EXECUTIVE SUMMARY

Advancing the climate resilience of critical infrastructure in the water sector in Lesotho

Application of the PIEVC Protocol to conduct a comprehensive Risk Assessment of the Metolong Dam System

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We are a river

The project "Using the PIEVC Protocol and related resources to improve risk-informed decision-making processes in the Kingdom of Lesotho" (Agreement Number: 81274990) is funded by the German Federal Ministry for Economic Cooperation and Development (BMZ) and supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH.

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The climate analysis used for the PIEVC Assessment of the Metolong Dam and Supporting Systems was carried out by Climalogik. WSP reviewed and refined the preliminary findings of the risk assessment and supported the development of the recommendations and conclusions presented in this report.

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Executive summary

The Kingdom of Lesotho is susceptible to various natural hazards, including floods, droughts, soil erosion, frost, strong winds, and heavy snowfall. Lesotho's climate is generally classified as temperate, characterised by hot summers and cold winters. The rainfall pattern in the region is highly unpredictable. With climate change, the threat of natural hazards is expected to worsen, making it crucial to better plan for and adapt to these changes. It is vital to understand the specific influences of climate change on the potential frequency and character of hazard events, and their impacts on built and natural systems.

In Lesotho, the water sector infrastructures play a dual role, catering to the nation's own domestic water, food, and energy security, and fulfilling its commitments under transboundary agreements with neighbouring states. The Metolong Dam and reservoir hold a distinct purpose within this context. The 83 metre high dam is a pivotal asset aimed at enhancing water accessibility and bolstering water supply reliability to urban and peri-urban areas, particularly in Maseru and nearby towns. This infrastructure is essential for broader economic growth, benefiting the water-intensive textile industries by serving as a vital water source for two-thirds of Lesotho's population. However, climate change considerations have not been integrated explicitly into the design, operation and maintenance of the water supply system and interdependent systems, thereby jeopardising the reliability of water services. Furthermore, the COVID-19 crisis revealed weaknesses in societies' planning and response to major hazards, exposing inadequate governance structures and decision-making processes, and exacerbating the climate impacts.

To build resilience and adapt, it will be important to use climate risk assessments to enhance the risk-informed nature of governance structures and decision-making at all levels. The project 'Using the PIEVC Protocol and related resources to improve risk-informed decision-making processes in the Kingdom of Lesotho' was designed and delivered to support this objective. It introduced practitioners and decision-makers to an important set of resources for assessing climate change and infrastructure risk, the PIEVC Protocol and family of resources. It also provided decision-makers with valuable insights into climate impacts, vulnerabilities, risks, and adaptation planning for the Metolong Dam infrastructure and supporting systems, including the upstream components (watershed and reservoir) and downstream components (distribution system and users). Recommendations have been identified to better manage risks stemming from the impacts of climate change on the dam and catchment. These options range from technical to policy and institutional measures.

The primary focus of the project was to enhance the knowledge base for risk-informed decision-making by utilising the Public Infrastructure Engineering Vulnerability Committee (PIEVC) climate risk assessment methodology. This methodology is supported by a range of resources, including the PIEVC Protocol for Infrastructure Vulnerability and Risk Assessment, the PIEVC High-Level Screening Guide (HLSG), and the PIEVC Green Protocol. The PIEVC protocol consists of five steps:

Step 1: Scope, context, and criteria.

Step 2: Data gathering and sufficiency, encompassing climate and infrastructure data.

Step 3: Risk assessment, involving:

- the development of an impact chain to conceptualise drivers of vulnerabilities and climate impacts;
- the scoring of climate hazard likelihood and severity of impact;
- used to evaluate key impacts and for risk prioritisation.

Step 4: Engineering analysis, an optional process not covered in this assessment

Step 5: Reporting, which presents key findings and recommendations.

The assessment is aimed at raising awareness on the importance of protecting public infrastructure within the water sector and their vulnerabilities towards associated risks. It is also aimed to provide a comprehensive understanding of the dam and its related systems that support reliable drinking water provision, considering both current and future climate conditions. It examined the potential consequences of varying or reduced service levels for key user groups and assessed the implications for sustainable development in Metolong's catchment and Lesotho's water sector. To offer effective guidance for disaster risk management policy and decision-making, the assessment integrated three geographical scales: the watershed and reservoir scale, the dam scale, and the water user's scale, encompassing both grey and green infrastructure elements. This approach ensures a holistic view of the situation, benefiting the catchment area, region, and Lesotho as a whole.

The assessment process included active stakeholder engagement, involving infrastructure owners, government departments, community representatives, and industry stakeholders. These participants actively contributed data sets and valuable information and offered insights about climate impacts and risks, also conducting scoring. Participant involvement was crucial for formulating recommendations to prioritise and manage risks. The engagement process included several interactive activities, including virtual and in-person workshops, training sessions, one-on-one interviews, and validation sessions. This collaborative approach fostered a comprehensive and well-informed assessment, benefiting from the expertise and perspectives of a broad range of stakeholders.

The assessment addressed three different time periods, each requiring its own set of climate analyses: present day (baseline), the 2050s (2041–2070), and the 2080s (2071–2100). Climate statistics for each of these time periods represent mean values across thirty years of data. Analyses of the 1981-2010 baseline period provided a basis for bias adjustment of the modelled future climate and for general reference and analysis. The climate analyses suggest the area around the Metolong Dam will undergo significant changes by the 2050s and 2080s, particularly if global greenhouse gas emissions continue to rise for the foreseeable future.

The following climate trends are expected:[1]

- **Warmer conditions**: Warming is projected across all seasons, with summers warming the most.
- **Dryer conditions**: Total precipitation is projected to decrease in the winter and spring.
- **More extreme precipitation:** Precipitation extremes are projected to intensify and high intensity events to occur more frequently.
- **More severe drought periods:** The combination of warmer, hotter, and drier conditions is projected to lead to more severe droughts and increase the likelihood of wildfires.
- **More stormy weather:** Future climate change will favour the occurrence of intense storms, lightning, thunderstorms, and extreme winds and gusts.

And the following:

- **More heatwaves:** Periods of extreme heat are projected to become more frequent and significantly increase in duration.
- **Shift in seasons:** The timing of seasons is projected to shift, with summer conditions extending approximately two weeks longer by the end of the 21st century.
- **Fewer cold days:** The number of days with lows below 10°C are projected to reduce by 34% by the 2050s, and 82% by the 2080s.

To effectively understand and address key impacts of the aforementioned climate conditions, impact chains were used to explain cause-effect pathways. This analysis revealed impacts related to livelihoods, food security, local economic systems, human health, environmental quality, water security, infrastructure damage, and water supply.

Risk assessment results

Risks are categorised into six groups based on their severity and the necessary mitigation measures.

1. **Negligible risks** typically do not require further consideration or can be managed with ongoing operations and maintenance procedures"
2. **Low risks**, pertain to risks that can be effectively managed through routine operations and maintenance procedures.
3. **Special cases** encompass a) risks stemming from extreme climatic events with a low probability of occurrence but with the potential to cause severe damage; or, b) frequently occurring climatic events that may have minimal impact individually but can lead to premature wear of physical components due to their repetitive frequency.
4. **Moderate risks** require medium-term risk mitigation controls to reduce their impact.
5. **Significant risks** demand high-priority mitigation measures that should be considered, planned, and addressed in the near future.
6. **Major risks** necessitate immediate risk

1 Values shown were computed using SSP5-8.5 scenario and the median value of 35 climate models.

mitigation controls and prompt action to avert or minimise their potential consequences.

Certain climate hazards and system elements were determined to have no interaction. For example, for the three time periods, daily maximum snowfall, along with all elements from the dam scale and most elements from both the watershed and water user scales, did not exhibit any interaction. These instances are recorded among risk categories as instances of "no exposure".

The number of significant and major risks are expected to increase in the future, demonstrating the need for mitigation measures in anticipation of future climate change conditions.

Table ES-1: Number of climate hazard-infrastructure element interactions resulting in risk category ratings ranging from "no exposure" to "major," for each system scale and the three time periods assessed by the study.

	Watershed scale			Dam scale			Water users scale		
Risk category	**Baseline (%)**	**2050s (%)**	**2080s (%)**	**Baseline (%)**	**2050s (%)**	**2080s (%)**	**Baseline (%)**	**2050s (%)**	**2080s (%)**
No exposure		14			28			28	
Negligible	11	7	10	10	6	10	18	9	11
Low	17	18	16	24	25	18	24	30	20
Special case	0	0	1	0	0	5	0	0	9
Moderate	35	27	15	30	29	12	26	22	8
Significant	22	25	26	7	19	22	5	13	20
Major	0	9	18	0	0	6	0	0	5

Results of the risk assessment are summarised for each of the three scales of the assessment below.

Watershed and reservoir scale results

The assessment highlights that the watershed scale presents the highest number of **major risks with 9% in the 2050s** and **18% in the 2080s**. In the 2050s, major risks primarily stem from precipitation-related climate hazard indices, including very heavy precipitation days, extremely wet days, five-day maximum rainfall, and 100-year and 200-year rainfall events. The 2080s show a continuation of major risks related to precipitation-related events, along with the emergence of major risks related to hazards like heatwaves and lightning.

A significant threat to the reservoir's lifespan is the impacts of increased **sedimentation**, which can be further intensified by climate change. Extreme heat and drought can lead to drier soils, which can exacerbate run-off and soil loss when rainfall events do occur, increasing the rate of sedimentation.

Various elements within the watershed and reservoir are susceptible to major impacts, including the **complete loss of assets and services** due to intense rainfall and subsequent flooding. These assets include pedestrian bridges, roads, agricultural land, crops, wetlands, and ecosystems._

Projected increases in **heat waves** and **high temperature** events are likely to pose considerable challenges. Elevated temperatures can accelerate evapotranspiration; disrupt river flows; harm wetlands and aquatic ecosystems; deplete soil moisture; reduce agricultural yields; and impact water quality by affecting pH levels, dissolved oxygen, nutrient content, and microbial reactions.

The frequency and severity of **droughts** are expected to increase and affect the amount of water stored in the reservoir, potentially causing damage to agricultural lands, forests, and crops. These drought events could adversely affect the livelihoods of communities both upstream and downstream of the dam. Conversely, hazards such as **hail** and **snowfall** demonstrate a lower overall risk profile as their likelihood is projected to either remain the same or decrease over time, thereby reducing associated risks.

Dam scale results

The assessment did not identify any **major risks** at the dam scale for the baseline or 2050s time periods. However, this increases to **18 interactions by the 2080s**, primarily associated with extreme precipitation and heat events. The dam scale had several **significant risks** in all three time horizons: **7% of all scored risks for the baseline period, 13% for the 2050s and 22% for the 2080s were "significant**. These **significant risks** are linked to precipitation-related climate hazard indices, extreme heat, lightning, and wind. Considering the implications of significant and major risks, it is imperative to prioritise risk mitigation control measures for implementation in the near future.

The Metolong Dam was designed to withstand loads associated with the Safety Evaluation Flood (SEF). The current assessment was not able to specifically assess the effect of climate change on the SEF. Rather, the current assessment relied on extreme events such as extreme wet days, 1-in-100 and 1-in-200-year floods, which represent significantly lower intensity events than the SEF used in the design and what a climate change-adjusted SEF could be. As a result, the dam itself, including its wall, foundation, and spillways, exhibits resilience to all extreme precipitation events considered in the study.

By the 2080s, certain types of climate events could pose major threats to the operations of the dam, including heat waves, high temperatures, extremely wet days, 100-year and 200-year rainfall events, and lightning. The projected impacts to the dam and operations could, in turn, ultimately affect many elements at the water users and stakeholder scale.

One concern is the possibility of **heavy precipitation events** (such as the 1-in-100-year event) leading to excessive **sediment and contaminant loads** in the water supply. Once transported to the pump station and treatment system, water with high sediment and contaminant loads can pose a considerable risk by disrupting the water supply and the provision of water to local populations and industry. The increase in sediments can increase levels of manganese, metals and bacterial growth in the water that can change the **operational requirements and long-term costs**.

Workers at the dam site face various hazards, including exposure to heavy rain, extreme heat, and lightning. It is crucial to implement appropriate **safety measures** to ensure the wellbeing of the workers under such conditions and, as such, the continuity of services.

Furthermore, the **service life of pumps and equipment** can be reduced by operating under high temperatures. This underscores the potential need to implement measures to mitigate the possible impacts of elevated temperatures on the operational equipment.

Lastly, it is important to recognise that multiple hazards can result in **power outages**, which can impair the systems responsible for controlling the dam's operation. Lightning strikes can disrupt data collection by damaging ICT infrastructure, while wildfires generated by dry conditions can damage the water treatment works and ICT infrastructure.

Water users' scale results

The water conveyance system comprises transmission mains, downstream reservoirs, distribution mains, pump stations, command reservoirs, and connections to households. **Major risks** emerge in the 2080s, related to 10 (5%) infrastructure element – climate hazard interactions related to **precipitation, heatwaves and lightning**. **Significant risks** are present across all time horizons related to 10 (5%) infrastructure element – climate hazard interactions in the baseline, 25 (13%) in the 2050s and 40 (20%) in the 2080s. These significant risks all relate to a range of temperature, precipitation, and high wind conditions.

Multi-hazards, including **excessive rainfall and flooding** can lead to damage of conveyance system elements, resulting in **significant** and **major** risks. Heavy rainfall may trigger **landslides** causing harm to the distribution mains. During heavy rainfall events, pump stations can be overwhelmed or damaged impeding pump operations. Floods can also wash away roads and bridges, limiting safe movement.

Furthermore, the increasing frequency and severity of **droughts** may alter the availability of water, necessitating increased irrigation and other water uses downstream and potentially leading to food insecurity and water scarcity. **Extreme heat** events pose a risk as they cause pump systems to overheat.

Finally, workers and water users face exposure to various hazards, including floods, extreme heat, wildfires, high winds, and lightning.

Socioeconomic impacts

Communities directly upstream and alongside the reservoir and dam face challenges due to low incomes and limited access to services, such as health facilities and schools. Community members often need to travel long distances to access these services, and any damage to transportation networks can severely impact their ability to access essential services, leading to increased poverty, marginalisation, and adverse health effects. Ecosystems are also at risk, with soil erosion, contaminated runoff, and droughts leading to economic losses and affecting livelihood activities such as agricultural production, ultimately leading to food insecurity and heightened poverty levels. Additionally, the safety of communities depending on the Metolong water supply also hinges significantly on land cover management. The potential for sedimentation to diminish the dam's water storage capacity and impair its functionality poses a real threat of water shortages for those relying on the reservoir. To combat these challenges, it is imperative to prioritise proper land cover management, as it plays a crucial role in safeguarding water quality within the dam, thus ensuring a safe and clean water supply for downstream communities. An essential aspect of this endeavour recognises the interdependence between healthy land cover, efficient water resource management, and the overall wellbeing of the communities.

The absence of clean drinking water upstream creates vulnerabilities to waterborne pathogens. Uncontrolled agricultural practices near the reservoir cause soil erosion and sedimentation, reducing water storage capacity downstream. The community's potential role in enhancing resilience was identified as an opportunity for adopting improved land use practices and catchment stewardship. Achieving these goals requires resource allocation, community engagement, awareness-raising, and mobilisation of efforts. By actively participating in catchment management, the community can cope better with climate change impacts. Supporting the community with alternative water sources or integration into the water service system will foster trust and responsible behaviour, aligning with water protection and security efforts.

Contaminated water consumption can have severe consequences, leading to waterborne diseases that could result in widespread health crises. These crises affect the community's productivity and well-being, which could lead to disruption of societal stability, social dissatisfaction arising from inadequate access to clean water and potentially political unrest. Industries downstream, like the garment industry, heavily rely on the Metolong Dam's water supply, making them vulnerable to disruptions that could result in economic losses and worker unemployment. Ensuring a stable and uninterrupted water supply is crucial not only for the wellbeing of the communities but also for the sustainability and prosperity of water reliant industries.

Challenges related to law enforcement, environmental policies, crisis management, and waste management exacerbate climate change's impacts. Finally, one notable issue is vandalism, where unauthorized households connect to pipelines, compromising water quality and the overall reliability of the water supply network, posing risks to public health and the environment. This scenario exemplifies how poverty and lack of water access can amplify the system's risks.

Recommendations

Based on the risk assessment results at all three scales, recommendations have been grouped into different categories, including governance, management and policy actions; future studies, data collection and monitoring; and remedial measures.

These recommendations represent the final outcomes of the PIEVC Risk Assessment, however, do not replace a more in-depth risk treatment evaluation and selection process that in many cases will still be required. Adaptation recommendations may still require additional evaluation, including costing and identifying decision support mechanisms needed to implement a course of action to reduce risk.

Governance, management and policy actions

It is recommended that three **climate risk and adaptation working groups** be established and institutionalised, one for each of the three scales: - Watershed and reservoir; dam; and users. The groups can discuss, revisit, and reassess climate-related risks and adaptation recommendations, while supporting and informing the integrated catchment plans led by ReNOKA. These groups would bring together stakeholders with diverse knowledge and expertise. To facilitate this process, the **risk assessment** should be used as a foundational tool for identifying, prioritising, and implementing risk treatment options. Furthermore, it is important to encourage the integration of **climate resilience** concepts in all proposed infrastructure projects across Lesotho.

Efforts should be made to develop, utilise, and regularly update **emergency response plans** to address climate-related emergencies. **Educational initiatives and awareness campaigns** on climate change impacts should also continue, ensuring a broad understanding of the consequences. Prioritising **disaster risk management** across Lesotho is crucial. Investment in **asset management** practices is necessary to effectively manage risk, minimise costs, and improve service delivery of infrastructure.

To support these efforts, **adequate funding and improved procurement** processes should be implemented to facilitate repairs and routine maintenance of equipment from pumping stations to the distribution system. In addition, it is essential to establish **multi-hazard monitoring and early warning systems**. Regular review of worker **health and safety plans** is also necessary to ensure a safe working environment. Moreover, when **developing plans**, particularly for new residential areas, consideration should be given to the current and future capacity of the water supply system to meet the anticipated increase in water demand.

Land use measures

It is recommended that **sustainable agricultural practices** be adopted. **Climate change considerations** should be **integrated into agricultural policies, strategies, plans and regulatory frameworks**. One way to enhance the resilience of farmlands and agricultural areas to extreme climate events is by encouraging the **integration of crop-livestock-forestry systems**.

To address erodible soils in the watershed, it is advisable to **increase the frequency of irrigation**. This can help mitigate the risks of soil erosion. Education and outreach efforts should also be focused on promoting the use of **heat-resistant crops**. These crops can better withstand high temperatures, contributing to a more resilient agricultural sector.

Furthermore, **restoration plans** for degraded farmlands should be established. The emphasis should be on planting native forage, grass and trees. This approach not only reduces soil erosion but also helps mitigate high temperatures. Additionally, **investment in agroforestry** should be pursued whenever feasible.

To ensure appropriate land use, the development of **sustainable land use policies** and strategies is essential. These policies should consider the utilisation of farmlands, rangelands, forests, and residential lands within the watershed and reservoir area. Regular reviews of **hazard creep based on land use plans** are recommended, and zoning laws should be developed, reviewed, and updated as required.

Finally, the implementation of land use policies should aim to encourage **sustainable agricultural practices**.

Assessment of sedimentation issues

The dam's **lifespan** is threatened by increased sedimentation. To better understand and manage the sedimentation issue, a comprehensive **multi-prolonged plan** supported by studies and models should be developed and implemented. This plan should encompass a range of measures, including the implementation of sedimentation dams. Key studies addressing sedimentation should address bathymetry, sediment erosion, land use, sediment removal evaluation, watershed modelling, and streamflow assessment. By conducting these studies, a clearer picture of the sedimentation problem can be formed, and effective strategies can be developed.

In addition to these technical measures, it is also recommended to implement **land use policies** that support the mitigation of sedimentation issues and promote sustainable land practices (see above).

Future studies, data collection and monitoring

An **analysis of wetlands and aquatic habitats** should be conducted to assess their ecological health and identify potential risks. Furthermore, reassessing the reservoir's storage capacity through **bathymetric surveys** is recommended to ensure accurate understanding and planning of water resources. In light of extreme weather conditions, it is important to **assess the resilience of transmission mains**. This evaluation will help identify vulnerabilities and inform necessary upgrades or improvements to maintain reliable water supply during adverse events.

To address potential sedimentation concerns, a **reassessment of the command reservoir** is necessary. This study should focus on identifying settlement patterns of suspended particles and developing strategies to mitigate their impact, ensuring the reservoir's long-term functionality.

Additionally, a study should be conducted to **explore water usage diversification, including**

alternative sources like groundwater to meet the increasing demands of both domestic and commercial sectors. Moreover, it is crucial to **regularly evaluate critical services and infrastructure vulnerable to high-risk hazards**, such as heavy rain and extreme temperatures. By assessing their vulnerabilities, appropriate measures can be implemented to enhance their resilience and ensure their continued functionality. Risk assessments should be revisited to identify any changes to infrastructure vulnerability.

Specific studies aimed at addressing sedimentation issues include **sediment erosion studies**, which will identify vulnerable areas prone to erosion. Additionally, it is recommended that the PIEVC protocol is used to develop a **deterministic watershed model** that simulates changing flow regimes resulting from climate change influences on precipitation, as well as an **engineering analysis on the streamflow dynamics** of the dam.

Lastly, it is important to establish a **monitoring programme** to periodically monitor the overall structure and function of the ecosystems; monitor the water treatment plant system for **emergence of new pathogens**; and implement **data collection procedures**. Ongoing analysis to monitor the expansion and contraction of the dam during extreme heat events will need to be conducted.

Remedial measures

Operations and maintenance

Frequent inspections of infrastructure elements are crucial to identify issues and facilitate timely repairs and upgrades. Furthermore, conducting **post-extreme event inspections** will help assess any damage caused and inform necessary remedial actions. To address components exposed to extreme heat, it is important to perform more **inspections** and implement appropriate measures to mitigate potential risks. **Repairing** pipe leakages and bursts is essential to minimise water loss and **maintain** efficient water supply. To account for climate considerations, **upgrading operations manuals** is recommended. These manuals should incorporate guidelines and protocols to address the challenges posed by climate change and extreme weather events. Efforts should be made to investigate both **the feasibility of additional backup power options** to ensure uninterrupted operations and the conducting of regular **dam safety evaluations** to assess the structural integrity and mitigate any potential risks. To enhance **adaptive management practices**, changes to water treatment facility operation procedures should be made based on extreme weather conditions. Utilising forecasting tools for improved reservoir management will aid in optimising water resources. Establishing **dynamic programming systems** and expanding treatment facilities will help manage water quality during extreme precipitation events. Finally, **sedimentation dams** should be implemented to help address sedimentation issues.

Additional remedial actions

Installing **flood protection barriers** for transmission mains is recommended to safeguard against potential flood-related damage. Additionally, **implementing wind barriers and breaks** will help protect ICT infrastructure from the adverse effects of high wind speeds. To ensure the safety of the dam and water treatment plant equipment, it is advised to install **lightning protection systems**. Regular inspections of **safety boom anchors** should also be conducted to maintain their effectiveness in securing critical infrastructure.

Furthermore, implementing **terracing, mulching, or bioengineering techniques** is recommended to stabilise slopes. These techniques will help prevent soil erosion and slope failure, thereby ensuring the stability of the surrounding area.

The infrastructure elements of the Metolong Dam and its Supporting Systems were generally resilient, but a significant subset of risks indicates potential vulnerability to more substantial future climate changes. Approximately 50% of the identified risks fall into the significant and moderate risk categories across all three timeframes. Although these risks are considered manageable within the dam's usual operating conditions, they require attention.

For the full assessment please visit the ReNOKA website **www.renoka.org**

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