands, salts, pozzolana, dimension stones, gemstones, gold and crude oil [1, 4-6]. Artisanal and small scale gold mining (ASGM) has been reported in Ugandan gold districts of Mubende (Kamalenge and Kisita), Kabale (Chiruruma, Chilima, Bugarama, Mugyera), Kisoro (Murindi, Mpororo, Rubuguri and Karamba), Namayingo, Bugiri, Mayuge, Busia (Tiira, Syanyonja, Makina, Amonikakinei), Buhweju (Kahengyere and Muti), Rukungiri (Bikongozo valley), Bushenyi (Mashonga in Kyamuhunga), Mbarara (Kitaka), Ibanda, Kanungu (Kashenyi, Kanungu, and Muramba), Moroto (Rupa, Katikikele and Kamalera), Abim (Alarek and Morulem), Nakapiripirit (Acherer), Kaabong (Lopedo, Sokodo, Kanguoth, Lemoyne, Nakapiril-Kekuli and Lugoto), Nakapiripirit, Hoima (Kafu River) and Amudat (Karita) [4, 7, 8]. Except in Kisita, Kamalenge, Tiira and Amonikakinei where gold is recovered from reefs (hard rock), gold is often recovered from alluvial auriferous materials, with Busia being the pioneer gold mining district [4, 6].

The Ugandan government recently accorded artisanal mining greater cognizance through its prominent inclusion in a draft of the National Mining and Minerals Policy. This initiative is believed shall establish the basis for the upcoming mining laws and regulations and related strategies and actions by the government. In view of the foregoing, more robust evidence of the significance of artisanal mining and clarity on the opportunities and challenges presented by the sector are needed.

Busia have underground workings and surface mining of both alluvial and hard rock gold ores. The principle livelihood activities in this area include trade (as it is at the border with Kenya), gold mining and agriculture [9]. Up to 600 vulnerable people of Buteba, Sikuda and Busitema sub-counties in Busia subsist on ASGM. A demographic ratio of 4:1 (men to women) was reported, with individual annual earnings estimated at 17 million Uganda shillings [10].

Globally, the upsurge of ASGM and the growing awareness of the negative impacts of mercury use, both in terms of environmental and human health, has culminated in the drafting and ratification of the Minamata Convention which constrain signatories to phase out mercury use. As a contribution to decision making, this study evaluated the impacts of mercury-based ASGM on the environment and a mining population in Uganda, taking evidence from Namukombe stream and its propinquity (Syanyonja village) as an example due to the intermittent ASGM in this area.

2. Materials and Methods

2.1. Brief Description of the Study Area

The study was conducted in Syanyonja village, Syanyonja Parish, Busitema subcounty, Samia Bugwe constituency, Busia gold district, South East of the Republic of Uganda. The choice of this area is explained by the high intensity of mercurial ASGM in it. Busia lies between 33°05' E 00°10' N and 34°01' E 00°35' N [6], covering an expanse of about 730.9 km² of land. It is flanked by Tororo district to the North, Kenya to the East, Lake Victoria to the South, Namayingo district to the Southwest and Bugiri district to the West [6]. Busia comprises of a mixture of auriferous hard rock (70%) and 30% alluvial soil which are part of the Cretaceous to Miocene intrusive alkaline carbonatite complexes of the Ugandan frontier with Kenya [4]. Namukombe stream, a tributary of River Malaba is one of the

water bodies in Syanyonja village characterized by mercury based ASGM activities [6] and was of interest in this study.

2.2. Apparatus Used

A calibrated Mettler PM200 analytical balance (Marshall Scientific, Hampton, USA), retort, single use disposable hand gloves, dust masks and eye goggles.

2.3. Ethical Approval

This research required no ethical approval. However, field studies were approved by Department of Mining and Water Resources Engineering, Faculty of Engineering, Busitema University, Tororo, Uganda (Approval No. BU/UG/2013/95).

2.4. Determination of Amount of Mercury Discharged with Slurry Tailings

Informal interviews with artisanal gold miners (stampers) was conducted to assess the mercury losses during gold recovery. Mercury recovered after squeezing and panning the amalgams were estimated by mercury mass balance method described by preceding investigations [11, 12] as follows;

The mass of mercury (quicksilver) entering the system (X_g) was measured using an analytical balance before being introduced into the amalgamation process to concentrate gold with heavier particles in a pan. The mass of the solid mercury-gold amalgam formed (Y_g) and the amount of pure gold recovered (Z_g) were measured after amalgamation and panning respectively. The mass of mercury recovered after amalgamation (excess mercury), M_g was determined as the mass of mercury recovered after squeezing the amalgam. The amalgam was burnt in open air on a retort to evaporate the mercury and then the solid was re-weighed and the mass noted.

The mass of mercury lost in the slurry tailings (discharged), D in grams was estimated from the difference in the masses of the mercury measured utilizing **Equation 1**.

$$D = X - (Z - Y) - M \quad (1)$$

The percentage of mercury discharged in slurry tailings was calculated from **Equation 2**.

$$\% \text{ discharged} = \frac{D}{X} \times 100 \quad (2)$$

The assumptions made were that no mercury was lost through evaporation during amalgamation and losses due to adsorption onto pan walls are negligible. The procedure was repeated using different masses (2, 3, 4, 5 and 6g) of mercury which are typical of the quantities of mercury used for amalgamation at different ASGM sites in Syanyonja village.

2.5. Collection of Field Data

Direct field observation was done in the mining sites in order to appreciate the rate of environmental destruction and the various phases involved in mercurial ASGM. The fieldwork in Syanyonja village was conducted between April 2019 and June 2019. Stampers (at least 18 years old with a seniority of at least 1 year and consenting) were selected. Because of the absence of an exhaustive list of stampers working on the ASGM sites due to the intermittent nature of this activity, selection by simple random sampling was impossible. A quota sampling according to sex (1/3 of women, 2/3 of men) was performed considering the fact that approximately one-third of women work in ASGM sites [13]. To compensate for the selection bias associated with this type of sampling, the estimated size of the sample ($n = 25$) was doubled to 50 subjects to cover potential non-respondents. In quantitative terms, the power of the target study was at least 75%, sufficient in the event where less than 50% of the stampers are unaware of the impacts of mercury use in ASGM on miners and the environment [14]. Individual interviews (face to face) was conducted basing on an anonymous, standardized questionnaire (**Figure 1**). The questionnaire captured socio-demographic

characteristics, common illness in the area, number of family members engaged in ASGM, types and sources of proteinaceous food eaten, and source of water for domestic use (drinking) and for livestock.



Figure 1. Administration of questionnaires in Syanyonja village (*photo used with verbal permission from the interviewed household*).

2.6. Statistical Analysis of Results

All data collected in this study were entered into Microsoft Excel for Office 365 (version 16, Microsoft Corporation, USA). Statistical analyses (One-way ANOVA, averaging and other descriptive statistics) were done using Minitab statistical software (Version 17, Minitab Inc., USA). Statistical significance was set at $p = 0.05$.

3. Results and Discussion

3.1. Mercury Lost in Slurry Tailings

The results of mercury discharged with tailings are given in **Table 1**.

Table 1. This is a table. Tables should be placed in the main text near to the first time they are cited.

Mercury added, X (g)	Mass of amalgam formed, Y (g)	Mass of gold recovered, Z (g)	Mass of mercury recovered after amalgamation, M(g)	Mass of mercury lost in tailings, D (g)
1	0.36	0.13	0.51	0.26
2	1.24	0.22	0.70	0.28
3	2.34	0.30	0.69	0.27
4	3.45	0.36	0.63	0.28
5	4.39	0.40	0.71	0.30
6	5.51	0.42	0.62	0.29
3.5±1.87 ¹	2.88 ±1.94	0.31 ±0.11	0.64 ±0.08	0.28 ±0.14

¹ Results in this row are means of the corresponding columns with standard deviations attached.

About 8% of mercury used in amalgamation is discharged into the environment through slurry tailings during gold processing in Syanyonja and this poses a great threat to the environment. According to the interviewed mercury sellers around the mining sites, an average of 60 g of mercury is sold and used daily, implying that 4.8 g and 1,756.8 g of mercury are discharged into the slurry tailings daily and annually respectively. A report [13] indicated that about 58% ($n = 118$) of sampled gold stampederers in a study done in Mubende and Busia gold districts of Uganda use about 1–50 g of mercury per person weekly. This computationally translates into 2,800 g per stampeder per year. The results of this study is in complete agreement with the anecdotal finding of COWI [15], which observed that, although there are no recent estimates on the use of mercury for ASGM in Uganda, the mean mercury consumption per miner from Busia and Mubende gold-mining sites could give a mercury consumption rate of about 40.5 tonnes per year. This is further substantiated by an estimate which indicated that approximately 1,400 tons of mercury are used every year by ASGM miners globally [16]. In Rwamagasa ASGM area located in Geita district of Tanzania, about 27 kg of mercury was estimated to be released to the environment yearly, with about 12 Kg of gold recovered from the process [17]. It is equally likely that the amount of mercury lost to the slurry tailings is re-emitted to the atmosphere on a relatively short time scale of one to several years as the tailings are accumulated in above-the-ground piles and later reprocessed. It should therefore be over emphasized that the population living near to or downstream of Namukombe stream and the ASGM sites are at risk of mercury pollution [6].

3.2. Socio-Demographic Characteristics and Exposure to Mercury

A total of 50 stampederers were contacted in this study. The characteristics of the participants are given in Table 2. The average age of the respondents was 26 years. The sample consisted of 64% men ($n = 32$) and 36% women ($n = 18$). There was no significant difference ($p = 0.05$) in the number of people who had stayed for 1 to 5 years and over 16 years in Syanyonja village (Table 2). Most of the family members of the respondents (80%) were either directly or indirectly involved in mercury based ASGM. The gold mines are dominated by people between 20 years and above (70%) though children (stampederers below 18 years of age) constituted about 14% of the mining population (Table 2). Overall, the levels of child labour were higher in ASGM sites that are more informal and where participation is poverty rather than enterprise driven. Some of the children in these mines are orphans, are from child-led households or lack school fees and scholastic materials, corroborating preceding studies in other parts of Uganda [7, 18]. This study also agrees well with previous reports that women realize fewer benefits from artisanal and small-scale mining than men but bear the brunt of negative impacts [7, 19-22].

In addition, the mines consist of people of various ethnic origins namely: Bagishu, Basoga, the Iteso, Karamojong (Karimojong) and the Congolese. This is similar to a report [7] which cited that Acherer, an ASGM site in Karamoja region (Nakapirpirit district) hosts different ethnic groups: the Iteso, Western Ugandans and Rwandese during peak periods of ASGM. It is known that decentralization, economic turmoil, the ten-fold gold price increase within the period of 1996 to 2002 coupled by prospects of improved livelihoods from ASGM attracts unemployed people to engage in ASGM [7, 20, 23].

In terms of exposure, the findings indicated that most respondents (50%, $n = 25$) had spent 31 years or more using mercury, most of which (68%, $n = 17$) were women. In a similar cross-sectional study in some sites of Mubende and Busia districts of Uganda, it was reported that 44% ($n = 90$) of the respondents had used mercury for ASGM for 1 to 4 years while the remaining percentage (56%, $n = 114$) had lived for 5 to 29 years handling ASGM mercury [13].

Pertaining health, it was noted that malaria (36%) and abdominal pain (20%) tops the list of the illnesses reported in the last two (2) years (Table 2). This could be because pits left after harvesting auriferous rock materials holds stagnant water which act as breeding grounds for female anopheles' mosquitoes, the plasmodium vector which enhances the spread of malaria-causing plasmodium (*P. falciparum* and *P. malariae*). Abdominal pains are probably due to the manual nature of ASGM in Syanyonja which involves digging, crushing and panning of auriferous materials, usually involving

bending for long hours in scorching sun [6]. Gold artisans in Syanyonja employ rudimentary methods of gold extraction including panning [6], typical of other ASGM sites in Uganda [18, 20, 21] (Fig. 2). Human health problems, diseases and neuropsychiatric disorders such as malaria, cholera, venereal diseases (HIV/AIDS, gonorrhoea, syphilis), musculoskeletal disorders (upper and lower limbs, back), sleep disruption (insomnia), headache, anorexia, tremor of the fingers, loss of fecundity, and abnormal fatigue have been reported in other ASGM communities [7, 24-26].

Table 2. Characteristics of the sampled respondents ($n = 50$).

Variable	Categories	Number	Percentage
Sex	Male	32	64
	Female	18	36
Residence time in Syanyonja village	1-5 years	22	45
	6-10 years	04	7
	11-15 years	02	3
	Over 16 years	22	45
	Family members engaged in ASGM	Yes	40
	No	10	20
Age of stampedeers engaged in ASGM ¹	1-10 years	04	8
	10-15 years	03	6
	15-20 years	08	16
	20-30 years	10	20
	31 years and over	25	50
	Major sicknesses in the last 2 years	None	16
	Malaria	18	36
	Acute respiratory problems	02	4
	Abdominal pain	10	20

¹ Ages cited were from averaged information provided by the respondents in regard to their family members engaged in ASGM.



Figure 2. Panning of alluvium along Namukombe stream : (a) by children (school dropouts). Notice the plastic tin used for storing recovered gold nuggets; (b) by a man. Notice the ditches created; (c) quality of water from the stream. Notice the destruction of shrubs in the right background (modified from [6], photos reproduced with permission).

It was noted that in mines in Syanyonja, women are multitasked. They actively engage in ore processing and transportation, water collection, catering, prostitution, operate clinics amongst others.

Unfortunately, this pivotal role played by women are not anywhere recognized in official ASGM policies [27] and in some cases they end up being victims of rape [18]. Also, ASGM is combined with domestic and reproductive work as well as small scale farming. Most women and girls are involved in low paying jobs, as most high paying opportunities are usually work prohibited by cultural norms for females to do. Therefore, women usually end up in panning, collecting water, transporting auriferous rock materials for crushing and burning of mercury in open air. Some operate eateries, sell airtime and consumables (such as waragi, cigarettes, cakes) around the mines. This is corroborant with preceding studies elsewhere in Uganda [7, 18, 21, 27].

Children are taken to the mining sites and this may expose them to atmospheric mercury vapour resulting from burning of mercury in open air. Inhalation of mercury vapours results in high blood concentration of mercury which are implicated for many respiratory, neurologic, renal, immunologic, dermatologic and reproductive complications [28]. Human health impacts emanating from the utilization of mercury in ASGM have been reported in African countries of Benin [29], Burkina Faso [30], Ghana [31, 32] and Mali [33]. This is evidenced by elevated levels of mercury in human blood, hair, urine and breast milk [26, 34, 35].

ASGM is largely a poverty-driven activity, used as a coping mechanism with thousands of families engaging in the mining practice [18, 36]. This unfortunately exposes the miners to dermal contact with mercury in the dredged sediments as well as mercury-contaminated water [6]. Like reported for other parts of Busia (Tiira and Amonikakinei) [37], Karamoja region [7, 18], Mubende and Buhweju [13, 20, 21], miners in Syanyonja village do not employ any form of personal protective equipment during mining activities. This could partly be due to lack of sufficient income to purchase them and lack of awareness on the dangers of mercury [21]. In addition, miners are also exposed to other heavy metals such as Copper, Lead and Chromium because these metals are naturally part of auriferous rocks as arseno-pyrite (FeAsS_2), Copper II Sulphide (CuS_2) and Iron (II) Chromium trioxide ($\text{FeO.Cr}_2\text{O}_3$) [38, 39]. These metals are released into the tailings during gold processing. Mbonimpa [9] also reported the presence of heavy metals in samples of rocks and sediments taken from around Namukombe stream and other areas between River Solo and River Malaba in Busia gold district. It is worth noting that most of the respondents, as reported previously [13], have explicit fears regarding the health and ecological impacts of mercury usage in gold recovering, peculiarly on the risk of polluting food and water resources and losing fecundity.

3.3. Sources of Water Used for Drinking, Domestic Use and Animal Husbandry

In Syanyonja village, the weather pattern influences a household's choice of the main source of drinking and cooking water. Accordingly, more than half (55%) of the respondents reiterated that they rely on both borehole and Namukombe stream water for drinking and cooking purposes when compared to using borehole water only (**Figure 3**). Many residents turn to the stream water when the dry season sets in and the boreholes are dry. Contamination of Namukombe stream, boreholes, springs and bottled water in Uganda are well documented [6, 40-45], and thus, the results of this study agrees well with studies which indicated that ASGM communities in Uganda have contaminated ecosystems supporting their livelihoods [6, 18, 46-48]. Water is an indispensable part of life on planet earth and the availability of sufficiently clean and safe water is an important aspect of a community [40].

3.4. Sources of Food

The various sources of food consumed in Syanyonja village are given in **Table 4**. The major foods consumed are beef, fish, chicken yams, beans, maize and millet flour. A preceding study indicated that fish and yams harvested from Namukombe stream are polluted with mercury [6]. Fish is widely consumed in many parts of Uganda [37, 49, 50] because it has high protein content, low saturated fat and also contains omega-3 fatty acids, calcium, phosphorus, iron, trace elements like copper and a fair proportion of the B vitamins known to support good health [6, 49, 51, 52]. Besides the good health benefits of fish, there have been many reports on contamination of fish by carcinogenic chemicals in Uganda [6, 49, 53, 54].

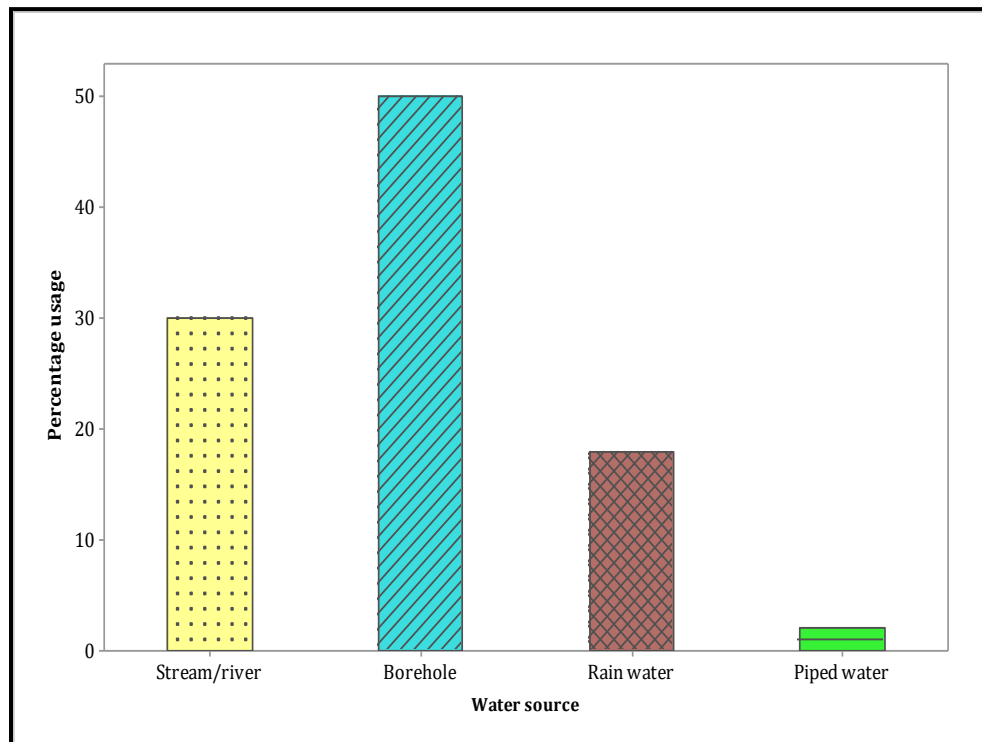


Figure 1. Major water sources used by residents of Syanyonja village

Table 4. Major sources of food for the sampled residents of Syanyonja village.

Variable	Categories	Frequency in a month	Percentage
Major sources of proteins	Chicken	02	10
	Fish	10	46
	Beef	12	41
	Others (yams, beans, millet, e.t.c.)	01	3
Sources of fish consumed	Unknown	11	44
	Nearby market	05	20
	Namukombe stream	08	32
	Greater than 10 km from ASGM sites	01	4
Origin of yams consumed	Nearby market	08	32
	Namukombe stream and banks	16	64
	Greater than 10 km from ASGM sites	01	4

Since most of the foods consumed by the community is from within the village, there is high chances that the locals are consuming mercury-contaminated foods and these risks are expected to be high if most of the fish are consumed whole, especially by children or pregnant women [6]. Other foods such as beef, milk and yams are equally unsafe as they can also get contaminated through water, food and atmospheric deposition of mercury.

3.5. Impacts of ASGM on the Environment of Syanyonja Village

Field observations and responses gathered reveal that the major environmental problems of ASGM mining in Syanyonja village are deforestation, land degradation, soil erosion, dumping of

tailings, air and stream water pollution (Fig. 2). Deforestation will leave degraded and fragmented habitats for wildlife [55]. More so, this shall increase the vulnerability of forest ecosystems to invasive plant and animal species. Exposure of top soil may initiate soil erosion which when coupled with the open pits may lead to landslides [55].

Secondary impacts from erosion, including sedimentation and siltation are evident in Namukombe stream. Siltation reduces light penetration into water bodies, causing reduced photosynthetic activity in aquatic organisms as well as increased biochemical oxygen demand, clogging of fish gills thus death of aquatic organisms.

Wildcat pitting in many shallow pits and shafts across the mines were evident and these are excellent breeding grounds for mosquitoes and other disease vectors. In addition, the numerous small shafts and pits dispersed across the mines are hazards for livestock and humans (particularly children), who may fall in the pits, causing loss of lives, income and time. These observations have been reported in other ASGM sites of Uganda [7, 18, 48].

It was noted that some parts of Namukombe stream is experiencing siltation due to the cumulative effects of water-intense gold panning. This has greatly increased the turbidity of water from this stream (Fig. 2). Turbidity greater than 5 Formazin Turbidity Unit (FTU) indicate high levels of bacteria, pathogens or particles that can shelter harmful organisms from disinfection [40].

Land is a key denominator in food production and any economic development. Artisanal gold mining in Syanyonja is done on land that could otherwise be utilized for agriculture, which supports food security. Reluctancy to backfill open pits exacerbate the situation. The interviewed mining stampeders are incrementally phasing out agriculture and other livelihood enterprises for mining as an economic activity that will salvage them from poverty. It is known that ASGM cause environmental havocs in no small magnitudes [6, 16, 56]. Therefore, whereas the gold industry continues to be a valuable source of income to Ugandans, there is need to blend ASGM with environmental conservation [57].

Conclusion and Recommendations

From this survey, the ecological and livelihood challenges associated with ASGM in Syanyonja definitely span beyond the anticipated benefits. Artisanal gold miners are typically poor, hardworking, illiterate with little or no formal education, under health stresses, malnourished and often somewhat transient. Miners in Syanyonja are better acquainted with the health impacts of the mercury based ASGM than the accompanying environmental impacts. ASGM in Syanyonja have led to deforestation and pollution of land, air and water. Further research should examine the physicochemical and microbiological profile of the water sources utilized by the residents of Syanyonja village, the mercury levels in the blood, hair and urine of the community as well as the atmospheric flux of mercury in this area.

Author Contributions: Authors TO & SK designed the study and performed fieldwork. Authors SS & OB organized data and performed the statistical analysis. TO, SK, KMK, OB, RO & SA wrote the first draft of the manuscript. Authors TO, KMK, & OB managed the analyses of the study. TO, SK, SS & SA managed the literature searches. All authors read and approved the final manuscript.

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