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Assessment of the environmental impact of tailings in the Republic of Armenia

Evaluación del impacto ambiental de escombreras de mina en la República de Armenia

Avaliación do impacto ambiental de escombreiras de mina na República de Armenia

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RETHINKe

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Tatev

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Summary

Mine tailings and accidents related to them are one of the most dangerours environmental problems all over the World. This problem is specially acute in small countries where mining industries are important, particularly mining of metallic ores. Armenia currently hosts about 400 mining operations, 22 of which are polymetallic. The total area occupied by mining factories accounts for 10000 hectares, 8000 of which comprise the exploited grounds and 1500 hectares correspond to the area underlying the tailing dams. Being Armenia a mountainous country with a small area, problems of occupation of space and soil and water pollution become particularly acute and urgent to be solved. In fact, there are more than 1 million tons of mining wastes in the Republic of Armenia already, located in the tailing dams of more than 20 enrichment tailings. The construction of new storage facilities, and consequently, the occupation of new territories appear regularly, and it becomes a serious, unsolvable problem since those areas used for tailings become unsuitable for further use.

In this work, we edited and summarized the information about the enrichment tailing dams of the Republic of Armenia mining activities. From all existing tailings, 8 of them are already closed. Some of them were closed without being fully exhausted. One of the main reasons for this fact is that during their design, the amount of rainwater accumulation was not properly calculated and therefore tailings mothballed ahead of the planned time. Most of the Armenian tailings are located in the region of Syuniq, with 9 tailings, followed by the region of Lori with 8 tailings. From these, the biggest mining operations are Geghanush in Syuniq and Teghut in Lori. In this work, we used these two big tailings as representative of the general condition and risks of tailings in Armenia. Accordingly, we made laboratory (solid material and water composition) and social analysis for both tailings and we conclude that the high amount of hazardous heavy metals in these tailings spread to nearby territories and contaminate the soil, water and air, enter the food chain, and adversly affect the human health. At first glance, these problems seem unsolvable.

However, correction measures must be implemented in order to reduce the pollution.

Resumen

Las escombreras de minas y los accidentes realcionados con ellas son uno de los problemas ambientales más peligrosos que existen en el mundo. Su problemática es especialmente acusada en aquellos países con importantes explotaciones mineras, particularmente en yacimientos metálicos. En Armenia, existen actualmente alrededor de 400 explotaciones mineras, de las cuales 22 son polimetálicas. El área total ocupada por factorías mineras es de 10000 hectáreas, de las que 8000 son los yacimientos en sí, y 1500 se corresponden con el área ocupada por las escombreras. Al ser Armenia un país montañoso de área pequeña, los problemas de ocupación de espacio y de contaminación de suelos y aguas derivados de la minería son particularmente acuciantes y su solución se torna urgente. De hecho, existe más de un millón de toneladas de residuos de minería acumulados en más de 20 escombreras. La construcción de nuevas instalaciones de almacenaje de residuos, y consecuentemente, la ocupación de nuevos terrenos, es una cuestión recurrente y puede ocasionar problemas graves e irreversibles, ya que las áreas ocupadas por escombreras no pueden ser utilizadas para otros usos.

En el presente trabajo, se ha recopilado y resumido la información disponible sobre las escombreras que existen en la República de Armenia. De estas escombreras, 8 han sido cerradas. Algunas de ellas han sido cerradas sin haber sido llenadas por completo. Una de las principales razones ha sido que en su diseño no se ha tenido en cuenta la acumulación de agua de lluvia, y por tanto las escombreras se llenaron antes de la fecha prevista. La mayor parte de las escombreras se sitúa en la región de Syuniq, donde se sitúan 9, y Lori, donde hay 8. De éstas, las mayores explotaciones mineras son las de Geghanush, en Syuniq, y Teghut, en Lori. En el presente trabajo, se han analizado estas dos escombreras, como ejemplos representativos de la situación general de estas acumulaciones de residuos mineros en Armenia. En consecuencia, se han realizado análisis de laboratorio (material sólido y composición de las aguas) y sociales de ambas esombreras, y se ha concluido que presentan gran concentración de metales pesados, los cuales se movilizan y afectan las áreas

circundantes, contaminando suelos, aguas y aire, penetrando en las cadenas tróficas, y afectando a la salud humana. Estos problemas parecen irresolubles, aunque deben implementarse medidas correctoras para reducir la contaminación.

Resumo

As escombreiras de minas e os accidentes realcionados con elas son un dos problemas ambientales mais perigosos que existen no mundo. A súa problemática é especialmente acusada naqueles países con importantes explotacións mineiras, particularmente con xacimentos metálicos. En Armenia, existen actualmente arredor de 400 explotacións mineiras, das que 22 son polimetálicas. A área total ocupada polas factorías mineiras é de 10000 hectáreas, das que 8000 son os xacimentos en sí, e 1500 hectáreas corresponden coa área ocupada polas escombreiras. Ó ser Armenia un país montañoso de área pequena, os problemas de ocupación de espazo e de contaminación de solos e augas derivados da minería son particularmente acuciantes e a súa solución é urxente. De feito, existe mais de un millón de toneladas de residuos da minería acumulados en mais de 20 escombreiras. A construcción de novas instalaciós de almacenaxe de residuos, e consecuentemente, a ocupación de novos terreos, é unha cuestión recurrente e pode ocasionar problemas graves e irreversibles, xa que as áreas ocupadas polas escombreiras non poden ser utilizadas para outros usos.

No presente traballo, recopilouse e resumiuse a información dispoñible sobre as escombreiras que existen na República de Armenia. Destas escombreiras, 8 foron pechadas. Algunhas delas pecháronse sen terse henchido completamente. Unha das principales razón foi que no seu diseño non se contou coa acumulación de auga de chuvia, e polo tanto, as escombreiras enchéronse antes da data prevista. A meirande parte das escombreiras está na rexión de Syuniq, con 9 escombreiras, e Lori, con 8. Déstas, as explotacións mais grandes son Geghanush, en Syuniq, e Teghut, en Lori. No presente trabaallo, analizáronse estas dúas escombreiras como exemplos representativos da situación xeral destas acumulacións de residuos en Armenia. Fixéronse análises de laboratorio (material sólido e composición das augas) e análisis sociales das dúas escombreiras, e observouse que ambas presentan gran concentración de metales pesados, que se movilizan e afectan as áreas próximas, contaminando solos, augas e aire, penetrando nas cadenas tróficas, e afectando á

saúde humana. Estes problemas parecen irresolubles, aínda que deben implementarse medidas correctoras para reducir a contaminación.

Introduction

Nature is an invaluable wealth and any harm caused to it will results in heavy social-economic losses. Despite this common assumption, many activities lack an ecosystem-oriented approach towards nature conservation, derived from a weak legislative system, private interests and inefficient management. This is the situation with mine tailings in the Republic of Armenia (RA) nowadays.

The present work aims to analyze the state-of-the-art in RA, and its drawbacks examining the leading global experience. This is a first step in order to improve the situation of tailings in the country and to put it on a right track.

In the last 30 years, the price of mineral raw materials has been increasing by 5-10% annually. The current high prices, the constant growth of demand and the present technical-technological opportunities have turned previously discarded poor ore materials into valuable resources[1,2]. As a result, mining ventures need to construct new mining factories and tailing dams which will accumulate the tails formed during ore processing[3,4]. It should be mentioned that during the processing of ferrous and other precious metals, more than 80-98% of ores are discarded as wastes and taken to enrichment tailing dams where some amount of metals is mobilized and lost.

The most dangerous type of mine configurations is the openly exploited mines of non-ferrous metals which the geology of the RA (Republic of Armenia) is rich in[5]. More than 670 mines including 30 metal mines are listed in the balance of the IMR (Imetal Resources) RA. More than 400 of these mines are currently exploited, being the most valuable ones the 22 metal mines. According to their economic impact, we can single out the Cu-Mo (7), Au and Au-poly-metallic (14), and Cu (4) mines as the most profitable ones, where the ores are extracted mainly in an open-air technique. Our evaluations state that about 40-45 million tons of mountain material is mobilized in order to obtain metals. Half of this mass consists of ores.

Enrichment tails pose one of the highest environmental risks because of the toxicity of their components and because they consist of small crushed particles that can penetrate into soil pores and move with flowing water easily[6]. Besides, the tails usually contain production sewage water and flotation chemicals-reactants.

The characteristics of different tails can vary drastically, depending on both the minerals the ore consists of and the materials used in the technologies for the extraction of useful components. Their characteristics need to be defined in order to explain the behavior of the tails in the storage place and their influence on the environment, as well as to determine the responsibilities and activities of the people in charge[7,8]. Only after a laboratory examination and an experimental industrial analysis of the characteristics of the tails, it is possible to determine the project demands necessary to reduce the impact of the tails on the environment, as well as to define their optimal operational characteristics[9,10].

It must be noted that, in RA, enrichment tails were considered as wastes and thus money from the state budget must be allocated for them as harmful formations, without considering the fact that some of them are technogenic raw material accumulations[11]. Thus, it is crucial to precisely characterize the material accumulated in the tailing. Currently, enrichment tails accumulated in mine enrichment factories are not considered as wastes anymore, but as technogenic mines, in a wrong approach that contradicts Armenian Law. In fact, the 9th point of the Article 3 of the RA Underground Resources Code gives the following definition:

Technogenic mine- accumulations of minerals in tailings, mountain openings or on the surface of the earth, created as a result of mineral examination, mining, procession and enrichment, *having received an ecologic-economic evaluation in a determined order*.

Contradicting this legal definition, none of the mining and ore-processing wastes considered as technogenic mines in the RA has received an ecologic-economic evaluation. Thus, none of them can be considered as technogenic mines so far, and their inclusion in this category is only aimed at avoiding the payments for wastes. Besides, Article 4 of the RA Law about Wastes clearly defines production wastes and dangerous wastes as:

Production and consumption wastes (hereafter referred to as wastes)- remains of materials, products, food or raw material created in the process of production or consumption; products that have lost their original consumption qualities;

Dangerous wastes- wastes that are or can be harmful for human health and the environment because of their physical, chemical or biological qualities, and require special methods, ways and means of treatment.

Due to such a "free" interpretation of the nature of mine tailings, the RA budget misses tax revenues for an amount of USD 98 million annually, according to the numbers declared by the National Assembly.

In addition to the loss of income for the State that a wrong classification entails, there are different phenomena related to the tailings that have a negative impact on the environment. Among them, the risk of dam rupture and surface and underground water contamination are some of the most important. Considering the demands for reducing the impact of technogenic accumulations on the environment, the Sustainable Development Center (SDC) has discussed the engineering-geological and seismic stability demands of tailing dam construction[12]. It has also given guidelines about the structure of tailings and the isolation of wastes from the environment.

Accidents and incidents in the tailings can mainly be caused by the lack of control over water balance and construction, excessive deformation of the dam walls, or seismic overload[13]. A base that does not meet the requirements, and an excessive amount of tails, can lead to the rupture of the dam that holds back the water. Other important potential impacts on the environment are crashes of tailing pipes, water leakage through the dam wall and pollution of surface and groundwaters by the leaked waters, dust or gas releases, and the impacts on the biota. Thus, the main measures taken for the security of tailings should be directed towards the minimization of harms caused by 1) collapses, 2) filtration losses and 3) dust formation[14].

The most unfavourable ecological situation that can occur in the tailing is the dam rupture. As any hydro-technical construction, the limits of the area potentially affected by the rupture, or the flooded areas and surface and groundwater water at risk, must be delimited. In this respect, it is extremely important to monitor and engineer seismic risks to prevent the possible dangers and the negative impacts of the tailings on the environment, or at least to reduce their risks. Far from this ideal situation, the majority of the tailings in the RA were projected several decades ago and whether they meet the modern normative demands of seismically resistant dam constructions is still under question. To solve this issue, it is suggested to carry out investigations of engineering-geological conditions of both the tailings and tailing pipes, in order to reveal the geological and technical dangers, as well as to evaluate their possible effects. It is suggested to carry out investigations of geotechnical qualities of the front dam grounds, the coastal brace dam, and the pond area tails, and to evaluate the front and brace dam stabilities in static and seismic conditions according to the modern demands of the RA construction norms and rules. It is also necessary to create a monitoring network in order to have a constant control over the tailings, make a survey to control the deformations, control the position of the depression curve by placing piezometers, determine the pore pressure with the help of wellpoints, and other geotechnic control measures. The results of the monitoring must be thoroughly analyzed and modelled. This will help to predict the possible dangerous phenomena and to adopt suitable measures to eliminate current risks.

The list of measures directed to the evaluation of the seismic risk in the areas of the tailings and the possible seismic impacts have been clarified[14]. It is suggested to carry out seismic investigations on 3 levels:

Level 1 - regional seismic investigations

Level 2 - thorough seismic zonation

Level 3 - seismic microzoning

Among the abovementioned, the most important investigation is the seismic microzoning, which implies the implementation of local seismological investigations in the areas covering the tailing surroundings in a radius of 5-10 km. On this level of investigations, the research has to reveal the peculiarities of tailing platforms and dam grounds as well as to give a quantitative evaluation of the possible seismic reactions of the grounds in order to determine the seismic risks.

Considerable harm to the environment is caused by water emissions from the tailings[15]. A great factor of risk is constituted by the drainage waters that can reach groundwater and pollute them. Though waters in the tailings undergo a long-time sedimentation that contributes to their purification, such waters contain not only heavy metals but also harmful elements and mixtures whose concentrations exceed the Maximum Allowed Concentration for cisterns. It is possible to reduce filtration losses through maximum hydro-isolation by constructing a water-resistant layer made of clay material and polymer film. Also, a drainage system for the accumulation of filtration waters can be constructed with a closed recirculatory water supply system for enrichment factories[16]. The amount of drainage and evaporation losses can be reduced also by means of applying dry methods for tail installation and obtaining paste. In this case, the tails must be well processed beforehand to reduce the amount of metals they contain. In order to evaluate the risk of underground water pollution and the risk of floods in the areas surrounding the tailings, level measurements and water sampling must be carried out in an observation network of wells constructed for this purpose. In addition, factories must provide information about the chemical composition of the waters emitted from the tailings in order to enable the evaluation of the ecological risks, while local and regional monitoring services must inform the population about the cases when the environmental pollution rates reach a dangerous level.

The fact that the tailings have a huge and open surface (1-10 hectares), and consist of small-grained material, makes them a powerful source for toxic pollutants in the form of dust. Dust reduction is achieved through the creation of sanitary zones around the tailings, as well as through the re-cultivation of tail material.

Taking into consideration the great amounts and variety of enrichment tails and ore accumulations and their harmful impacts on the environment, classifying them in classes according to their potential harm is a priority, and it must be done through respective directives[17]. In RA, however, these directives do not contain clear explanations and demands for the evaluation of waste harms, and do not include a wide list of materials, neither the upper limits of harmful substances. The criteria to classify wastes according to their environmental harm are defined for the activities that produce those wastes. The enterprises are obliged to confirm the attribution of wastes to a specific harm class., and the payments to the state budget must be calculated accordingly. This process must be preceded by the issue of passports to tails and tailing dams, which is mentioned in the decisions of the Government as well: in RA, these decisions are not fulfilled either, with a few exceptions. Thus, the information available to the public is limited, and the necessary inspection of tails has not been carried out. It is imperative that the State, in its turn, manage the state cadastre of wastes. This cadastre must include the registry of each class of waste, the waste locations, and information about the utilization and neutralization of wastes according to their class.

A vital problem of waste management in RA is the absence of sanitary zones around the mining installations. In many countries, such sanitary zones are determined for the objects operating with dangerous technologies that can harm the environment and human health. The sizes of such zones are determined on the basis of the sanitary classification of the installation. During the delimitation of sanitary zones, the following criteria are taken into account: the size of the installation, the conditions of exploitation, the closeness of objects on a limited area, the types and amounts of toxic and odorous materials thrown out into the environment, the noise produced during the operations, fluctuations, and other dangerous factors. In Europe, for instance, it is prohibited to locate factories using cyanide technologies on an area less than 30 km far from inhabited territories. In RA, the factories of ferrous metallurgy and those producing non-ferrous metals and metal concentrates, including mining factories, are considered first degree risk factors and are surrounded by sanitary zones with a radius of no less than 2 km. This definitely excludes the exploitation of mines near populated areas. This question directly refers to the problem of the Hrazdan iron mine near the town of Hrazdan in RA[18].

Special attention should be paid to the monitoring of soil, surface and groundwaters and atmosphere quality in both the mines and their surrounding areas. The environmental impact assessment (EIA) should determine the monitoring system so the producing company, government departments and the society will be able to control the operation of the mining project and the influence of mines on the environment. During the evaluation of the impact of the mining activities on the environment, background levels should be defined for each potential pollutant, so the impact of the activity can be assessed. In this way, undesirable influences can be documented and improved at an early stage. The producing company must have a monitoring plan in order to discover the most harmful pollution sources and shortcomings and to take measures for their elimination.

Another mechanism of control over the maintenance of a secure entrepreneurial activity is the adoption of insurances. In developed countries, the insurance of responsibility for the harm caused by the crash of a dangerous object is a strict demand for the owner of such an object. This refers especially to the objects involved in mining activities and enrichment of minerals, and having hydro-technical constructions (.i.e., dams that block the reservoirs of liquid wastes). The insurance of risk liability takes into account the possibility of compensation for the caused harm. The use of insurance allows guaranteeing the compensation rights of the people who have suffered losses because of accidents, to protect the polluting factories against wrack caused by lawsuits against them, and to assist in the prevention of accidents through regular ecological audits carried out by the insurance company. The insured subjects are interested to increase the ecological rates of their companies as the premium rates grow together with the increase of accident probability. The insurers take up precautionary means: ecological audits of the insured enterprise and monitoring of environmental quality.

The evaluation of the industrial significance of technogenic mines differs from the traditional evaluation in several ways. For instance, the strict normative rquirements that are compulsory in the traditional evaluation of mines, such as the minimal industrial content in the calculation unit, the minimal power of ore bodies, the determination of mineral types and sorts, the minimal amounts of separate ore bodies, etc., do not operate here. Modern criteria for a rational utilization of natural resources and evaluation of environment conservation include aspects like the level of extraction of minerals and adjacent valuable components, the reduction of waste amounts, decrease of harmful components in the wastes, maximal utilization of mining wastes[19].

In the process of revelation of their economic value, mining resources and technogenic formations are exposed to geological, technical-economic and economic evaluations with the consideration of social-economic and ecological factors. The economic evaluation is the revelation of the importance that technogenic raw material has for the economic activity of the society (in both monetary and non-monetary values). It can refer to both mineral values and to the health of the population, and it can be manifested in economic expenses and influences (illness prevention, production losses, etc.).

As some consequences of technogenic mines cannot be expressed in money forms, in the process of evaluation they are complemented by an economic analysis with the application of suitable evaluation criteria. The evaluation, in its turn, can be presented by value and non-value forms (material, labor). The current procedure of economical evaluation is the value form. Its main advantage is its integral character. Thus, during the economic (monetary) evaluation of mines, the most commonly used criterion is the one that will provide a complete monetary view of the results of the factory's activities – economic, ecological, social, and environmental. The ecological-economic influence is the sum of the product price, obtained from the exploitation of a technogenic mine, and the residual ecological-economic harms before and after the activities of a technogenic mine, excluding the monetary expenses for production organization[20].

Thus, in the last decades there has been an increase of allocations for ecological activities by mining enterprises. According to foreign sources, cash expenses of mining factories for ecological activities account for a number between 3 and 20% (8.8% on average) of production value in different conditions. The ecological program of processing mining wastes is supposed to include 4 stages: The first one is the evaluation of the ecological situation; the second stage – the inventory of mining wastes – involves the collection and coordination of the main parameters of mining wastes that define their qualities, spheres of exploitation and the possible ways to reduce their harmful effect on the environment; the third stage involves classification of mining wastes according to the directions of their usage (the ore containing wastes are separated from the rest for the purpose of an additional extraction of useful components), and; the fourth stage is the processing of mining wastes as a technogenic mining material.

An ecological and geochemical analysis of risks of the impact of mining industry upon sustainable development of the RA was performed on a case study of two mining centres - the cities of Kajaran and Kapan[15,21]. A complex ecological and geochemical assessment of major environmental compartments of the cities was provided, and ecotoxicological investigations were performed in farm crops growing on the territories of the re-cultivated tailing repositories and lands situated between the city of Kapan and the active tailing repository. These are the basic food sources for the population of Kapan, Kajaran and adjacent villages. To assess the level of environmental impact upon the human health, studies of heavy metals contents in infant hair were carried out in Kajaran. These studies concluded that pollution of farming lands with heavy metals induced by the operation of mining plants is a limiting factor for sustainable development of the Republic of Armenia[15,21].

The research covered issues of safety of farm produce of both plant and animal origin obtained from farmlands located within mining impact zones. Ore deposits are located within the boundaries of biogeochemical provinces. Basic ore formations dominate geochemical landscape and the ecosystems have adapted to their natural concentrations. Ores contain insignificant quantities of commercially invaluable mixtures of elements, which are not practically fixed in environmental substrates before their deployment in waste deposits. Such elements are not extracted while mining and treating the ores, and are deposited in mining dumps and dressing tails. There they become mobile, entering geochemical pathways. A good example of this is Armenia's active deposits of various ore formations, e.g., the Kajaran copper-porphyry deposit. In this area, Hg transfer to runoff that originates from tailing repositories was detected, since soils of re-cultivated tailings were polluted with Hg. Thus, Hg was detected in fodder crops and, via the food chain, in cow milk. In vegetable crops, Hg contents exceeded maximum allowed concentration (MAC) by 8-30 times. On the Kapan copper-pyrite deposit, ore waters were transfered into the irrigation network, consequently polluting irrigated farmlands with heavy metal(oid)s, specially lead. Thus, Pb concentrations in cultivated farm crops were 3-6 time higher than MAC. In Akhtala, effluents from the dressing ores of the polymetallic (Pb-Zn) deposit and tails were mixed with surface water streams polluting downstream farmlands with metal(oid)s including Cd, whose concentrations in farm exceeded MAC by tens to hundreds of times[22]. All these elements belong to the 1st category of hazard. They have bioaccumulation properties and entering food chains become the major risk factor to local population.

In light of the potential environmental and health problems derived from an erroneous management of mine wastes, the aim of this work is to review the current conditions of the tailings of the main mining operations in Armenia.

Chapter 1

Tailings construction

Tailings are fine-grained wastes of the mining industry, output as slurries, due to mixing with water during mineral processing. Tailings dams can be very different, since its design depends on factors like exploitation characteristics and mill output, topography, hydrology, geology, subsurface hydrology, seismicity, available material, and disposal methods.

The tailings that accumulate large amounts of crushed material mixed with chemically contaminated water are not only a technological necessity of the mineral exploitation, but a big danger to the surrounding environment. On the other hand, the reclamation of tailings increases the costs of the exploitation. Much of the mining companies have closed due to unsafe working conditions, largely due to problems related with tailings.

There are three methods for constructing tailing dams, which depends of the geological features on the ground and soil mechanics (figure 1).

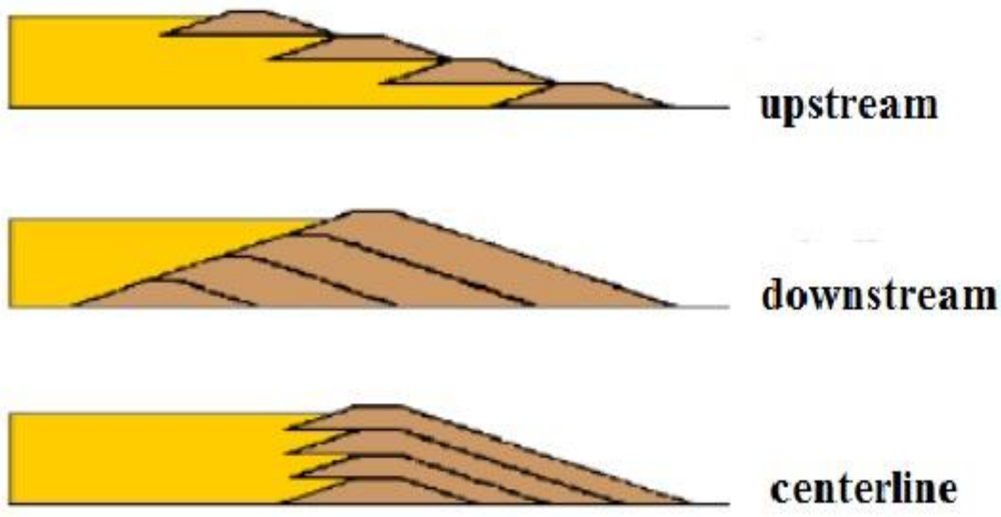

Figure 1. Tailing dams types[13]

Each type has its own safety requirements:

1. The upstream construction method, while a low cost solution, implies a number of specific hazards for dam stability. These hazards require a thorough assessment and continuous monitoring and control during siting, construction, and operation of the dam.
2. Downstream-types and water-retention type embankments provide better safety margins for dam stability.
3. The centreline method is a compromise between both the upstream and downstream designs. It is more stable than the upstream method but does not require as much construction material as the downstream design[23].

As mentioned in the previous section, the major ecological risk associated with tailing dams is their failing. As a result, serious environmental hazards can occur, including floods and flood waves and spills of potentially toxic sludge and waters with serious consequences. The typical modes of failure are affected by different causes such as dam overtopping, seismic impacts, landslides within the valley of the basin or structural dam failure due to instability and unexpected seepage forces. In table 1, the severity categories of effects and consequences of tails failure are shown.

Table 1. Categories of severity of effects and consequences

Severity	*Biological impacts & land use*	*Property & economic loss*	*Health & safety*	*Regulatory impacts & censure*	*Public concern & image*
Extreme	Catastrophic impact on habitats or productive land	Extensive damage to buildings & property; major economic loss	Fatalities	Unable to meet regulatory obligations; closed down	Consistent international & NGO outcry; large stock devaluation
High	Significant irreversible impacts	Widespread damage to property and/or economic interests or entity	Severe injury or disability	Regularly (>one per year) exceed regulatory obligations	Regular international & NGO attention
Moderate	Significant, reversible	Damage or loss limited in scope or severity	Lost time or injury	Occasional exceed regulatory obligations	Occasional international & NGO attention
Low	Minor impacts	Small maybe temporary damage or loss	First aid required	Obligations seldom exceeded	Infrequent international & NGO attention
Negligible	No measurable impacts	Damage or loss to property or economic entity very minor	No concern	Regulatory obligations not exceeded	No international or NGO attention

Figure 2 shows World data on tailings dam failures by dam type. It is clearly seen that the occurrence of failure in a dam is closely related to the type of dam construction, being the upstream type the most problematic.

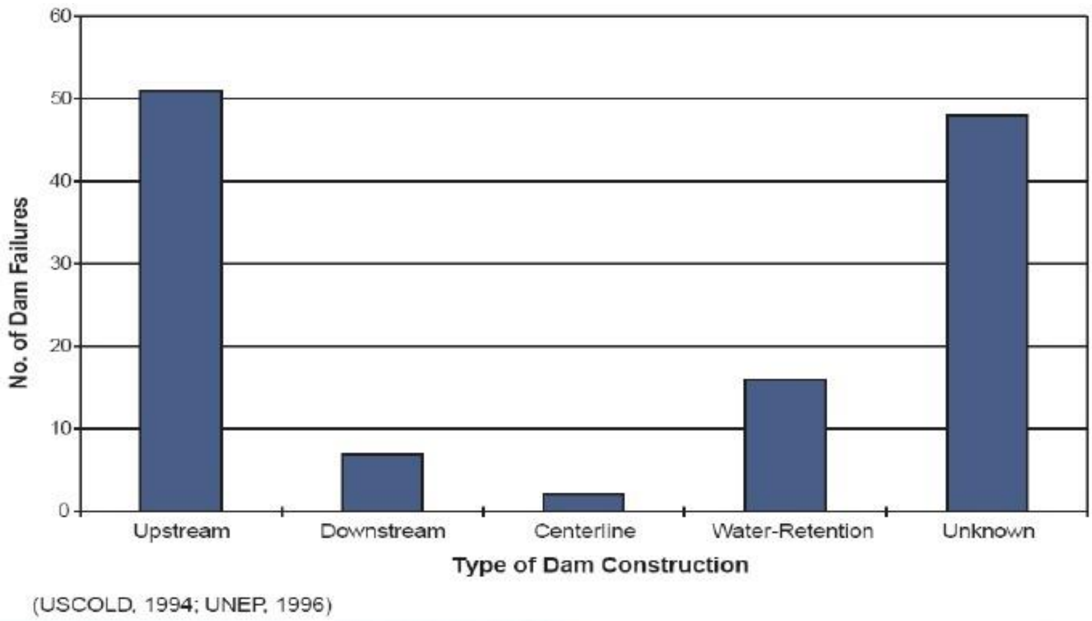

Figure 2. Tailings dam failures by dam type[24]

In addition to the particular concerns about dam location, there are other inherent problems related to dam construction and stability. For example, safer tailings can be created using material in paste consistency rather than the usual slurry disposal.

Thus, due to their potential danger, risk assessment is vital prior to define the location and mode of construction of the tailing dam. This assessment must be a structured methodology aimed at:

- Identifying the hazardous substances
- Identifying possible accidents
- Estimating the frequency of each event
- Defining the causes for each event
- Estimating the frequencies of each scenario
- Assessing the magnitude of the consequences of each scenario

There are several methodologies for risk assessment. The most commonly used are two:

- Qualitative analysis (HAZard Operability Study)
- Quantitative analysis (CPQRA – Chemical Process Quantitative Risk Analysis)

Qualitative risk analysis

There are three main types:

- Preliminary Hazard Analysis (PHA), was developed according to military standards in this field, and can be applied in the preliminary project phases. It focuses on the main areas that might contain dangerous substances, and on the main installations, and monitors the possible failure points where dangerous substances or energies could be released.
- Hazard and Operability studies (HAZOP), is designed to identify safety and operability problems using a systematic and structured approach by a multidisciplinary team. Using brainstorming and certain keywords, deviations in the process from the normal functioning are identified, and their causes and consequences on the process, humans and environment are evaluated qualitatively. HAZOP is one of the most used methods in technological hazard evaluation.
- Failure Modes and Effects Analysis (FMEA) determines how the failures of certain components affect the optimum system performance. This ensures that proper safety measures are taken and safety systems are installed. The qualitative methods focuses mainly on identifying the possible hazards and express the level of risk as low-L, medium-M, high-H and extreme-E[24].

Quantitative analysis

The CPQRA is used to identify incident scenarios and evaluate their risk by defining the probability of failure, the various consequences and the potential impact of those consequences. It is an invaluable methodology of evaluation when qualitative analysis cannot provide adequate understanding and when more information is needed for risk management. This technique provides a means to evaluate acute hazards and alternative risk reduction strategies, and identify areas for cost-effective risk reduction. There are no simple answers when complex issues are concerned, but CPQRA2 offers a cogent, well-illustrated guide to applying these risk-analysis techniques, particularly to risk control studies[25].

Chapter 2

Classes of tailings danger in Armenia

As mentioned in the introductory chapter, man-made mineral wastes are usually classified in classes according to their danger. According to the legislation of the Republic of Armenia, wastes are classified into five classes of dangerous and hazardous waste. The classification is based on the duration of the exposure of these wastes on the environment, taking into account the harmful substances included in their composition[26].

The following clases of wastes are defined:

I. Extremely dangerous - environmental irretrievably broken system, without possible recovery. With extremely hazardous substances (beryllium, mercury, thallium, lead oxide, soluble salts of lead, tellurium, hydrogen fluoride, and others).

II. Highly dangerous - ecological system heavily broken. With a recovery period of at least 30 years after the complete removal of the pollutant source. Containing highly dangerous substances (cadmium, cobalt, molybdenum, arsenic, sodium, lead, selenium, antimony, cyanides and others).

III. Moderately hazardous - ecological system violation. With a recovery period of at least 10 years after the removal of the harmful waste from an existing source. With moderately hazardous substances (aluminium, barium, iron, manganese, copper, nickel, silver, phosphates, chromium, zinc).

IV. Low hazard - broken ecological system. Self-healing period of not less than 3 years. Containing low hazardous substances (sulphates, chlorides, simazine).

V. Practically non-hazardous - environmental system virtually broken[27].

In RA, most of the listed compounds can be found in metal ore deposits, and thus they should be classified as class II and III wastes. However, nowadays, most of the wastes are classified in class IV. The most dangerous tails are those of Ararat Gold Recovery Company (Class II), which involve the use of cyanide in the extraction process. The next most dangerous tails are those which contain lead-zinc, copper and copper-molybdenum (III class). For the exact definition of the class of waste, it is necessary to conduct relevant studies of each case. As a consequence of the misclassification currently done in RA, the State budget is losing the necessary environmental payments. As indicated in the report of the RA Control Chamber, a number of ministries - Nature Protection, Energy and Natural Resources, Emergency Situations- have not taken measures to define the proper class of hazardous waste accumulated in the tailings. The reports of tailings provided by mining enterprises to the Ministry of the Nature state that these wastes are non-hazardous, or that available tailings are not considered as waste, but as a man-made resource. Tailings, first of all, must be regarded as waste; only after technological tests on leaching ability and economic evaluations of the operations, a tailing can be qualified as a technogenic deposit. Besides clarifying size payments, identification of waste is of paramount importance for their recycling, since each type of waste needs a certain type of disposal. For example, the methods to recycle waste belonging to class IV are not suitable for waste class II. After its classification, a passport must be issued on wastes defining the limits for their disposal in the environment and selecting the most effective method for their recycling and disposal.

It must be noted that each man-made accumulation of material has its own structure and features, amounts of valuable components, or zoning, resulting from differences in company staff, feedstock production, processing and enrichment, and a number of other factors. Therefore, for an objective assessment of the material, a complex evaluation of each anthropogenic accumulation is needed. Furthermore, it is recommended to recycle the maximum possible amount of waste instead of dumping and accumulation in landfills. In a previously published paper, we presented the economic evaluation of the resource potential of man-made mineral wastes in RA and the feasibility of exploiting some of them[27]. In the following sections, a description and analysis of some of the most important tailings in Armenia is provided.

Chapter 3

Tailings in Armenia

There are more than 1 million tons of mining wastes in RA already, located in the tailing dams of more than 20 enrichment tailings. The total area occupied by mining factories accounts for 10000 hectares, 8000 of which comprise the exploited grounds and 1500 hectares correspond to the area underlying the tailing dams.

Our investigations have enabled us to edit and summarize the information (Table 2) about the enrichment tailing dams of the RA mining activities. The need for such a table is based on the lack of summarized information about the tailing dams and their cadastre, while there is an urgent need of this inventory from the legal point of view. Based on their structure, the tailing dams fall into the following classes: class 1 (over 100 million cubic meters), class 3 (10-100 million cubic meters), and class 5 (no more than 10 million cubic meters). These tailing dams are formed mainly in the canyons of mountain rivers, in areas characterized by complicated relief.

Table 2: Tailing dumps of the ore-dressing plant of metallic mineral deposits of RA and tail accumulated in them, as of 01.01.2014

N	Tailing dump	Location	Deposit	Status	Volume, million m^3	
					designed	current
1	Artsvanik	River Artsvanik	Kajaran (Cu, Mo)	active	310.0	270.0
2	Voghji	River Voghji, near Lernadzor	Kajaran (Cu, Mo)	closed in 1977	30.0	19.4
3	Pukhrut	Right-bank stream of RiverVoghji, near Pukhrut	Kajaran (Cu, Mo)	closed in 1969	6.0	3.2
4	Daradzor	Right-bank stream of River Voghji, near the ruins of Darazam	Kajaran (Cu, Mo)	closed in 1961	4.0	3.0
5	Geghanush	River Geghanush	Kapan, Shahumyan (Cu, Pb, Zn, Au)	active	11.3	5.8
6	Artsvanik's area	Tailing dump of Artsvanik, separate area	Kapan (Cu)	started in 2004 closed in2008	1.1	1.0
7	Agarak-1	First canyon of Agarak	Agarak (Cu, Mo)	active	9.1	1.0
8	Agarak-2	Second canyon of Agarak	Agarak (Cu, Mo)	active	17.9	7
9	Agarak-3	Third canyon of Agarak	Agarak (Cu, Mo)	active	40.9	38.6
10	Dastakert	River Ayriget	Dastakert (Cu, Mo)	closed in 1968	3.1	1.5
11	Terterasar	Near the deposit Terterasar	Terterasar (Au)	active	-	0.03
12	Hanqasar	Next to Hanqasar, on the River Geghi, nea Nor Astghaberd	Hanqasar (Cu, Mo)	active	2.5	0.04
13	Alaverdi	Next to Alaverdi town	Alaverdi (Cu)	closed	0.5	0.4
14	Akhtala-1	River Nahatak, near the settlement Mets Ayrum	Akhtala, Shamlugh (Cu, Pb, Zn)	active	3.2	1.1

Table 2 (continuation): Tailing dumps of the ore-dressing plant of metallic mineral deposits of RA and tail accumulated in them, as of 01.01.2014

N	Tailing dump	Location	Deposit	Status	Volume, million m^3	
					designed	current
15	Akhtala-2	Near Akhtala, on the River Nazik	Akhtala, Shamlugh (Cu, Pb, Zn)	closed in 1988	0.5	0.4
16	Akhtala-3	Near Pokr Ayrum	Akhtala, Shamlugh (Cu, Pb, Zn)	closed in 1989	0.4	0.3
17	Armanis	River Dzoraget	Armanis (Cu, Pb, Zn)	active	-	0.08
18	Mghart	Near the Mghart's deposit, Area 3	Mghart (Au)	active	0.1	0.08
19	Teghut	Teghut, canyon of Kharatanotc	Teghout (Cu, Mo)	active	180	-
20	Tukhmanuk	Near the village Melik, 2+1 area	Tukhmanuk (Au)	active	1.5	0.2
21	Ararat	Near the village Arazap Sotk	Meghradzor (Au)	active	20.0	12.5

As noted above, some tailings were closed without filling up to the end. One of the main reasons for this situation is that during the design, the amount of rainwater accumulation was not properly calculated and therefore the tailings were conserved before the end of their planned lifetime[28].

Most of these tailings are located in the region of Syuniq, followed by the region of Lori. Therefore, the following chapters will focus on these regions, and more precisely in the biggest mining operation in each of these regions: Geghanush in Syuniq and Teghut in Lori.

Chapter 4

Tailings of Syuniq and Lori

Two are the main regions in Armenia where mine tailings concentrate: Syuniq, in the SE of the country, and Lori, in the NE. Thus, the next chapters of this work concentrate in those regions, and especially in the biggest mine tailings there: Geghanush in Syuniq, and Teghut in Lori. The location of both tailings can be observed in Figure 3 These two tailings can be used as a model to describe the current problems, characteristics and possible improvements in the work processes of tailings in Armenia. For each tailing, a description of its design and operation, and solid phase and water chemical analysis are provided, as well as an analysis of the social implications for the human health of the neighbouring population.

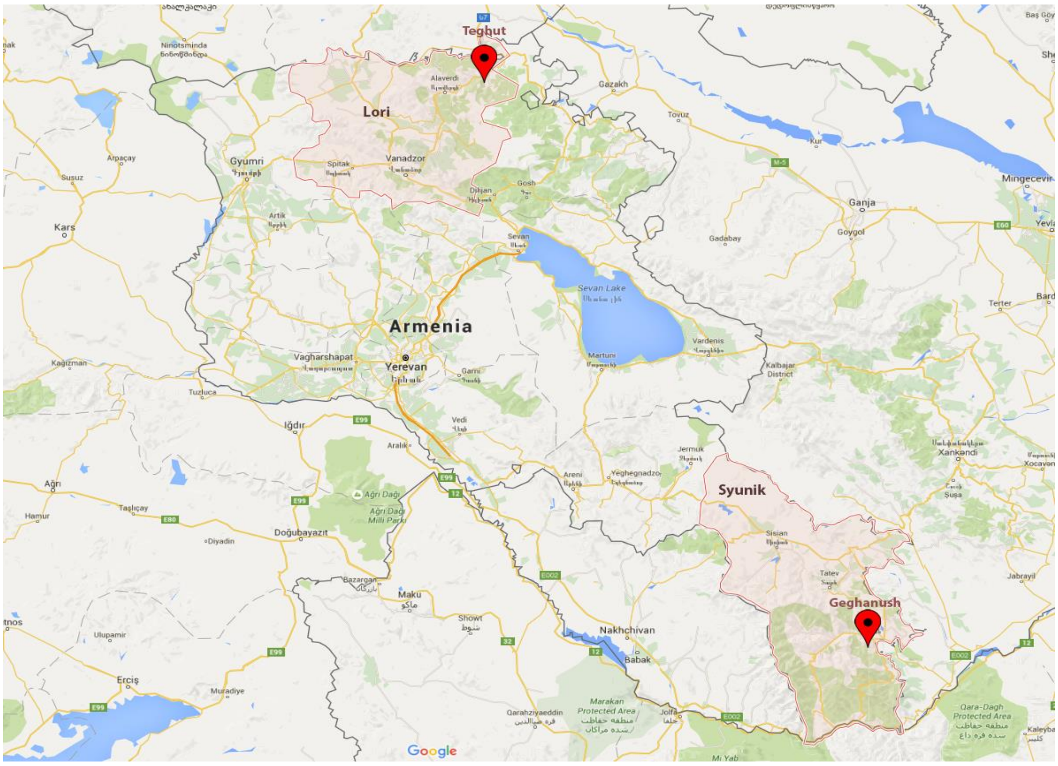

Figure 3. Location of the tailings Geghanush and Teghut in the regions of Syunik and Lori

4.1"DINO GOLD MINING COMPANY" CJSC activity OVERVIEW

4.1.1 Short description about company

"Dino Gold Mining Company" CJSC mining factory is located in the South-eastern part of the regional center of Kapan-Syunik provinces, in the midstream part of the Voghji river (left bank), 698 m above sea level[29]. This polymetallic mine began operating in 1863, and comprises the following units:

a) Main units:

- Shahumyan mine and Tejadin station
- Kapan enrichment plant

b) Auxiliary units:

- Mechanical workshop
- Foundry or casting station
- Vehicle production (assembly)
- Energy production
- Construction-repair workshop
- Compressed air plant (compressors, etc.)
- Chemical laboratory

4.1.1.1 Technological processes

The ore processing scheme begins with a two-phase crushing. The first phase is implemented in a big jugged grinder and the second in a conical grinder. Fragmented ore passes to the main unit bunker, with capacity for 2000 tons of material, using conveyors. After weighing, the ore from the bunker, with help of conveyors, move to the grinding phase 1. In this stage, the sand fraction of the material is sieved and directed to the second phase of processing, which is implemented by the pellet mill. At this stage, two hydrocyclones work in a closed cycle separating the sand part of the material and returning them to the sieving phase. Wastewater generated in this process is classified according to test specifications and is sent to the main copper and lead flotation units, where copper and lead concentrates, in one hand, and tails in the other hand, are separated. Then, the tails access to the basic Zn flotation unit, where minerals containing Zn are concentrated and receive a two-phase cleaning. The extract is condensed, and the intermediate products obtained during the cleaning process are returned to the previous operation. The primary Zn flotation tails pass the test flotation, and the flotation concentrate returns to the main Zn flotation while final tails are directed to the tailings dam.

The basic collective flotation concentrate of Cu-Pb is subjected to a five-step cleaning process, in which intermediate products are returned to the previous head cleaning step. After that, the cleaned Cu-Pb concentrate is dried at a temperature of 600-700º C, and then directed to selective flotation of Cu, where sodium dichromate is used for lead minerals deposition. This separation results in a Cu concentrate, in foam form, and a Pb concentrate in sediment form (flotation tails). The resulting concentrates are sent to the concentration and compaction workshop. Cu-concentrate wastewater is returned to the selective flotation process, and Pb-concentrate is previously cleaned from Cr, with iron vitriol, and then redirected to the flotation process. Thickener concentrates are compacted, and and finished Cu, Pb and Zn concentrates are packed, stored and sent to consumers.

4.1.1.2 Tails and Tailings

As a result of the processes occurring in the enrichment plant, tails are produced and directed to the tailings. Currently, all tails of this factory are moved to Geghanush tailing dump. The resulting tails are characterized by the following parameters[30]:

- Total production of solids: 568624.0 t/year.
- Solids real density: 3.2 t/m^3
- Consistence of sludge: 40%
- Sludge dumping rate: 220 m^3/hour

- Sludge bulk density: 1.22 t/m^3

- Tail bulk density: 1.6 t/m^3

The tails reach the pumping station by gravity, from where they are pumped to Geghanush tailings.

4.1.1.3 "Geghanush" Tailing

Short introduction

Geghanush dam was built in the Geghanush river gorge. It was designed by the "Mekhanobr" design institute (Leningrad), and was put into operation in 1962 and closed in 1983. In this year, a new project was developed by "HayGunMet project" Institute, which planned to raise the dam by 10 m and to provide space for an additional volume of 4.1 million m^3. The new tailings dam has a recirculation water system[31].

Figure 4. Aerial view of Geghanush tailing

After the privatization of the factories of Zangezur Copper-Molybdenum Combine and Kapan, separate tailings for both factories were demanded, in order to stop the movement of the Kapan mine tails to the tailing of Artsvanik. A decision was made to develop a project that would provide additional volume to Geghanush tailings. This decision had an environmental significance: using an existing dam decreased the affected land area, and rising its height allowed the water system would allow to operate through gravity.

Geghanush tailings area

Geghanush tailings dam (Figures 4 and 5) is located in the South of the Zangezur physiographic region, characterized by sharp mountainous relief. Morphologically, this region is situated in the offset of the Southern mountain range of Bargushat, and it is relatively low, with an altitude from 700 to 1250 m above the sea level[32]. The relief is mountainous. The dominant vegetation is represented by grasses and bushes. The river valley of the upper stream runs through a narrow gorge with steep slopes. The relief of the watershed shows a complicated drainage network, with many streams and gorges.

Figure 5. General view of Geghanush tailing

Description of the existing tailing

The former tailings dam was a river-type tailing situated in Geghanush river gorge. The former design had a capacity of 8.7 million m^3, and a dam with a height of 45 m. After the construction of the new one, the dimensions are: a volume of tailings of 4.6 million m^3; a height of dam of 28 m; an affected area of 32 hectares.

Description of the new project for the tailings

The dam axis of the new tailings is separated 185 m from the old one. The altitude from the top of the dam is 852-854 m above sea level, and the altitude from the outlet is 848.2 m above sea level. The outer face of the dam is covered with a 3-m thick (on average) waterproof clay layer.

The current thickness of the tailing dam wall is 2.5 m, which will be increased in 1.5 m in the future. Water intake wells made of steel pipes with 1120 mm diameter and 9 mm wall thickness are located along the collector in the floor of the tailings, and serve like and outlet for removal of clarified water from the tailings after sedimentation.

The last water intake well is considered permanently working; waters that will accumulate on the surface of the tailings (from the factory, rain or thaw) are removed through it. The old tailings, which were left on the base of the new one, serve as an anti-filtration layer and prevent the penetration of industrial wastewater into the groundwater. The infiltration waters accumulated in the space between old and new dams are removed through the collector left from the previous tailings and are directed towards the recirculating system.

Sludge filling technology

Tailing filling with sludge is performed along the whole protective dam. During the sludge filling, puree is thrown through a puree-way, which runs through the top of the dam, through outlets and semi-pipes. In the first sector, ridges are made with removed material, and puree is poured in a first layer. Meanwhile, the preparation of ridges along the whole dam continues. After the first sector is full, puree pouring is continued in the middle sectors, and finally in the last sector. When the first layer is completed, the puree supply is transported back to the beginning and the sludge filling of the second layer starts. The sludge filling of the other layers is performed similarly to the first one. The filling of the tailings is performed in two sides; in lower and in upper dams.

4.1.1.4 Building concerning to "Geghanush" tailings

Water removing tunnel

As Geghanush tailings is built in the gorge of a river, a tunnel to channel the river water bypassing the tailings is to be built. In the past, the flow of river waters through the tailings area was performed through two concrete pipes, which ran over the floor of the tailings. The construction of the tunnel started during the Soviet Union times, but it was stopped when the old tailings were closed.

The total length of the tunnel will be 1114.5 m, from which only 36 m at the entrance are left to finish the project. In addition, renovation works are being performed along 40.6 m inside the tunnel. In the tunnel exit, a 126.8 m fast-flow with right-angled profile will be built. The width of the tunnel is 4.6 m; its height, 4 m; the radius of the bow, 2.3 m; and the thickness of walls, 0.3 m. The surface of the cross section is 13.52 m^2; the maximal passability, 10.5 m/sec, in case of a flow velocity of 142 m^3/sec. The height from the mark of the entrance part is 793.65 m above sea level, and the height from the mark of the flow exit is 752.6 m above sea level.

Tail pipe

The tails of the enriching factory are directed towards the tailings through pipes. The tailing is formed using two steel pipes with 2.6 km total length, which have 325 mm diameter and 8 mm wall thickness each.

The tails formed in the enriching process are directed to the pumping station through a drift pipe with 480 m length. A pressure tail pipe 2.12 km in length runs from the pumping station toward the tailings. Anti-crash reverse valves are located in the pumping station and prevent the activity of the pump in case of crash in the tailing. An emergency pool is located in the pump station area, and, in case of damage of the tailing, the puree will accumulate in the pressure tailing. Besides, an emergency emptying pipe is planned to be constructed.

Circulating water system

Geghanush tailings wastewater recirculating system is made of electrically welded pipes with 325 mm diameter and 8 mm wall thickness, and is directed towards the enriching factory[33]. The total length of the system is 2.4 km. Transportation of the circulating water through the whole length of the gutter channel is performed by gravity. A part of the circulating water enters into the factory directly, and the surplus goes into a reservoir above the factory.

The amounts of circulating water that can run in the system are:

Daily………………………6912.0 m^3

Maximal hourly…...............288.0 m^3

Maximal flow………....80 L/s

4.1.2 The description of Zero, Alternative and main variants of the management system planned for tails

For the management plan of the tailing we have considered two variants: The "Without action" or zero variant and the implementation in the project of conclusions obtained from technical and economic research.

4.1.2.1 "Without action" variant

The "without action" variant includes the situations when the tail security system is not built. In this variant, in case of the collapse of the existing tailing, the surrounding soil, water bodies and nearby vegetation cover will be polluted, which, in turn , will damage the health and social conditions of the population. Given the observed risks in Geghanush tailings, this variant was not considered.

4.1.2.2 Suggested alternative variants

During the elaboration of the project, several options were considered to minimize the damage caused by a possible tailing collapse to the surrounding environment and health of the population. Those are:

Rill variant

Rills will be dig along the whole tailing, collecting the outflowing tails and directing to holes lined with concrete. From there, the material will be transported by special machines to the appropriate sector of the factory.

Piping variant

Concrete flow storage deposits (1.5 m wide each) and pools attached to the pipelines to prevent spillage in case of accident (3 m wide each) will be built at the hookup sectors (compensators) of the piping. Crash pools of large dimension will be located in the service zone of the flow-way of the tailing.

From the economical point of view, both variants do not differ much. However, the second variant prevents large-volume soil activities and doesn't need additional area for its implementation. Given this fact, the second variant was selected.

4.1.3 Analysis of Geghanush tailing

In Geghanush, most of the material removed in the mining operations ends up in the tailings. In fact, 96-97% of the total amounts of ore are dumped in the tailings. The volume of the solid mass is 25-30% of the total volume, diameter of the solid particle fraction >0.2 mm amounts for 15% of the total weight, the particles with size from 0.2 to 0.08 mm amount for 25%, and the particles <0.08 mm are the remaining 60% of the solid weight. Tails are not flammable, not explosive, not soluble and belong to the fourth group of danger. Some samples of the solids were taken from the tailing in 2013, and X-ray fluorescence analyses were performed to identify their chemical composition. Average results are presented in Table 3.

The liquid phase of the tail, which contains some soluble ions, is redirected to the factory after cleaning process. During exploitation of the tailings, wind erosion produces the mobilization of dust from the tailing walls. About 25.6 tonnes of solids, or 0.128 tons per day, are eroded by wind. In windy days, suspended particles around the tailing can exceed the MAC. In addition, water erosion by rain adds to the total amount of solids mobilized from the tailing.

Table 3. Average chemical composition of the solids of the tail.

Element	Amount
SiO_2	55-58%
Al_2O_3	12-14%
MgO	4-5%
K_2O	-
Na_2O	4-6%
TiO_2	0.5-1%
CaO	3-4%
MnO	0.1-0.12%
Fe	3-5%
Cu	0.03-0.05%
Pb	0.02%
Sb	0.006%
Zn	0.23%
As	0.07%
Au	0.25 g/t
Ag	3-6 g/t

Geghanush tailing was constructed in order to replace operations that were taking place in Artsvanik, when this tailing was completely exhausted. In 2005, the expected capacity of Artsvanik was reached, and a temporary tailing with a total capacity of 800,000 m^3 was established close to the former one before the construction of the new tailings in Geghanush. Then, the closure of Artsvanik began, with the idea of stopping the operations, ensuring its safety, restoring disturbed areas, and minimizing its harmful effects on the environment. Remediation work lasted 60 days. The first operations included the removal of 12,000 m^3 of water stored in the ponds directly in the river Voghji. Then, the tailings area was lined 28,700 m^3 of stones from the mine. Finally, the lined area was covered with a layer of soil 30 centimeters thick, for which it was necessary to use 17,500 m^3 of soil.

The reclamation of the tailings took into account some important considerations: a drainage channel was built on the slope of the reservoir, aiming to prevent runoff and melting water from reaching the pond. A collector was installed to remove the accumulated water from the tailings surface. The entire surface of the tailings had to be covered with a 30 cm thick layer of soil and revegetated with native plants.

4.1.3.1 Rivers water quality and wastewater composition

Allowed concentrations of pollutants in wastewater are determined by taking into account the river background composition, which can be measured upstream the wastewater discharge point. Potential pollution sources from "Dino Gold Mining Company" are not only a consequence of accumulation of tails in Geghanush tailing dump, but of all mining operations. For this reason, Voghji, Kavart, Achanan, and Geghanush rivers water and wastewater flowing into these rivers are being monitored every year since 2007. As a part of the monitoring program, heavy metals concentrations were measured in water samples using ICP-MS. Other parameters monitored included pH, electrical conductivity, dissolved oxygen, color, smell, BD and COD among others. The tests were performed in the Department of Environmental Protection of «Dino Gold Mining Company» CJSC. Tables 4 to 7 show average values of parameters both in the river water at sampling locations upstream of the discharge point, and mining wastewater being discharged to the river.

Table 4. Composition of Tejadins mine and Achanan river waters

Parameter	Content, mg/l, mgO_2/l		
	Mine waters	River Achanan	MAC
pH	7.1	8.5	6.5-8.5
Copper	1.7	Undetected	1
Zinc	30.5	0.004	1
Lead	0.001	0.001	0.03
Nickel	undetected	Undetected	0.1
Iron	1.5	0.027	0.3
Molybdenum	undetected	0.015	0.25
Cobalt	0.039	Undetected	0.1
Manganese	12.3	0.04	0.1
Cadmium	0.004	Undetected	0.001
Chromium (3+)	0.04	0.009	0.5
Chromium (6+)	undetected	Undetected	0.1
Calcium	310.6	43.6	-
Magnesium	203.1	27.1	-
Potassium	32.3	7.7	-
Sodium	58.5	18.0	200
Arsenic	undetected	0.002	0.05
Phosphate-ion	0.058	0.041	-
Hydrocarbon-Ion	61	249.7	-
Carbonate-ion	undetected	10	-
Sulfate-ion	1240	50.1	500
Chloride-ion	18.9	5.2	350
Nitrate-ion	3.4	6.4	45
Nitrite-ion	0.147	0.075	3.3
Suspended solids	50	204	68.25
Oil	0.4	Undetected	0.3
Hardness	32.2	4.4	-
BOD	18.1	23.1	≤ 30
COD	1.2	0.8	≤ 6

Table 5. Composition of Achanan river waters and N 2,5 mine waters

Parameter	Content, mg/l, mgO_2/l		
	Mine waters	Achanan river	MAC
pH	8.0	8.3	6.5-8.5
Copper	1.8	Undetected	1
Zinc	18.46	0.4	1
Lead	undetected	0.001	0.03
Nickel	undetected	0.001	0.1
Iron	1.02	0.06	0.3
Molybdenum	0.064	0.83	0.25
Cobalt	0.02	Undetected	0.1
Manganese	0.7	0.1	0.1
Cadmium	Undetected	Undetected	0.001
Chromium (3+)	0.02	0.012	0.5
Chromium (6+)	Undetected	Undetected	0.1
Calcium	124.9	42	-
Magnesium	83.7	25.9	-
Potassium	22.1	35.9	-
Sodium	38.4	56.9	200
Arsenic	0.007	0.015	0.05
Phosphate-ion	0.039	0.034	-
Hydrocarbon-Ion	194.3	156.9	-
Carbonate-ion	12.6	4.1	-
Sulfate-ion	619	296	500
Chloride-ion	14.6	10.9	350
Nitrate-ion	30	6.3	45
Nitrite-ion	0.14	0.484	3.3
Suspended solids	93	139	68.25
Oil	0.02	Undetected	0.3
Hardness	13.1	4.2	-
BOD	21.3	21.3	≤ 30
COD	1.8	0.8	≤ 6

In all locations, mine waters reaching the rivers show lower pH, and higher concentration of several metals, like Cu, Zn, Fe, Mn, and other ions like sulfate, probably as a result of the oxidations of ores containing metal-sulfures. It must be noted that, in Tejadins (Table 4) and N 2,5 mines (Table 5), pH of mine waters, as well as river ones, is neutral or basic, while usually non-ferrous metal mining results in mine waters with very low pH. Acid mine waters were observed in "Transporte" mine waters (Table 6) and N3 (Table 7).

Table 6. Composition of the new «Transporte» ore direction mining waters and waters of river Voghji

Parameter	Content, mg/l, mgO_2/l		
	Mine waters	River Voghji	MAC
pH	4.6	8.2	6.5-8.5
Copper	15.5	0.04	1
Zinc	9.7	0.06	1
Lead	0.003	0.001	0.03
Nickel	Undetected	Undetected	0.1
Iron	2.1	0.05	0.3
Molybdenum	Undetected	Undetected	0.25
Cobalt	0.09	Undetected	0.1
Manganese	4.2	0.047	0.1
Cadmium	0.001	Undetected	0.001
Chromium (3+)	0.029	0.009	0.5
Chromium (6+)	Undetected	Undetected	0.1
Calcium	196.8	44.6	-
Magnesium	115.5	27	-
Potassium	19.8	10.2	-
Sodium	30.3	11.1	200
Arsenic	Undetected	0.002	0.05
Phosphate-ion	0.006	0.307	-
Hydrocarbon-Ion	2.44	201.1	-
Carbonate-ion	Undetected	5.52	-
Sulfate-ion	850.4	72.7	500
Chloride-ion	11.8	6.59	350
Nitrate-ion	8.7	9.2	45
Nitrite-ion	0.033	0.48	3.3
Suspended solids	473	65	68.25
Oil	0.05	0.032	0.3
Hardness	19.5	4.4	-
BOD	18.7	25.5	≤ 30
COD	1.2	2.65	≤ 6

Table 7. Composition of Kavart-jur River waters and N 3 ore direction mine waters

Parameter	Content, mg/l, mgO_2/l		
	Mine waters	River Kavart-water	MAC
pH	4.9	6.9	6.5-8.5
copper	23.1	0.41	1
zinc	5.8	4.94	1
lead	Undetected	Undetected	0.03
nickel	Undetected	Undetected	0.1
iron	8.6	0.49	0.3
molybdenum	0.048	0.067	0.25
cobalt	0.12	0.007	0.1
manganese	5.2	2.1	0.1
cadmium	0.002	0.00067	0.001
Chromium (3+)	0.029	0.005	0.5
Chromium (6+)	Undetected	Undetected	0.1
calcium	196.2	127.6	-
magnesium	121.8	77.8	-
potassium	8.1	11.2	-
sodium	13.6	15.6	200
Arsenic	0.005	0.004	0.05
Phosphate-ion	0.017	0.18	-
Hydrocarbon-Ion	62.96	111	-
carbonate-ion	0.48	6	-
Sulfate-ion	1150	569	500
chloride-ion	8.9	11	350
Nitrate-ion	5.9	15.1	45
nitrite-ion	0.06	0.208	3.3
depends materials	127	99	68.25
oil	Undetected	0.9	0.3
Hardness	19.8	12.8	-
BOD	20.04	23.9	≤ 30
COD	2.5	1.2	≤ 6

4.1.3.2 Social analysis

In addition to the harm to the environment, tailings cause great damage to human health. There are several risks for human health associated to toxic waste in Geghanush tailings. One of them is the evaporation of hazardous toxic substances into the atmosphere from the open storage. A second one comes from the seismic vulnerability. Millions of tons of toxic waste are accumulated in the tailings[34]. These tailings are located in the vicinity of residential areas, near water sources and pastures. However, seismic risk has not been evaluated properly, despite the fact that the Caucasus and the Armenian Highland are areas of high seismic activity.

To make things worse, the low level of awareness of the local population, led to people to begin to cultivate surface tailings (especially with potatoes). It is a well known fact that heavy metals accumulate in plants and animals once they enter the trophic chain. Metals in the food, added to metals in dust transported by the wind end up in the human body, which gradually leads to severe health problems (bone deformation, various cancers and other incurable diseases)[35]. More evidences of pollution from metals were found as arsenic and other heavy metals in the hair of children living in the villages nearby the tailings and Lernadzor.

In Syunik, sometimes effluents from the tails flow into the river Achanan. These waters are used by the local population to irrigate cultivated plots. The agricultural products from this region are distributed throughout the territory of Armenia, which, in all lights, constitute a serious threat to human health.

Metals from tailings reaching the river waters are not only happening in Geghanush. Recently, "Ler-Ex" Ltd. production tails, from the copper-molybdenum ores of Hankasar, ended in Geghi river and polluted it. It should be noted that a study by “Environmental Impact Monitoring Centre" SNCO performed in December 2013, showed that the chemical environment in the mouth of the river Geghi was polluted with molybdenum and manganese, and thus the quality was defined as 3 points on a 5-point scale [36].

Medical studies have shown that in Meghri, young people up to 30 years have serious health problems. This is due to the impact of the mining industry and their toxic emissions, which damaged not only the nature around Meghri, but also an increasing number of diseases: lung disease, heart failure, blood pressure.

4.2 Teghut Copper-Molybdenum Combine

4.2.1 Tailings

4.2.1.1 Total information

Teghut copper-molybdenum mine is located in Tumanyan district of Lori Region, 29 km southwest from Alaverdi city. The mine nearby settlements are Teghut (4 km) and Shnogh (6 km) villages. The mine is located in area of Teghut village community.

The composition of tailings of Teghut Copper Molybdenum Combine consists of the following items: the tailings, tailings hydraulic transport, water pumping facilities and recycling water supply. Tailings were planned in the river Haratanots Gorge (Left tributary of the Shnogh river), at a distance of 3.5 km from the processing plant. The river valley is a narrow V-shaped gorge, almost entirely covered with deciduous forest (Figure 6).

Figure 6. Aerial view of Teghut tailings, adjacent structures and surrounding villages

4.2.1.2 Geotechnical conditions

Geotechnical and hydrogeological conditions of the territory, wich is located in the gorge of the river Haratanots, occupies an area about 110 hectares, are conditioned are characterized by a several factors, including physiographical, geostructural, geomorphological and antropogenic. The geological structure of the territory belongs to the Shnogh-Koghb massif unit[36]. In the tailings, the complex geological-lithological structure is defined as follows (top to bottom):

1. Topsoil with plant roots.

• Average bulk density = 1400 kg/m^3

• Group workability- II (paragraph 9B tabl.1-1 SNIP IV-2-82)

2. Lumps-detrital soil with sandy-loam texture (30%).

• Average bulk density = 2300 kg / m^3

• Group workability - Vr (paragraph 6d tabl.1-1 SNIP IV-2-82)

3. Boulder-pebble soil with varying grain size with sandy texture (up to 30%).

• Average bulk density = 1950 kg/m^3 - 30% γ = 2300 kg/m^3 - 70%.

• Group workability - III - 30%, Vr-70%

4. Diorite-porphyry, fractured, fragmented, dense.

• Average density = 2600 kg/m^3

• Group workability - VII (paragraph 19 tabl.1-1 SNIP IV-2-82)

5. Conglomerats, weakly fractured.

• Average density = 2600 kg/m^3

• Group workability - VI (paragraph 18b tabl.1-1 SNIP IV-2-82)

4.2.1.3 Tailings

The gorge of Haratanots River can accommodate the volume of 173.65 million m^3 of tailings. With this capacity, and for a factory processing capacity of 7.0 million tons per year, the operations of the factory are ensured for about 28 years. This duration would be reduced to 20 years if the production of the factory is increased to 10 million tons/year[37].

The tailings consist of the following facilities:

- Primary enclosing dam.
- Discharge structure (rainwater collector wells).

The slope of the beach, depending on the size fractions of tailings, ranges from 170 to 180%.

According to the nature of factory productivity (output tails), the degree of liability structures, and the alluvium height, date of exploitation and volume, the tailings belongs to Class II. In order to reduce the accumulation of non-aggregated material in the surface of the tailing, reclamation includes the deposition of a soil layer with a thickness of 30 cm, where grasses are planted (Figure 7). The area of recultivation includes the slopes of alluvial levees performed during operation, and the shore area[38].

Figure 7. General view of Teghut tailing

4.2.1.3.1 Primary enclosing dam

The primary enclosing dam is designed to create the necessary original volume for operations, which includes the sedimentation ponds for water clarification. The body of the dam was shaped using rock fragments. The upstream side of the dam, an impervious layer, was created on the slope with sand and sandy-gravelly soil. An access road runs along the ridge of the dam.

4.2.1.3.2 Discharge structure (collector with receiving waters wells)

In this tailing, we designed a discharge structure that was later constructed by the mining company in order to divert surface runoff from the adjacent areas out of the sedimentation pond were water from the tailing undergo a clarification process. The capacity of the reservoir wells and culverts were designed taking into account this diversion of surface water entering into the tailings pond, after calculating the water needed for the extraction and processing of ore at 15 million tons per year. The collector consists of a steel pipe DN 1000 mm in a reinforced concrete shell that runs along the perimeter of the sedimentation pond. This collector is reinforced with 13 wells, 20 m deep each, which serve as a buffer to control runoff peaks. When tailings are filling, the wells are closed. Downstream of the tailings reservoir, a pond was constructed to store water coming from the collector and water infiltrating from the primary dam. At the same time, this reservoir serves as a buffer for the pumping station used to recycle water. The water from the collector enters the primary dam downstream, where recycled water reaches the pumping station of the recirculation system.

4.2.1.4 In situ observation of the state of the tailings

The tailings dam is equipped with field monitoring equipment: piezometers for hydrological characterization, and controling signs (benchmarks) to determine the sediment depositio and the horizontal displacement of the dam. Sedimentation is determined by monitoring changes in the depression curve, turbidity of the water, and flow velocity and direction of the flow. The total number of piezometers is 50, located at depths of 15.0 and 30.0 m deep (25 piezometers for each depth), which are placed on the alignments through 70 m in the berm of the dam. The benchmarks are set near the piezometers, also in a number of 50.

4.2.2 Analysis of Teghut tailing

Teghut tailing consists of 2 parts: the first is a genuine tailing dump, where the mixture from the mine is emptied (stream 1) and undergoes sedimentation. After this process, the effluent is transferred to the second part, a pond where the water is cleaned by sedimentation (Stream 2) and is pumped back to the factory.

Water samples from the first and second ponds of the tailings were collected on February 2016. Each sample was split in two parts, and one of them was filtered through a 0.45μm filter. The retentate and filtrate obtained were analyzed along with the other part of the samples using ICP-MS. Results are presented in Table 8 for the first pond, Table 9 for the second pond, and Table 10 for the sediments retained in the filter. It must be noted that sedimentation and removal of suspended particles in the first pond reduces the levels of several metals, including Ag, Mo, Nb, Rb, Zn, Cu, Fe, Ca, K, Si, Cl.

Table 8: Concentration of several elements in the water collected from the first pond of the Teghut tailing (Stream 1)

Element	Concentration, ppb	Std.Error
Ba	<LOD*	218.632
Sb	<LOD	62.002
Sn	<LOD	64.834
Cd	34.289	17.805
Pd	17.528	10.674
Ag	79,304	16.844
Mo	61.688	35.327
Nb	1203.873	4.965
Zr	12.876	12.325
Sr	<LOD	25.672
Rb	641.833	4.905
Bi	26.517	15.162
As	24.342	24.005
Se	<LOD	25.261
Au	<LOD	33.695
Pb	<LOD	22.673
W	201.852	131.103
Zn	79.733	32.411
Cu	79.884	44.12
Ni	<LOD	87.706
Co	<LOD	120.597
Fe	2208.537	256.969
Mn	<LOD	200.6
Cr	<LOD	103.499
V	<LOD	122.384
Ti	<LOD	176.665
Ca	235397.172	3919.392
K	14980.718	489.775
Al	<LOD	1651.7
P	<LOD	5521.768
Si	8702.750	534.051
Cl	19085.695	304.394

*<LOD= below detection limit

Table 9: Concentration of several elements in the water collected from the second pond of the Teghut tailing (Stream 2)

Element	Concentration, ppb	Std.Error
Ba	<LOD*	153.291
Sb	<LOD	51.768
Sn	<LOD	42.046
Cd	<LOD	35.339
Pd	<LOD	17.701
Ag	<LOD	17.979
Mo	585.857	22.427
Nb	14.774	5.176
Zr	<LOD	16.792
Sr	838.346	32.181
Rb	14.970	4.244
Bi	<LOD	32.006
As	<LOD	15.5
Se	<LOD	28.171
Au	<LOD	29.984
Pb	<LOD	24.957
W	295.918	138.622
Zn	<LOD	45.364
Cu	<LOD	92.226
Ni	<LOD	86.177
Co	<LOD	95.784
Fe	<LOD	176.899
Mn	<LOD	220.968
Cr	<LOD	165.335
V	91.796	56.418
Ti	<LOD	230.280
Ca	371721.8	5556.849
K	9951.237	388.063
Al	<LOD	1814.552
P	<LOD	453.159
Si	6465.233	482.158
Cl	16767.1	249.843

*<LOD= below detection limit

Table 10. Sediment from stream 1

Element	Concentration, ppb	Std.Error
Ba	165.06	76.823
Sb	<LOD*	30.055
Sn	<LOD	28.762
Cd	<LOD	16.06
Pd	<LOD	7.650
Ag	<LOD	7.785
Mo	26.289	3.609
Nb	<LOD	3.683
Zr	64.801	5.329
Sr	263.562	9.212
Rb	13.636	2.253
Bi	<LOD	8.904
As	<LOD	6.769
Se	<LOD	4.142
Au	<LOD	13.274
Pb	<LOD	7.839
W	<LOD	91.57
Zn	26.089	15.799
Cu	862.764	56.961
Ni	<LOD	57.836
Co	<LOD	184.609
Fe	20821.3	441.656
Mn	<LOD	187.312
Cr	46.265	29.369
V	97.950	33.161
Ti	1897.329	73.485
Ca	6834.123	347.057
K	9205.72	268.349
Al	14512.4	701.197
P	416.569	148.656
Si	106325.1	1446.894
Cl	320.463	27.421

*<LOD= below detection limit

4.2.2.1 Social Analysis

Besides the destruction of ancient forest ecosystem, Teghout mine also caused other serious negative consequences, like the extreme deterioration of the Shnogh River water flowing in the areas adjacent to the mine[39].

The quality of the river water is steadily deteriorating in parallel with the mining activity from 2009-2015. As compared with 2009, the average concentrations of some elements (Mn, Ni, Cu, Zn, As, Se, Mo, Pb) have increased according to the hydrological seasons. As a consequence, the Shnogh River is classified as risk water body according to the EU Water Framework Directive.

There are sufficient grounds to suspect that the tails produced by the ore dressing plant flow directly into the river, whose water is used to irrigate orchards. River water is used for irrigation and as drinking water for domestic animals. Local farmers have reported health problems in livestock and decreasing quality in their crops[40].

Chapter 5

Last considerations about tailings in Armenia

The most significant enrichment tails not included in the previous chapters are the ones located in the tailings of Akhtala, Shamlugh and Alaverdi mines in the North of the country, the chemical wastes of the Alaverdi copper smelting factory, and the dumps of non-balance ores of the above mentioned[41]. It must be noted that some of these tailings still contain materials of commercial value. It was estimated that a ton of processed tails will provide an additional profit of USD 13-14. These calculations have taken into account the expenses of tail neutralization and re-cultivation, so the simultaneous extraction of rare and scattered metals and the removal of harmful elements of these wastes can be not only advisable but economically profitable[42]. The amounts and contents of metals in tailing dams can be classified as P1 class resources and not as industrial raw materials. Thus, further investigations on the composition and management of these wastes must be carried out.

We should also mention the most important question concerning the re-cultivation and conservation of tailings. Before obtaining the permission for mine exploitation, a project for the closing of a mine should be provided, including the financial guarantees of such a program and the payments for reclamation and re-cultivation of the exploitation once it is closed.

The greatest ecological consequences of mining activities arise at the end of the activities, during the closing of the mine. Disposal wastes, open mines, tailings and heap leaching platforms release highly toxic production sewage into the environment that can cause colossal harms. Mining companies should project and carry out reclamation measures together with mining activities in order to reduce the amount of wastes at early stages and avoid expensive cleaning operations after the closing of the mine. Currently, the tailings in the North of the country, as well as the tailing in Dastakert, are in very bad condition, as they were not re-cultivated at an earlier stage and continue degrading, causing a very harmful effect on the environment.

Mercury (Hg) contamination of environmental compartments has been a concern to lots of mining regions all around the World, and it is one of the most polluting elements resulting from mining activities. Presently, data on Armenia's pollution with Hg available in international and national references are scarce. Mercury pollution in Armenia's largest mining regions was inferred through generalization and overview of data obtained from complex investigations implemented at the Center for Ecological-Noosphere Studies NAS RA between 2005 and 2011[43]. The studies focused on Hg in surface and irrigation waters, atmospheric dust, soils, local farm produce and human bio-substrates. The data have indicated that, as a result of ore mining and processing, Hg is released, travels through air and water migration streams, and finally contributes to pollution of all environmental compartments. Especially hazardous are the operating and idle tailing repositories that have been involved in different ways in agricultural cycles. Due to its bioaccumulation properties, Hg enters the food chain and intensively accumulates in farm crops and fodder grasses, and consequently enters dairy products and poses a threat for population health. Mercury was detected in hair of children residing in the studied region.

Conclusions

The main tailing dams in Armenia pose an environmental problem, since the water streams in the catchments where the tailings are located show high concentrations of several heavy metals. At first glance, it seems that these problems are unsolvable. However, correction measures must be implemented in order to reduce the pollution. These include:

- To identify and evaluate all potential hazards associated with the tailings correctly.
- To extract all useful products from ore materials and leave as little waste as possible (nowadays, most of the tailings accumulated millions of tons of useful substances).
- To build stronger dikes that can withstand earthquakes.
- To calculate the amount of rainfall correctly, and to implement methods to prevent rain from entering the tailing, in order to fully exploit tailings volume.
- To give precise formulations of the wastes of mining factories and to define their classes according to the risk level. This must include the control of the compulsory process of waste passport determination and the cadastre of wastes, which will contribute to proper taxation.
- To define the list and allowed amounts of dangerous elements in soil, water and atmosphere, specifying the correct methods for their determination.
- To force the mining factories to evaluate all the possible catastrophes related to wastes and their hazards, to publish the composition of the waters emitted to the environment and the materials they contain, and to provide all the necessary information for their correct monitoring.
- To determine the engineering-geological and seismic demands of tailing construction and the monitoring program.
- To review the demands for re-cultivation and conservation of mines and their production wastes, controlling the fulfilment of these demands.

● To raise level of public awareness about the pollution stemming from mining activities.

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ANNEXES