



Assessment of Water Quality in the Artisanal Gold Mining Area in Area in Arba't Reigion, Eastern Sudan

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ARTICLE INFO	ABSTRACT
<i>Keywords:</i> Arba'at Sudan, Groundwater, mining, Mercury <i>Article History:</i> Received on: Accepted on <i>Article Type:</i> Research Article DOI:	Artisanal gold mining is a major threat to water resources in most mining communities across Sudan. This research assessed the water in the Arba'at market, which is located in the eastern region of Sudan where the artisanal gold mining take place and focused mainly on the quality of the surface water that comes from the Arba'at Dam, as well as on the groundwater in the study area. Observed in smell and color, either for surface or ground water. Mercury analysis was performed based on atomic absorption spectroscopy (AAS or AA) for all samples and showed the purity of the surface water from any presence of mercury. In contrast, groundwater analysis showed the appearance of a trace amount of mercury at a level well below the Sudanese Standards Organization limit for drinking water.

1. INTRODUCTION

1.1 Gold and traditional mining in Sudan

The gold mineral is spread in several states in Sudan with huge quantities that made the country the third largest gold producer in Africa after South Africa and Ghana. To extract the gold, traditional miners extract the rocks from the areas they think are rich in gold by heavy machinery or traditional tools and transport the crushed rocks (usually carried in bags) to specific markets to the separation the gold from the ores. According to the Ministry of Minerals, there are about 73 legal artisanal markets in 13 states in Sudan. These markets mainly use mechanical mining machines combined with addition of elemental mercury to separate gold from ores.

Artisanal gold mining is widely practiced and continues to grow in the gold-rich communities of Sudan. It is estimated that more than two million traditional miners are distributed in several states in Sudan for gold mining activities, thus playing a pivotal role in increasing the country's GDP. Due to its vitality, this sector is legal and officially regulated by the Government of Sudan.

1.2 Gold separation from the ore

To separate the gold, there are specific markets that collects ores from traditional miners to separate the gold. The common method used is discharging the crushed ores in a mechanical mining machine which consists of two rotating drums placed in a large spherical bowl as shown in Figure 1. The drums rotate inside the bowl in aqueous solution, so that the ore becomes finer into a slurry form. Mercury is also added directly in an appropriate amount. Aqueous slurry is discharged out to artificial pond (figure 2) while gold-mercury amalgam is formed at the bottom of the bowl. The operators scrape the concentrate from the bottom and stir the solution in a pan by hand until the Hg-Au amalgam is collected and then filter all the excess mercury with a cloth. The final stage of the process is burning the Hg-Au amalgam in an open area to increase the purity of the gold.

1.3 Arba'at market

The study area (Arba'at market) is the main market for artisanal gold activities in the Red Sea State in Sudan. The site is around 25 km away from Port-Sudan city. According to interviews with workers and

miners, more than 400 companies employing at least 3,000 workers participate in the market. mechanical mining machineries exceeded 2000 to separate gold. There are also many people who benefit from the market in the services of spare parts stores, workshops, groceries, and others.

The Hg-Au amalgamation process taking place in Arba'at market consumes a large amount of water due to its extensive work on site. Hazardous wastewater from the ponds is recycled back into the process, evaporates from ponds by the heat of sunlight, or seeps into groundwater. During the survey, it was noted that the water quality at the site is likely to be affected under workplace conditions and the risk of hazardous exposure to water must be taken into account.

The aim of this study is to perform an assessment of drinking water from the site. During the survey, there are two types of water sources that are used by the residents. Borewells are exist and extensively usable for drinking and irrigation while some companies prefer to fill their underground tank with water that comes by trucks from the Arba'at Dam located about 20 km from the site.

2. MATERIALS AND METHODS

2.1. Sanitization for bottles

Glass bottles were sterilized in a laboratory hot air oven that uses extremely hot temperatures over several hours to destroy microorganisms and bacterial spores. The bottles were closed with a tight-fitting cap and only opened when samples were collected. The oven uses conduction to sterilize glassware by heating the outside surfaces of the item, which then absorbs the heat and moves it towards the center of the item. Reusable plastic bottles were first emptied (brought as a fresh bottled drinking water) on site prior to sampling and then carefully rinsed with alcohol (60%) which helps for sanitization and evaporate excess water. The bottles were dried completely before sample collection.

2.2 Sampling areas

Samples were taken from two underground concrete tanks filled with water coming from Arbaat Dam, which retains water from springs, valleys, rain-water (surface water) and from neighboring wells (ground water). Samples were taken during daytime on December 15, 2021 from two locations, the first was from an underground reservoir (from Arbaat Dam) adjacent to the labor camp in the mechanical mining machinery area, while the second sample was

taken from an underground reservoir (from ground-water wells) that is on gardening areas and widely used for irrigation. One sample was collected from each site as marked in Figure 3.

3.4 Sampling technique

Since the sampling was for an underground concrete tank (figure 4), each bottle was held on to a rope and slowly immersed in the tanks. The tanks are about three meters deep and the samples were submerged until the middle. Further cleaning was performed twice by proper flushing before collecting the samples. For each spot, 3 plastic packages and a single glass bottle were collected to cover all required parameters. An in-situ analysis of some parameters was performed as presented in Table 1.



Figure 1. Samples locations



Figure 2. samples points for A. sample 1 and B. sample 2

For proper preservation and according to the guidelines, nitric acid and sulfuric acid were carefully added via a pasteurization pipette to the mercury and oil/grease test samples respectively in order to reduce the pH below 2. Each Sample collected

were tightly sealed immediately and labeled for identification then put inside an ice chest cooler which keep refrigeration for preserving the samples. All samples were kept in ice until delivered to the laboratory for quality testing.

Table 1. Onsite analysis for pH and Temperature

	Sample (1)	Sample (2)
Location	in Arba'at AGM market	2 km northwest of Arba'at AGM market
Source	Surface water	Groundwater
Sampling point	Underground concrete tank	Underground concrete tank
pH	7.26	6.58
Temp (°C)	29	32
Observation	• High traffic • Dusty area due to activities on tailing piles • Non covered tank Water is Highly consumed	• Low traffic • Adjacent to gardens • Highly usable for irrigation • Non covered tank

3. RESULTS AND DISCUSSION

Following are the results of samples collected from location 1 and location 2 in Arba'at gold market, presented in table 2:

The analysis was performed in the Environmental Engineering Laboratory, Department of Chemical Engineering, University of Khartoum for all parameters except for mercury. Mercury was analyzed at the Shambat Central Laboratory, University of Khartoum. Samples were received on December 17, 2021 and the analysis report was released on March 17, 2022.

3.1 Analysis of in-situ parameters

There are certain parameters that must be taken on site during collection such as pH and temperature. The season was winter, and the collection took place in the middle of the day. The climate temperature was 30-40 in the site. For the samples, the temperature was 29 and 32 for sample 1 and 2, respectively. The temperature of the samples appeared in the atmospheric temperature range which may be due to the collection of water from the open and shallow reservoirs. pH of samples was tested in field as well via

portable pH meter and with result of 7.26 and 6.58 of samples 1 and 2 respectively. The results show no anomalies and also indicate that the mineral activities at the site had no obvious effect on the water pH.

Table 2. Analysis result for sample 1 and sample 2

Parameter	Sample 1 (surface water)	Sample 2 (borewell water)	Unit	SSMO Limit
1. pH	7.26	6.25	-	6.5-8.5
2. Temperature	29	32	C°	
3. Color	0	7	TCU	15 TCU
4. Odor	Acceptable	Acceptable	-	
5. Turbidity	7.34	11.40	NTU	5
6. COD	50.0	22000	Mg/l	
7. Acidity	18	16	Mg/l	
8. Alkalinity	396	336	Mg/l	
9. Chloride	95.1	57.77	Mg/l	
10. Total Chlorine	0.024	0.15	Mg/l	3
11. Sulfate .. R100	Out of R	Out of R	Mg/l	250
12. TS	765	577	Mg/l	
13. TSS	165	179	Mg/l	
14. TDS	410	370	Mg/l	1000
15. Oil/Grease	0.012	0.00	Mg/l	
16. Mercury	0	0.0956	ppb	

3.2 Analysis of physical parameters

It was noted that the samples taken are odorless and optically transparent. Additional lab testing was performed to determine true color values and showed zero TCU and 7.0 TCU for sample 1 and sample 2, respectively. These results give a hint that the water at both locations is not contaminated with suspended materials. Samples were also tasted on site by three people, and the taste of the water was not sour, salty, sweet or bitter and did not seem to have any unnatural taste.

The turbidity of water samples is measured in the laboratory as an indicator of the clarity of the water. High turbidity means that there are many suspended and colloidal particles in the water and no light can pass through them while low turbidity shows fewer particles and therefore higher clarity. The results for the turbidity samples were 7.34 NTU and 11.40 NTU for sample 1 and sample 2, respectively. These results reflect relatively low turbidity values for both samples, and thus can be considered as non-turbid water

even though the values for both samples slightly exceeded the SSMO standard of 5 NTU.

The total solids content of water is defined as the residue remaining after evaporation of the water and drying the residue to a constant weight at 103 °C to 105 °C. The organic fraction (or volatile solids content) is considered to be related to the loss of weight of the residue remaining after evaporation of the water and after ignition of the residue at a temperature of 500 °C. The volatile solids will oxidize at this temperature and will be driven off as gas while the inorganic (or fixed solids) remain as inert ash.

The total solid content comprising both the suspended and dissolved substances is 765 mg/L and 577 mg/L for sample 1 and sample 2 respectively. Among them, the suspended solids were 165 mg/L for sample 1 and 179 mg/L for sample 2. The results for total dissolved solids were 410 mg/L and 370 mg/L for sample 1 and sample 2, respectively. The TDS results were within the limits of the SSMO standards where the TDS limit should not exceed 1000 mg/L.

3.3 Analysis of chemical parameters

Chlorine in water occurs mainly as free and combined chlorine. Both forms have oxidizing and disinfecting properties, although free chlorine is generally more effective, while combined chlorine is more persistent. Total chlorine is the sum of free and combined chlorine. In the laboratory, total chlorine was measured and the results were 0.024 mg/L and 0.15 mg/L for Sample 1 and Sample 2, respectively. These results were within the SSMO standard limit of 3 mg/L for total chlorine.

Chloride (Cl⁻) is tested as well and is considered a natural compound in drinking water where the amount depends on the source. It's generally combined with calcium, magnesium, or sodium. Sample 1 where its source from surface water was with 95.1 chloride, while sample 2 where its source bore-well water was with 57.7 chloride. Both values of chloride fall with the limit of SSMO where Chloride should not exceed 250 mg/l.

Sulfate was tested in laboratory as its presence in drinking water can cause noticeable taste, and high levels might cause a laxative effect for consumers. Taste impairment varies with the nature of the associated cation; taste thresholds have been found to range from 250 mg/l for sodium sulfate to 1000 mg/l for calcium sulfate. It is generally considered that taste impairment is minimal at levels below 250 mg/l (Guidelines for Drinking -Water Quality, 1996, p. 227). The measuring range of the test device is up to 100 mg/L and due to the limitation of the device, it

gives out-of-range results for both samples. However, based on the tasting threshold, it was very likely that the sulfate concentration was below 250 mg/L (SSMO standards) for both samples.

3.4 Analysis of Oil and Grease

Oil and grease include fats, oils, waxes, and other related constituents found in water, generally wastewater. It refers to a combination of substances that do not readily mix with water and are commonly used in industry and daily activities. Examples include motor oils, lubricating oils, fuels, animal fats like bacon grease, and cooking oils. If these compounds are not removed, oil and grease can interfere with biological life in surface waters and create unsightly films that hinder Photosynthesis. These effects are primarily considered a threat to aquatic animals because they can deplete oxygen levels in water. Moreover, in large quantities, oil and grease can even be deadly. It is also might be hazardous to public health as some petroleum hydrocarbons found in oil and grease can affect human kidneys, livers, and blood and increase the risk of cancer.

The oil and grease were tested in the laboratory and showed the zero value of the sample collected from the ground water and the value of 0.012 mg/L from the surface water sample. These results indicate that the groundwater is safe from any oil/grease contamination. A small value of 0.012 mg/L also indicates proper separation of oil storage, kitchen waste, and workshop waste from drinking water reservoir. SSMO's standards for drinking water quality generally do not include oil/grease but some individually organic components (some might be harmful) that can be found in oils and greases. Therefore, the limit of oil and grease in drinking water should be zero or at least as little as possible.

3.5 Analysis of Mercury

Mercury analysis is at the core of this research due to its extensive use and the severe risks associated with handling mercury in all artisanal gold mining activities in Sudan. Contamination of water supplies with mercury (Hg) can occur from natural sediments, mining drainage, runoff from mining sites or by penetrating soil to reach groundwater. Consumption of polluted water of a high-level lead to significant risks to human health and the environment in general. It has also been observed that workers on the site are unaware of the risks associated with mercury from being completely unaware of the handling and storage of mercury and the use of inappropriate personal protective equipment. These observations drew attention

to the importance of testing mercury in drinking water at the site. Other research may also be needed to test soil and air in the area.

Mercury has been analyzed by Atomic Absorption Spectroscopy (AAS or AA spectroscopy), one of the earliest elemental analysis techniques. AAS is an analytical technique used to determine how much of certain elements are in a sample. It uses the principle that atoms (and ions) can absorb light at a specific, unique wavelength. When this specific wavelength of light is provided, the energy (light) is absorbed by the atom. Electrons in the atom move from the ground state to an excited state. The amount of light absorbed is measured and the concentration of the element in the sample therefore can be calculated.

Mercury was analyzed at Shambat Central Laboratory, University of Khartoum. The report was released on April 4, 2022. The result of sample 1 showed a zero value for mercury while sample 2 showed a very small amount of 0.0956 parts per billion (ppb). The report proved that the water collected either from wells or surface water in Arba'at market are safe for drinking, irrigation and even for domestic use as the results of the analysis are much lower than the SSMO standard where the mercury limit should not exceed 0.006 parts per million (ppm)

4. CONCLUSIONS AND RECOMMENDATIONS

Drinking water supply is a real challenge in eastern Sudan as the largest source of water there is the Red Sea water requires a desalination process to make the salty water safe to drink. These process of desalinating red sea water requires high capital cost in addition to high expenses for operation and maintenance. Unfortunately, it cannot be affordable at present because the capabilities of the Eastern State and the governments of Sudan are insufficient (for various reasons) to meet the challenge of providing potable water to the public from the Red Sea. Moreover, no clear strategy has been developed to address the water shortage problems in the eastern region. In Port-Sudan, for example, peoples in some neighborhoods still pay a lot of money to purchase potable water, from third parties, for their drinking and domestic use. Other poor areas of the state suffer seriously from a lack of potable water and some people there are unable to purchase drinking water from third parties.

These facts have made a clear public opinion about the importance of keeping the existing water supply safe and available for the present and the next generations. The public water network that started from Arba'at area is considered a vital artery that

feeds the city of Port Sudan with drinking water, and it must be intact and in good condition. Arba'at area which contains the main source of portable water has also received a great public attention recently to make its water source sustainable and protected from any polluting activities. This was like the spark for this research that focused on areas where artisanal gold mining activities take place and are very close to water sources. The primary objective for which is to evaluate the water that is not only used for Arba'at areas but for the Eastern region in general to ensure its safety, especially from not being contaminated with mercury.

The water assessment conducted in the area focused mainly on potential mercury contamination in the water and the result of the analysis showed no evidence whatsoever of any mercury in surface waters coming from Arbaat Dam. These zero presences of mercury may be due to the great distance between the activities and the dam site, despite the fact that the water is dumped into underground tanks next to the mechanical mills area which largely consumes the mercury. The assessment output also showed a little appearance of mercury in ground water. This appearance, although its tiny amount, should be as a warning alarm to all interested parties serving on water quality in eastern region to figure out the causes and long-term effects, to establish adequate plan for preventing accumulation of mercury in groundwater. Therefore, the research conclude that regular sampling of wells' water conducted by companies working in the field to analyze mercury would be considered a proactive measure that helps keep the water safe and eliminate any potential risk and they should commit to submitting their analysis reports to the concerned parties on a regular basis. In addition, official permit must be mandatory from the authority for any individual intend to use well water for irrigation. Companies' activities for waste management in artisanal gold mining also must be monitored regularly by enforcement agencies, and they should take their responsibilities in protection of people, fauna, flora, natural resources, air, and water, and to move forward their activities toward sustainability.

At conclusion, there are other water toxic contaminants than mercury might need to be highlighted such as cadmium, lead, Arsenic. Assessment of such element is highly recommended as the original ores are likely be extracted from areas containing some toxic above-mentioned elements. Assessment of air and soil in Artisanal gold mining areas is also crucial to be performed. This study contains a baseline data

that can be used in relevant research to assess water in artisanal gold mining areas in Sudan.

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