NAMIBIA UNIVERSITY OF SCIENCE AND TECHNOLOGY

Review of Mine Water Management Practices in Namibia

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1.0 Introduction

Namibia is one of the driest countries in sub-Saharan Africa and most vulnerable to climate change (World Bank, 2021). This environmental reality dictates the need to improve water-use efficiency across all mining process components and underlies this study's purpose. Water is the second most important commodity in mining after orebody itself, and one of the most significant challenges the mining industry faces is water management. Water is a vital input for all mining operations, including closure—water is used for several functions in mining, such as processing, mineral conveyance, dust suppression, etc. Most of the mines in Namibia are located in water-stressed areas, and these are increasingly facing competition from different users, presenting challenges to the security of supply. The dependency and impact on a shared resource create material risk for the mining and metals sector that requires effective management. However, it is widely recognized that a holistic approach to water management is necessary to achieve resource sustainability and secure future access (ICMM, 2017).

According to the Namibia water statistics, the mining industry is the fourth highest water consumer after Irrigation, livestock, tourism, etc. Though other sectors consume more water, the primary concern with water used in mining is that, in most cases, it cannot be recycled for human consumption. The industry requires a large amount of fresh water for day-to-day operations; only a small part of the water is supplemented through recycling. The mining sector has felt water constraints acutely, to the point of building the first desalination plant by the Orano mine in the Erongo region. Nonetheless, Namibia is one of the countries that could face an especially significant increase in water stress by 2040 (Maddocks et al., 2015).

Therefore, the future of mining depend**s** on the sustainability of the earth's water resources, which are increasingly under pressure. Water scarcity is consequently a constraint for Namibian development. This means that businesses, farms, and communities in these countries may be more vulnerable to water scarcity than they are today, as shown in Figure 1. This study seeks to analyse the mining companies' water management strategies and benchmark these leading practices across the globe.

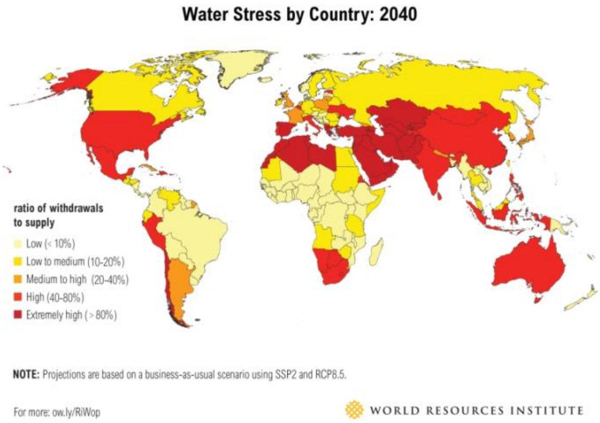

Figure 1. Water stress by country (Maddocks et al., 2015)

2.0 Mining Activities in Namibia

Mining has a long and complex history in Namibia. The earliest evidence of mining in the country is proven through archaeological evidence of copper smelting near the present-day Matchless Mine, which dates back to the 17th century (Schneider, 1998). Namibia's mineral industry is endowed with a wide variety of minerals, which can be grouped into six major groups: precious metals, nuclear fuel minerals, gemstones, base minerals, rare earths, ferroalloy minerals, and industrial minerals. The minerals industry continues to grow with significant exploration activities underway in battery minerals, notably lithium, graphite and cobalt, and rare earths. The country is among the world's top ten gem-quality diamond producers, conducting these mining operations on land and offshore. In addition, uranium oxide produced in the country is exported as "yellow cake." Namibia has significant uranium mines capable of providing 10% of the world's mining output and is currently the world's second-largest producer of uranium (World Nuclear Association, 2022). The country also produces various industrial minerals, including wollastonite, bentonite, graphite, limestone, and salt. Classification of the minerals produced in Namibia is presented in Table 1, and Figure 2 shows the location of mines in Namibia.

Table 1: Minerals produced in Namibia.

Mineral Classification	**Minerals or Metals**				
Precious and Semi-Precious Stones	Diamonds	Coloured Gemstones			
Nuclear Fuel Minerals	Uranium				
Base Metals	Copper	Zinc	Lead	Cobalt	Lithium
	Tin	Tantalum			
Precious Metals	Gold	Silver			
Steelmaking/Ferroalloy Metals	Iron	Manganese	Tungsten	Vanadium	
Rare Earth Elements	Dysprosium	Yttrium	Lanthanum	Cerium	Gadolinium
Industrial Minerals	Phosphates	Salt	Dimension stone	Limestone	Gypsum
	Graphite	Silica sand	Clay		

The Namibian mining industry strives to play an active role in sustainable development by implementing world-class environmental practices. Through implementing these practices, exploration and mining companies can maintain a good relationship with regulators, lawmakers, investors, and the communities in which they operate (NCE, 2019). In Namibia, this led to the industry and government working together to produce a Best Practice Guide for the Mining Sector in Namibia. Although the mining industry's overall' water footprint is relatively small compared to other sectors, most mining companies have recognized the importance of fresh water and the need to reduce the mining industry's water consumption. Mining is vital for the growth of the Namibian economy, and the country must therefore reconcile development objectives and mineral exploitation with environmental protection for its long-term socio-economic growth and stability.

Figure 2: Map of mines in Namibia (Chamber of Mines, 2022)

3. Legal Framework in Namibia

Namibia is one of the few countries incorporating environmental sustainability in her constitution. Article 95 emphasizes the importance of environmental protection by stating that Namibia shall actively promote and maintain the welfare of her people by adopting policies aimed at the maintenance of ecosystems, essential ecological processes, and biological diversity of Namibia and the utilization of living natural resources on a sustainable basis for the benefits of all Namibians (Constitution of Namibia, 1990). Water is increasingly recognized as a critical issue for sustainable development.

The Ministry of Environment and Tourism and Forestry (MEFT) was established in 1990 and is responsible for safeguarding Namibia's environmental resources. Since then, the MEFT has implemented far-reaching policy and legislative reforms in the environmental sphere in an attempt to alleviate many of the constraints that the environment places upon people and vice versa. Namibia's Policy for Prospecting and Mining in Protected Areas and National Monuments aims to promote sustainable development in Namibia by allowing prospecting and mining in protected areas with strict environmental management. The policy stipulates that any mining developments in a National Park must be balanced against the risk of negatively interfering with the potential for long-term sustainable growth.

The Namibian government has also implemented various policies and regulations to promote sustainable water use and conservation in the mining sector. For instance, the government has established a national water policy that outlines the principles and guidelines for managing and using water resources. The policy emphasises the need for sustainable use and management of water resources to ensure their long-term availability and the protection of the environment. In addition to these practices, the Namibian government has also implemented policies and regulations to ensure sustainable water use in the mining industry. For example, mining companies are required to obtain water use licenses and comply with strict water quality standards.

3.1 Water Quality Regulations

It is required that all mine water in Namibia is adequately monitored and analysed to ensure compliance with regulatory standards, according to the required industrial and domestic effluent discharge exemption permit under sections 21(5) and 22(2), and 110 of the Water Act (Act 54 of 1956) and Parts 11 – 13 of the Water Resources Management Act, No. 11 of 2013 (NCE, 2019). This Act provides for managing and conserving Namibia's water resources, including the whole or any part of a watercourse or aquifer, the sea, and meteoric water.

The Water Act, No. 54 of 1956, is the primary extant statute that most directly regulates groundwater abstraction for mining purposes. The Water Resources Management Act No. 11 of 2013 was enacted to ensure that the water resources of Namibia are managed, developed, used, conserved, and protected in a manner consistent with, or conducive to, the fundamental principles set out in the Act. The Act was passed and published but is not yet in force, providing more specific procedures for water abstraction permitting that are much more tailored to Namibia's climate and geohydrology than the Water Act of 1956. Once enacted, it will supplant the Water Act (IGF, 2018). Other laws also bear on the management of water resources. These include the Environmental Management Act, No. 7 of 2007; the Minerals Act, No. 33 of 1992; the Namibia Water Corporation Act, No. 12 of 1997; and the Traditional Authorities Act, No. 25 of 2000. For much of the country, the only water resource is groundwater, and these reserves are very fragile, and their scope and condition are little understood. Some critical points of Water Resources Management Act 2013 that are related to mining are

- A person may not cause or allow any groundwater to run to waste from a borehole, well, shaft, mine, or other excavation except when the water interferes or threatens to interfere with mining operations or the performance of any other underground work.

- Except under the authority of a groundwater disposal license issued by the Minister, a person may not abstract and dispose of groundwater from a mine or other excavation to facilitate mining or other underground operations.
- A lessor of land or premises where the lessee carries on any industrial, mining or other activity that may cause water pollution is responsible for remedying the effects of any pollution caused by such action if the lessee fails to remedy the effects of such pollution.
- To issue a license to discharge effluent or operate a wastewater treatment facility or a waste disposal site, Minister may also request the application of cleaner production techniques in industrial, agricultural, and mining activities designed to improve efficiency in the use of resources by reducing or preventing pollution and waste generation at the source thereof.
- Limitations or prohibitions may be imposed in respect of a water protection area related to operations for mining, dredging, or the reclamation of land.

The Environmental Management Act is in line with modern legislative trends, including adherence to the polluter pays principle, the inherent need to incorporate adequate provisions to achieve 'reduction-at-source' in the areas of pollution control and waste management, and the need to consider alternatives and to avoid or minimize adverse impacts wherever possible (IGF, 2018). Before a mine can commence with its activities, it must obtain a Record of Decision and a Letter of Authorization. However, the Letter of Authorization from the MEFT is not a blanket permission to implement the project. The applicant is still required to obtain a sectoral license or permit, depending on the nature of the envisaged project. Individual mines are responsible for managing their wastewater and industrial effluents and applying for exemption permits if required.

The Minerals (Prospecting and Mining) Act, 1992 (Act 33 of 1992) stipulates that it shall be a term and condition of any mineral license that the holder of a such mineral license shall: prepare in such form as may be determined by the Commissioner for the approval of the Commissioner: an environmental impact assessment indicating the extent of any pollution of the environment before any prospecting operations or mining operations are carried out and an estimate of any pollution, if any, likely to be caused by such prospecting operations or mining operations. If any pollution is expected to be generated, an environment management plan indicating the proposed steps to be taken to minimize or prevent to the satisfaction of the Commissioner any pollution of the environment in consequence of any prospecting operations or mining operations carried out under such mineral license (MME, 1992). The above clause is essential in preventing the pollution of water resources by the mining industry.

3.0 Global Mine Water Management Practices

Water is the second most important commodity in mining after orebody itself, and one of the greatest challenges facing by the mining industry is water management. A water balance model is commonly used to monitor and management of water in the industry. The mining environment is dynamic regarding the mineral type, the methods used to extract the mineral, processing methods used in mineral liberation, external conditions such as seasonal climatic variations, etc. Thus, it is impossible to develop one size fits all water management strategy for the mining industry, requiring a thorough understanding of existing conditions. According to Western Australian Water in mining guidelines (2013), the objective of a water management plan must

- Ensure all possible water sources are considered when planning water supply for mining operations.
- Ensure that fit-for-purpose water is used wherever possible and high-quality water is used only when it is essential or no other suitable water source is available and with the fewest adverse effects.
- Maximise water-use efficiency at all mine sites, particularly water-deficient sites, to reduce the need for water to be abstracted from the environment.
- Optimise the use of mine dewatering surplus, either onsite or off-site, to maximise efficiency and reduce adverse effects of releases to the environment.
- Minimise the adverse effects of the abstraction and release of water on environmental, social, and cultural values.

- Ensure mining activity does not adversely affect the quality and quantity of public-and-private drinking water supplies.
- Adopt a consistent approach for reporting water use, which links to the national water accounting framework and enables sharing of water information.
- Ensure the cumulative effects of mining operations are considered and managed.
  Distinguish between mining activities that relate to consumptive uses (e.g., ore processing) or non-consumptive purposes (e.g., dewatering and surplus water disposal requirements)
- ensure water management planning includes consideration of mine voids after mining operations cease
- Use a monitoring and evaluation process to adaptively manage the effects of abstractions and releases on the water resources.
- Maximise cooperation in water management activities between nearby water users to reduce impacts on the environment.
- Develop and maintain positive relationships between stakeholders so they share the information needed to manage water resources properly.
- Plan for, and manage, the effects of climate variability and change.

Reducing freshwater resources globally puts a lot of pressure on industries to conserve water resources and avoid water contamination. Several methods and technologies were developed in mining to save water resources in compliance with environmental norms. Some of these approaches are reducing the volume of water required for mining operations, using lower quality, alternative water sources such as seawater when possible, treating mining water for reuse and protecting the quality of water discharged after use. Some of these practices are discussed in sections 3.1 to 3.4.

3.1 Multi-stakeholder Engagement

Public participation has become an indispensable condition in water management; several legislations and policies support the involvement of less vocal, marginalized, and local communities at all levels of water management. Solutions generated locally with stakeholders are more likely to lead to appropriate actions, promote flexible and adaptive working practices, and foster and strengthen the development capacity of local organizations and communities. Water resource in a mining area is shared between communities living in the area and the mining operations. Thus, the roles and responsibilities in water provision, maintenance of infrastructure, and water quality monitoring should be shared between the mining industry, government, other private organisations, and local communities. Moreover, stakeholder involvement in water management can help to define long-term solutions to water management situations. Tools for effective and transparent data communication include staging online forums, including third parties or community members in all phases of monitoring, and providing data in an accessible and unbiased manner.

3.2 Fit-for-Purpose Water Treatment

In the mining industry, water is used for several purposes, such as mineral processing, including comminution practices, classification by screening and hydrocyclones, dust suppression, slurry transport, and drinking, among others. Water reuse is an option to increase the water supply and decrease the dependence on freshwater supply. Globally, 7000 Mm^3/year of reclaimed water was used after treatment in 2011, comprising 0.59% of total water use (EU, 2016). Non-potable reuse is common, although potable reuse has been practiced in Namibia since 1968 and in Singapore in 2002 (Asano et al., 2007). Water is reused in agriculture (32%), landscape irrigation (20%), industrial uses (19%), urban uses (8%), environmental enhancement (8%), recreational uses (7%), groundwater recharge (2%), indirect potable use (2%), and others (2%) (EU, 2016, Lautze et al., 2014). For example, mines use poorer-quality water in areas that aren't impacted by water quality and save better-quality water for sensitive areas. The water quality required for each activity may differ; thus, mines must select a need-appropriate water treatment technology that meets their project-specific needs. This not only conserves water resources through recycling but also energy. For example, water quality for dust suppression may not be as good as drinking water.

3.3 External Water Contamination Control

Mining exposes a lot of water rock; when fresh external water, such as rainwater and snowmelt runoff, comes in contact with the waste rock can produce acid mine drainage. Rainwater and surface drainage from the mine site will continue carrying acid away and depositing it in nearby water sources, including groundwater, lakes, rivers, and streams. This severely degraded the water quality, killing off aquatic life and making the water unusable. Thus, reducing the potential for external water contamination needs to be top of the agenda for mining corporations. Not only does this positively impact the surrounding environment, but it will also drive significant cost savings when minimizing the volume of water requiring treatment. Water quality control options can consist of methods to limit reactions between water and mine wastes and manage the flow of potentially impacted waters. Surface water runoff needs to be prevented from entering the mine site - this can be achieved by building upstream dams to reduce the potential for water contamination from exposed ore and waste rock. Other methods include locating mine wastes in areas with limited usable water resources, isolating mine wastes from the environment through the use of liners and caps, and subaqueous disposal of tailings and other mined materials, which uses overlying water to limit the amount of oxygen that can react with the materials. Water flow management on a mine site can include leachate collection systems, diversion features for run-on and runoff water, and tunnels and cut-offs (e.g., grout curtains or bulkheads) for water within underground workings. Further, capturing drainage water from precipitation at the mine site through liners and pipes and directing the water to tailings dams to prevent potentially contaminated water from entering groundwater or flowing off-site will help with water management. To reduce the volume of contaminated water, in dry regions, enough water may be evaporated so that no water needs to be discharged, resulting in the containment of contaminates at the mine site (SME, 2022).

3.4 Water Management in a Tailings Facility

In the past few years, several tailings dam failure incidents have been reported around the world. The release of large quantities of processing waste and water had catastrophic impacts on the surrounding community and environment, and the costs and clean-up work for the operating company are severe. Thus, the effective management of mine-affected water in tailings dams represents a significant safety, environmental and commercial priority for mining operators with these important facilities designed to store wastewater, a byproduct of the mining beneficiation process. The methods outlined in sections 3.4.1 to 3.4.2 are practiced internationally for tailing dam water management.

3.4.1 Water Evaporation System

The safety, environmental, and commercial risks of tailings dams can be mitigated by implementing a water evaporation system designed to remove excess water, reduce dam water levels and ensure compliance with global standards.

3.4.2 Water Recovery from Tailings

Filtered dry stacked tailings is one technique used to recover water from the tailings. This technique produces an unsaturated cake that allows storage of this material without the need to manage large slurry tailings ponds, as shown in Figure 3. Pressure or vacuum force is used to recover water. The most common filtration plant configurations are drums, horizontally or vertically stacked plates, and horizontal belts. The application of this technology has many advantages, including increased water recovery from tailings, reduced Tailing Storage Facility (TSF) footprint (impacted areas), decreased physical instability risk, and better community perception. This technology can recover 80-90% of the water from the tailings,

Dewatering technologies can reduce tailings volume by an additional 5-10%, but more importantly, sufficient water is removed, creating a dry, stackable material, as shown in Figure 4. Dewatered tailings can still contain 10-20% moisture, but the material behaves more like a solid, making it possible to dry stack the tailings in containment areas. After being placed in the containment areas, the low-moisture tailings are stable, significantly reducing safety and environmental risks.

Figure 3: Dewatered cakes (tailings) discharge from a Filter Press into a pile (Zink, 2020)

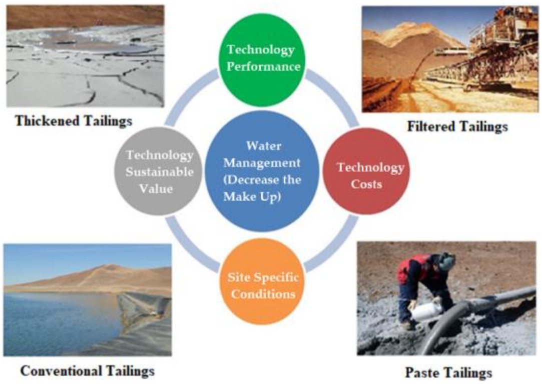

Figure 4: Water recovery from tailings (Cacciuttolo, 2022)

4.0 Namibia Water Practices in the Mines

Over the last few years, the mines have applied several different water management strategies which are aimed at reducing their freshwater intake, reducing the volumes of effluent discharged to the environment, minimizing the deterioration in water quality in the mine circuits, and treating the water to the required level for reuse or discharge (Musiyarira et al., 2017) Namibia's industrial leaders have increasingly recognised that reducing the water footprint of mining activities must be one of the key performance indicators for management. Realizing that the water life cycle challenges cannot be solved by any one party acting alone has been fundamental in ensuring environmental compliance within the mining industry in Namibia.

The ICMM (2014) report on catchment management strategies reveals that historically mining has approached water as an operational issue, managed inside a fence with a focus on water efficiencies and control of effluent discharges to demonstrate good corporate practices and minimize risk. One of the central tenets of the ICMM Water stewardship framework is the need for the industry to move from managing water as solely an 'inside the operational fence' issue to adopting a catchment-based approach that considers other users. Impacts of sub-standard water management may not only be felt at a local level but may escalate rapidly to become national and international issues, consuming large resources. Namibia has water availability challenges, so water management remains a critical issue. Most mining companies in Namibia have been developing a vision of water stewardship, which includes a broader concept of catchment water management as opposed to the individualistic water management approaches of the past.

4.1 Water Consumption Patterns in Namibian Mines

Water consumption patterns in Namibian mines vary depending on the type of mineral being extracted, the location of the mine, and the water management practices in place. However, some general trends in water consumption can be observed. According to Namibia's Ministry of Agriculture, Water, and Land Reform, mining consumes around 5-6% of the country's total water resources. This is significant, considering Namibia is a semi-arid country with limited water resources. To address the high water consumption in mining operations, Namibian mines have implemented various water management practices, such as water conservation and reuse, desalination, groundwater management, water quality management, monitoring, and control, among others. These practices aim to reduce water consumption and promote sustainable use of water resources in the mining sector. Overall, while the mining sector in Namibia is a significant water user, implementing effective water management practices has helped mitigate the impact of mining operations on water resources in the country. Figure 5 shows the philosophy that informs water management practices in Namibian mines.

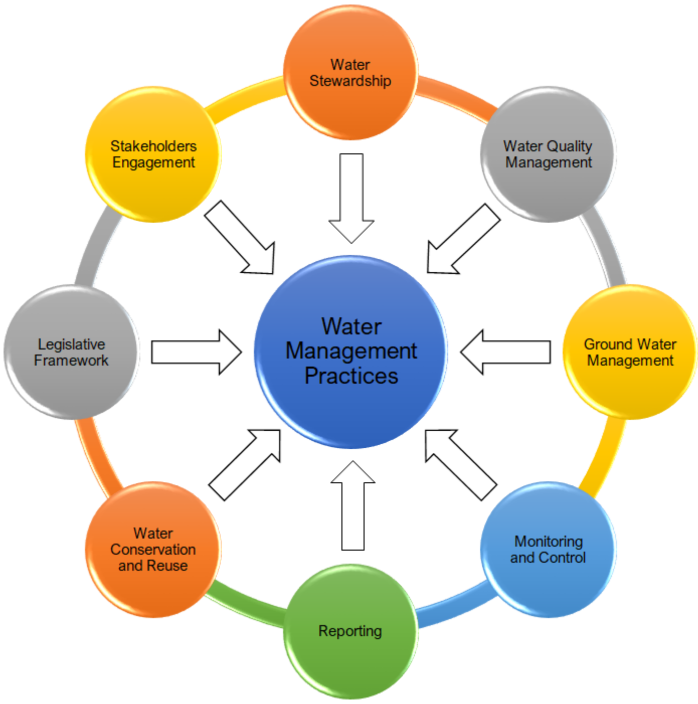

Figure 5: Water management practices used in Namibia.

4.2 Water Conservation and Reuse

Mines use water-efficient technologies, such as closed-loop systems and water recycling, to reduce water consumption and minimize water wastage. The water reuse and recycling rate in ore processing is often very high at mine sites, especially in areas with arid climates (Rankin 2011). Several innovative water conservation practices are being developed and implemented to reduce water use. Recognizing and adopting best practice principles are considered fundamental cornerstones of sustainable development for the Namibian mining industry. Best practices are the development of operation-specific methodologies that integrate global and local knowledge. This enables planning to produce the best available and most practicable methods to address an operation's site-specific requirements and conditions. Best practices, by nature, are not static but continuously evolving in response to new technology, increased understanding and awareness of environmental and social impacts, and increasing regulatory requirements and public expectations.

An excellent example of water conservation, recycling, and reuse was Skorpion Zinc. The mine was committed to minimising water use and recycling water, with the ultimate goal of a Zero Discharge Philosophy. Skorpion Zinc refinery had a closed loop system, with all water recycled back into the system. In line with Skorpion Zinc's Water Management Policy and the drive to conduct business responsibly, Skorpion Zinc assessed its challenges with solution balance in the refinery. A careful review of the Solution Balance was undertaken, and corrective actions were implemented to reduce the water consumption to levels below design capacity. In addition, domestic effluent was treated and recycled into an artificial wetland (Bird Pond) to divert birds away from its processes. Different water conservation projects were identified through reduction, recycling, and progress monitoring against water consumption reduction targets. Although Skorpion has attained significant success concerning water management, the mine continued to explore other avenues for further water reduction before it went on care and maintenance (NCE, 2019).

4.3 Rossing Uranium Water Management Strategies and Recycling

The Management of water at Rossing falls under the Environmental and Water Division. Rossing has been monitoring and managing the water resources system in conjunction with the Tailings Storage Facility (TSF) management. Figure 6 outlines the TSF with embarkments and the water and seepage control points around the mine. The mine has been recycling some of the water from the TSF back to the plant for other non-essential applications not associated with uranium extraction. This has led them to reduce water consumption significantly. The Tailings Storage Facility (TSF) management heavily depends on how water is used at the plant and the recycling at the TSF (Figure 7). It is essential that the net water balance that leaches out is of sufficiently neutral pH (pH7.0-8.0) to be within the Ministry of Environment and Tourism regulations on Environmental management and the discharge of water to natural water courses such as the Khan River, where Olive and vegetable farmers abstract water downstream of Rossing mine (Rossing,2021). To achieve this, Rossing Uranium Limited recycles water that leaches out of the TSF into the groundwater drainages and monitors its pH as it moves towards the Khan River.

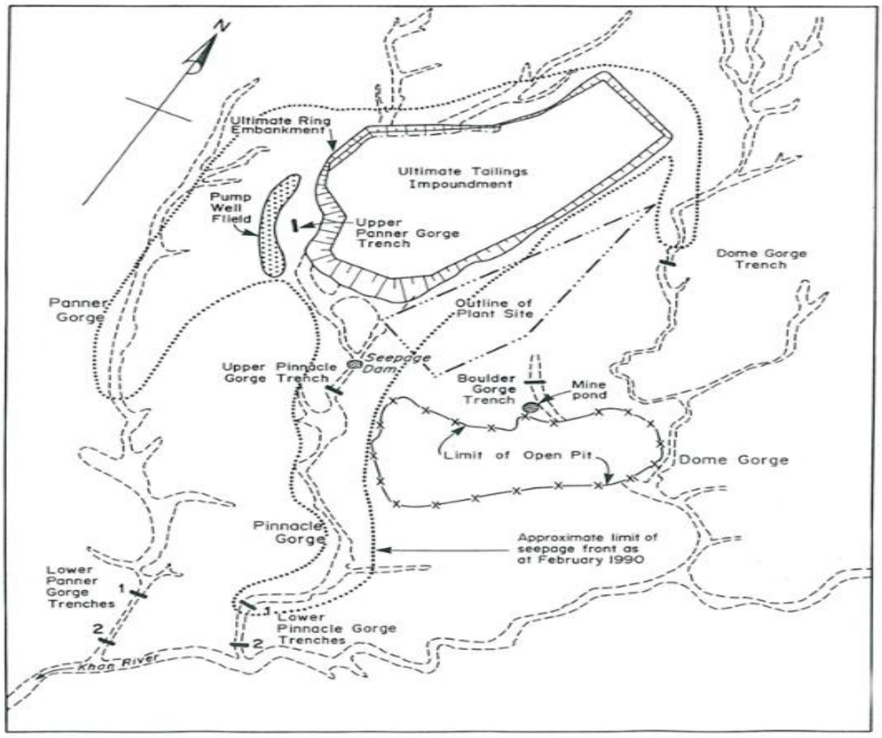

Figure 6: An outline of the Rossing Mine with water control points for seepage monitoring.

Figure 8 shows a statistical bar chart of planned water use, actual water used at the mine, and the amount of fresh use at the mine over the years 1994-2021 as a percentage of every tonne of U_3O_8 produced, the years 1997-1998 had the highest water usage. The amount has significantly reduced at present. The TSF receives 21,519 cubic metres of water per day from the Processing plant, and 12,805 cubic metres per day are recycled from the TSF to the plant as of 2021 (Figure 7). The net change in storage of 485 cubic metres per day is lost as leachate into the groundwater and evapotranspiration. This is the water that needs to be addressed as it percolates into the groundwater on its way to the Khan River.

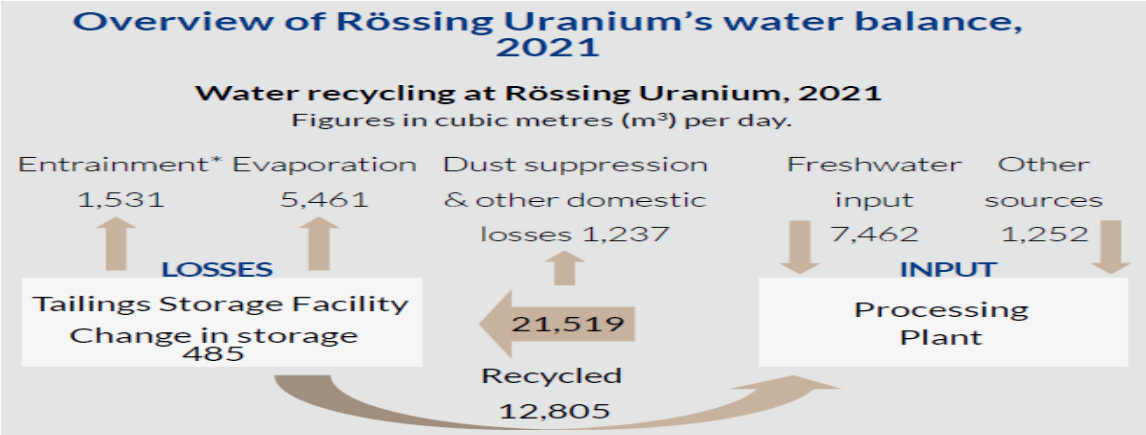

Figure 7: Monthly Water recycling at Rossing Uranium in 2021; Souce: (Rossing, 2021)

Literature studies show that freshwater consumption was reduced over the past three decades from an average high of 0.65 m^3 to an average low of 0.33 m^3 per tonne of uranium ore milled, as shown in Figure 8. This freshwater reduction resulted in substantial financial savings and delayed water augmentation through desalination (Musiyarira et al., 2017). Therefore, water segregation plays a crucial role in the water management strategies the mines advocate, leading to decreased freshwater consumption per tonne of milled ore.

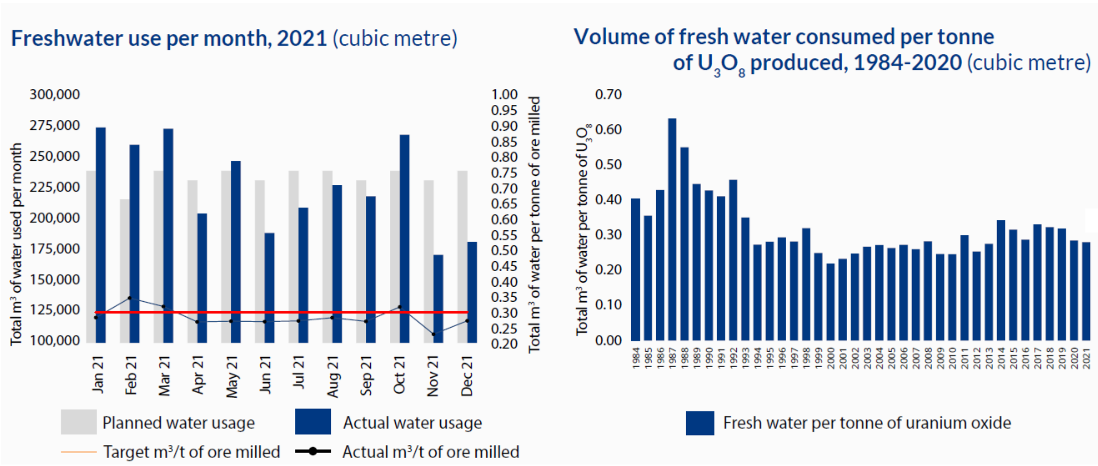

Figure 8: Freshwater use per month in 2021 on the left and right, the volume of freshwater consumed per ton of U_3O_8. produced (1984-2020).

Figure 9 is a schematic diagram showing Rossing's conceptual water management model.

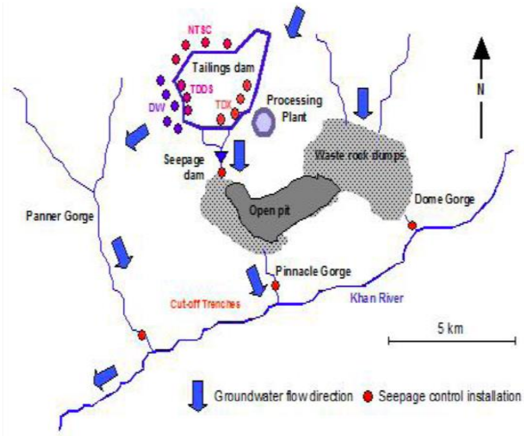

Figure 9: Groundwater flow direction from the TSF of Rossing Uranium Limited, Source (Rossing, 2021)

The TSF, control boreholes are installed, where if the pH is too low, the water is pumped back to the plant for re-use. The water in the pit is also systematically dewatered and recycled for other purposes, such as dust control and washing of plant floors.

At Rossing mine, all spillages in the Processing Plant are captured and channeled to a large recycle sump for reuse. In addition, effluents from the workshops are treated to remove oils, and sewage is processed in the onsite sewage plant. These semi-purified effluents are used in the open pit for dust suppression.

At the deposition pool (active paddy) of the TSF, water is recycled and reused continuously in the Processing Plant, minimising surface evaporation and infiltration into the tailings pile. Water that infiltrates the TSF is recovered by pumping boreholes and open trenches installed on the facility to reduce the underground water volume within the tailings pile (Rossing, 2021).

4.4 Water Demand and Security

According to the World Bank, water demand is determined by four major driving forces, population, technology, trade, and the environment. The past two decades have seen increased population, building activities, the establishment of numerous industries, and new uranium mines in the Erongo region in Namibia. All this resulted in a steep water demand growth to the extent that it almost exceeded the available resources. This led Orano, formerly Areva Namibia Uranium Company, to build its desalination plant with a 20 million cubic meters capacity per annum. Of late, there has been a growing outcry from mining companies in the Erongo region to set up their desalination plants to secure water supply for their operations. Rossing and Husab Mines have engaged the government with proposals for setting up the plants. The born of contention has been on who will own the rights to the water and what would happen to the desalination plant when the mine closes prematurely or after the life of mine. These discussions are ongoing; they will have to agree sooner or later since they must reconcile development and water security. The case study in section 4.5 shows how water security is becoming a risk to operations in the gold sector in Karibib.

4.5 Water Security Issues and Recycling at Navachab Mine

Navachab mine is one of the primary consumers of water sourced from the Swakoppoort Dam by NamWater. NamWater uses the same pipelines to supply Karibib Town Council and Otjimbingwe village. NamWater pumps the raw water to the Karibib Water Treatment Plant, where the water is treated and distributed to the three entities: Navachab Mine, Karibib Town Council, and Otjimbingwe Village settlement. From Swakoppoort Dam, the water is pumped to the Ongava Reservoir, which feeds the Navachab Mine and Karibib Town Council.

The storage facilities consist of the following reservoirs:

- The Okongava reservoir is a PVC-lined, open earth bank reservoir with a capacity of 15 000 m^3. The reservoir is divided into two compartments, each with a capacity of approximately 7 500 m^3. The full supply level is at 1 289.43 mAMSL, and the lowest abstraction level is at 1 286.36 mAMSL. From these reservoirs, the water is gravity fed to Karibib and Navachab Mine. The inlet structure and split between the two reservoirs is outside the fenced area.

Okongava-Karibib/Navachab Scheme storage facilities consist of the following:

- The 500 m^3 concrete raw water reservoir at the Navachab Mine, is located on a hill at the eastern side of the mine premises. The concrete reservoir is cylindrical and is covered with a corrugated IBR roof and steel support structure. Inlet and outlet pipes to the reservoir are constructed above ground and appear to be in reasonable condition. Although Navachab Mine owns the reservoir and is not the responsibility of NamWater, it can be reported that the concrete appears to be in good condition, and no leaks were visible on the joints in the walls.

- The Karibib terminal reservoir is a 1 250 m^3 potable water reservoir located downstream of the Treatment Plant and used to store treated water for Karibib town. The reservoir is close to the treatment works and situated at the highest point in town. Treated water is pumped by means of the Clearwater Pumps to the reservoir inlet pipes, which pass through the base of the reservoir walls. The outlet pipes are below ground and discharge into the town's water reticulation. The inlet and outlet pipes and fittings appear in a reasonable condition where visible above ground and the manholes.

The Karibib Town Council, where research on water losses is almost complete, shows that the LA receives 34,000 m^3 of water from NamWater per month, and only 25,500 m^3 is accounted for in the supply system. This is a 25% water loss of 8,500 m^3 per month; per year, it amounts to 102,000 m^3 of lost water. Hence the dire need to have below-ground detection mechanisms such as magnetometers and acoustic technologies. As a result of the large quantities of water lost, a plan to reuse wastewater at Karibib has been suggested. The coming on board of a new mine between Omaruru and Karibib, Osino Twin Hills Mine, will put further pressure on freshwater resources, such that the optimisation of wastewater reuse will go a long way to reducing the water deficit. For Osino, NamWater cannot currently supply all the fresh water they require, and that will put constraints on the re-opening of the mine. Current estimates are that Osino Mine requires between 250 m^3/day to 300 m^3/day. This amount can be realised from the water reuse of the Wastewater Treatment at Karibib Town Council (KTC).

In a properly studied concept of using wastewater-treated water (Figure 10 and Figure 11) and slowly increasing this capacity over time, with minimal investments, Osino can have adequate water for most services at the mine and augment its water budget from groundwater boreholes near the Twin Hills property.

In the Erongo Region, due to a high concentration of mines and limited water resources, it can be shown that there is a need to persuade the Local Authorities (Town Councils) to adopt the idea of water recycling and selling or availing of recycled treated water to neighbouring mines such as Navachab, Rossing, Husab, Langer Heinrich and the soon to open in 2025-2026 Osino Gold Twin Hills Mine. Instead of using fresh water for most purposes, e.g., dust control, equipment cleaning; non-plant services; recycled water from the wastewater treatment plants can be used.

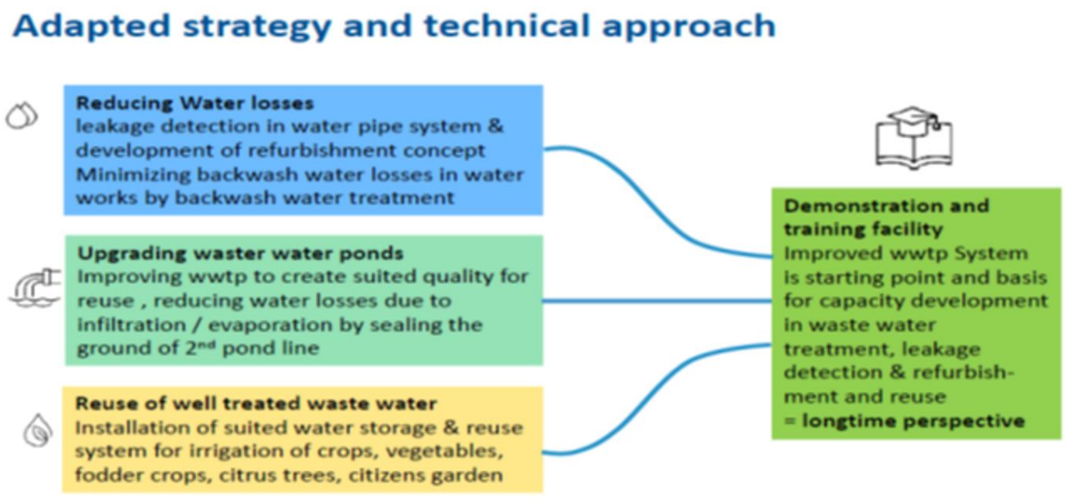

Figure 10. Adapted strategy to increase water availability in the Karibib Area for Navachab Mine, Karibib Town, and possibly Osino Twin Hills Mine, expected to come online in 2025-2026.

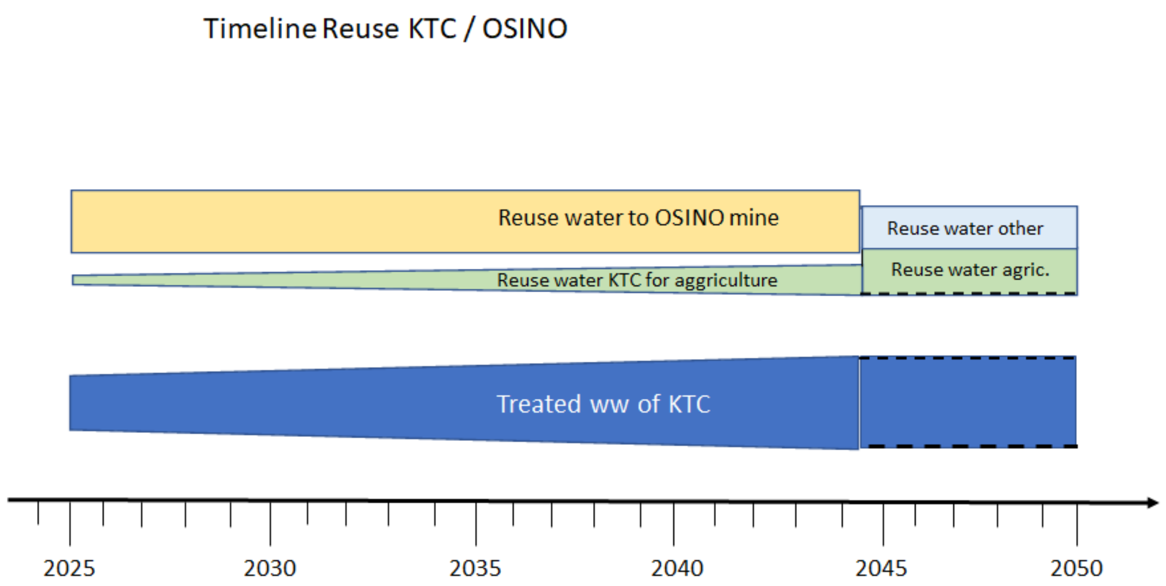

Figure 11. Forecasting of the water from the proposed recycling facility at Karibib to augment water volumes from NamWater

4.6 Monitoring and Control

Using water in mining can affect surrounding surface water and groundwater quality. In response to environmental concerns and government regulations, the mining industry worldwide increasingly monitors the water discharged from mine sites (Houlding, 2016). It has implemented several management strategies to prevent water pollution. Water issues and management vary from site to site and must be addressed locally. Water plays a vital role in any mining operation, and managing water is fundamentally part of many operational activities at a mine. Each situation has its unique water characteristics. All mines in Namibia are obliged to adequately monitor and analyse water in compliance with the industrial and domestic effluent discharge exemption permit under sections 21(5) and 22(2) of the Water Act (Act 54 of 1956). Water usage at mines can potentially affect the quantity and quality of surface and groundwater downstream. One of the tools needed to achieve the aim of surface and groundwater protection is an effective water quality monitoring program, which includes water quality sampling and analysis (including surface water, groundwater, sewage effluent, and leachates); monitoring of pH and flow volumes of seepage points; monitoring of water table elevations, and potable water quality monitoring. Remedial actions need to be taken based on the results of monitoring data evaluation. Ultimately, a water monitoring program should be designed to cover remedial actions and achieve sustainable water management. At Rössing Uranium Limited, one of the oldest operational mines in Namibia, hydro-chemical data have been collected within the mining grant since the start of operations in 1976. About 150 sites have been monitored for groundwater composition at varying intervals (mostly monthly or quarterly) initially, later reduced after evaluating long-term trends and the composition of a water balance for the mine.

Section 17 of Part V of the EMA empowers the Environmental Commissioner to conduct inspections to monitor compliance with the Act and conditions stipulated in the Environmental Clearance Certificate. If monitoring and/or inspections reveal that a developer is not abiding by the conditions of the Environmental Clearance Certificate or has contravened the EMA, the Environmental Commissioner has the power to suspend or cancel the Certificate for a period s/he may determine. The certificate can be reinstated once the environmental Commissioner is satisfied that the person concerned has rectified the failure that led to the suspension. Mines carefully monitor and manage their groundwater resources to ensure sustainable use and avoid over-extraction. Namibian mines also face unique challenges related to water management, such as the high salinity of groundwater in certain regions, which can affect the quality of the water used in mining operations. Therefore, groundwater is monitored to assess the water level of the aquifers and the possible impact of abstraction on the water systems. Most mines have an existing groundwater monitoring network, whereby boreholes are located in the mining area, non-mining areas, and on neighbouring farms.

4.7 Water quality management

Mines treat and monitor the quality of water discharged from their operations to minimize environmental impact. Water treatment technologies can be classified mainly as passive or active treatment. Active treatment requires the input of chemicals and energy. Passive technologies use natural processes such as plant systems, gravity, and microorganisms (Fraser Institute, 2012). The pollution level determines the treatment technology that will be used, and the technology used depends on the water quality requirements. The focus of water treatment has historically been on removing contaminants; however, this often results in secondary waste streams. Many active treatment systems create byproducts such as sludges and brine, which must be considered in the long-term viability of the site-wide water management strategy (Simair, 2022). Namibian mines have realized that each mine is unique in water quality and needs, requiring a customized and site-specific approach to water treatment. While traditional turnkey water treatment systems still have a role in the overall water treatment and water management strategy, it is now recognised that they work best as part of a more comprehensive strategy. Some other considerations of a site-specific approach include:

- End use of water
- Water chemistry and constituents targeted for treatment
- Lifespan of the treatment system
- Lead time for system operation
- Constructible land area
- Climate
- Periodicity of treatment
- Site infrastructure that can be repurposed (e.g., pit lakes, mine pools, tailings ponds)
- Availability of local materials

4.8 Stakeholder Engagement

The mining industry in Namibia operates in a semi-arid region with limited water resources. As a result, mining companies work closely with local communities and stakeholders to ensure sustainable water use and minimize their operations' impact on water resources. This includes engaging in community-based water management initiatives, such as building water infrastructure and supporting water conservation programs. To achieve this, public meetings, interviews, and consultations are held to reveal community concerns related to mining activities. This initiative has led to more freshwater availability, decreasing the competition for water between mining operations and human consumption. The all-inclusive stakeholder engagement strategy employed by the uranium mines was seen as an excellent leading practice that other countries seeking to balance

4.9 Reporting

Reporting is an essential mechanism for authorities to ensure compliance from mining companies to the conditions outlined in the Environmental Clearance Certificate, the EMP, and any other requirements such as permits and licenses (NCE, 2019). Namibian reporting requirements for exploration and mining companies are outlined in the Minerals (Prospecting and Mining) Act, No. 33 of 1992. Mines belonging to global companies also do internal reporting on various aspects determined by their parent companies; some also do annual reporting to the public—to give stakeholders an overview of activities, including interaction with society, the economy, and the environment (NCE, 2019. Mining companies submit (also voluntarily) annual environmental reports to various state departments (i.e., the Directorate of Environmental Affairs, the Directorate of Mines, and the Directorate of Water Resource Management). However, these annual reports on environmental performance are not prescriptive in format or content for reporting. It is best practice to have a reporting format in place. In compliance with conditions stipulated in the water permits issued by the Department of Water Affairs at the

Ministry of Agriculture, Water, and Land Reform (MAWLR), annual reports about water abstraction, disposal and management of effluent, and vegetation monitoring are submitted to the head office in Windhoek.

5.0 Possible Areas for Improvement

While Namibian mines have implemented comparable water management practices to the best practices in the world, there are still areas where they can improve.

5.1 Reviewing and Enforcing Legislation

The ultimate way of ensuring the sustainability of mining is through developing and strengthening legislation and sound policies coupled with enforcement mechanisms and putting proportionate pressures on the industry to instill sound corporate citizenship principles in all their operations. In as much as there has been such enforcement, there are still capacity challenges for the enforcement agencies, which is further complicated by having overlapping roles and responsibilities in administering environmental-related Acts administered under different line ministries. The best way to ensure that mining is done sustainably is to enforce standards and protocols for pollution prevention and monitoring strictly.

The Water Act of 1956, which governs the use of water resources, is outdated, and the Water Resources Management Act (2013) was passed but is not enforced. As a result, implementing the effluent permitting process for mining entities is inconsistently applied. Namibia does not have its effluent discharge guidelines and relies on South African standards. Environmental compliance reporting to the MEFT occurs on a biannual basis; however, the MEFT has limited resources for reviewing environmental clearance certificates and biannual reports in a timely manner (IGF, 2018). It is unclear to what extent mining entities report volumes of water abstracted and discharged, and its quality, to the MAWF as required. MAWL and MEFT have a disjointed approach to enforcing compliance with water or discharge permit requirements. There is no legal requirement for companies operating in Namibia to comply with international standards or guidelines for key environmental risk areas, for example, in the design of tailings storage facilities. The Environmental Commissioner has limited ability to enforce fines or penalties for non-compliance with the law; cases that require legal enforcement are handed over to the police.

Legislation has not been passed to prevent and regulate the discharge of pollutants from mine sites, establish a waste planning and management system, and enable Namibia to comply with its obligations under international law. The draft Pollution Control and Waste Management Bill was developed to do so, but despite being drafted in 1999 it has not yet been adopted by the government. In the absence of such legislation, the EIA process requires that mining entities ensure that structures are designed and operated in accordance with responsible waste management standards. Like many others in Namibia, the mining sector produces hazardous waste, and the disposal of this waste is problematic, as the country does not have a registered hazardous waste site compliant with international standards. This poses a problem for international companies operating in Namibia, as they have internal standards that require hazardous waste disposal at registered facilities. The Chamber of Mines' environmental subcommittee recognizes the need for a hazardous waste site, and the sector is working with key stakeholders to develop a strategic waste site (IGF, 2018).

5.2 Capacity Building for Government Officials and Communities

The Ministry of Agriculture, Water, and Land (MAWL) has limited capacities to enforce and apply appropriate penalties for not complying with the Water Act due to financial and human resources. In contrast, the penalties set in the Act are inadequate. The Ministry of Environment and Tourism (MET) is mandated to regulate environmental performance but lacks the technical skills, resources, and equipment to regulate effectively. The government could use funds from the treasury for human capital development and work with local universities to build the capacity. In addition, international agencies and mining companies could be called upon to raise awareness and build capacity in local communities. The social license to operate has become a key threat to mining operations.

5.3 Water Research

The most worrying fact found by this study is that during the past decades, the global mining industry has dedicated only small expenditures to Research and development, compared to the 15% to 40% levels in other sectors (ICMM, 2019). The same applies in Namibia, where, with the prevailing low commodity prices, most companies have embarked on cost-cutting measures, including activities related to strategic research for the organizations. Mining companies will continually need to undertake water-saving actions and initiatives, set targets, and develop a vision of water stewardship, including a broader concept of catchment water management. Modern water management practices and mine designs significantly reduce the potential for water contamination at mine sites (Houghton, 2016). In general, old abandoned mine sites have a higher potential to pollute nearby waterways because the water control techniques that modern environmental regulations now require were not in place when the mine was opened or closed. Knowledge of water management and impact reduction has dramatically increased over time, and preventing water contamination is now an essential component of mine operation and closure plans.

5.4 Reducing Carbon Footprint and Planning for Closure

Most mines in Namibia have started using solar energy in their operations. There is a need to increase the use of renewable energy sources in water treatment and desalination processes to reduce the carbon footprint of mining operations. Most mining closures' significant challenges and costs are linked to water monitoring and treatment. In 2018, a Mining Policy Framework Assessment revealed no legal framework for mine closure or relinquishment. While the Minerals (Prospecting and Mining) Act refers to remedying the environmental impacts that result from the cancellation and/or abandonment of mining rights, the legislation does not explicitly address the ideals of life-cycle responsibility or concurrent or post-closure rehabilitation. Based on the assessment and capacity training carried out by the Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development (IGF), the government is developing a mine closure framework from a regulator's viewpoint since there is already one that the Namibian Chamber of Mines developed.

6.0 Conclusions

Namibia is a water-stressed country with a limited amount of fresh water. This study sought to investigate the strides made regarding water management practices in mining in Namibia. The strategies employed by the Namibian mining industry involve inclusive stakeholders' engagement and joint water stewardship approaches, recycling and reuse, and minimizing losses. Namibian mines have implemented various water management practices to address their unique challenges in the semi-arid region. These practices promote sustainable use and conservation of water resources while minimising the impact of mining activities on the environment and local communities. It is clear that demand management, through the improvement of water-use efficiency across the whole water chain, is vital for future economic sustainability in the sector. Overall, water management practices in Namibian mines have played a crucial role in ensuring the country's mining industry's sustainable use and conservation of water resources. Realising that the water challenge cannot be solved by any one party acting alone has been fundamental in ensuring environmental compliance within the mining industry in Namibia. Overall, Namibian mines' water management practices are comparable to the world's best practices for water management. Still, there is always room for improvement and continued innovation in this critical area of mining operations.

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