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The Environmental Impact of the Traditional Gold Mining in Abu Hamad, Sudan

الأثر البيئي للتعدين الأهلي للذهب في منطقة أبوحمد

A Thesis Submitted In Fulfillment of the Requirement of the Degree of MSc. in Chemistry

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الإستهلال

قال الله تعالى :

﴿ زُيِّنَ لِلنَّاسِ حُبُّ الشَّهَوَاتِ مِنَ النِّسَاءِ وَالْبَنِينَ وَالْقَنَاطِيرِ الْمُقَنطَرَةِ مِنَ الذَّهَبِ وَالْفِضَّةِ وَالْخَيْلِ الْمُسَوَّمَةِ وَالْأَنْعَامِ وَالْحَرْثِ ۗ ذَٰلِكَ مَتَاعُ الْحَيَاةِ الدُّنْيَا ۖ وَاللَّهُ عِندَهُ حُسْنُ الْمَآبِ ﴾

سورة الزخرف الآية (71)

صدق الله العظيم

Dedication

To the soul of my father, my mother, husband, sister and brothers

Acknowledgement

I wish to express my sincere appreciation to my supervisor Dr. Adil Elhag Ahmed who has been guided and encouraged me to do the right things.

I would like to thank Dr. Essa Ismail; his help is truly appreciated. I also would like to thank Dr. Sydah from minster of minerals who has provided me with the geological map of the mining area.

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Abstract

The environmental impact of traditional Gold mining activity has become a concern. The concern is due to the methods that are used in the extraction of the Gold from its co-metals, particularly the use of the Mercury. The purpose of the study to identify the impact of the traditional gold mining in Elcrow in Abo Hamad district. This research was undertaken to determine the concentration of toxic heavy metals that have been used to extract gold such as Mercury or has been released during mining processes such as Lead, Arsenic and Cadmium in the mining area. The analysis results showed that the concentration of these metals was high in water, plant and soil samples that were taken from the mining area especially, Mercury. The concentration of these metals exceeded the international acceptable levels, the concentration of Mercury in some samples of water was 2004 ppb Arsenic was 14.23ppm, lead 1233ppm and Cadmium was 14.67ppm, in soil Hg 3459ppb, As585.4, Pb592.5ppm and Cd 4.439ppm, the results of plants was Hg 3840ppb, As 5.871ppm Pb 79.94ppm and Cd 1.612ppm. The high concentration of these metals in the soil could leach and cause ground water contamination. could also get absorbed by the plant and eaten by human which could cause serious health problems. The presence of these metals in a water sample in River Nile indicates the washout of these metals by rain or superficial water to the Nile basin which is the main source of the potable water for the people in the study area.

المستخلص

أصبح التأثير البيئي لنشاط تعدين الذهب التقليدي مصدر قلق. يرجع القلق إلى الأساليب المستخدمة في استخراج الذهب من معادنه المشتركة ، ولا سيما استخدام الزئبق. الهدف من الدراسة التعرف على اثر تعدين الذهب التقليدي في الكرو بمنطقة ابو حمد. تم إجراء هذا البحث لتحديد تركيز المعادن الثقيلة السامة التي تم استخدامها لاستخراج الذهب مثل الزئبق أو تم إطلاقها أثناء عمليات التعدين مثل الرصاص والزرنيخ والكادميوم في منطقة التعدين أظهرت نتائج التحليل أن تركيز هذه المعادن كان عالياً في عينات المياه والنباتات والتربة التي تم أخذها من منطقة التعدين وخاصة الزئبق. تجاوز تركيز هذه المعادن المستويات الدولية المقبولة ،كان تركيز الزئبق في بعض عينات الماء في 2004 جزء من البليون، الزرنيخ 14.23 جزء من المليون والرصاص 1233 جزء من المليون والكادميوم 14.67 جزء من المليون .

في التربة الزئبق 3459 جزء من المليون والزرنيخ 585.4 جزء من المليون و الرصاص 592.5 جزء من المليون و الكادميوم 4.439 جزء من المليون.

وكانت نتائج التراكيز في النبات: الزئبق 3840 جزء من المليون و الزرنيخ 5.871 جزء من المليون و الرصاص 79.94 جزء من المليون و الكادميوم 1.612 جزء من المليون. يمكن أن يؤدي التركيز العالي لهذه المعادن في التربة إلى الترشيح والتسبب في تلوث المياه الجوفية. يمكن أيضًا أن يمتصه النبات ويأكله الإنسان مما قد يتسبب في مشاكل صحية خطيرة. يدل وجود هذه المعادن في عينة مياه في نهر النيل على انجراف هذه المعادن عن طريق الأمطار أو المياه السطحية إلى حوض النيل الذي يعد المصدر الرئيسي لمياه الشرب لسكان منطقة الدراسة.

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List of Abbreviations

DMA	Direct Mercury Analyzer
EISs	Environmental Impact Statement
GPSS	Global Positioning System
ICP-AES	Inductively Coupled Plasma Atomic Emission Spectroscopy
IQ	Intelligent Quotient
NEPA	National Environmental Policy Act
WHO	World Health Organization
PLRS	petroleum laboratories, research and studies
GRAS	Geological Research Authority of the Sudan

Chapter one

Introduction and Literature Review

Chapter one

Introducteion and Literature Review

1.1. Theoretical and Historical Background

Environmental chemistry is the study of the source, reaction, transport, effect and fates of chemical species in water, soil, air and living organism and their effects thereon. There are number of inorganic contaminants (metals) that are important in water and soils includes heavy metals such as cadmium, arsenic, lead and mercury and they are of concern due to their toxic properties.

Sudan has a long history and a big heritage of mining culture which go back to three thousand years when Nubians extracted gold and base metals and smelted iron to make water wells. Mineral resources have not been fully explored as of yet but include: petroleum, natural gas, gold, silver, gold, silver, chrome, asbestos, manganese, gypsum, mica, zinc, iron, lead, uranium, copper, kaolin, cobalt, granite, nickel and tin (Yousif, 2015).

Traditional gold mining in Sudan has become an important economic activity particularly in the northern part of Sudan. There are more than 40,000 gold sites in Sudan, about 60 gold processing companies operating in thirteen states of the country and there are more than 350 small scale (traditional) gold mining in Sudan according to information was given from the ministry of minerals. The environmental impact of such activities has become noticeable according to the method that has been used in gold extraction ((GRAS), 2018).

1.2. Mining process

Mining is the extraction of valuable minerals or other geological materials from the earth, usually from an orebody, lode, vein, seem, reef or placer deposit. These deposits form mineralized package that is of economic interest to the mine Ores recovered by mining include metals, coal, oilshale, gemstones, limestone, chalk, dimension stone, rock salt, potash, gravel and clay. Mining is required to obtain any material that cannot be grown through agricultural processes or created artificially in a laboratory or factory. Mining in a wider sense includes extraction of any non-renewable resource such as petroleum, natural gas, or even water. Mining activity is one source of pollution, which result from human activity. One of the oldest substantial mining activities is gold mining.

Gold mining is the extracting gold from gold ores or from the ground. It has been carried out in both large and small scales. Examples of large-scale gold mining in Sudan include Ariab mining company and Managem mining company. However, there are more than 350 small scale (traditional) gold mining in Sudan. In this research project Elcrow was surveyed, it is one of the traditional gold mining projects in Abo Hamad district.

Traditional mining, also known as old-school mining, is a mining method involving the use of simple manual tools, such as shovels, pickaxes, hammers, chisels and pans (Benjamin N A Aryee, Ntibery and Atorkui, 2003). It is done on both surface and underground environments. Until early 1900s, traditional mining was widely used throughout the world. It is still used as mining method in some countries, including Sudan. In traditional surface and underground mining, hammers and chisels with pickaxes and shovels are used. Mine carts are used to move ore and other materials in the process of mining, whereas, pans are used for placer mining operations, such as gold panning. Gold panning, or simply panning, is a form of placer mining and traditional mining that extracts gold from a placer deposit using a pan. The process is one of the simplest ways to extract gold, it is popular with geology enthusiasts especially because of its cheapness and is considered relatively simple and easy process. This process is the oldest method of mining.

The first recorded instances of placer mining are from ancient Rome, where gold and other precious metals were extracted from streams and mountainsides using sluices and panning. However, the productivity rate is comparably smaller compared to other methods such as the rocker box or a large extractor, which have led to it largely being replaced in areas with capital for more sophisticated equipment. (Benjamin , Ntibery and Atorkui, 2003).

The environmental impacts of mining occur at local, regional, and global scales through direct and indirect mining practices. These impacts can result in erosion, sinkhole, loss of biodiversity or the contamination of soil, ground water, and surface water by the chemicals emitted from mining processes. They also have an impact on the atmosphere from the emissions of carbon leading to severe human health and biodiversity effects. Some mining methods may have such significant environmental and public health effects that mining companies in some countries are required to follow strict environmental and rehabilitation codes to ensure that the mined area returns to its original state. (Sonter et al, 2018).

Erosion of exposed hillsides, mine dumps, tailings dams and resultant siltation of drainages, creeks and rivers can significantly impact the surrounding areas. In areas of wilderness, mining may cause destruction and disturbance of ecosystems and habitats and in areas of farming it may disturb or destroy productive grazing and croplands. In urbanized environments, mining may produce noise pollution, dust pollution and visual pollution. A sinkhole at or near a mine site is typically caused from the failure of a mine roof from the extraction of resources, weak overburden or geological discontinuities. The overburden at the mine site can develop cavities in the subsoil or rock, which can infill with sand and soil from the overlying strata. These cavities in the overburden have the potential to eventually cave in, forming a sinkhole at the surface. The sudden failure of earth creates a large depression at the surface without warning, this can be seriously hazardous to life and property. Sinkholes at a mine site can be mitigated with the proper design of infrastructure such as mining supports and better construction of walls to create a barrier around an area prone to sinkholes. Back-filling and grouting can be done to stabilize abandoned underground workings. (Singh and Dhar, 1997).

Mining can have harmful effects on surrounding surface and groundwater. If proper precautions are not taken, unnaturally high concentrations of hazardous elements such as arsenic, lead and mercury are going to spread over a significant area of surface or subsurface water. With large amounts of water used for mine drainage, mine cooling, aqueous extraction and other mining processes, the potential of these chemicals will increase to contaminate ground and surface water. As mining produces copious amounts of wastewater, disposal methods are limited due to contamination within the wastewater. Runoff containing these chemicals can lead to the devastation of the surrounding vegetation. The dumping of the runoff in surface water or in a lot of forests is the worst option. Therefore, submarine tailings disposal is regarded as a better option (if the waste is pumped to great depth). Land storage and refilling of the mine after been depleted is even better, if no forests need to be cleared for the storage of debris. The contamination of watersheds resulting from the leakage of chemicals also has an effect on the health of the local population. (Larmer, 2009).

1.3. The process of gold mining in Elcrow:

The gold containing rocks are brought in from wells, crushed and ground, then the gold extraction begins in small basins. The second process is panning, panning some mined ore is placed in a large metal or plastic pan, combined with copious amount of water, and agitated, so that the gold particles being of higher density than the other material settle to the bottom of the pan. The lighter gangue material such as sand, mud and gravel are then washed over the side of the pan, leaving the gold behind. Once a placer deposit is located by gold panning, the miner usually shifts to equipment that can treat volumes of sand and gravel more quickly and efficiently. Then mercury is mixed with the materials containing gold. A mercury-gold amalgam is formed because gold will dissolve in the mercury while other impurities will not. The mixture of gold and mercury is then heated to a temperature that will vaporize mercury, leaving the gold behind. This process does not result in gold that is 100% pure, but it does eliminate some impurities.

The problem with this method is the release of the mercury vapor and other heavy metals into the environment. Mercury also can get into the soil and water if it still is contaminating other waste materials from the mining process that may be discarded.

1.4. Area of the study

Alkaro is small hilly area in Abu Hamad locality in the River Nile State. It lies around 21 km to the south of Abu Hamad town and 650 meters from the nearest village (Alghurayb village) and only one kilometer away from the Nile River. Its GPS position is (Latitude: 19°20'57.05"N, Longitude: 33°21'56.37"E). According to the 2008 census, Abu Hamad has 128000 populations of which, 68 are males and 60 are females. (COUNCIL, 2009)

The area has a desert hot and dry weather. The temperature ranges between 49.5 °C (summer) to 4.5 °C (winter). Rain fall is between July and September with average of 22 mm/year ('Abu_Hamad_2006.pdf', no date). The wind is mainly dry northeast most of the year with short duration of southwest wind. (Madani, 2011)

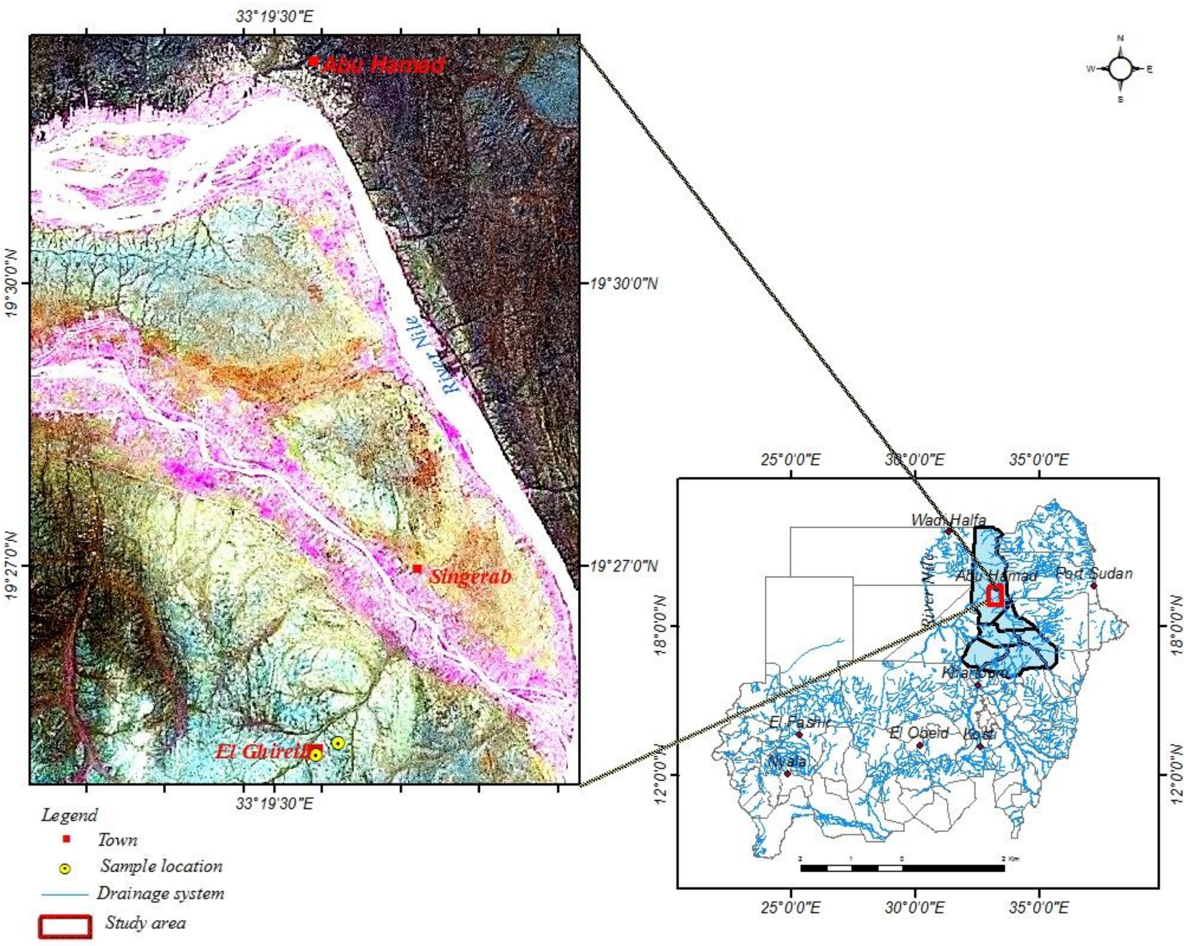

Figure 1-1 the map of Study area (Sudan ministry of minerals section of underground water)

1.5. The potential risk of heavy metals

The most common heavy metals found at contaminated sites are, Lead (Pb), Arsenic (As), Cadmium (Cd) and Mercury (Hg). These metals contaminate soil and decrease crop production. They can also contaminate water and groundwater due to the risk of bioaccumulation and bio magnifications in food chain.

1.5.1. Lead poisoning

Lead is not an essential element. It is well known to be toxic and its effects have been more extensively reviewed than the effects of other trace metals. Inhalation and ingestion are the two routes of exposure, and the effects from both are the same. Lead (Pb) accumulates in the body organs (i.e., brain), which may lead to poisoning (plumbism) or even death. The gastrointestinal tract, kidneys, and central nervous system are also affected by the presence of Lead. Children exposed to lead are at risk for impaired development, lower IQ, shortened attention span, hyperactivity, and mental deterioration, but children under the age of being at a more substantial risk. Adults usually experience decreased reaction time, loss of memory, nausea, insomnia, anorexia, and weakness of the joints when exposed to Lead (Baldwin and Marshall, 1999). Exposure to lead can result in a wide range of biological effects depending on the level and duration of exposure. Various effects occur over a broad range of doses, with the developing young and infants being more sensitive than adults. Lead poisoning, which is so severe as to cause evident illness, is now very rare. Lead performs no known essential function in the human body, it can merely do harm after uptake from food, air, or water. Lead is a particularly dangerous chemical, as it can accumulate in individual organisms, but also in entire food chains.

1.5.2 Arsenic poisoning

Exposure to arsenic (As) can result in a variety of health problems in humans, including various forms of cancer (e.g. skin, lung, and bladder cancer), cardiovascular and peripheral vascular disease, and diabetes (Henke, 2009). Overall, both inorganic and organic As (III) forms tend to be more toxic to humans than the As (V) forms. Humans may be exposed to arsenic through inhalation, dermal absorption, and ingestion of contaminated food, water, and soil. Inhalation exposure can result from ore smelters. In air, arsenic primarily sorbs onto particulate matter. Once arsenic-bearing gases or particles enter the airway and deposit on lung surfaces, the arsenic is absorbed further into the body. Inhalation of arsenic depends on the size of the particles and absorption depends on the solubility of the chemical form of the arsenic. When compared with ingestion, the risks associated with the dermal absorption of inorganic arsenic are generally low. Like ingestion, any dermal effects would depend on the source of the arsenic (e.g. water, soil, chromated copper arsenate (CCA)-preserved wood). Controlled ingestion studies in humans indicate that both As (III) and As (V) are well absorbed from the gastrointestinal tract. Between 45 and 75% of the dose of various As (III) and As (V) forms are excreted in urine within few days, which suggests that gastrointestinal absorption is both relatively rapid and extensive. (Henke, 2009).

1.5.3 Cadmium poisoning

Cadmium (Cd) may cause health effects upon both acute and long-term exposure. Epidemiological studies concerning adverse health effects in humans have been reported to an increasing extent during recent years Cadmium is a metal that accumulates in the body with age and has an extremely long biological half-life. Because of its long biological half-life, long-term toxicity has attracted attention. However, there are also some important aspects of short-term toxicity, which will be briefly described in the following section. Acute toxicity after ingestion of drinks with more than 15 mg/ L of Cd has been described in children exposed to Cd via a soft drink machine (4). Symptoms of acute toxicity are nausea, vomiting, and abdominal pain. High Cd concentrations can occur when acid food comes in contact with Cd-plated utensils.

Acute toxicity by inhalation may occur in workers welding Cd-containing materials. Pulmonary edema and pulmonary respiratory distress (2) characterize acute toxicity after inhalation of fumes containing Cd.

Skin contact or Cd exposure via the skin is not known to cause health effects in humans or animals. Metallothionein-4 is present in the squamous epithelium of the skin and may have a protective role against development of skin effects.

Pollution of the general environment by Cd has as yet been related to the development of human disease only in some special situations, such as itai-itai disease in Japan and renal dysfunction and increased occurrence of osteoporosis in Belgium and in China. Long-term exposure to Cd in air, food, or water increases Cd concentration in the kidneys and gives rise to kidney disease. Other effects due to Cd exposure are lung damage, bone effects, liver dysfunction, and reproductive toxicity. (Lawrence et al, 2009)

1.5.4 Mercury poisoning

All forms of mercury (Hg) are toxic, particularly the organic forms such as methylmercury (MeHg), which is a neurotoxin (Liu, Cai and O'Driscoll, 2012). Acute mercury exposure can produce permanent damage to the nervous system, resulting in a variety of symptoms such as paresthesia, ataxia, sensory disturbances, tremors, blurred vision, slurred speech, hearing difficulties, blindness, deafness and death (Zuiderveen, 1996). In addition to neurotoxicity, mercury, in inorganic and/or organic forms, can affect other systems and sequentially cause adverse effects including renal toxicity, myocardial infarction, immune malfunction, and irregular blood pressure (Sciences, 2000). Human exposure to Hg can pose a variety of health risks, with the severity depending largely on the magnitude of the dose. Historically, there were two notorious poisoning episodes associated with the extremely high MeHg exposures, that is, in Minamata where individuals were poisoned by MeHg through consumption of contaminated fish and in Iraq where the consumption of MeHg treated (as a fungicide) grain led to poisoning. (Management, 2000)

Nowadays, acute poisoning incidents from high Hg exposure are rare and the health risks mercury poses to human population are mainly from chronic MeHg exposure through consumption of contaminated fish and other aquatic organisms, particularly large predatory fish species (Management, 2000). A major concern related to the health risks of chronic MeHg exposure is the possibility of developmental toxicity in the fetal brain, since MeHg can readily cross the placenta and the blood–brain barrier (Baldwin and Marshall, 1999). Prenatal Hg exposure interferes with the growth and migration of neurons and has the potential to cause irreversible damage to the developing central nervous system. For instance, because of prenatal MeHg exposure from maternal fish consumption, infants might display deficits in subtle neurological endpoints such as IQ deficits, abnormal muscle tone, and decrements in motor function. (Clarkson and Magos, 2006)

1.6. Previous Studies

A review of environmental impact statements (EISs) found that water quality predictions made after considering the effects of the standard mitigation measurements largely underestimated the actual impacts to groundwater, seeps, and surface water. (Maest et al., 2006)
The identification of geology and mineralization as currently conducted in EISs is generally blunt tool for predicting water quality impacts. Geologic and mineralogical information is usually focused on the ore body rather than on all mine materials that could potentially impact water resources.Tthey found a relatively weak relationship between geology and mineralization and the potential for water quality impacts. The discrepancy or lack of good agreement between identified mineralization and acid drainage potential highlights the importance of coordinating mineralogical and acid drainage potential evaluations in the National Environment Policy Act (NEPA) process. As noted in the companion report, the same geochemical test units should be used for testing of all parameters used to predict water quality

impacts. In addition, more extensive information on mineralogy and mineralization should be included in EISs. (Maest et al., 2006)

The EISs reviewed in detail spanned a period from 1978 to 2004. The availability of geochemical characterization data affects their ability to determine the potential for mines to release contaminants to water resources. Starting in 1980, mines began to provide basic information on geochemical characterization, such as static and short-term leach testing. After 1990, many of the mines were conducting combinations of kinetic testing and static or short-term leach testing. EISs performed after 1990s should have more reliable information on water quality impact potential than those with EISs completed before this time. Mines with close proximity to surface water or groundwater resources and with a moderate to high acid drainage or contaminant leaching potential have a relatively high risk of impacting water quality and must rely on well executed mitigation measures to ensure the integrity of water resources during and after mining. These results, although not comprehensive, suggest that the combination of proximity to water resources (including discharges to surface water or groundwater) and moderate to high acid drainage and contaminant leaching potential does increase the risk of water quality impacts. These combined factors at a mine appear to be a good indicator of future adverse water quality impacts. Mines in this category are also the most likely to require perpetual treatment to guarantee acceptable water quality. (Maest et al., 2006)

A Study done in Ghana found a varying degree of environmental damage associated with mining operation have been a source of concern to governmental impact of mining activity such small operation has however varied depending on methods and scale of operation (Benjamin et al, 2003) .

Another research study was done in Brazilian Amazon to determine the fate of mercury from gold mining on the environment. The data reviewed showed a widespread and substantial contamination of Amazon sites with mercury from gold mining. High concentration of mercury has been reported in nearly all-natural compartment of the region's ecosystems. High mercury levels also occur in human population especially those riverine people with high fish diets in areas of gold mining. Many studies which were done in gold mining sites in the Amazon, suggested that acute signs of contamination. The results depicted an obvious increment in concentration of mercury in the soils, sediment, waters and biota of the region (Malm, 1998).

A research study from Ethiopia found that an absolute dependence on water resources for panning operation was the main reason for variation of participation in traditional gold mining in the district among seasons, more participation was registered in summer season. Data analysis indicated that traditional gold mining in Asgede Tsimbka district poses a serious threat to the natural resources which in turn jeopardizes human live and their livelihoods if the problem remains unabated. The activity has been attributed to promote quick drying up and pollution of water sources, extreme land disturbance and soil erosion, reasonable destruction of vegetation and biodiversity loss. (Hagos *et al.*, 2016)

The gold mining plant of Oman was studied to assess the contribution of gold mining on the degree of heavy metals into different environmental media. Samples were collected from the gold mining plant area in tailings, water streams, soils and crops plant. The collected samples were analyzed for thirteen heavy metals including vanadium (V), chromium (Cr), manganese (Mn), nickel (Ni), copper (Cu), cadmium (Cd), cobalt (Co), lead (Pb), zinc (Zn), aluminum (Al), strontium (Sr), iron (Fe) and barium (Ba). The water in the acid evaporation pond showed a high concentration of Fe as well as residual quantities of Zn, V, and Al. Whereas, water from the citizens well showed concentrations of Al above those of Omani and WHO standards. The desert plant species growing closed to the gold pit indicated high concentrations of heavy metals (Mn, Al, Ni, Fe, Cr, and V), while the similar plant species used as a control indicated lesser concentrations of all heavy metals. The surface water indicated very high concentrations of copper and significant concentrations of Mn, Ni, Al, Fe, Zn, lead, Co and Cd. The results revealed that some of the toxic metals absorbed by plants indicated significant metal immobilization. (Abdul-Wahab and Marikar, 2011)

A research study was conducted in Sudan summarized the impact of artisanal gold mining follows defacing of landscape and consequent change in the natural hydrology of the mining areas. The pollution of desert's environment that occurs as a result of gold extraction through using toxic and hazardous substances such as mercury, arsenic and cyanide, acid drainage can threaten the neighboring rivers and ground water sources. Therefore, pollution of ground and surface water in nearby water body (e.g. River Nile) occurs during the rainy season because rainwater will wash these pollutants towards the previously mentioned sources. Moreover, Artisanal gold mining has resulted in polluting the soils of the neighboring agricultural lands and range lands as well. Risks of accidents (land subsidence) and occupational hazards are significant and therefore cannot be ignored. (Ahmed El Tohami, 2018)

A detailed study was done in Indonesia shows that the local farmers, community structure and agricultural sector in the study area suffered a shock in social, economic and environmental impacts from the gold mining activities. The shock is due to the shift of farmers becoming miners, drought and damage on agricultural fields, soil and water pollution and change on the ownership of property structure. (Meisanti et al., 2012)

Another study from Kenya, it was concluded that the concentrations of heavy metals, mainly Mercury (Hg), Lead (Pb) and Arsenic (As) are above the acceptable levels. Tailings at the panning sites gave values of 6.5–510 mg kg^{-1} Pb, 0.06–76.0 mg kg^{-1} As and 0.46–1920 mg kg^{-1} Hg. Stream sediments had values of 3.0–11075 mg kg^{-1} Pb, 0.014–1.87 mg kg^{-1} As and 0.28–348 mg kg^{-1} Hg. The highest metal contamination was registered in sediments from the Macalder stream (11075 mg kg^{-1} Pb), Nairobi mine tailings (76.0 mg kg^{-1} As) and Mickey tailings (1920 mg kg^{-1} Hg). Mercury has a long residence time in the environment and this makes its emissions from artisan mining a threat to health. Inhaling large amounts of siliceous dust, careless handling of mercury during gold panning and Au/Hg amalgam processing, existence of water-logged pits and trenches in additison to large number of miners sharing poor quality air in the mines are the major causes of health hazards among miners. (Ogola, Mitullah and Omulo, 2002a)

The results of a second research study which was conducted in Kenya revealed the existence of contaminations of both soil and water by trace elements such as As, Cr, Ni, Pb and Zn for the samples taken in gold zone with values exceeding the WHO limits. The study recommended the establishment of a monitoring and treatment program for polluted soils and waters in the gold zones to preserve human health. (Tankari Dan-Badjo et al., 2019)

Another research project was done in Ghana, the levels of Cadmium, Manganese, Lead and Mercury showed values beyond the WHO standards at certain boreholes. In addition, there was strong evidence of contribution by anthropogenic sources. The presence of these metals was attributed to the exposure of mineralized rocks to air and acidic water through mining activity. Over 40% of boreholes had Lead above the WHO recommended value of 10 μg/l, which calls for a critical attention. Mercury pollution of the basin was clearly assigned to the indiscriminate prospecting and mining of gold using the amalgamation method (Dorleku, Nukpezah and Carboo, 2018).

Another research study was done in Southern Ecuador in small scale Gold mining in the Puyango river basin. This research investigated that gold mining in the Portovelo-Zaruma mining district is severely impacting water quality and aquatic ecosystems in the Puyango river catchment. Although the mining and processing activities are small in scale, the poor management of tailings, mercury and cyanide ensures that the impacts are both severe and geographically extensive, reaching at least 160 km downstream of the mining district. Due to the prevailing neutral or slightly alkaline conditions, riverine metal contaminants were generally not present in water soluble forms but were instead associated with suspended particles and river sediment. It was concluded that high levels of metals in biota were considered potentially bioavailable. (Tarras-Wahlberga et al, 2001)

1.8. Problem statement

Previous studies showed how gold mining affects the environment and human health by quantifying the impact of the traditional or unmonitored gold mining activities in areas all over the world. However, the studies of the impact of traditional gold mining in Sudan has not been extensively carried out. Therefore, this study focuses on one of the major gold traditional mining areas in Sudan, Abo Hamad.

1.9. Objective of the study

The main objectives of this study are;

- To collect water, soil and plant samples from the study area (Elcrow)
- To determine the concentration of some heavy metals in the collected samples such as Mercury, Arsenic, Lead and Cadmium.
- To evaluate quantitatively the impact of these hazardous chemicals on the environment.

Chapter Two

Materials and methods

Chapter Two

Materials and methods

2.1 Samples collection

Ores samples were taken from mining wells to identify and quantify the naturally occurring heavy metals in the mining area. Ores samples (C1) were taken from mining area following the reverse squaring method. The collected samples were mixed well then flatten and divided into four parts placed in a quadrangle shape against each other. The parts in each opposite two angles were mixed together and further divided into four parts and so on until a sample of 2 kg was obtained to represent the whole area.

Water samples (A1and A2) were taken from the basin where gold panning has been done traditionally. The samples were taken from two different depths within 10 cm and 50 cm from the surface water using a homemade dipper sampler. Sediment sample (A3) was taken from the same basin within 70 cm depth.

Two water samples were also taken from a stream flow from the Nile River close to mining area (B1, B2), which is considered the primary source of water for the residents of the area. The samples were taken from two different depths within 10 cm and 70 cm from the surface water using the dipper.

Soil samples were taken from the canal located in the southern side of the basin of gold panning (D1, D2), where the water of the basin is poured by miners when it gets too dirty and it is linked with the stream. The samples were taken from the beginning (D1) and the end (D2) of the canal to trace the concentration of toxic metals that have been swept to the stream through the rainwater draining.

Two samples of the plants within the mining area were taken randomly from the western side of the basin (E1 and E2). These samples were taken to measure and reflect the contamination of heavy metals due to the lack of air sampler. The first sample was 4 meters distance from the basin, whereas the second sample was 5 meters further from the basin.

All samples were prepared for the detection of targeted elements (except mercury) by ICP-AES. Mercury was measured directly in all the samples without digestion according to validated method using Direct Mercury Analyzer DMA-80.

2.2 Determination of Heavy metals in samples

Water samples were filtered and preserved by adding one milliliter of 1% (v/v) hydrochloric acid to each 100 mL of the water sample. The presence of heavy metals, such as Cd, AS and Pb, was detected using inductively coupled plasma atomic emission spectrometry (ICP-AES).

Soil and sediments were dried then digested using a microwave acid digestion technique ((PLRS) and Department, 1988). The analysis of heavy metals was conducted by adopting established analytical method ((PLRS), 2015). 0.5 gram of the soil sample was digested using acidic mixture containing 8 mL of concentrated nitric acid (65% HNO_3), 5 mL of concentrated hydrochloric acid (37% HCl) and 1 mL of concentrated hydrofluoric acid (40% HF). After microwave digestion was over (about fifteen minutes), 5 mL of boric acid aqueous solution (5% H_3BO_3) were added then one milliliter was taken from the mixture and diluted to 100 mL with ultra-pure water to obtain 1% (v/v) solution. The concentrations of heavy metals in the sample solutions were then detected by ICP-AES.

The contamination of the plants in the mining area was investigated by adopting the method reported by petroleum laboratories,research and studies (PLRS, 2015). In a typical run, the plant samples were digested and analyzed using by ICP-AES following the same procedure applied for soil except the digestion was conducted using 0.5 gram of the plant sample and 6 mL of concentrated nitric acid (65% HNO_3) and 2 mL of concentrated hydrogen peroxide (30% H_2O_2) only.

The concentration of Mercury was measured directly in all the samples without digestion according to the validated method reported by ((PLRS) and Department, 2015) using Direct Mercury Analyzer DMA-80.Murcury was liberated by heating the solid sample then the sample was dried by thermally and chemically decomposed within the decomposition furnace. The decomposition products are carried by flowing oxygen to the catalytic section of the furnace. Oxidation is completed and halogens and nitrogen/sulfur oxides are trapped. The remaining decomposition products are then carried to an amalgamator that selectively traps mercury. After the system is flushed with oxygen to remove any remaining gases or decomposition products, the amalgamator is rapidly heated, releasing mercury vapor. Flowing oxygen carries the mercury vapor through absorbance cells positioned in the light path of a single wavelength atomic absorption spectrophotometer. Absorbance (peak height or peak area) is measured at 253.7 nm as a function of mercury concentration. The typical working range for this method is 0.05 - 600 ng. The instrument detection limit (DL) for this method is 0.0015ppb of total mercury.

Chapter three

Results and Discussion

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Results and Discussion

3.1 Water and sediment analysis

The presence of the heavy metals was in a low concentration in the Earth's crust however, the concentration of these metals was high in the soil and water samples that were taken from the mining area. Contamination was found to be caused by the use of mercury in the mining process in the study area. There was high concentration of other heavy metals such as arsenic, lead and cadmium in the mining studied area compared with the Earth's crust sample (C1) exceeded the international standard. (Balentine, 1995)

The analysis data of basin samples are listed in Table 1. The results showed that there is a significant increase of Lead (Pb), Arsenic (As), Cadmium (Cd) and Mercury (Hg) in the water sample taken from sediment (downstream), A3, beyond the natural concentration of those metals in water according to WHO standards for drinking water (*World Health Organisation Guidelines for Drinking water Quality: Incorporating 1st and 2nd Addenda, Recommendations*. 3rd, Vol. 1 edn, 2008). The high concentration of these heavy metals in the sediments might be due to increasing of pH causing precipitation of heavy metals and immobilization. When the pH is high metals become more soluble and metals particles become more mobile but, in the sediment, metals can become immobile because of the increasing of pH. In some previous studies the concentration of heavy metals in the sediment was also higher than upstream. (Ogola, Mitullah and Omulo, 2002b)

Table 3-1 Concentration of heavy metals in water and sediment collected from El crow mining area.Concentration of heavy metals in water and sediment collected from El crow mining area.

Samples	TDS	PH	As/ppm	Pb/ppm	Cd/ppm	Hg/ppb
Water						
A1	258	7.67	0.0281	0.1050	0.0019	2.605
A2	272	7.73	0.0281	0.0325	0.0020	1.755
A3			14.23	1233	14.67	2004
B1	142	7.07	0.0281	0.1050	0.0025	1.444
B2	120	8.57	0.0281	0.1050	0.0027	10.12

A=samples from the basin, B=samples from the stream (B1=sample from upstream, B2=sample from middle stream, 3=sample from downstream)

The concentrations of As, Pb and Cd were normal in samples B1 and B2 which were taken from the closest stream to the mining area. However, there was an increase of mercury concentration in middle of stream B2. This stream is very close to mining area since mercury is a volatile metal, this may lead to increasing of its concentration in the water sample.

3.2 Soil and plants analysis

The levels of heavy metals were also investigated in soil and plants adjacent to mining areas and the results are listed in Table3-2. The sample C1 (ore sample), which was taken from mining well, shows the concentration of heavy metals which occurs naturally, and it is presents as gold co-metals. The analysis results of the canal samples show an extremely high concentration of Arsenic, Lead and Mercury in the sample taken from the beginning of the canal (D1). The high concentration of heavy metal species could be due to the disposal of basin water by miners. This assumption is most likely true because extremely lower concentrations of heavy metals were detected in the sample taken from the end of the canal and very close to the stream (D2). However, their levels are still considered high, especially for

Lead and Mercury. As time is passing, the metallic species can accumulate and get washed to the stream during the rainy season and cause a severe danger to the people who are living there.

Table 3-2 Concentration of heavy metals in soil and plants collected from the research area.Concentration of heavy metals in soil and plants collected from the research area.

Samples	TDS	PH	As/ppm	Pb/ppm	Cd/ppm	Hg/ppb
Soil						
C1			54.32	592.5	2.785	6.510
D1			585.4	2914	4.439	3459
D2			6.241	69.38	2.263	145.2
Plant						
E1			5.871	79.94	1.612	3840
E2			5.717	43.146	1.432	2315

C1=ore sample, D1=sample from the beginning of the canal, D2=sample from the end of the canal; E1=plant sample 4meters from mining area, E2=plant sample 5meters from mining area.

The analytical data obtained from the plant samples (E1 and E2) shows the presence of high concentrations of Lead and Mercury as they are volatile elements. Whereas, the existence of Lead, Arsenic and Cadmium could be attributed to splashes from rock grinding processes in the mining areas. Extremely high levels of Mercury are solely assigned to the amalgamation method in the mining areas.

It is obvious from the results of this study that the area of the study was environmentally affected by the mining activities. The presence of the heavy metals was in a low concentration in the Earth's crust (sample C1), however, the concentration of these metals was high in the soil and water samples that were taken from the mining area. The levels of these species were found beyond the in the international standards levels (Pollution, 2010). Mercury contamination was assumed to be caused solely by Mercury used in the mining process in the study area. Whereas, the high concentrations of other heavy metals such as Arsenic, Lead and Cadmium in the mining studied area compared with the Earth's crust samples is believed to be resulted from the disposal of basin water by miners.

3.3 Conclusions

- All collected samples are contaminated by Mercury and other heavy metals
- The level of contamination is well beyond the WHO recommended limit
- All these heavy metals are absorbed by plant, could result in adverse effect on human and animals
- Traditional gold mining poses serious health effect to environment and inhabitant

3.4 Recommendation

- Government should regulate the use of mercury in mining process
- To avoid environmental pollution and health affect miners should be provided the knowledge and the right equipment to reduce the negative effect on the environment and health
- Government should help to construct dams for the chemical waste of mining process
- Further studies of impact on human health around mining area are needed

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