Submarine Tailings in Chile

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In several countries, and especially in northern Chile, most mining operations and tailings disposal are carried out near the mine. However, the tailings disposal has turned out to have certain exceptions in managing waste from ores processing by froth flotation. Countries like Chile, Peru, Norway, Canada, the Philippines, Spain, and Indonesia have active or abandoned underwater tailings on the coasts and at the submarine level. The underwater tailings of Chañaral Bay, Chile, and Ite Bay, Peru, are examples of the lack of scientific studies that can damage the marine environment. Potential environmental disasters caused a change towards the surface disposal of the tailings. Nowadays, society's pressures on surface tailing dumps have driven research on sustainable mining waste discharge to the seabed.

Keywords: underwater tailing dumps ; environmental impact ; mining waste

1. Underwater Tailing Dumps in Chile

1.1. Chañaral Bay

Ramírez et al. carried out a study on heavy metals speciation in a large Chañaral Bay coastline area. Tests determined the large concentration of heavy metals such as Cu, Cd, Fe, Mn, Ni, Pb, Zn, and As in the Chañaral bay's beaches due to the tailings deposited by the El Salvador plant from Codelco [1]. In the last century, investigations were carried out on the marine environmental impact resulting from the disposal of copper mine tailings on the Atacama region's coasts. Approximately 130 million tons of tailings have been discharged on the shore of Chañaral bay. These discharges formed artificial beaches more than 7 km long. These underwater tailings deposits from the El Salvador copper mine have hindered port activities, seriously affecting marine ecosystems and social life in the Chañaral population [2].

In 1989, a claim by the population of Chañaral against Codelco forced the company to stop the tailings deposition in Chañaral Bay. Codelco had to build a surface tailings dump called Pampa. This dump is currently the facility for the discharge of residues from the El Salvador concentrator plant. At present, the tailings in Chañaral Bay are in the same conditions deposited in the past and are sources of heavy metal contamination for the environment.

1.2. Chapaco Bay (Huasco)

The small Chapaco bay (Huasco, Atacama Region) was a place for the disposal of mining tailings from the iron pelletizing process. The Pellet Plant residues from CAP mining company were discharged directly into the sea from June 1978 and continued for more than 18 years. Mining wastes were piped from the plant to the rocky intertidal zone of Chapaco Bay. The average rate of waste discharge was 118 t/h of clay and iron ore. The sea suffered continuous turbidity in the water. The subtidal zone caused continuous sedimentation by non-native material [3]. However, Stotz et al. 1994 did not give relevance to these marine tailings discharge's environmental impact. The authors explain that no active chemical reagents were added during the processing of the iron ore. Electromagnets' magnetic mineral was concentrated, which allowed the discharged material to be classified as "inert solid waste" [4].

In 2015, the Pellet plant presented an environmental impact study (EIS) to the Chilean environmental authority to update and improve their marine tailing dump. The project consisted of the construction and operation of an enhanced deep underwater tailings deposition system. The system was based on two big pipelines (twin pipes) that will alternately conduct the tailings. The new waste deposit was located approximately 6.6 km offshore and more than 200 m below sea level, southwest of Chapaco Bay [5]. The EIS presented by the Pellet Plant details the main physical and chemical characteristics of the tailings. The analyses show that this mining residue is geologically inert. The chemical composition of the solid and water phase of the tailings presents the same chemical characteristics that they had in the natural environment from which they were extracted. Thus, mining waste is below standards or within the reference criteria. Therefore, solids and water subjected to the pellet plant's grinding and concentration processes are not adverse to the environment. Eco-toxicological studies show that the material does not react or release substances that may be harmful to aquatic life under environmental conditions. Consequently, for the environmental studies of 2015, the tailings of the Pellet Plant are entirely assimilable for the concept of “geological origin material”. Therefore, they are classified as substances that can be dumped into the sea, with only a physical impact [4].

In 2019, the Chilean Environment Superintendence carried out a series of inspections of the Pellet Plant. Various breaches of the Environmental Qualification Resolutions that regulate this company were revealed. The audit focused on verifying compliance with obligations on aspects related to the management of atmospheric emissions, the impact on soil, the impact on renewable natural resources, and the effects on the marine environment. The latter having the most significant negative impact. The environmental authorities of Chile ordered the Pellets Plant to cease its tailings discharge operations in Chapaco Bay [6].

2. Mechanism and Stability of the Tailings Disposal System

The general concept of DSTP proposes that the tailings move by gravity through a pipeline from the plant to a mixing/deaeration tank, the tailings are mixed with seawater in a ratio of approximately 1:1.5 per cent. volume. The mixing tank is generally located on the same shoreline.

The difference in density between the tailings and seawater will be equalized by introducing seawater into the tank through a feed pipe. The seawater intake is usually carried out at depths of more than 60 m to ensure an adequate mixing density. After mixing, the diluted glue will flow through a subsea pipe with a density of approximately 1100 kg/m^3.

The depth of the tailings outlet must be appropriate to the local characteristics, but in most cases it is carried out at minimum depths of 30 m below the seabed. This is due to the fact that the exit point is below the deepest sunlight zone (euphotic zone), also the zone where currents driven by the coastal wind can occur. The angle of the submerged pipe, as well as the submarine slope, should be approximately 12° [7].

Because the mix of tailings and water deeper than 50 m is denser than seawater, after discharge, the tailings will flow down the sea slope. This great movement is called shale flow.

The tails will be deposited along the flow path. Eventually, a density equal to that of seawater is reached at the periphery of the density stream and some of the liquid fraction and some of the finer particles will escape at this point and create an underground plume in the water column. This occurs due to nonconformities of density in the water column.

The remaining solids in the shale flow, especially the coarse fraction, will continue to move down the slope. In the well (main deposition zone), a dilute plume with vertical expansion may occur, which is known as a nepheloid layer.

Eventually, the sediment escapes from the subsurface shadow and settles to the bottom of the ocean. The process of density flow and plume formation is consistent with the pattern that describes how sediments are transported from their terrifying origins [8].

Based on the above, the modulation of the performance of the tails is carried out based on the performance of the terrigenous sediments that flow from the estuary of the rivers to the deep ocean basins to maintain their stability in deep waters and to not achieve sedimentation of these fines that, with the nautical movement of the marine currents, reach the surface and consequently come into contact with living beings.

3. Impacts on the Ecosystem

The environmental impacts of subsea tailings disposal operations are described below. The need for environmental evaluation, the negative impact on flora and fauna, and the adversities that the social environment may suffer from these marine tailing dumps are highlighted.

3.1. Environmental Impact

As already mentioned, Chilean mining is concentrated in the north of the country. The associated environmental impacts of mining have a long history. Millions of tons of mine tailings have been disposed of in coastal basins and bays [9]. As more mines are exploited nearshore, the disposal of mine tailings on the ocean floor is increasingly likely.

Although the discharge of tailings to the sea occurs in a few countries (Chile, France, Greece, Indonesia, Norway, and Papua New Guinea), the marine environment’s impacts repeat specific patterns. The warming, acidification, and deoxygenation of the oceans are the main impacts on the ecosystem [10].

Climate Change, Acidification, and Deoxygenation of the Oceans

The environment of the oceans is changing rapidly. Marine ecosystems at the continental level are highly vulnerable to climate-related factors. Thus, changes such as warming, acidification, oxygen loss, and nutrients have been detected [9]. The effects are intense and cumulative with direct human action, such as oil extraction and spills, pollution, and eventual underwater mining [11]. On the other hand, mining tailings can alter the seafloor further, exacerbating climate-related disturbances to the oceans [12]. These cumulative effects are likely to become widespread, altering the properties of the habitat. Ecological functions (e.g., biodiversity, calcification by habitat-forming species such as cold-water corals) and ecosystem services (e.g., nutrient cycling, carbon adsorption, and fish production) will be irretrievably affected [13].

3.2. Flora

Flora and fauna, and the social environment, are affected by the mining tailings' contamination. The main flora of the marine environment is algae. Algae retain heavy metals, shorten their life cycle, and are food for living beings; they also cause serious disease. For many years, seaweed has served as plant food for humans thanks to its health benefits, providing high fiber, vitamins, minerals, and oligo-elements. Some minerals in the algae are Na, K, Ca, Mg, and P, and some oligo-elements are Fe, Cu, Zn, and Mn [14]. Marine algae are also used to manufacture pharmaceuticals, cosmeceuticals, nutraceuticals, biofuels, and cheap raw materials. Chile is the leading exporter of seaweed in Latin America. Thus, they have implemented new political measures and regulations to improve cultivation and to not affect fishers [15]. Chile is in the 12th place of the world aquaculture producers, contributing to salmon, trout, and seaweed production. The chemical composition of algae includes carbohydrates, proteins, and bioactive molecules. Algae biomass is an attractive resource, as it is used for alginate production and as a feeding medium for abalone mollusks. This type of flora is affected by the pollution caused by mining companies, affecting the aquaculture sector [16].

An example of environmental contamination by mining tailings occurred in the Valparaíso region (Chile). The accident was caused by the Andina mine (from Codelco). Approximately 50 cubic meters of tailings were dumped into the Blanco river in the Aconcagua Valley. Serious problems were caused in the population and the ecosystem by chemicals and a large amount of powdery solid material [17].

3.3. Fauna

Disposal of mining tailings to the sea becomes a significant environmental challenge for industries that choose to use this waste management method. Large volumes of potentially toxic waste must be managed appropriately [18]. On the other hand, heavy metals can become bioavailable, which leads to significant changes in the ecosystem, whether biotic or abiotic [19].

Two types of ecosystems can be affected by tailings' disposal in the sea, benthic and pelagic. The benthic is made up of organisms associated with the seabed. It encompasses the abyssal trenches from the intertidal region; this includes infauna, epifauna, coral reefs, and seagrasses. The pelagic ecosystem consists of all the organisms that inhabit the middle waters of the oceans and seas. The species in this area are fish, phytoplankton, zooplankton, and predators [20][21][22]. The disposal of tailings in the sea has a more significant impact on the benthic fauna because they directly contact the seabed. Mining waste will affect its surface (epifauna) or within the substrate (infauna). Infauna is at risk as they ingest sediment and process its organic content [23][24]. Benthic fauna can be affected in the following ways [25]:

- Suffocation due to tailings material moving downhill or in response to accumulated tailings falling.
- Increase in suspended sediment.
- Change in the habitat of the benthic ecosystem due to the presence of tailings.
- Exposure to heavy metal contaminants and reagents from previous processes.

On the other hand, pelagic organisms such as zooplankton (meroplankton, holoplankton) can carry out vertical migrations up and down the water column. Diel vertical migration (DVM) is massive migration to the surface that occurs throughout the day, representing the most massive documented migration in biomass [26][27]. These migrations generate patterns and ranges, which are essential to determine marine systems' structure and dynamics. The changes in the flow of organic matter between the bottom and the surface are essential for transporting carbon, other substances, and pollutants and the organisms that will later be consumed by humans [23][28].

The pelagic ecosystem is an essential food source due to the diversity of organisms that compose it, from phytoplankton and zooplankton to crustaceans, fish, and marine mammals. These organisms are found in the ocean's euphotic zone (sunlight arrives) and are a vital source of organic carbon for the seabed. Pelagic impacts generated by tailings disposal can indirectly affect benthic organisms, such as organic matter and food supply limitation. The risk of biological impacts depends on the levels of toxicity, turbidity, and sensitivity of the organisms. On the other hand, they could also bioaccumulate pollutants in organisms [4].

According to Compañía Minera del Pacífico (CAP), the Chapaco cove biotic environment comprises zooplankton but showed less seasonality and variability in location than phytoplankton. The data on ichthyoplankton's taxonomic composition showed no evidence that the larvae or eggs of the critical commercial species have been impacted by tailings discharge in the Chapaco cove [4]. The subtidal benthic fauna of the Chapaco cove is made up of small nematodes and polychaetes, physiologically adapted to low oxygen conditions. Abundance, biomass, richness, and diversity are lower near the current tailings discharge than most reference transects [1].

Mining tailings deposited on the intertidal coasts of northern Chile were found to reduce the number of sessile species drastically. The decrease in marine species is probably due to the tailings' mechanical effects [29]. The low concentration of dissolved oxygen of the Subsurface Current of Peru-Chile contributes to decreasing species, richness, and abundance [30].

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