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Tuguldur Delgertsoo

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Szent István Campus

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Analyzing the ATO (Altan Tsagaan Ovoo) gold mine project in Dornod, Mongolia. Environmental impact assessment recording in the aspect of local water quality.

Supervisor: **Dr. András Barczi**

Author: **Tuguldur Delgertsoo**

Institute: **Institute of Environmental Sciences**

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Table of contents

Abstract

This thesis presents a comprehensive assessment of water quality in a specified region through the analysis of groundwater, surface water, and drinking water samples. Groundwater samples predominantly exhibited mineralization content within acceptable limits, with chloride, sulfate, calcium, and magnesium adhering to specified standards, indicating soft water quality. However, the identification of manganese, arsenic, nitrate, and pH in limited samples, primarily from herders' hand wells, implies potential stagnancy in the aquifer at control points, surpassing maximum allowable concentrations. Recurring instances of elevated pH values in monitoring wells near the heap leaching area highlight ongoing concerns.

Surface water analyses revealed concentrations of certain elements exceeding specified limits at monitoring points, both before and during project activities. This is attributed to irregular flows in lakes and rivers, solely dependent on rainfall for replenishment. The natural composition of soil, rocks, and water in the area further contains concentrations surpassing maximum allowable limits.

Drinking water and microbiological tests focused on workers' quarters and camps. Levels of manganese and iron in Camp's water supply well 3 exceeded maximum allowable concentrations due to infrequent use as a reserve. However, other parameters remained within specified drinking water standards.

In conclusion, the findings underscore the need for ongoing monitoring and remediation efforts to ensure water quality standards are maintained. The identified issues, such as aquifer stagnancy, irregular flows, and infrequently used wells, necessitate sustained attention for effective water management and environmental safeguarding. Recommendations include comprehensive investigations into leaching control wells and continuous monitoring to address potential challenges in the studied area.

1. Introduction

Gold mining contributes significantly to improving livelihoods in various regions across the globe (J. Ontoyin 2014). Approximately thirteen million households globally were directly engaged in mining activities. Large-scale mining operations serve as crucial sources of employment, income, and foreign currency (W.M. Wale 2021). This is a result of the rising global demand for gold, iron, and other mining raw materials. While mining stimulates significant economic growth and development, poorly managed mining operations can have detrimental effects on the environment (Krutilla 2021). Furthermore, when mining activities disregard environmental concerns, they cause harm and contribute to environmental degradation. This results in land destruction, soil erosion, water pollution, ecosystem disruption, and other adverse impacts. Additionally, the health and well-being of society, individuals, and the public at large are affected due to the negative environmental consequences of unsustainable mining operations (W.M. Wale 2021).

In general, unsustainable mining has substantial negative effects on society, the economy, and the environment. Consequently, it is advisable for the mining industry to formulate strategies to alleviate the detrimental environmental impacts (M. Belayneh 2021).

Steppe Gold is Mongolia's precious metals company. Founded in 2016, the Company has made significant progress quickly, completing an IPO on the Toronto Stock Exchange (TSX) in 2018, and rapidly building up its ATO Gold Mine from greenfield project to production stage, with over 90,000 oz Au produced by June 2023, and an additional over 70,000 oz yet to be produced. The ATO Gold Mine – a multi-phase precious metals project - is located in Dornod Province in the Eastern Mongolia (Gold 2022).

This paper concentrates on examining the impact of the gold mining industry on local water quality, such as groundwater, surface water, drinking water.

The current body of literature explores the purpose and importance of Environmental Impact Assessment (EIA), emphasizing the potential contamination that inadequate EIA applications in mining may cause. Additionally, it delves into the analysis of water quality in the surrounding region and the impacts of the heap leaching method.

2. Literature review

2.1 Understanding the purpose of EIA (Environmental Impact Assessment)

Definition of EIA abundant. “To identify and predict the impact on the environment and on man’s health and well-being of legislative proposals, policies, programs, projects and operational procedures, and to interpret and communicate information about the impacts” (Munn 1975). “EIA is sometimes perceived as a bureaucratic add-on, and functions as one of the many unavoidable barriers for a project to be approved” (M. Cashmore, The role of science in environmental impact assessment: process and procedures versus purpose in the development of theory 2004).

“In evaluations of EIA, the focus has often been on the “quality” of the EIA, primarily addressing procedures for performance and quality of environment impact statements (EIS) and ignoring the relation between EIA procedures and quality, as well as the contribution to effectiveness of the EIA.” (Pischke and Cashmore 2006). Essentially, EIA represents a systematic procedure that anticipates and evaluates the environmental effects of developmental activities. On the contrary to other methods of safeguarding the environment, EIA gives significant importance to preventive measures. While planners have traditionally assessed the impacts of developments on the environment, they have done so without the comprehensive, systematic approach that EIA demands.

Concepts in the document that refer to a specific stage of EIA implementation are classified according to the name of each stage. To trace “what happens between the establishment of an EIA and its relationship to decision making”, the stages before and after the EIA are also identified and studied. The factors influencing the stages of an EIA can be diverse, but if they have the same meaning then it will be distilled under the most commonly used name. Ultimately, all these steps are categorized into five areas identified in our implementation model, which include:

- The Pre-EIA stage (plan setting, initiation/decision making and project formulation)
- The EIA 1st stage aka “preparing the ground” (screening, scoping, consideration of alternatives, description of the project/development action and environmental baseline, identification of the main impacts)
- The EIA 2nd stage aka “assess and protect” (prediction, evaluation and impact assessment, mitigation)
- The EIA 3rd stage (public consultation, review, EIS presentation and monitoring)

- The post-EIA stage (application and implementation, feedback and evaluation, project maintenance, succession, or termination, in general auditing)

2.1.1 Pre-EIA stage

This area includes plan setting, initiation/decision making and project formulation.

- Plan setting, the EIA's context and objectives are established by identifying the need for the assessment, setting clear goals and objectives, identifying stakeholders, and determining the level of assessment required.
- Initiation/Decision making formalizes the start of the EIA process, involving obtaining regulatory approvals, securing funding and resources, appointing a responsible authority, and establishing a timeline for the assessment.
- Project formulation, the specific details of the proposed project or plan are defined, creating a detailed project description that serves as the basis for the EIA. This phase also includes identifying project alternatives and conducting a preliminary impact assessment to identify potential environmental impacts.

2.1.2 Preparing the ground

This area includes screening, scoping, consideration of alternatives, description of the project/development action and environmental baseline, identification of the main impacts.

- *Screening* limits the scope of EIA to projects that potentially possess substantial environmental consequences. Screening needs to follow specific procedures often described in the legislation, such as: facilitates informed decision making providing clear, well-structured, factual analysis of the effects and consequences of proposed actions., influences both projects section and policy design by screening out environmentally and /or socially unsound proposals, as well as modifying feasible action (Glasson, Therivel and Chadwick, Introduction to environmental impact assessment fourth edition 2012). A clearly defined checklist is crucial in the screening process to prevent excessive time allocation for minor projects that do not seem to have a noticeable environmental impact (Christensen 2006). In cases where the threshold or criteria are not explicitly presented, there are opportunities for political will to influence the screening decision (Kolhoff, Runhaar and Driessen 2009). The conclusion drawn is that screening serves not just as a filtering mechanism but also functions effectively as a more autonomous regulatory tool, as decisions rely on alterations to the project proposal (Critical factors for EIA implementation: Literature review and research options Jie Zhang*, Lone Kørnøv, Per Christensen)

- *Scoping* is a crucial step in EIA preparation, as it identifies the most important issues during the implementation process while excluding the less concerning ones. It's a systematic process that sets the boundaries and forms the basis for analyses at each stage. A high-quality scoping studies to reduce the risk of including inappropriate components or omitting necessary ones, involving: identifying all relevant issues and factors, including cumulative effects, social impact, and health risks., facilitating meaningful public participation and review., determining the appropriate time and space boundaries of EIA., identifying the important issues to be considered in the EIA, such as setting the baseline and identification of alternatives (The 7 Steps to an EIA, Learn - Step 2: Scoping n.d.). Lack of tailored methods could be a barrier to "the identification of both indirect and secondary impacts that determine the depth of the EIS" and thus "produce the loss of valuable information for decision making" (Toro, Ignacio and Zamorano 2010). Snell and Cowell posit that engaging the public during the scoping phase is premature because there is no finalized project proposal. They suggest that involving the public at this point may lead to confusion due to the project's uncertain design, potentially resulting in unwarranted objections to the project. "Of course, timeframe and resources are important, but also scoping should be dependent on professional judgement and the expertise of local authorities, as there is uncertainty over the baseline data, and lack of clarity regarding government guidelines, which are also constraints for effective scoping" (Snell and Cowell 2006).
- *The consideration of alternative* is to ensure that the advocate has considered an alternative in other words, other feasible approaches, including different project locations, process, layouts, scales, conditions of the operation and the "no action" option. Alternatives, mentioning that legislative requirements play a crucial role as "the lack of coverage of alternatives was apparent in a number of Member States and this was explained by the fact that this is not required by the legislation" (Barker and Wood 1999).
- *The description of the project/development action and environmental baseline* involves an explanation of its objectives, reasons, and an awareness of its different attributes, encompassing its developmental phases, geographic location, and operational processes. The environmental baseline description involves determining the current and anticipated future condition of the environment without the influence of the project. This assessment considers alterations caused by natural occurrences and other human actions.

- *Identification of the main impacts,* it consolidates the preceding steps, ensuring that all potentially significant environmental effects are comprehensively recognized and considered throughout the process.

2.1.3 Assess and protect

This area covers about the traditional stages in EIA prediction, evaluation and impact assessment, and mitigation.

- *Prediction* seeks to determine the extent and various aspects of the anticipated environmental changes resulting from a project by contrasting them with the conditions in the absence of that project. Tailored method is often a bottleneck for forecasting environmental effects, especially as the officially recommended methods are often outdated or unsuitable for the context of a specific case (Kruopiene, Zidoniene and Dvarioniene, Current practice and shortcomings of EIA in Lithuania 2009). Predictive endeavours typically favour qualitative methods over quantitative approaches. (Ogunba 2004). Expert opinion can sway predictions towards either overestimation or underestimation, and there was unequal emphasis placed on both the positive and negative impacts. Biases in prediction: "Naturally, being financially dependent, EIA practitioners are exposed to potential attempts of influence and often become biased" (Kruopiene, Zidoniene and Dvarioniene, Current practice and shortcomings of EIA in Lithuania 2009).
- *Evaluation and impact assessment* involves a thorough examination of the environmental and social consequences of a proposed project and its alternatives in relation to existing conditions. This entails both qualitative assessments, categorizing impacts as high, medium, or low, and quantitative assessments, quantifying factors like water withdrawal, sewage generation, and pollutant emissions. This process applies to both the planned project and its alternatives, enabling comparisons. After the comprehensive assessment, strategies to mitigate or prevent adverse impacts are identified (The 7 Steps to an EIA, Learn - Step 3: Impact Assessment and Mitigation n.d.).
- *Mitigation* refers the reduction or prevention of the outlined impacts. In general, these measures are a direct response to the results of the impact assessment and should encompass all identified areas. The primary emphasis of mitigation efforts should be on: preventive measures that avoid the occurrence of impacts and thus harm or even produce positive outcomes., measures that focus on limiting the severity and duration of impacts., compensation mechanism for those impacts that are unavoidable and cannot be reduced further (The 7 Steps to an EIA, Learn - Step 3: Impact Assessment and Mitigation n.d.).

“EIA provides the mechanisms for development proposals to be amended where necessary, and likely adverse impacts ameliorated. Although EIA may lead to the abandonment of certain proposals, its focus is more strongly on the mitigation of any harmful environmental impacts likely to arise” (Jay, et al. 2007).

2.1.4 EIA 3rd stage

- *Public consultation,* from a public standpoint, the willingness and ability to participate effectively are significant factors when engaging with representatives from various stakeholder and interest groups (Fitzpatrick and John 2009). If the general public is not well educated or indifferent, it is necessary to empower the public, so as to boost the public awareness and inform about their rights. As for the general public side and a representative from non-governmental organization, both felt that in order to be regarded seriously and potentially have an impact on decision-making, they needed to possess expertise in conventional environmental assessment techniques. Consequently, they acquired proficiency in specific technical methodologies (Cashmore, Bond and Cobb, The Contribution of Environmental Assessment to Sustainable Development: Toward a Richer Empirical Understanding 2007). Efficient and productive communication methods, including the deliberations of working groups, the establishment of an information center, and hosting public meetings, are essential for garnering public support (Cashmore, Bond and Cobb 2008). The motivation for initiating public participation is “the public participation program aimed at reducing anger and protest of those affected and to motivate them to support the project, but it was not concerned with the public input in the decision making process”- said Ahammed and Harvey, (Ahammed and Harvey 2004, p.74).
- *EIS (Environmental Impact Statement) presentation* is a crucial step in the process. If its poorly executed, it can ruin the significant efforts put into the EIA. The EIA practitioner’s subjectivity is also a factor when they act as an advocate of a developer, and thus may “prepare a subjective report in attempt to persuade the council to approve the project” due to their financial dependence on the developer (Kruopiene, Zidoniene and Dvarioniene, Current practice and shortcomings of EIA in Lithuania 2009). EIS is for people from different backgrounds, such as local authorities, assessment experts and the general public. Therefore, it is very important to present the results in a logical and coherent manner so that they can be easily understood. (M. Cashmore, The role of science in environmental impact assessment: process and procedures versus purpose in the development of theory 2004).

- *Review,* entails a methodical assessment of the Environmental Impact Statement's (EIS) quality, serving as a valuable input to the decision-making process. The central issue at hand is determining the composition of the EIS review team, a decision influenced by the varied backgrounds of its members. It's particularly important that the review body maintains its independence from the project proponent to mitigate potential bias ((Barker and Wood 1999). Glasson and Salvador also make the argument that an extended duration for the EIS approval process can lead to excessive bureaucracy, underscoring the need for imposing a time limit on EIS reviews (Glasson and Salvador, EIA in Brazil: a procedures–practice gap. A comparative study with reference to the European Union, and especially the UK 2000).
- *Monitoring* serves to gather information regarding the environmental and social effects of the project throughout its entire lifecycle. In the course of their activities, the majority of development projects engage in ongoing monitoring of various indicators, such as the quantity of extracted ores, processed materials, energy consumption, sewage release, and more. To be more precise, the data collected during monitoring activities plays a critical role in verifying the implementation of priorities outlined in the Environmental Management Plan (EMP), the effectiveness of mitigation measures, and the functionality of contingency plans in addressing the project's impacts (The 7 Steps to an EIA, Learn - Step 7: Monitoring n.d.). Successful monitoring relies heavily on essential resources, with qualified and experienced personnel along with financial backing being recognized as the most pivotal factors (Ahmed and Wood 2002)

2.1.5 Post EIA stage

- *Auditing* is a natural progression after monitoring. It may contain the comparison of the real results of monitoring with the anticipated results and can serve as an evaluation of the accuracy of predictions and effectiveness of the mitigation process. It’s a crucial element in the learning process of the Environmental Impact Assessment (EIA) (Glasson, Therivel and Chadwick, Introduction to environmental impact assessment fourth edition 2012). An environmental audit involves evaluating whether an operational business complies with environmental protection regulations, adheres to good environmental practices, and aligns with sustainable development principles in its environmental management and performance. It's worth noting that environmental audits are obligatory only when mandated by legal requirements. During a typical environmental audit, a team of qualified inspectors conduct a comprehensive examination of the facility to determine whether it's adhering to the environmental laws and regulations. They often use a checklist, audit protocols, professional judgment, and evaluation of site-specific conditions the team systematically verifies compliance with applicable requirements. The team might also appraise the efficiency of existing systems for overseeing compliance and analyze the environmental hazards linked to the facility's activities (Hari n.d.)

2.2 Mining

Mining, especially metal and coal production, is widely criticized for its environmental impact, particularly in remote areas. Rock quarries, gravel pits, and certain industrial mines in various settings also draw attention for their visible and significant harm. Concerns revolve around the lasting physical and aesthetic damage to the land, as mining, though temporary, alters landscapes noticeably. Abandoned mines become conspicuous, leading to conflicts involving citizen groups, government agencies, and the mining industry. These disputes centred on issues such as current land use and potential disturbances' consequences (Environmental Impacts from mining n.d.). The conflict centred on the following issues:

- Destruction of the landscape
- Degradation of the visual environment
- Disturbance of watercourses
- Destruction of agricultural and forest lands
- Damage to recreational lands
- Noise pollution
- Dust
- Truck traffic
- Sedimentation and erosion
- Land subsidence
- Vibration from blasting and air blasts

2.2.2 Gold mining

Gold deposits originate from a diverse array of geological processes, primarily categorized into three groups:

- Lode deposits: These can take the form of ore filling crevices within rock formations or veins of ore sandwiched between layers of rock. Lodes result from a process known as mineralization. Gold dissolves in hydrothermal fluids, which are extremely hot and acidic groundwater, and then flows into existing rock fissures or layers where it cools and solidifies, forming a deposit. Native gold nuggets exemplify lode deposits.

- Intrusion-related deposits: These are akin to lode deposits but differ in the source of mineralization. Instead of hydrothermal fluids, magma intrudes into fractures and fissures within rock formations, subsequently solidifying into a mineral deposit.
- Placer deposits: These deposits are secondary in nature, originating from pre-existing lode or intrusion-related deposits. Placer deposits erode from primary deposits and form through gravity separation and the alluvial process (Warren Yeend 1989).

Miners identify fresh gold prospects by exploring regions with the geological conditions suitable for the creation of lode, intrusion-related, or placer deposits. Moreover, they rely on various geological clues as indicators to refine their exploration efforts.

Gold deposits can be found in a variety of geological settings such as vein deposits, placer deposits. Vein deposits are often associated with quartz veins and occur in a range of host rocks, including granite, metamorphic rocks, and sedimentary rocks. As for placer deposits, the gold erodes from its primary source and is transported by rivers and streams. It accumulates in sediments such as gravel beds, where it can be extracted through placer mining.

Over time, secondary geological processes such as weathering, erosion, and tectonic activity can further concentrate and expose gold deposits, making them accessible to human exploration and mining.

2.2.3 Gold mining techniques

There are several different types of gold mining techniques, each having its own unique technique and environmental considerations:

- Heap leaching, it involves piling ore into a heap and then applying a chemical solution to dissolve and separate the gold. This method is used for low-grade ores and can be more environmentally friendly than some other methods, as it minimizes the amount of earth moved (Future of Strategic Natural Resources 2016).
- Open pit mining, it involves excavating substantial amounts of soil to uncover gold-containing ore. It is frequently employed for extracting gold from extensive, low-quality deposits. This technique can result in notable environmental impacts, such as the disturbance of ecosystems and contamination of water sources (Future of Strategic Natural Resources 2016).

- Hard rock mining involves extracting gold from underground deposits of quartz or other hard rock types. It is required the use of tunnels, shafts, and machinery to access the ore. This method can be more expensive side and has a greater environmental impact due to its excavation and waste disposal (Future of Strategic Natural Resources 2016).
- Placer mining, is one of the most traditional methods and involves extracting gold from alluvial deposits, such as riverbeds and floodplains. Miners use tools like pans, sluice boxes, and dredges to separate gold particles from sand and gravel. It is relatively simple and has low environmental impact compared to other methods (Future of Strategic Natural Resources 2016).
- Cyanide leaching, in this approach, a cyanide solution is employed to extract gold from ore. While it is a commonly utilized method, it is considered contentious due to the environmental and health hazards linked to cyanide. To address these risks, strict regulations and safety precautions have been implemented (Future of Strategic Natural Resources 2016).

2.2.4 Heap leaching

Heap leaching for gold and silver recovery is straightforward approach that eliminates numerous steps required in conventional mining. A standard process for precious metal heap leaching involves crushed ore onto an impervious pad. A dilute sodium cyanide solution is applied to the heap, typically via sprinkling or drip irrigation (Texler, Flynn and Hendrix 1990). This solution drips through the material, causing to dissolve the gold and silver in the rock. The pregnant (gold bearing) solution drains from the heap and is collected in a large plastic-lined pond (Figure 1).

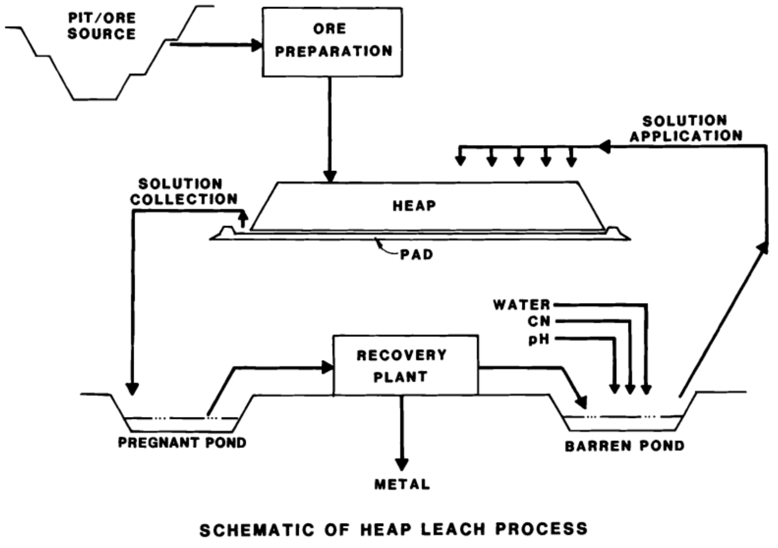


Figure 1. Schematic of heap leaching process *(Michaud 2016)*

Pregnant solution is then pumped through tanks containing activated charcoal at the processing facility. In these tanks, the charcoal effectively captures and retains the gold and silver. The now barren cyanide solution is then transported to a storage basin, where lime and cyanide are added to repeat the leaching process. The charcoal that contains gold undergoes a chemical treatment to release the gold and is reactivated by heating for future applications. The resulting solution, now containing a higher concentration of gold than the original pregnant cyanide solution, is processed at the facility to produce an impure gold bar (Figure 2).

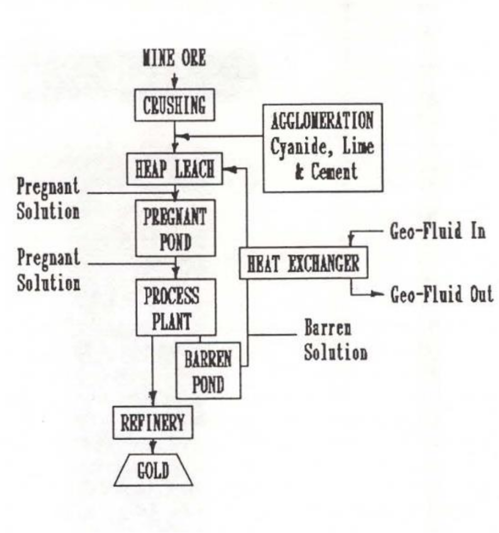


Figure 2. Heap leach process flow

One of the common problems associated with heap leaching is that it has a low gold recovery. Typically, untreated ore yields about 70% or less of the gold content. Crushing the ore will increase the recovery but it also increases the production cost. There are few means to enhance gold recovery which consists of crushing, grinding, vat leaching, roasting, agglomeration, chemical pre-treatment, or wetting depending on the specific ore characteristics. Cyanide leaching can achieve high gold recovery percentage as much as exceeding 95% (Texler, Flynn and Hendrix 1990).

Heap leaching offers a cost-effective approach for treating low-grade metalliferous ores, especially those with oxidized ore bodies. Given that heap leaching facilities typically entail lower operational expenses compared to conventional hydrometallurgical plants, it presents a potentially economical method for processing ores that might otherwise remain untreated. It could therefore be contended that without affordable treatment options like heap leaching, numerous low-grade ores might not be economically viable for processing. As a result, the failure to address low-grade ore due to lack of cost-effective processing alternatives could lead to a range of unacceptable economic, social-political, and environmental impacts (Reichardt 2008).

2.2.5 Environmental impacts of gold mining

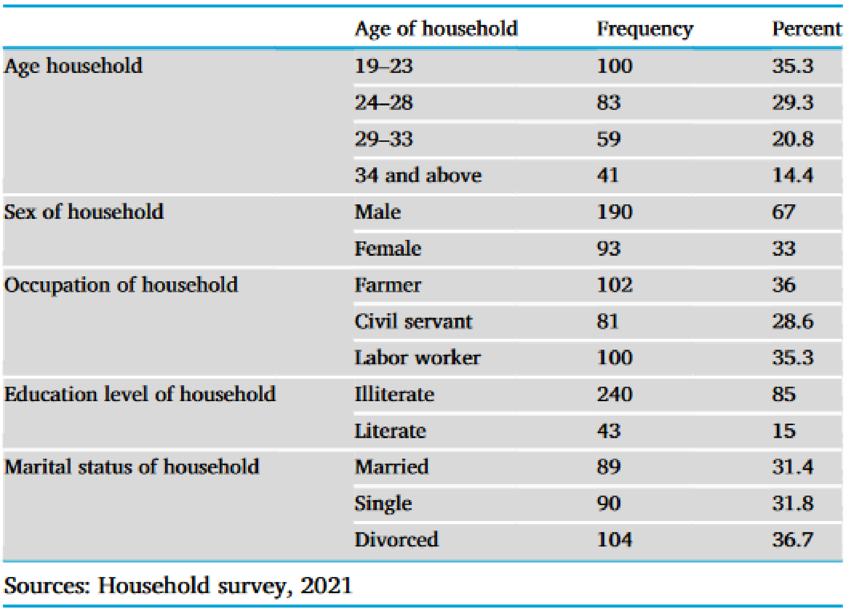
The majority of consumers are unaware of the source and extraction methods of the gold used in their products. Gold mining stands out as one of the most environmentally harmful industries globally, capable of displacing communities, contaminating drinking water, harming workers, and ravaging pristine landscapes. It introduces pollution into water and soil through substances like mercury and cyanide, posing risks to both human health and ecosystems. To produce a single wedding ring, a staggering 20 tons of waste is generated (Environmental Impacts of Gold Mining 2023).

In the gold mining sector, open-pit mining presently constitutes around 75% of the total global mine production. Although open-pit mines generally provide a safer working environment compared to underground mines, they are less labor-intensive since they require fewer workers to extract equivalent quantities of ore. Additionally, owing to their immense size, open-pit mining is often associated with more significant environmental harm and can exert a profound and enduring influence on local livelihood systems.

According to the survey findings presented in Table 1, approximately 67% of the households consisted of males, while the remaining 33% were composed of females. Regarding the age distribution within these households, about 29.3% of them fell within the age range of 24-28 years, and 20.8% were categorized as being between 29-33 years old (as detailed in Table 1). This highlights that the majority of households were concentrated in the 19-23 years age group. Furthermore, 85% of the households were classified as literate, with the remaining 15% categorized as illiterate.

Additionally, in terms of occupation, 36% of the households were involved in farming activities, 35.3% were employed as labor workers, and the remaining 28.6% of households comprised civil servants. Furthermore, the data in Table 1 regarding household occupations clearly indicates that 31.4% of the households were married, while 36.7% of households were either divorced or single, accounting for 31.8% of the total (Mencho 2022).

Table 1. Characteristics of sample households *(Mencho 2022)*

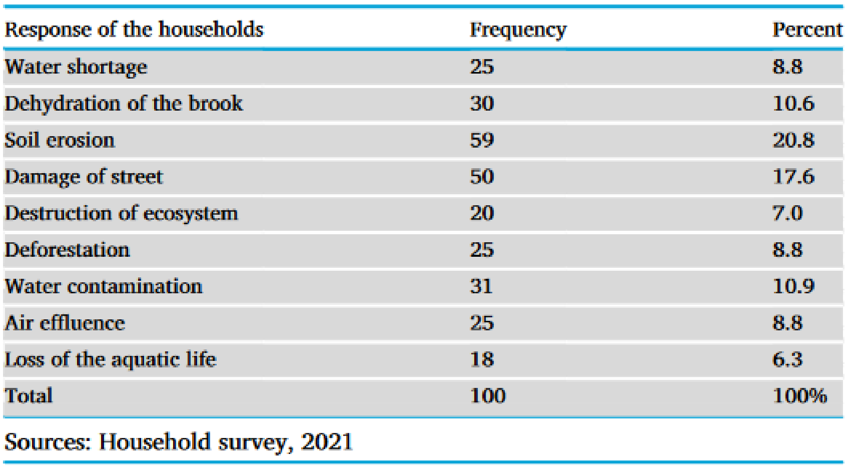


	Age of household	Frequency	Percent
Age household	19–23	100	35.3
	24–28	83	29.3
	29–33	59	20.8
	34 and above	41	14.4
Sex of household	Male	190	67
	Female	93	33
Occupation of household	Farmer	102	36
	Civil servant	81	28.6
	Labor worker	100	35.3
Education level of household	Illiterate	240	85
	Literate	43	15
Marital status of household	Married	89	31.4
	Single	90	31.8
	Divorced	104	36.7

Sources: Household survey, 2021

The results, as presented in Table 2, reveal that the mining operations in the study area have notable consequences on the environment. Major impacts include brook desiccation at 10.6%, soil erosion at 20.8%, and street damage at 17.6%. The extraction of gemstones and gold mining has detrimental effects on the environment, leading to ecosystem destruction, deterioration in water quality, and the depletion of vegetation.

Table 2. Environmental impacts of gold mining in Shekiso district, Guji zone, Ethiopia *(Mencho 2022)*



Response of the households	Frequency	Percent
Water shortage	25	8.8
Dehydration of the brook	30	10.6
Soil erosion	59	20.8
Damage of street	50	17.6
Destruction of ecosystem	20	7.0
Deforestation	25	8.8
Water contamination	31	10.9
Air effluence	25	8.8
Loss of the aquatic life	18	6.3
Total	100	100%

Sources: Household survey, 2021

2.2.6 Environmental impacts of heap leaching

Despite the increased effectiveness, incidents at mines worldwide caused significant concerns regarding the use of cyanide in mining. In many instances, the release of cyanide into the environment occurred as a result of damage to heap leach liners or spillage from solution ponds and tailings storage areas, raising alarm. The most notorious incident serves as the Baia Mare cyanide spill in Romania during 2000, in which a substantial amount of cyanide, estimated to be between 50 and 100 tons, was released. Although cyanide can occur naturally in the environment and undergo degradation, elevated concentrations of cyanide present significant and potentially deadly risks to both human and non-human ecosystems. The chemical characteristics and toxicity of cyanide are influenced by several factors, including exposure to light and air, as well as the presence of other metals (Verbrugge, Lazano and Matthew 2021).

One specific combination that holds particular relevance in the context of Artisanal and Small-Scale Gold Mining (ASGM) involves the formation and persistence of mercury-cyanide complexes. These complexes develop when mercury-contaminated tailings are subjected to reprocessing with cyanide. (Verbrugge, Lazano and Matthew 2021).

“Environmental concerns associated with heap leach facilities revolve primarily around failure to contain process solutions within the heap leach circuit and their potential release into the receiving surface and subsurface environment, with resultant impacts on the health of people, livestock and ecosystems” (Reichardt 2008).

While this gold production method is economical, it is also highly inefficient, with approximately 99.99 percent of the heap turning into waste.

Regions involved in gold mining often feature these immense, toxic piles. Some of them can reach towering heights of 100 meters and can completely engulf entire mountain slopes.

To cut costs, these heaps are frequently left abandoned. This can lead to the release of contaminated water containing cyanide and other harmful substances, posing a threat to groundwater, and endangering nearby communities such as Miramar, Costa Rica (Environmental Impacts of Gold Mining 2023).

Cyanide is a chemical category comprising carbon and nitrogen elements. Cyanide compounds, like hydrogen cyanide gas and basic cyanide salts such as sodium cyanide and potassium cyanide, can either be naturally present or synthesized, and many of them possess potent and fast-acting toxic properties. The primary sectors extensively employing cyanides include the steel industry, electroplating, mining, and the chemical sector (Committee on the Environment, Public health and food safety 2013).

Cyanide is highly toxic and can result in substantial environmental impacts and public health risks if released into the environment. Such as soil contamination, water contamination, air emissions, wildlife hazard, habitat disruption, chemical spill, and long-term environmental problems.

Soil contamination

Soil contamination resulting from gold mining using the cyanide heap leaching method is a pressing environmental concern due to its lasting and far-reaching impacts. This contamination poses health risks to both humans and wildlife, disrupts ecosystems, and pollutes nearby water bodies and groundwater. The persistence of contaminants in the soil, potential legal and financial liabilities, and public opposition to mining projects make this issue a significant challenge. Addressing it requires responsible mining practices, strict regulatory compliance, and ongoing monitoring, reclamation, and remediation efforts to mitigate long-term consequences (Osei Akoto 2022). Soil contamination from gold mining using the cyanide heap leaching method can result from several factors, including:

- Cyanide Leachate: The use of cyanide to extract gold from ore can lead to the formation of cyanide compounds that may leach into the soil. These cyanide compounds can persist in the soil and pose risks to the environment.
- Heavy Metals: Gold ores often contain other heavy metals, such as arsenic, lead, and mercury. The process of heap leaching can release these metals into the soil, contributing to contamination.
- Chemical Residues: Residues of chemicals used in the leaching process, such as sulfuric acid and lime, can remain in the soil, altering its pH and potentially harming soil quality.
- Tailings Disposal: The waste materials from gold mining, known as tailings, can be disposed of in nearby areas. These tailings may contain harmful substances and, if not managed properly, can contaminate the surrounding soil.
- Runoff and Erosion: The leaching process can create runoff and erosion that carries contaminants from mining sites into nearby soils and water bodies, further spreading contamination.

Soil contamination from cyanide heap leaching in gold mining is a significant environmental concern due to the potential long-term impacts on soil quality, plant and animal life, and human health if these contaminants migrate beyond the mining site. Effective management and regulation are crucial to mitigate these environmental risks (Mencho 2022). Over an extended period, both small and large-scale gold mining activities have played a significant role in the removal of substantial quantities of lush surface vegetation. This extensive destruction has a direct impact on biodiversity within natural environments. Consequently, it results in the loss of ecological services and disrupts terrestrial ecosystems to such an extent that they may not be able to recover. “Shallow mining operations for small scale gold often fail to support crop production due to loss of soil nutrients from topsoil (organic horizon) through erosion and finally leave the bare land” (Mencho 2022).

Air emissions

Air emissions from gold mining with the cyanide heap leaching method can lead to contamination through the release of various pollutants, such as volatile cyanide compounds, dust and particulate matter, fugitive emissions, sulfur dioxide, greenhouse gasses, vehicle emissions. The following will contain detailed information on each of the categories that’s listed above.

- Volatile Cyanide Compounds: During the cyanide leaching process, volatile cyanide compounds may be emitted into the air. Hydrogen cyanide gas (HCN) is one such compound, and its release poses health risks to workers and can contribute to air pollution.
- Dust and Particulate Matter: Mining and ore crushing activities generate dust and particulate matter, which can contain heavy metals and other contaminants. When released into the air, these particles can affect air quality and potentially have adverse health effects on nearby communities.
- Fugitive Emissions: Fugitive emissions from various mining operations, including material handling, transportation, and equipment operation, can release pollutants into the air. These emissions can include particulate matter, volatile organic compounds (VOCs), and other hazardous substances.
- Sulfur Dioxide (SO_2): Some gold ores may contain sulfur-bearing minerals. The combustion of these minerals during the refining or processing of gold can release sulfur dioxide, contributing to air pollution and acid rain.
- Greenhouse Gases: Energy-intensive processes associated with gold mining, such as crushing, grinding, and transportation, can result in the release of greenhouse gases, such as carbon dioxide (CO_2), which contribute to climate change.
- Vehicle Emissions: The use of heavy machinery and transportation vehicles at mining sites can release emissions such as nitrogen oxides (NO_x) and carbon monoxide (CO).

Efforts to mitigate air emission contamination in gold mining with cyanide heap leaching methods may include implementing pollution control technologies, optimizing operations, and adhering to environmental regulations to minimize the release of pollutants and protect the surrounding environment and communities.

Water contamination

Addressing issues related to sustainable development poses significant challenges in the enhancement of water quality, the equitable distribution of potable water, and the preservation of ecological systems. Concerns surrounding river and environmental contamination have persisted as critical concerns, and their importance continues to escalate in today's global context (Mouhamed , et al. 2022).

Water, a vital, abundant, and essential natural asset on Earth, serves as an indispensable prerequisite for life, without which existence would be impossible. Its role as a fundamental necessity for human life underscores the crucial need for it to meet the highest standards of quality. The evaluation of water quality is based on its physical, chemical, and biological characteristics. In the planning and administration of water distribution to communities, the emphasis lies more on the quality of water than its quantity. Purity is a prerequisite for ensuring water is suitable for consumption. The condition of water, as determined by its quality, is a critical factor in meeting the needs of both living organisms and any human requirements or objectives (Mouhamed , et al. 2022).

The Water Quality Index (WQI) is a valuable and distinct evaluation that provides a comprehensive depiction of the overall condition of water quality in a singular measure. It proves to be beneficial in determining the most suitable treatment methods and in dealing with the associated challenges. Knowledge about water quality holds significance for the general public as well as for legislative decision-makers (Mouhamed , et al. 2022).

Water contamination from gold mining with the cyanide heap leaching method can occur due to several factors, including:

- Cyanide Spillage: Accidental spills or leaks of cyanide solution used in the leaching process can lead to the contamination of nearby water sources, posing a severe threat to aquatic life and ecosystems.
- Heavy Metal Leaching: The mining process can release heavy metals such as arsenic, lead, and mercury into water bodies, contaminating them and posing significant health risks to both aquatic life and human populations that rely on these water sources.

- Acid Mine Drainage: The exposure of sulfide minerals during mining operations can result in the formation of acidic runoff known as acid mine drainage (AMD). This acidic water can dissolve heavy metals and other contaminants, polluting nearby water bodies and affecting the entire aquatic ecosystem.
- Sediment Runoff: Erosion and sedimentation resulting from mining activities can lead to increased sediment runoff into rivers, streams, and other water sources. This sediment can carry pollutants and other harmful substances, degrading water quality and impacting aquatic habitats.
- Altered Water Chemistry: Chemicals used in the gold extraction process, such as cyanide, can alter the pH and chemical composition of water bodies, leading to imbalances in aquatic ecosystems and potentially harming aquatic life.
- Reduced Water Quality: The large-scale water usage in mining operations can deplete local water sources, reducing the availability of clean water for both local communities and wildlife, thereby impacting their health and survival.

Efforts to mitigate water contamination from gold mining with the cyanide heap leaching method include implementing proper containment and treatment processes for mining-related materials, as well as the establishment of effective water management and treatment systems. Compliance with stringent environmental regulations and the adoption of best practices for responsible mining are essential to prevent and minimize water contamination and its adverse effects on the environment and local communities (Mouhamed , et al. 2022).

Nature conservation

Hydrogen cyanide and other compounds that release free cyanide ions are extremely poisonous to nearly all forms of wildlife and plant life. Cyanide acts swiftly, and its toxicity is inversely related to the strength of the bond between metal atoms and cyanide ligands. Sodium cyanide, for instance, leads to the death of fauna by hindering enzyme reactions that impede the flow of oxygen to the blood. When cyanide is inhaled or ingested, within seconds, and if the rate of absorption exceeds the detoxification rate, it can cause rapid and incapacitating reactions such as asphyxiation, often resulting in death within minutes. Acute, sub-lethal exposure to cyanides can be metabolized in the body with minimal long-term effects (D., et al. 2017).

“A concentration below 50 mg/L weak-acid-dissociable cyanide in mine waste solutions has been reported as safe to wildlife”- (D., et al. 2017).

The heap leaching method can pose significant risks to wildlife if not conducted with proper precautions, such as habitat destruction and contamination, water pollution, altered water source, noise and vibration, increase human activity, chemical exposure, and erosion and sedimentation (D., et al. 2017).

- Habitat Destruction, mining operations often involve clearing land, excavation, and construction of mining facilities, leading to the destruction and fragmentation of natural habitats. This can displace wildlife species and disrupt migration routes and food sources.
- Habitat Destruction, mining operations often involve clearing land, excavation, and construction of mining facilities, leading to the destruction and fragmentation of natural habitats. This can displace wildlife species and disrupt migration routes and food sources.
- Water Pollution: The use of cyanide and other mining-related chemicals can result in the contamination of nearby water bodies, harming aquatic ecosystems. This pollution can impact fish and other aquatic species, disrupting the food chain and reducing biodiversity.
- Altered Water Sources, gold mining operations often require significant water usage, depleting local water sources. This reduction in water availability can negatively affect wildlife that relies on these sources for drinking, breeding, and foraging.
- Noise and Vibrations: Mining activities, including blasting, heavy machinery operation, and transportation, can generate loud noise and vibrations that disturb or drive away wildlife. These disturbances can disrupt mating and nesting behaviors and induce stress in animals.
- Increased Human Activity, mining operations bring an influx of human activity to remote areas, leading to increased vehicular traffic and infrastructure development. This can result in collisions between wildlife and vehicles, habitat destruction, and altered animal behavior.
- Chemical Exposure, wildlife may come into contact with and ingest toxic substances, such as cyanide, heavy metals, and other pollutants, either directly or through contaminated food sources. This exposure can lead to health problems and even mortality in affected animals.

- Erosion and Sedimentation, mining activities can lead to soil erosion and sedimentation in nearby water bodies. Increased sediment in rivers and streams can smother aquatic habitats and negatively affect wildlife that depends on these ecosystems.

Efforts to mitigate wildlife hazards from gold mining with the cyanide heap leaching method typically involve implementing environmental safeguards, such as tailings management, habitat restoration, and the establishment of buffer zones to protect ecosystems and wildlife. Compliance with environmental regulations and close monitoring of the mining operations' impact on the surrounding environment are also important steps to minimize these hazards.

2.3. Water quality

Globally, people acknowledge water as the foremost and essential natural resource, understanding that both societal and economic progress, as well as environmental variety, cannot persist without it. Presently, nearly every nation confronts increasingly difficult obstacles in trying to fulfil the swiftly rising need for water, fuelled by expanding populations (Peter Ashton 2001). The issue is especially critical in drier parts of the globe, where shortages of water and the subsequent rise in water contamination hinder societal and economic progress, closely intertwined with the high prevalence of poverty, malnutrition, and illness (Ashton 2001).

Water contamination is one major concern in mining operation. Accidental release of effluent containing harmful substances or the discharge of leachate from mining waste, as well as surface runoff from excess soil dumps, all contribute to the deterioration of water quality (Karmakar 2012). In 2003, the Karnataka State Remote Sensing Application Centre conducted a survey in Bellary Hospet and Sandur Taluk. The study revealed the presence of sediment build-up in water sources near mining zones. Furthermore, the discharge of effluent from a gold mine was identified, containing hazardous substances like cyanide within the mine waste from Hutti gold mines. Gold mining is responsible for significant water contamination due to the existence of harmful chemicals like cyanide in the mine waste.

The mining process can cause a dreadful impact on surrounding environment. This can lead to an abnormally high accumulation of certain substances, like arsenic, sulfuric acid, and mercury, across a considerable expanse of surface or underground water (Karmakar 2012). The potential for extensive pollution in the vicinity of mines exists because of the diverse chemicals employed in the mining procedures, alongside the potentially harmful elements and metals extracted from the ore (Hudson 2012). The substantial volume of water generated from mine drainage, cooling operations, aqueous extraction, and other mining activities enhances the risk of these chemicals polluting both groundwater and surface water (Dasgupta 2012).

Streams, lakes, and, in some instances, ocean water can be compromised by unintentional release of harmful chemicals, erosion of waste materials, or the discharge of polluted water from mining activities. These are the important reasons which are affecting surface water due to mining activities:

- Spills and tailings
- Erosion
- Acid Drainage

2.3.1 Spills and tailings

The possibility of unintended leakage of hazardous chemicals from storage or processing facilities is a potential worry wherever such substances are utilized. Following the extraction of metals, residual leaching chemicals may persist, prompting mines to frequently utilize a mix of rinsing, physical segregation, and detoxification of heap leach pads before their reclamation to prevent adverse effects on contaminated surface water bodies (Hudson 2012).

2.3.2 Erosion

The erosion of waste materials, particularly waste rock and tailings, can impact the quality of surface water (Hudson 2012). Prominent contributors to erosion in mining areas encompass open pit regions, heap and dump leaching sites, waste rock and overburden mounds, tailings heaps and dams, haul roads, access roads, ore stockpiles, zones for vehicle and equipment maintenance, exploration areas, and reclamation zones (Sills 2006). To reduce transportation expenses, waste rock disposal sites are positioned in close proximity to mines, but inadequate placement can result in the erosion of metal-bearing components into streams or other water bodies. In such cases, the material can interact with water and oxygen, releasing metals and other potentially harmful elements into streams. Metals dissolved in surface water this way become more accessible to organisms. For instance, even small amounts of dissolved copper can impact the nervous system of fish and result in lesions in their gills. Furthermore, sediment deposited in layers due to erosion in floodplains or terrestrial ecosystems can have various effects on surface water, groundwater, and terrestrial ecosystems (Hudson 2012). The minerals linked with deposited sediments can lower the pH of surface runoff, thereby mobilizing heavy metals that can seep into the neighbouring subsoil or be transported to nearby surface water bodies (Sumi 2001).

2.3.3 Acid Drainage

One of the key environmental challenges encountered by the mining industry is the occurrence of acid drainage and the subsequent mobilization of pollutants. Referred to as acid mine drainage (AMD) or acid rock drainage (ARD), this phenomenon primarily relies on the mineral composition of the rock material and the presence of water and oxygen. Acid drainage is observed in both abandoned and operational mining sites. The acidic water has the capacity to dissolve toxic metals, such as copper, aluminum, cadmium, arsenic, lead, and mercury, from the nearby rock. Notably, these metals, especially iron, can create an orange-red slime known as yellow boy, coating the bottom of streams (Hudson 2012).

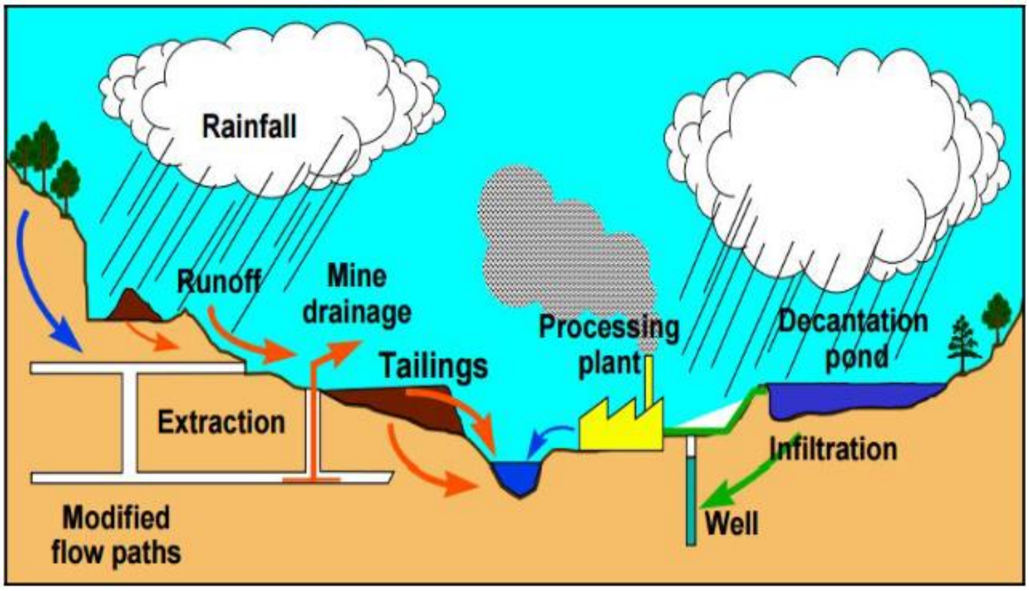


Figure 3. General sketch of surface and ground water by mining operation *(Review of potential environment and social impacts of mining. 2000)*

2.3.4 Groundwater

Groundwater quality and quantity can be influenced by various factors such as surface hydrology, soil texture, and terrestrial vegetation. Water quantity may decrease due to interception, pumping, or evaporation, leading to a decline in the water table. Groundwater quality is compromised when wastewater seeps through surface water into groundwater, and hydraulic connections between groundwater and surface water also contribute to groundwater contamination. A 2002 study conducted by the National Environment Engineering Research Institute found that during the monsoon season in the Bellary Hospet region, fine materials from dump sites were carried along the hill slopes via surface runoff, ultimately entering nearby water bodies. The presence of iron and manganese in groundwater resources around mining regions has resulted in poor water quality in this area (Hudson 2012) (Review of potential environment and social impacts of mining. 2000).

Impacts of the mining are the following:

- Groundwater quality
- Groundwater level

2.3.4.1 Groundwater quality

Mining operation and acid drainage can also have a tremendous effect on groundwater. However, it is typically essential to install a waterproof barrier at the bottom of the tailing pond to prevent the seepage of acidic drainage. Older tailing ponds, which were built without impermeable bases, have produced acidic drainage, leading to contamination of groundwater. The acidic water moves into the groundwater and eventually loses its acidity, allowing it to dissolve heavy metals found in rocks and compromise the quality of groundwater (Hudson 2012).

2.3.4.2 Groundwater level

The process of mining leads to alterations in surface topography and drainage systems, involving the extraction of groundwater for mining operations that can lower the water table and alter the subsurface migration of groundwater (Hudson 2012). Chauhan investigated the Bijolia Mine and found that the extracted sandstone produces dust particles primarily made of non-soluble silica, which settles at the bottom of reservoirs like ponds and wells (Chauhan 2010). Although it does not affect the drinkability of the water, it does impact the recharge capacity of groundwater, leading to a decrease in the water level.

2.3.4.3 Dewatering mine

In the case of an open pit intersecting with the water table, groundwater enters the pit. Pumping and discharging mine water result in a distinct range of environmental consequences. During mining activities, pumping groundwater from wells around the mine creates a cone of depression in the groundwater table, leading to a reduction in infiltration and the groundwater level (Hudson 2012) (Karmakar 2012).

2.3.4.4 Loss vegetation

The mining process results in the loss of vegetation, leading to increased runoff and reduced infiltration, ultimately causing a decline in the groundwater level.

2.3.4.5 Subsidence

Mining involves the extraction of minerals from the earth, which can occasionally lead to the subsidence of the overlying material. This alteration can impact the movement of groundwater, change the catchment area, and influence the groundwater level (Karmakar 2012).

2.3.4.6 Rise of temperature

In mining regions, it is commonly observed that the temperature within the mining area is higher compared to the surrounding regions (Sumi 2001). During the commencement of mining operations, the removal of trees disrupts the process of evapotranspiration and increases the amount of carbon dioxide in the atmosphere, leading to a rise in temperature. This, in turn, impacts the groundwater level (Sumi 2001) (Karmakar 2012).

2.3.5 Gold mining contamination on water bodies.

Gold mining can lead to various types of water contamination, primarily due to the use of chemicals and the release of heavy metals during the extraction and processing of gold. Some common forms of water contamination associated with gold mining include:

2.3.5.1 Heavy Metal Contamination

Gold mining often involves the use of cyanide and mercury, which can result in the release of heavy metals such as lead, arsenic, and cadmium into water bodies. These heavy metals can persist in the water, posing serious health risks to aquatic life and humans, even in trace amounts (How Gold Mining Can Affect Water Quality 2019-2022).

2.3.5.2 Acid Mine Drainage (AMD)

The exposure of sulfide minerals in mining activities can lead to the formation of acid mine drainage. This acidic water can contain high levels of toxic metals and can severely degrade the water quality, making it unsuitable for various aquatic organisms and disrupting the local ecosystem (How Gold Mining Can Affect Water Quality 2019-2022).

2.3.5.3 Sedimentation

Mining activities can cause soil erosion and the release of sediments into nearby water bodies, leading to increased turbidity and sedimentation. This can negatively impact aquatic habitats, smothering aquatic life, and affecting the overall water quality and ecosystem balance (How Gold Mining Can Affect Water Quality 2019-2022).

2.3.5.4 Chemical Pollution

The use of chemicals such as cyanide and other leaching agents in the gold extraction process can result in chemical pollution, altering the chemical composition of water bodies and causing toxicity to aquatic organisms. Improper handling and disposal of these chemicals can further exacerbate the contamination (How Gold Mining Can Affect Water Quality 2019-2022).

2.3.5.5 Eutrophication

Inadequate management of wastewater and tailings from gold mining operations can lead to nutrient enrichment in water bodies, triggering eutrophication. This can result in excessive algae growth, oxygen depletion, and disruption of the aquatic food chain, ultimately affecting the overall water quality and ecosystem health (Mouhamed Ngounouno Ayiwouo 2022).

These forms of contamination pose significant environmental and health risks, highlighting the importance of implementing effective management practices and regulatory measures to minimize the adverse impacts of gold mining on water quality.

3. Material and methods

3.1 Sampling for water quality monitoring

The primary objective of the water monitoring initiative is to oversee and assess any potential adverse physical and chemical effects on both surface and underground water in the vicinity of the project site throughout the entirety of mining operations. This effort aims to mitigate any potential unfavourable consequences for stakeholders. Physical impacts on water encompass variations in water levels, while chemical impacts involve alterations in the water's chemical composition, shifts in color, odor, and taste. Within the scope of environmental monitoring through water sampling, a collective of 32 water samples were collected from the sited places shown in Figure 1 and 2, and subsequently analyzed. Among these, 32 samples originated from groundwater, 5 from surface water, 2 from drinking water, 2 from microbiological water, and an additional 2 from wastewater. These samples were subjected to analysis at the accredited "Han Lab" laboratory, and the findings were subsequently collated.

Sampling devices used in groundwater monitoring should consider well diameter and yield, as well as limitations in the lift capacity of the sampling devices and the effect on the analytes in the sample of water from the materials in the devices. Commonly used devices include electric submersible pumps, bailers, suction-lift pumps, and positive displacement bladder pumps.

Bailers are often used to both purge and sample small diameter shallow wells. For these experiments and measurements, we used bailers.

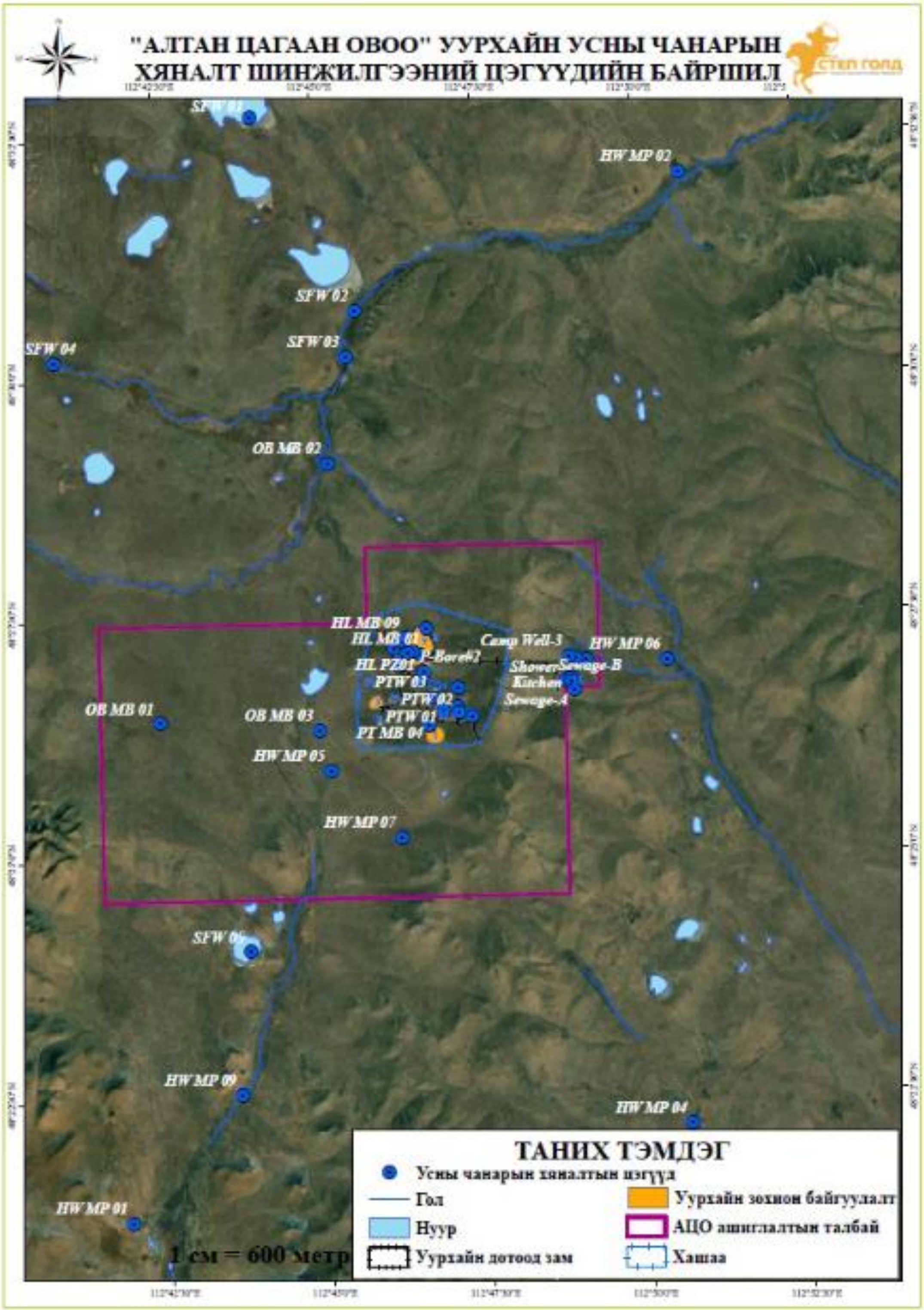


Figure 4. Water sampling map and location of the sampling point around the mining area, including herders' wells *(Gold 2022)*

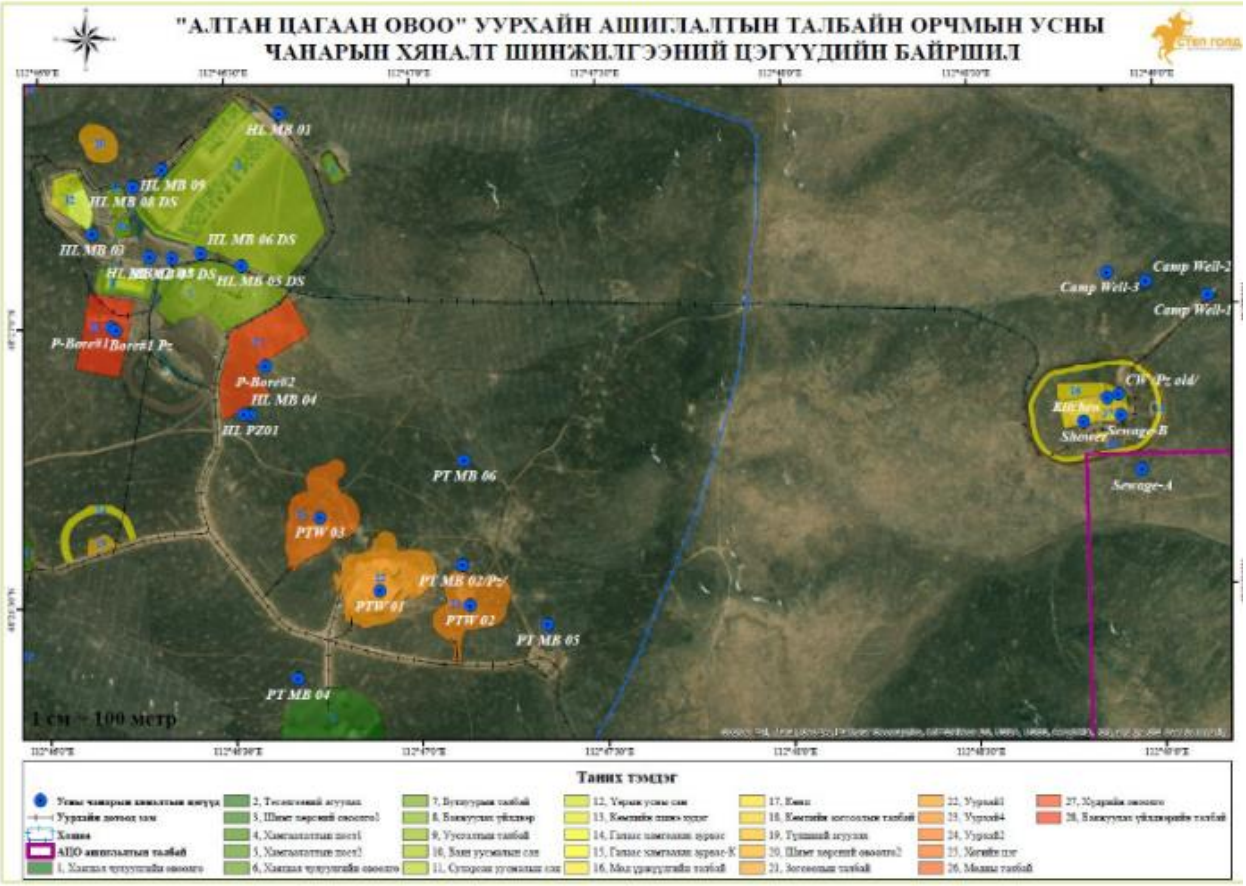


Figure 5. Water sampling map and location of the water sampling point near the camp site *(Gold 2022)*

3.2 Instruments

While conducting my sampling, I have used a bailer type for water sampling. A bailer is a cylindrical tube utilized for retrieving groundwater samples from monitoring wells. Usually constructed from slotted PVC casting. Bailers are attached to either nylon or polypropylene ropes or to Teflon or stainless-steel wires, which are then lowered into the water column. Equipped with a basic ball check valve, the bailer seals at the bottom to extract a sample of the groundwater table (Sampling Bailers n.d.). These bailers can be either disposable or reusable and are manufactured from materials such as polyethylene, PVC, FEP, or stainless steel. Bailer samples are collected when the bailer is attached to bailing cord and lowered slowly and gently down the well until the top of the bailer is below the groundwater surface. The bailer is pulled up when the desired depth is reached, with the weight of the water closing the check valve. It offers several advantages. It can be easily constructed in various diameters and from different materials, without the need for an external power source (Sampling Bailers n.d.). Its portability makes it highly convenient, and it has a low surface-area-to-volume ratio, minimizing the outgassing of volatile organics while containing the sample. Additionally, bailers are easy to clean, readily available, and cost-effective. However, this type of equipment has its drawbacks. The sampling procedure can be time-consuming, and it might sometimes be impractical to thoroughly evacuate the casing before taking samples. Aeration may also occur during the process of transferring water to the sample bottle (Sampling Bailers n.d.).

Figure 6. Bailer type that was used for water sampling *(Wikipedia Free Encyclopedia 2023)*

Simultaneously, we measured the water levels of the wells by employing a water level gauge as shown in Figure 9. The Water Level Meter comprises a Stainless-Steel sensor probe fitted to a flexible graduated cable, wound on a hand reel containing a transistorised switched circuit, audio indicator and battery. The product boasts various features that enhance its functionality and usability. Designed to be versatile, the instrument allows readings at multiple locations, ensuring efficiency in data collection. Its flat tape guarantees precise measurements, with a tape range of 30m–500m and 1mm divisions, accommodating different depth requirements. Its lightweight build makes it convenient for transportation and handling, while its user-friendly interface ensures easy operation. Additionally, the device is equipped with both audible and visual water level alert signals, with the added advantage of sensitivity adjustment for accommodating fluctuations in water conductivity. An optional digital temperature indicator further enhances its utility (Water level meter 2023).

Moreover, the product offers several benefits. Its portability makes it easily transportable to various monitoring sites, facilitating efficient data collection. The tape design prevents sticking to wet surfaces, ensuring accurate measurements even in challenging environments. Furthermore, the device provides an economical solution for water level monitoring, making it a cost-effective option for both small-scale and large-scale operations. Its compatibility with boreholes featuring small diameters makes it an ideal choice for a diverse range of applications, catering to various monitoring needs with precision and reliability (Water level meter 2023).

Figure 7. Water level Meter *(Ltd. 2023)*

Sampling of both groundwater and surface water was conducted within the designated region of the mining site. Designated sites shown in Figure 1 and 2. The sampling activities served various objectives, including:

- Performing laboratory analyses on the collected samples to determine their constituents.

- Utilizing well height measurements to ascertain potential cyanide leaching. A noticeable increase in well water levels would indicate leaching.

- Upon completion of the laboratory analyses, the results could be utilized as evidence to assure the local community that mining operations have not inflicted any harm on the neighbouring environment.

3.3 SWOT analysis

The SWOT analysis has undergone various developments since its inception. Initially, it originated in the early 1950s at Harvard Business School, where Harvard professors George Albert Smith Jr. and C Roland Christensen utilized it to analyze organizational strategies in the context of their environment. Alternatively, some scholars attribute the origin of SWOT to Albert Humphrey in the 1960s at Stanford Research Institute (Mostafa Ali Benzaghta 2021). Humphrey applied SWOT to analyze Fortune 500 companies with the aim of developing a novel system for change management and control. In 1963, during a business policy conference at Harvard, the SWOT analysis gained widespread attention, marking a significant advancement in strategic thinking. Post the 1960s, SWOT became a staple in the work of various researchers and strategic planning scholars. Its extensive reintroduction occurred in the 1980s, with Hoskisson et al. (1999) noting its dominance in the field of strategic management in the 1990s. Over time, the SWOT analysis has demonstrated its validity and accuracy, finding applications in diverse fields such as education, industry, and agriculture. Subsequently, scholars have integrated the SWOT model with other techniques, including the political, economic, sociological, technological, environmental, and legal framework, analytic hierarchy process (AHP), and the five forces model (Mostafa Ali Benzaghta 2021). These combinations have yielded more precise results and empowered strategic decision-making. Dyson (2004) argues that the adaptability of SWOT, demonstrated by its association with different techniques, positions it as a flexible model capable of incorporation with newer approaches and methods. Consequently, the enduring use of SWOT as a tool for organizations to assess their market position seems assured, given its ongoing relevance and adaptability (Mostafa Ali Benzaghta 2021).

The utilization of a SWOT analysis involves evaluating various aspects of a business, encompassing its strengths, weaknesses, opportunities, and threats. This analytical framework recognizes the significance of both internal and external factors in achieving a business's objectives. Internal aspects pertain to elements within the business's control, while external factors are those beyond its control (Mostafa Ali Benzaghta 2021). Through a comprehensive analysis of strengths, weaknesses, opportunities, and threats, the SWOT analysis becomes a valuable tool for generating alternative options for a business. These techniques facilitate a clear understanding of how strengths and weaknesses align with opportunities and threats (Mostafa Ali Benzaghta 2021). Drawing on internal and external factors, managers can formulate four strategic approaches: SO (Strengths - Opportunities), ST (Strengths - Threats), WO (Weaknesses - Opportunities), and WT (Weaknesses - Threats). Additionally, Davis (2007) suggests that tools like the External Factors Evaluation (EFE) matrix, Internal Factors Evaluation (IFE) matrix, or Competitive Profile Matrix (CPM) can be employed to construct the SWOT matrix. These complementary tools enhance the effectiveness of the SWOT analysis, providing a more nuanced understanding of the business landscape and contributing to informed decision-making (Mostafa Ali Benzaghta 2021).

The SWOT matrix can be summarized:

- SO strategies: taking advantage of opportunities.
- ST strategies: avoiding threats.

- WO strategies: introducing new opportunities by reduction of weaknesses.

- WT strategies: avoid threats by minimizing weaknesses.

Table 3. SWOT Matrix

Strength	**Weakness**
SO	**WO**
ST	**WT**

4. Results and discussion

4.1 Sampling for water quality monitoring

Table 4. Water quality monitoring check

Number	Name of the samples	Sample #	Samples were taken
1	OB MB 01	S - 1	Yes
2	OB MB 02	S - 2	Yes
3	OB MB 03	S - 3	Yes
4	PT MB 04	S - 4	Yes
5	PT MB 05	S - 5	Yes
6	PT MB 06	S - 6	Yes
7	SFW 01	S - 7	Yes
8	SFW 02	S - 8	Yes
9	SFW 03	S - 9	Yes
10	SFW 04	S - 10	Yes
11	SFW 05	S - 11	Yes
12	HL MB 01	S - 12	Yes
13	HL MB 02 D	S - 13	Yes
14	HL MB 02 S	S - 14	Yes
15	HL MB 03	S - 15	Yes
16	HL MB 04	S - 16	Yes
17	HL MB 05 D	S - 17	Yes
18	HL MB 05 S	S - 18	Yes
19	HL MB 06 D	S - 19	Yes
20	HL MB 6 S	S - 20	Yes
21	HL MB 07 D	S - 21	Yes
22	HL MB 07 S	S - 22	Yes
23	HL MB 08 D	S - 23	No
24	HL MB 08 S	S - 24	Yes

25	HL MB 09	S - 25	Yes
26	HW MP 01	S - 26	Yes
27	HW MP 02	S - 27	Yes
28	HW MP 04	S - 28	No
29	HW MP 05	S - 29	No
30	HW MP 06	S - 30	Yes
31	HW MP 07	S - 31	Yes
32	HW MP 09	S - 32	Yes
33	Camp Well – 1	S - 33	Yes
34	Camp Well – 2	S - 34	Yes
35	Camp Well – 3	S - 35	Yes
36	Production Bore #1	S - 36	Yes
37	Production Bore #2	S - 37	Yes
38	PTW 01	S - 38	Yes
39	PTW 02	S - 39	Yes
40	PTW 03	S - 40	No
41	Camp sewage water – before	S - 41	Yes
42	Camp sewage water – after	S - 42	Yes
43	Camp Kitchen /500ml/	S - 43	Yes
44	Camp Shower /500ml/	S - 44	Yes
45	Camp Kitchen /1500ml/	S - 45	Yes
46	Camp Shower /1500ml/	S - 46	Yes
47	Blank	S - 47	Yes

A total of 32 samples of groundwater, 5 samples of surface water, 2 samples of drinking water, 2 samples of microbiological water, and 2 samples of wastewater were collected from the water monitoring points around the "Altan Tsagaan Ovoo" project area. In the accredited "HanLab" laboratory, relevant parameters were determined, and the test results were compared with MNS 6148:2010, MNS 0900:2018, MNS 4586:1998, and MNS 4943:2015 standards, respectively.

Figure 8. Water sampling. Source: The photographs were taken by fellow colleague

Table 5. Test results that have exceeded the Mongolian standards

Name of the samples	**Elements**	**Unit**	**Mongolian standard**				**Results**
			MNS 4943:2015	MNS 6148:2010	MNS 4586:1998	MNS 900:2018	
PTW 01	Mn	mg/L		0.1			0.518
PTW 02	Mn	mg/L		10			0.211
SFW 01	pH				6.5-8.5		9.7
SFW 01	As	mg/L			0.1		0.3
SFW 02	As	mg/L			0.1		0.02
SFW 03	As	mg/L			0.1		0.02
SFW 04	As	mg/L			0.1		0.02
SFW 05	pH				6.5-8.5		9.57
SFW 05	Cl	mg/L			300		697.66
SFW 05	As	mg/L			0.01		0.32
HL MB 02 D	pH			6.5-8.5			9.1
HL MB 02 S	pH			6.5-8.5			8.9

HL MB 05 D	pH			6.5-8.5			10.99
HL MB 07 D	pH			6.5-8.5			8.77
HL MB 07 S	pH			6.5-8.5			8.78
HL MB 09	As	mg/L		0.1			0.02
Cam Well - 3	Fe	mg/L				0.3	0.95
Camp sewage water - before	TSS (Total suspended solid)	mg/L	30				424
Camp sewage water - before	COD (Chemical Oxygen demand)	mgO/L	50				468
Camp sewage water - before	BOD (Biochemical Oxygen demand)	mgO/L	20				182.4
Camp sewage water - after	TSS (Total suspended solid)	mg/L	30				688
Camp sewage water - after	COD (Chemical Oxygen demand)	mgO/L	50				696.3
Camp sewage water - after	BOD (Biochemical Oxygen demand)	mgO/L	20				260.6

4.2 Groundwater result

Upon comparing the analysis results of groundwater samples with relevant standards, the majority of samples demonstrated mineralization content within acceptable limits. Furthermore, the levels of chloride, sulfate, calcium, and magnesium fell within the specified standards, indicating that the water in question is characterized by low mineralization and is of soft quality. However, certain elements such as manganese, arsenic, nitrate, and pH were identified in a limited number of samples, predominantly from the hand wells of herders. This suggests that the aquifer at control points has been stagnant for a considerable period, and the natural data of the soil and water in the region surpass the maximum allowable concentrations outlined in the standard. This phenomenon is believed to be associated with... Additionally, there are recurring instances of the pH values in water samples from monitoring wells near the heap leaching area surpassing the specified standard. Therefore, if the results of the water analysis from leaching control wells persistently exceed the specified standard in the future, a comprehensive investigation should be conducted.

4.3 Surface water result

Upon evaluating the surface water sample analyses against the applicable standards, it was observed that the concentration of certain elements at surface water monitoring points surpassed the specified limits. Notably, the results from analyses conducted at these points prior to the commencement of project activities also exceeded these parameters. This occurrence can be attributed to the irregular flow of these lakes and rivers, solely relying on rainfall for replenishment. Additionally, the natural composition of the soil, rocks, and water in the area contains concentrations exceeding the maximum allowable limits specified in the standard.

4.4 Drinking water and microbiological test results

Drinking water samples were exclusively collected from the kitchen and toilets of the workers' quarters, with additional microbiological samples obtained from the kitchens of the workers' camp. The analysis of these samples indicated that the levels of Manganese and Iron in the water from Camp's water supply well 3 surpassed the maximum allowable concentration outlined in the standard. This can be attributed to the infrequent use of this well, as it serves as a reserve, and water exchange is not regularly conducted. However, the analysis confirmed that other parameters remained within the specified limits outlined in drinking water standards.

4.5 SWOT analysis

4.5.1 Strength

The ATO project demonstrates notable strengths in its water management strategies, particularly in groundwater quality. The majority of groundwater samples showcase mineralization content within acceptable limits, with chloride, sulfate, calcium, and magnesium falling within specified standards, indicating a commendable foundation of low mineralization and soft water quality. This reflects a robust foundation for sustainable water use. The comprehensive analysis extends to various water sources, including groundwater, surface water, and drinking water, ensuring a holistic understanding of the project's impact on water quality. Additionally, the proactive monitoring system is evidenced by the identification of specific elements like manganese, arsenic, nitrate, and pH in limited samples, showcasing a commitment to early detection and addressing potential issues. However, weaknesses arise in the form of a potentially stagnant aquifer at control points, indicated by the presence of certain elements in limited samples. This underscores the importance of continuous monitoring and remediation efforts to maintain water quality standards. Recurring instances of pH values exceeding specified standards in water samples from monitoring wells near the heap leaching area further reveal a weakness that requires attention and intervention to mitigate potential impacts on water quality.

4.5.2 Weakness

While the project showcases strengths in groundwater quality, weaknesses are apparent in potential aquifer stagnancy and exceeding pH values in specific locations. The presence of certain elements, such as manganese, arsenic, nitrate, and pH, in limited samples indicates a potential weakness in the aquifer at control points, suggesting stagnancy over a considerable period. As for recurring instances of pH values exceeding specified standards in water samples from monitoring wells near the heap leaching area represent a weakness, signaling a potential impact on water quality.

4.5.3 Opportunities

Opportunities arise from the proactive monitoring system, offering early detection and mitigation possibilities. Adopting remediation measures for irregular flows in lakes and rivers dependent on rainfall is an opportunity to enhance overall water quality.

4.5.4 Threats

Threats loom in the irregular flow of lakes and rivers, contributing to element concentrations surpassing allowable limits. The infrequent use of Camp's water supply well 3, acting as a reserve, poses a threat to drinking water quality, as evidenced by elevated levels of Manganese and Iron.

5. Conclusion

The comprehensive analysis of water samples from various sources provides a nuanced understanding of the water quality in the studied area. The majority of groundwater samples exhibited mineralization content within acceptable limits, indicating a foundation of low mineralization and soft water quality. Compliance with specified standards for chloride, sulfate, calcium, and magnesium further supports the favorable quality of the water. However, the identification of certain elements, including manganese, arsenic, nitrate, and pH in a limited number of samples, particularly from hand wells of herders, raises concerns. This suggests a potential stagnancy in the aquifer at control points, surpassing maximum allowable concentrations outlined in standards. The recurring instances of elevated pH values in water samples near the heap leaching area are also noteworthy, warranting continued attention.

The surface water results reveal concentrations of certain elements surpassing specified limits at monitoring points, both before and during project activities. This phenomenon is attributed to the irregular flow of lakes and rivers, heavily reliant on rainfall for replenishment. Additionally, the natural composition of the soil, rocks, and water in the area exceeds maximum allowable limits, highlighting challenges in maintaining water quality standards.

The analysis of drinking water samples from workers' quarters and microbiological samples from the workers' camp provides further insights. The levels of Manganese and Iron in Camp's water supply well 3 exceeded the maximum allowable concentration, attributed to its infrequent use as a reserve. Nonetheless, other parameters remained within specified limits outlined in drinking water standards.

In light of these findings, it is crucial to implement ongoing monitoring and remediation efforts. The potential stagnancy in aquifers, irregular flow of lakes and rivers, and the impact of infrequently used wells underscore the need for sustained attention to maintain water quality standards. Further comprehensive investigations, particularly regarding leaching control wells and the irregular flow of surface water, are recommended for effective water management and environmental safeguarding in the studied area.

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List of tables

List of figures

Abbreviation

TSX: Toronto Stock Exchange

IPO: Initial public offering

ATO: Altan Tsagaan Ovoo

EIA: Environmental Impact Assessment

EIS: Environmental Impact Statement

EMP: Environmental Management Plan

ASGM: Artisanal and Small-Scale Gold Mining

VOC: Volatile organic compounds

WQI: Water Quality Index

AMD: Acid mine drainage

ARD: Acid rock drainage

PVC: Polyvinyl chloride

FEP: Fluorinated ethylene propylene

SWOT: Strengths, Weaknesses, Opportunities, Threats

AHP: Analytic hierarchy process

EFE: External Factors Evaluation

CPM: Competitive Profile Matrix

IFE: Internal Factors Evaluation

MNS: Mongolian National Standard

COD: Chemical Oxygen Demand

BOD: Biochemical Oxygen Demand

TSS: Total Suspended Solid

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