MANDIWAS[1]

Membrane-based decentralized reclamation of acid mine drainage for improvement of water security and mitigation of environmental impacts in Southern Africa

Initial Phase- Final Report Part II (Detailed Report)

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Duration of the project: 12/2021 - 02/2023

Consortium partners:

Institution	Country
University of Duisburg-Essen (UDE) / Centre for Water and Environmental Research (ZWU)	Germany
IWW Rheinisch-Westfälisches Institut für Wasserforschung gGmbH	Germany
UN-Habitat (UNH)	Kenia / Germany
University of South Africa (UNISA)	South Africa
Stellenbosch University (SUN)	South Africa

Funded by

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[1] The logo was developed by Christian Wolkersdorfer, who kindly provided it.

Declaration of the coordinator

I, the coordinator of the project, declare that,

- The attached periodic report represents an accurate description of the work carried out in this project for this reporting period.
- The project has achieved its objectives and technical goals for the period with relatively minor deviations.
- To my knowledge, the financial statements submitted as part of this report are in line with the actual work carried out and are consistent with the report on the resources used for the project.

Date: 2023/05/31

Prof. Dr.-Ing. Stefan Panglisch (Coordinator)

Executive Summary

Mining-influenced water (MIW) flows untreated and often uncontrolled into the environment from most operating and abandoned mines. MIW includes acid mine drainage (AMD), neutral and alkaline waters, mineral processing waters and residual waters. This is an enormous challenge for a water-scarce country like South Africa (RSA), whose economy is largely based on the mining sector. RSA has a growing demand from various water use sectors, particularly domestic, agricultural, and industrial. Climate change has further exacerbated water stress through declining levels in reservoirs and groundwater. Lack of or inefficient water treatment systems degrade water quality in addition to MIW with massive impacts on local health and hygiene. There is general agreement among water experts and various stakeholders that the treatment of MIW for multi-purpose fit standards will improve access to water and sanitation, particularly in previously disadvantaged communities. The reuse of treated MIW could notably reduce water shortage in the industry such as agriculture and mining which are the main drivers of the economies in many southern African states. Without doubt, the boosting of water quality, particularly in the surrounding mining towns will provide socio-economic benefits for communities in terms of health, better sanitation, and the creation of job opportunities if the treated MIW is used for business approaches. In this way, the recycling and reuse of raw materials recovered from MIW could increase competitiveness, stimulate innovation of recent technologies, and promote entrepreneurship, which is in line with the South African goal to advance the industrialization of the economy. Incorporating aquatic systems assessment and implementing technological solutions will result in a significant improvement of the ecological status of streams impacted by mine water.

Against this background, the **MAMDIWAS** project aims to mitigate the impacts of AMD by focusing on local and decentralized solutions to improve water infrastructure through a holistic, integrated approach that addresses mine water challenges in the RSA while reducing water scarcity with its known human, health, economic, industrial, and social development impacts. The strategy is to develop a regional sustainable water resource management system for AMD to reduce water stress and to promote a circular economy related to community skilled development for income generation at the local level by recovering water and raw materials. This is reflected in the project design of the initial phase of **MAMDIWAS** with three main pillars: *i)* Technology Development which aimed to develop a flexible membrane-based water treatment system powered by renewable energy, adaptable to different mining conditions, and capable of reusing water and recovering recyclables, *ii)* Integrated Water Resources Management (IWRM) which focused on creating a regional sustainable water resource management system for MIW, and *iii)* Governance Mechanisms and Regulatory Framework with the aim to ensure transparency, enforcement of regulations, and widespread adoption of technological solutions and water management strategies, while also focusing on capacity building and skills development in communities.

MAMDIWAS generated strong interest among stakeholders from RSA and Germany through workshops, site visits, and expert interviews. This successful cross-sectoral stakeholder engagement facilitated a collaborative approach in co-designing the strategy and concept for the main phase. Based on the lessons learned from various discussions, some of the original ideas were sharpened, expanded, modified, or deleted, ultimately leading to the following conclusions for the main phase: Pillar 1: Further research on process intensification using membrane technologies to recover water and materials for further use is required. There is a need for smart integration of individual processes into an optimal overall process to leverage synergy effects. Alternative technologies for metal recovery such as modified nanofiltration must be investigated and adapted. Pilot testing cannot be conducted in abandoned mines for safety reasons,

but transferable results are important. Operating a pilot plant with renewable energies is only theoretically possible at this time due to limitations on site. Prior to piloting in RSA, a pilot phase will be conducted in Germany to optimize the technical concept at a representative mine. Within Pillar 2 research and implementation needs for setting up a local IWRM approach were identified. Toxicological impacts in the study region are largely unknown and need to be investigated, referring not only to the environmental burden downstream of mining areas but also regarding anthropogenic water reuse, e.g., for irrigation and drinking water purposes. As water reuse provides high potentials as an untapped water resource in a water scarce region, available water quality, fit-for-purpose water treatment, and governance conditions need to be investigated. Pillar 3: The transition to a post-mining society requires early local community engagement, the establishment of a stakeholder communication platform, the support of economic development including feasibility studies for the recycling of valuable materials with a focus on high-value product opportunities and the exploration of public-private partnerships for MIW treatment. Hereby, ensuring environmental protection as well as addressing regulatory gaps, establishing partnerships, promoting capacity building, and a collaborative management of mine water infrastructure are crucial.

General agreement was reached on the selected areas for pilot sites to test new technologies and IWRM and governance measures, and more than 10 stakeholders decided to participate in the main phase of the project, to which they committed through LOIs.

Finally, the concept for the main phase of **MAMDIWAS** was developed. The breakdown of the project into the three pillars in the initial phase has proven crucial for the success of the project. The combination of these pillars has a significant leverage effect on mine water treatment implementation, reinforcing the decision to maintain the original structure in the concept of the main phase. Pillar 1 will focus focuses on improving the widely used cascade concept with neutralization, sulfate removal and membrane desalination, the latter especially for water reuse. The basic features of the cascade process are reproduced and considerably intensified by integrating new membrane-based technologies, optimizing the operational conditions and modifying/adapting membrane materials. In pillar 2; a MIW-specific IWRM approach will be adopted to consider local conditions. It involves screening pollutants in the aquatic environment, conducting detailed sampling campaigns to assess inorganic pollutant loads, and using novel ecotoxicity and human toxicity assessments. The project analyses water uses and the potential for adequately treated MIW reuse, considering social and governance aspects. Pillar 3 will conduct a "state of the art" analysis of existing policies and regulations, identifying gaps and recommending sustainable strategies. Stakeholder involvement, community participation, and skill development are emphasized, aiming to create synergies between European and South African water operators. The project recommends a strategic plan for community skills development and income-generating interventions by an Urban Living Lab approach, particularly for the post-mining phase. Capacity building, training, technology, and knowledge transfer are prioritized in the MAMDIWAS main phase concept. By investing in these areas, societies can unlock their full potential, promote innovation, and address challenges effectively. Empowered individuals equipped with the right skills can drive positive change and foster inclusive growth. The concept includes a dedicated work package to train professionals, build local capacity, and promote entrepreneurship in response to community needs in RSA. This promotes collaboration between research and industry, with a focus on membrane-based technologies. The first main phase also addresses important tasks and measures to set the project on a successful course for implementation in the second main phase.

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1. Introduction

1.1. Problem definition

Mining is an important foundation for the global economy. For example, gold mining is considered one of the most traditional financial assets with the highest economic market value. The most important mining areas in the world are in Canada, Australia, the United States and South Africa (RSA). From most operating and abandoned mines so-called MIW (mining-influenced water) flows untreated and often uncontrolled into the environment. MIW is defined as any water whose chemical composition has been affected by mining or mineral processing and includes AMD (acid mine drainage), neutral and alkaline waters, mineral processing waters and residual waters. MIW contaminate surface waters or infiltrate groundwater and eventually reach aquifers that are interconnected over large areas, and thus are not only directly harmful to human health and to plants, animals, and aquatic life, but also permanently impair safe and sustainable access to drinking water resources by polluting the aquatic environment. Quality and quantity of MIW vary greatly depending on the conditions of the mining sites e.g., lifetime, geomorphology, rainfall, groundwater oxygen saturation levels and microbial activity. Due to its high acidity, AMD in particular leaches minerals and metals from igneous and sedimentary rocks, releasing toxic metals into the environment. Long-term drastic environmental impacts of AMD include increased heavy metal and sulfate concentrations in nearby waters and soils, and adverse ecosystem effects. In addition, some studies have reported adverse effects on human health and plant growth as a result of long-term soil contamination from AMD. The high levels of MIW in RSA are attributed to the large number of abandoned mining sites in the Western Basin (Krugersdorp), the Central Basin (Roode-Poort to Boksburg), and the Eastern Basin (Brakpan, Springs, and Nigel), as well as the huge pyrite-bearing tailings from coal and gold mines in the Witwatersrand Basin. This is an enormous challenge for a country like RSA, whose economy is largely based on the mining sector.

RSA has a growing demand from various water use sectors, particularly domestic (both urban and rural), agricultural, and industrial. Climate change has further exacerbated water stress through declining levels in reservoirs and groundwater. Lack of or inefficient water treatment systems (wastewater and drinking water) degrade water quality in addition to MIW with massive impacts on local health and hygiene. Hydrologically, the country is classified as a water-scarce region with the east coast receiving relatively higher average rainfall compared to the west coast. These necessitated the construction of dams and reservoirs which were seen as a solution. There is general agreement among water experts and various stakeholders, that the treatment of MIW for multi-purpose fit standards will improve access to water and sanitation, particularly in previously disadvantaged communities.

1.2. Project objectives

MAMDIWAS aims to promote the concept of a circular economy in the mining industry, which can significantly reduce pressure on the environment by improving the security of water and raw materials supply. Reuse of treated MIW[2] could notably reduce water shortage in the industry such as agriculture and mining which are the main drivers of the economies in many southern African states. Without doubt, improving water quality, particularly in the surrounding mining towns, will provide socio-economic benefits for communities in terms of health, better sanitation, and the creation of job opportunities if the treated MIW is used for business approaches. At the same time, recycling and reuse of raw materials recovered

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[2] The original MAMDIWAS project concept focused on AMD. In the course of the project, however, it has become apparent that non-acid mine waters also pose a problem and can in principle be considered in MAMDIWAS. Therefore, the term MIW will be used in the following when referring to mine water in general.

from MIW could increase competitiveness, stimulate innovation of recent technologies, and promote entrepreneurship, which is in line with the South African goal to advance the industrialization of the economy. The inclusion of aquatic systems assessment and implementation of technological solutions will result in a significant improvement of the ecological status of mine water-impacted streams.

The overall objective of the initial and main phases of MAMDIWAS is to mitigate the impact of AMD by focusing on local and decentralized solutions to improve water infrastructure through a holistic integrated approach that addresses mine water-related challenges in RSA while reducing water scarcity, with known human, health, economic, industrial, and social development impacts. The strategy is to develop a regional sustainable water resource management system for AMD to reduce water stress and to promote a circular economy related to community skills development to generate income at the local level through the recovery of water and raw materials. From the beginning, multipliers, and stakeholders such as mining companies, governments, government agencies, and funding agencies have to be identified and involved as well as early engagement with communities ensured.

Thus, MAMDIWAS has significant potential to improve the status of mine water management in RSA by bringing together key water use stakeholders to collaboratively design, implement, and enforce a framework for sustainable AMD (in general for MIW) treatment and water use.

The work and results described in this report were carried out as part of the initial phase, which essentially served to prepare for the subsequent main phases. Based on the lessons learned from the site visits, workshops, and various discussions with RSA stakeholders, some of the original ideas were sharpened, expanded, modified, or deleted. For example, during the project it became clear that although AMD is the most common type of mine water in South Africa, other types of mine water are also important and are grouped under the term MIW. As a consequence, the focus was shifted from AMD to MIW in the course of the initial phase and will be maintained when designing the main phase.

1.3. Initial phase concept

Already in terms of the main phases a concept has been developed that focuses on three main pillars (see Figure 1): Technology Development, Integrated Water Resources Management (IWRM), and Governance Mechanisms and Regulatory Framework. The original idea for the first pillar was to develop a purpose-built, flexible membrane-based water treatment system powered by renewable energy for the treatment of MIW. The technology should be specifically adaptable to different regional mining conditions and allow for both water reuse and recovery of recyclables to meet local needs.

The second pillar was designed to develop a regional sustainable water resource management system for MIW to reduce water stress and promote a circular economy at the local level through recovery of water and raw materials. This IWRM strategy should enable the management of water conflicts which will ensure equitable water allocation and support the functionality of river basin councils.

The third pillar was planned for governance mechanisms and legal frameworks that focus on society and policy to promote transparency and enforcement of regulations and ensure that governance mechanisms enable the broad application of technology solutions and water management strategies. In addition, the capacity development capacities as well as community skills development are added to the third pillar.

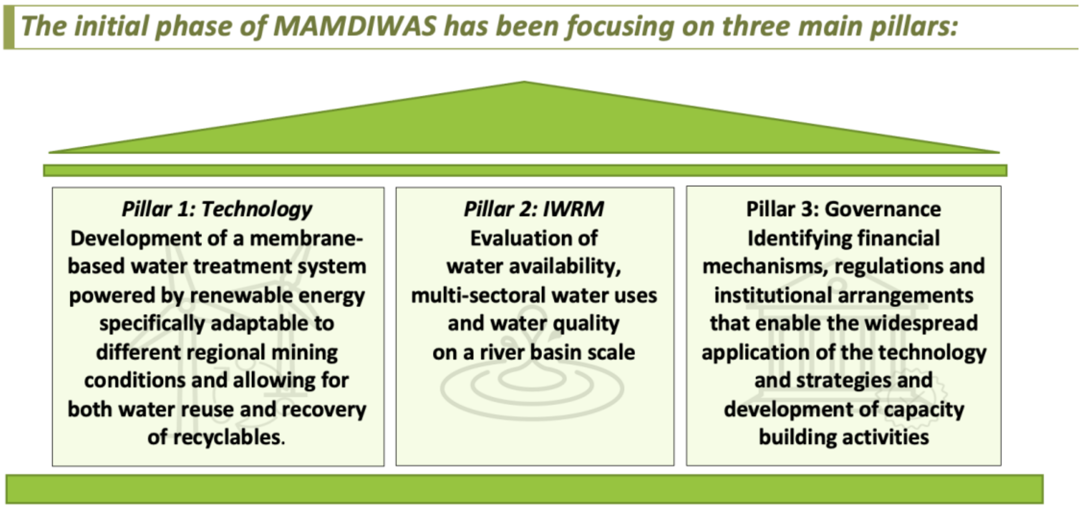


Figure 1: *The initial phase of MAMDIWAS focused on three pillars: 1. Technology considerations for MIW treatment; 2. IWRM strategy development; 3. Governance mechanisms and regulatory framework.*

In the initial phase of MAMDIWAS, the final project consortium and the final and detailed concept for the subsequent main phase were to be determined on the basis of existing contacts and cooperation between South African and German institutions, and scientific cooperation was to be strengthened in the sense of an effective and productive network between the project partners. The following objectives were set for the initial phase:

- Review of the preliminary concept for the main phase for the need of changes and additions.
- Expansion of the current core team consortium and arrangement of formal partnership agreements with key local professionals to address all relevant research topics for the main phase.
- Identifying potential co-funding opportunities (either public or private) for the main phase.
- Definition of the criteria for the selection of representative case studies for the main phase.
- Selection of the mining sites that are most suitable for conducting representative case studies in the main phase.
- Investigation of the transferability of solutions to other countries in Southern Africa.
- Mapping strengths and gaps of existing governance, regulatory and legislative structures relevant to MIW treatment, water reuse and resource recovery in RSA
- Establishing the strategy, concept, and work plan for the main phase
- Confirmation from mining companies to participate in the main phase and provide data and competencies.

2. Work package structure

The initial phase of the project focused primarily on investigating local conditions in relation to the three pillars. This involved assessing local experience and expertise in developing technologies to mitigate mine water issues, local implementation of the IWRM approach, and collaboration with government and the legal framework. Duplication of existing projects and knowledge should be avoided. Rather, gaps and opportunities should be identified where the MAMDIWAS project can add value and achieve maximum impact. Eight work packages (WP) (see Figure 2) were defined, each led by a German and an African partner.

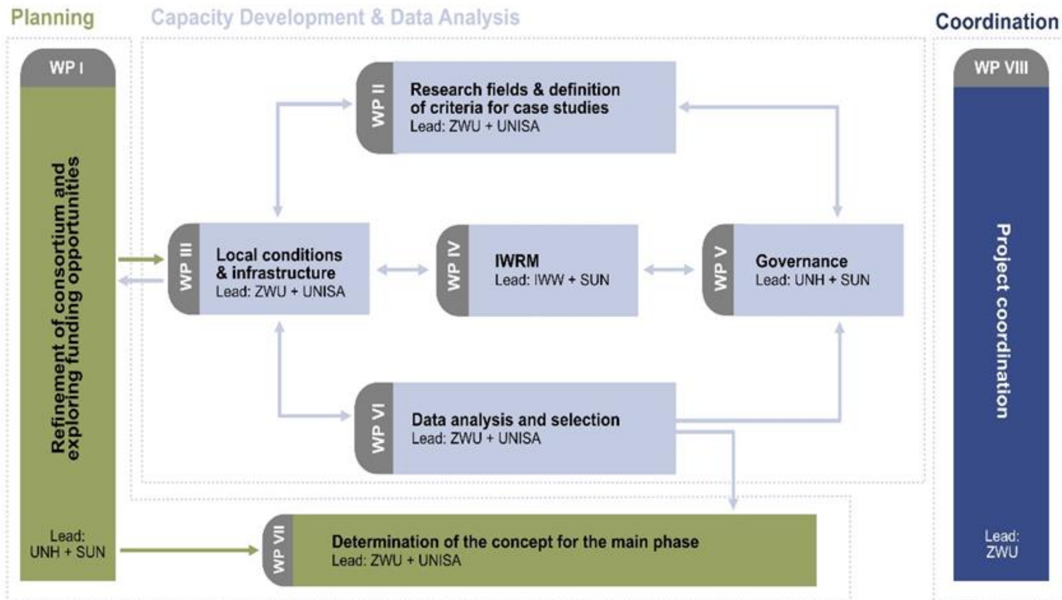


***Figure 2**: The overall eight working packages for the MAMDIWAS initial phase*

Table 1 provides an overview of the milestones and deliverables to be achieved during the initial phase and the linked key activities. A brief description of the activities carried out in the various work packages and the respective results and lessons learned follows. WP III has focused mainly on Pillar 1, WP IV on Pillar 2, and WP V on Pillar 3. WP II and WP VI were the brackets to link the three Pillars.

***Table 1:** Milestones (M)/ deliverables and key activities of the initial phase.*

Work package number	Milestones (M)/ Deliverables	Key activities/ Work steps
WP I	Expansion of the consortium and exploration of funding opportunities M1: Project kick-start M2: Project schedule and letter of interest (LOI) with partnerships	Organize workshops in SA and identify water use stakeholders
WP II	Research fields & definition of criteria for the selection of case studies M3: Agreement on the selection criteria catalogue and writing of the checklist	Online meetings with the entire project consortium
WP III	Investigation of local conditions and infrastructure	Field trips to six different mining sites. Mutual research visits. Online meetings. Review of literature and recent technical reports
WP IV	Sustainable water resources management, transboundary effects, and transferability	Analyse land and water use. Assess transboundary water conflict challenges. Analyse water quality. Field trips and roundtable discussions

Work package number	Milestones (M)/ Deliverables	Key activities/ Work steps
WP V	Governance and capacity building. M4: Interim report on the results of WP III, IV and V.	Review of governance, regulatory and legislative structures on MIW treatment in South Africa Site selection criteria for community development skill site projects including community stakeholders identification.
WP VI	Data analysis and selection of three case studies M5: Agreement on the three sites for the detailed case studies in the main phase	Online workshop with the entire project consortium. Presentation and discussion of results. Assessment of results based on the selection criteria.
WP VII	The strategy, concept, and work plan for the main phase. M6: Project end	Online workshop with the entire project consortium to discuss strategy and work plan. Bilateral information meetings with the mining companies.
WP VII	Project coordination	Establishment of an internal communication platform. Public relations and marketing. Organization of the planned research visits of SA and German scientists

3. Project results

The following project results are sorted according to the WP in which the results were determined. WP I and II primarily aimed at defining the methods and framework conditions for the compilation of all necessary information and data on pillars 1 - 3 to be carried out in WP III, IV, and V. Since the results cannot be evaluated individually, these three work packages are described in a single chapter. In WP VI the information, data, and lessons learned collected in WP III – WP V were evaluated and analysed, and the project sites were selected on the basis of the selection criteria defined in WP II. Finally, in WP VII the ideas for the main phase of MAMDIWAS were developed and described. Since WP VIII was exclusively assigned to project coordination and has not provided further results it is not described in detail. Nevertheless, an internal communication platform was established as planned, project information was published online and all site visits, research visits of RSA and German scientists but also workshops were organized.

WP I: Expansion of the consortium and exploration of funding opportunities

The MAMDIWAS team has managed to draw significant interest from Germany and RSA during the initial phase. Potential local and German stakeholders for each pillar were identified and invited to participate in joint discussions and subsequently in the two main workshops. Respective lists of stakeholders and individual experts that were visited and consulted during the initial phase of the project can be found in Appendix 7.1, Table 4 and Table 5. Numerous discussions were held to elaborate the stakeholder contributory role in the initial but in particular in the main phase of the project (see Appendix 7.2; Table 6). Table 7 in Appendix 7.3 provides brief summaries and key findings from the discussions that took place prior to the first workshop.

Workshop 1, held on the 1st and 2nd of June 2022 involved a multidisciplinary consortium to identify problems and find solutions that address all relevant spheres of society. This included a detailed presentation of the project objectives, and round table discussions on issues such as local clean water needs, waste discharge options, potential renewable energy sources and treatment methods currently in use. This workshop brought together a total of 18 multidisciplinary stakeholders with 55 participants, including government agencies and departments, the industrial sector (mining), SMMEs (small, medium, and micro enterprises), water-use associations, civil society leaders, IWRM professionals, academics, and research institutions. The workshop succeeded in breaking down complex issues into a series of questions for which practical answers are expected to be found in the main phase of the project. Hence, the German partners were able to gain a broader understanding of the challenges in treating and managing mine drainage in South Africa. An even more important outcome was the integration and open communication between water user consortia with the aim to build bridges between groups (hierarchical and functional) in all sectors of society (private, public, and community). This has created a unique opportunity to collaborate and mobilise institutions that historically would not work on the same project, which is critical to the development of new research approaches.

Workshop 2, carried out on the 26th and 27th of January 2023 focused on receiving feedback from stakeholders and on collaborating towards common goals of ensuring science-informed and people-centred decisions. This included discussing the results of the initial phase, identifying project partners for the main phase(s) and gathering further recommendations from participants for the main phase. In addition, a general agreement on the selected areas for potentially suited pilot sites to test new technologies and IWRM and governance measures were achieved (short reports on the workshops can be found in Appendix 7.5 and 7.6; Table 2 provides a list of the selected sites). Subsequently, many of the stakeholders decided to participate in the main phase of the project. Appendix 7.8 includes the letter of interests (LOIs) from mining companies, research institutions, government agencies, water associations and foundations, start-up companies, and community champions. In these LOIs, stakeholders commit themselves to actively contribute to or participate in MAMDIWAS in different ways, depending on their own goals, e.g.:

- provision of access to surface facilities of water treatment systems / to lab facilities,
- knowledge sharing based on full-scale plants experience (generic),
- participation in the steering committee of the network,
- performing water analysis and/or pilot experiments,
- provision of laboratory facilities to do development work that defines site pilot experiments,
- provision of a pilot site for treatment of MIW; support with pilot plant experiments,
- provision of a pilot site to demonstrate peri urban RENEWW[3] zone through Urban Living Labs[4] for community to undertake income generating activities; transformation from a mining to a post mining city/region,

[3] Renewable Energy, Nutrition, Environment, Water and Waste (RENEWW) aims for development of sustainable measures and considering the needs of the surrounding communities. RENEWW zone is a decentralized, closed loop model of spatial planning and peri-urban service provision that replaces fossil energy with renewable energy, derives new water, biogas, and fertilizer from wastewater, and produces food and biofuel with the recycled inputs, all co-generated at near net-zero waste.

[4] Urban Living Lab aims to create a platform for the collaboration between key stakeholders such as civil society, public institutions, academia, and the private sector to showcase sustainable interventions and inclusive development (McCormick &Hartmann, 2017; Sarabi et al., 2021). They provide a learning environment to co-identify problems, co-create solutions and co-implement actions with all stakeholders in a real-life setting ensuring an integrated approach that aims to deliver liveable and accessible cities for all (Mahmoud et al., 2021; Sarabi et al., 2021). Urban Living Labs test innovative solutions providing learnings that can be transferred into scaled up potential solutions which is a pivotal step towards transformative change. In the Urban Living Lab approach, community engagement occurs at the earliest during project initiation. The project results are then handed over to the community for sustainability.

- provision of capacity building through trainings, peer to peer learning and collaboration with water operators related to wastewater management during mining and post mining phase,
- provision of training opportunities for students and staff exchange,
- provision of water analysis data from different sources, of samples and of other information (e.g., location maps),
- participation in network events and workshops; if applicable, participation through lectures (e.g., in the context of events for young scientists),
- participation in the socio-economic and community engagement activities at the project site,
- reviewing of proposals, technical reports, and articles generated from the project,
- support in the areas of dissemination of results and transfer potentials.

Further on, some stakeholders, especially the mining companies, formulate not only their commitment but also their willingness to contribute to the project with their own funds. Other opportunities for financial support to MAMDIWAS are seen through the South African Water Research Commision (WRC).

WP II: Research fields & definition of criteria for the selection of case studies

The main research fields and the criteria catalogue for selecting representative case studies were discussed, identified, and specified in collaboration with local partners, primarily through online meetings with the MAMDIWAS project team, but also through workshops, site visits, and expert interviews mentioned above. At this point of the project, no research areas other than the three pillars mentioned above have been identified.

For the identification of the most suitable sites for the pilot plants in the main phase the list of selection criteria included the following aspects:

- safe implementation of the pilots (permanent monitoring by safety personnel),
- treatment methods currently in use and the state of local water networks,
- optimal general conditions for the operation: guarantee of energy, mine water in necessary quality and quantity, possibilities for wastewater disposal,
- periodic provision of analytical data of mine water and treated waters,
- access to the pilot plant is always allowed,
- potential renewable energy sources,
- possibility of maintenance by on-site personnel, and
- high self-interest of the potential operators of a later technical plant (e.g., mining companies, energy producers).

For the focus on sites or regions where IWRM and governance measures have high priority and which are significantly impacted by MIW, both anthropogenically and ecologically, the list of selection criteria included the following aspects:

- local water quality characteristics regarding MIW, surface water, drinking water and irrigation water,
- local water availability, clean water needs and water reuse options,
- product water quality requirements for reuse and regulations of local authorities,
- land-use types as boundary conditions for pollutant sources, impact zones, and potential reuse options,
- availability of urban basic services (provision of water, sanitation, solid waste, transportation, energy, and mobility) and public health care and education facilities,

- potential environmental impacts on water contamination, risks to neighbouring communities (sensitive to the local environment), and
- social impacts (socio-economic status, local community's willingness to cooperate and participate, potential marketing for the recyclables/products generated, availability of local labour).

WP III: Investigation of local conditions and infrastructure

The MAMDIWAS core team conducted several site visits to understand the local conditions not only with respect to MIW and wastewater treatment, management, and reuse, but also to water pollution, water availability, and access to sanitation. A respective list of conducted site visits can be found in Table 6 in Appendix 7.2. In addition, knowledge was gained through interviews, round table discussions, and extensive review of literature and recent technical reports. A list of the literature evaluated can be found in Appendix 7.7. Information according to the criteria developed in WP II was collected in order to allow the consortium in WP VI to decide which mining sites are most suitable for conducting representative case studies in the main phase.

After the site visits, interviews, and discussions, it became clear that the most appropriate technology for treating MIW must be site-specific, and that a variety of general concepts for MIW treatment have already been developed and tested in RSA. These include passive and active treatment processes such as neutralization by alkaline additives, hydroxide and sulfide precipitation, biological sulfate reduction, ion exchange and even ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). The main challenge for the operation of the dense membranes used for NF and RO is not so much the stability to AMD acidity as thought before starting the initial phase, but the fouling and scaling issues caused by operating at the saturation limit of the feed. It is also recognized that reuse of the water produced during treatment is possible for a variety of value-added applications and that this, along with the recovery of marketable products, represents an opportunity that can increase acceptance of the technical implementation of treatment plants.

One interesting concept with respect to that is the cascade scheme depicted in Figure 3. This cascade targets AMD, i.e., the dominant type of MIW in RSA enriched in sulfate and iron by microbially catalyzed oxidation of iron sulfide pyrite, marcasite, and pyrrhotite. In this concept neutralization, sulfate removal and membrane desalination are considered as crucial steps. This example shows that RSA has immense knowledge and technical expertise to design and implement on-site technologies to treat MIW/AMD. . A famous example for the realization of this concept is the multistage eMalahleni Water reclamation plant in the Nkangala District Municipality of Mpumalanga province, which was commissioned in 2007. In stage 1 of the so-called HiPRO process water is oxidized and neutralized by limestone neutralisation and the sludge is removed by clarification. UF acts as a pre-treatment for RO where the permeate recovery is 65%. The RO retentate is conveyed to stage 2 where precipitation (as high-density sludge process = HDS) is followed by hydro cyclones, clarification, and membrane processes like stage 1 (permeate recovery 65%). The RO retentate is further treated in stage 3 which is like stage 2. Final brine is formed in the stage 3 RO process. The chemical gypsiferous sludge is removed from all three clarifiers for further treatment. The produced water is of potable water quality and complies with requirements the RSA potable water standard SANS 241 sets for water for lifetime consumption. The eMalahleni municipality is the main user of the product water which does not require further treatment for drinking water supply. The treatment cost is 1.50 US $ /m^3 and the municipality pays 1.00 US $/$m^3$ for the water. The energy consumption of the plant is 2.5 kWh/m^3.

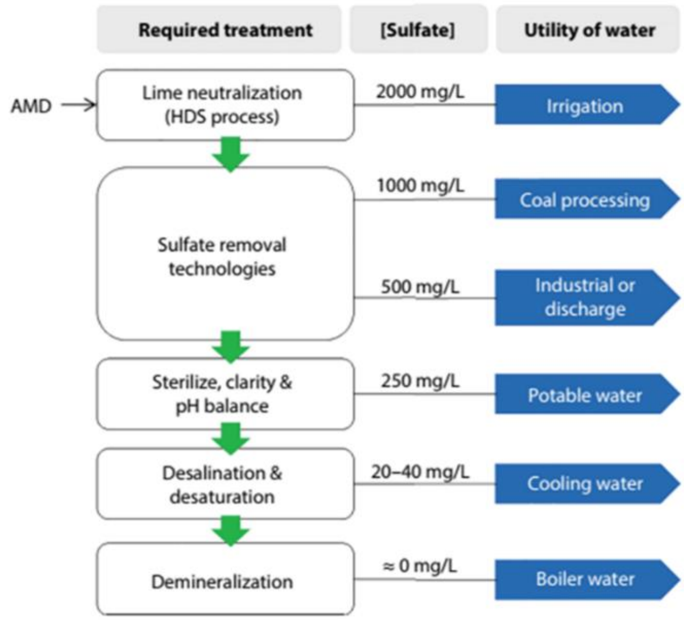


Figure 3: *Cascade concept for AMD treatment*[5]

Although this concept is already remarkably close to the idea of a membrane-based recycling plant, the technical implementation of MIW treatment plants of this complexity has so far only been realized in a very few cases. Mining companies lack the motivation to comply with national regulations, which clearly stipulate that MIW must be treated before discharge into the environment. Besides the prohibitive costs of treatment there are many other challenges, including sludge and brine management, high energy consumption, lack of maintenance, problems related to poorly performing processes (e.g., membrane blockage) but also insufficient funding for water infrastructure, water resource management, and research projects. Thus, in most cases, MIW is treated if at all, then merely neutralized prior to discharge into the river systems, and the water has no direct benefit to the surrounding communities including the mining houses. These traditional treatment methods are not tailored to water reuse and material recycling, which could reduce overall costs as in the case of eMalahleni.

The benefit of water reuse is essentially only considered in the operating environment of the mining companies themselves, i.e., the use of the water for tasks within the mine or to supply mine workers. Therefore, only as much water is treated as is necessary for these purposes. The broader potential that lies in treated water for SMME development (e.g., fish farming, bottled water) or for land reuse in the mining closure phase to create income opportunities in the community for transition to sustainable livelihoods and preparation for mine closure is not seen.

In addition, much research is being done in RSA on the reuse of valuable materials from MIW. The following are mentioned as potential recyclables: e.g., gypsum products that can be used in the construction industry, iron-based pigments (recoverable from iron ores such as goethite and hematite, iron-rich coagulants (e.g., essential for water treatment), sodium carbonates (for neutralization process), sulfuric acid and rare earth elements. However, there are currently no studies on whether there is even a market for these recyclables that would justify the costs of recycling, nor are there any studies on the

[5] Image taken from: Fosso-Kankeu, E., Wolkersdorfer, C., & Burgess, J. (Eds.). (2020). Recovery of by-products from acid mine drainage treatment. John Wiley & Sons

environmental impact of the technologically very demanding and energy-intensive task of separating the recyclables.

Another major problem has been the insufficient or inadequate technical training of the staff responsible for treating wastewater and reusing water, which usually requires advanced technologies, and the lack of companies to maintain the systems. There is simply a lack of appropriate capacity building.

It was recognized that, contrary to initial thinking, potential on-site renewable energy sources would not be relevant to the main phase. Although there are efforts by mining companies to support its own energy supply with renewable energy, there is currently a lack of opportunities on site to operate a pilot plant with it. Moreover, stakeholders repeatedly emphasized the safety issues at abandoned mines due to illegal miners and property theft, and discouraged piloting at these mines.

Through the discussions at the 2nd workshop with representatives of RAG, it became clear that mine water treatment for water reuse could become necessary even in Germany due to tlocal water shortage that is also expected in Germany in the future.

WP IV: Sustainable water resources management, transboundary effects, and transferability

RSA is characterised by local authorities and water experts as a water scarce country. This is mainly attributed to the arid and semi-arid climate prevailing in large parts of the country. In addition, river systems and groundwater bodies are often heavily polluted due to intensive mining activities in the past, making these resources unsuitable for human consumption or irrigation.

The Gauteng Province where all MAMDIWAS pilot and case studies are going to be located (see section on WP VI), is the capital province and the biggest economic hub within the country. It receives most of its water supply from the Lesotho highlands (via the Orange and Vaal River systems) and the Eswatini highlands through inter-basin transfer. This inter-basin transfer poses major challenges regarding the management of the available water resources, high energy consumption, and infrastructure, including high building and maintenance costs and the risks of long-distance water transport. Upstream-downstream water use conflicts prevail, both in terms of water quality and quantity. This is the case not only for provinces in RSA but also for other countries downstream of RSA.

Despite water quantity and quality problems, there are available water resources in Gauteng Province that are underutilised. Among these, MIW and treated wastewater are the largest untapped resources. Large amounts of MIW are currently needed to be pumped out across various underground mines in the Witwatersrand basin. These waters are often only neutralised via pH-adjustment and then discharged into the river systems, with potentially serious consequences for the environment and water users downstream. A study by the Strategic Water Partners Network (SWPN) has indicated that the MIW currently being discharged from the Witwatersrand basin has the potential to close the gap of water deficit that characterised the Gauteng Province, and this will not only mitigate environmental issues but could also be economically feasible as compared to the inter-basin transfer system that comes with high costs.

Although the often-devastating environmental impact of untreated MIW is well known to stakeholders in RSA, the environmental damage and associated economic costs are not seen as an additional argument for adequate treatment of all MIW generated. The MIW that is discharged from operational and non-operational mines (which include the abandoned mines) also causes uncontrollable discharge to the river systems that are ultimately used as a water source for downstream uses, such as agricultural activities. This leads to water use competition instead of water use cooperation between the mining and the agriculture sector which are the two biggest water consumer industries in South Africa. The current conditions indicate that the agriculture communities have concerns about water quality and quantity received further downstream. This not only negatively impacts the livelihoods of the farming communities but also poses a severe threat to national food security. The work that is being done by Stellenbosch University (SUN) on evaluating the effects of MIW on aquatic ecosystems, using effect-based methods, indicates that the contamination of the river system in the area such as East Crocodile River in the study area harms the aquatic system and could lead to the extinction of fish species, and above all could pose a serious health threat to the population that depends on the rivers for the livelihoods, especially the economically vulnerable part of the population.

There is a lack of institutional water quality monitoring in RSA and thus early warning systems for authorities and the population. By applying IWRM a comprehensive overview regarding occurrence of pollutants and their sources needs to be established. Within the initial project phase of MAMDIWAS three kinds of water samples were taken in the study area, as a first glimpse:

1. drinking (tap) water from Johannesburg City
2. MIW from Black Reef Krugersdorp
3. surface water from East Crocodile River (Merafong area)

The drinking water sample was analysed at the IWW lab in Germany by non-target/suspect screening and showed the occurrence of 7 herbicides, 2 fungicides, 1 artificial sweetener, and 10 pesticide metabolites. The concentration of 13 of these substances were below 100 ng/L and the remaining substances below 1,000 ng/L. 3 substances featured concentrations higher than the threshold provided by the European drinking water directive.

The MIW sample was analysed for inorganic substances. It showed, as expected, elevated concentrations for multiple metals, such as Fe with 154 mg/L and Mn with 26 mg/L.

The surface water sample was analysed at the IWW lab by non-target/suspect screening and included 87 organic pollutants (see Appendix 7.4, Table 9). The concentration of 75 pollutants were below and those of 12 pollutants above the threshold of 1,000 ng/L. They include a wide range of anthropogenic sources, such as pharmaceuticals, pesticides, and industrial chemicals.

As the first main phase of MAMDIWAS, which is dedicated to research, will introduce multiple biological assays to determine the toxicity, both ecological and human, of the MIW resources, it is important to already know the pollution level in both study areas. Hence, the comparison of inorganic and organic substances will allow to derive a link between toxicity and pollutant groups. So far, no such data and comparison have ever been published for South Africa. Even though inorganic substances will be the focus of MIW analyses in MAMDIWAS, the holistic IWRM approach, including bioassays, requires a full analysis of the occurrence of pollutants in general. Hence, the impact of MIW on local water resources can be evaluated and toxicity results classified.

WP V: Governance and capacity building

A review of governance, regulatory and legislative structures on MIW treatment in RSA was carried out. Key environmental regulations authorities in RSA are:

- Department of Water and Sanitation (DWS)
- Department of Mineral Resources and Energy (DMRE)
- Department of Forestry, Fisheries, and Environment (DFFE)

DWS is the first level that has overall responsibility for water management and particularly interest on mine water management. In addition, NEMA (National Environmental Management Agency) plays a crucial role in cooperative environmental governance. DWS works with entities such as Catchment Management Agencies (CMA) and the local water service authority (WSA) CMA is responsible for allocating, authorizing, and controlling water use under the National Water Act (NWA) while the local WSAs are responsible for guaranteeing reliable access to water services for all inhabitants (including industry) on the regional level, which would cover the decision to use mine water as a resource. The DMRE is tasked to ensure that the mines in particular adhere to their mining license conditions and is responsible for ensuring that the mineral resources are effectively developed. DFFE, both at the national and provincial levels, is responsible for ensuring that industries such as mines meet required environmental standards.

Regulations that support the Environmental Act and relate to mining include:

- National Water Act No 36 of 1998
- Hazardous Substances Act No. 15 of 1989:
- Mineral and Petroleum Resources Development Act, No 28 of 2002 (MPRDA)
- National Environmental Management Act No 107 of 1998 (NEMA)
- National Environmental Management: Air Quality Act No.39 of 2004 (NEM: AQA)
- National Environmental Management: Biodiversity Act No 10 of 2004 (NEM: BA)
- National Environmental Management: Protection Areas Act No 57 of 2003 (NEM: PA)
- National Environmental Management: Waste Act No 59 of 2008 (NEM: WA)

Water quality monitoring, such as the river monitoring conducted by DWS in conjunction with DMRE and DEFF, is undertaken under the responsibility of DWS. Despite these monitoring efforts, IWRM challenges remain, particularly with respect to unaligned policy, legal, and administrative frameworks, inadequate practices, inefficient knowledge and information management; inadequate funding, compliance, and enforcement, and unclear roles and responsibilities with respect to water quality management.

In 2021 DWS has set out a plan for managing pollution and mine water quality with key priority areas that include, water resource Management recovery plans (60% improvement of water quality until 2024), improved intergovernmental intervention plans and well capacitated officials through training programmes.

In addition to this, the nine existing river catchment agencies are facing challenges in terms of funding and shortage of skilled staff. The DWS as custodian of water resources in RSA has done immense work in the past years to improve and integrate the management of water resources, among these, including the establishment of the WRC which played a vital role in providing the knowledge about the conditions of water resources in terms of water quality and quantity. Additionally, DWS funds various non-profit organisations that work on neutral grounds to build cooperation between the private sector and the public sector, one such organisation is the SWPN which has done much research work to address mine water issues, mainly in the coalfields of the Mpumalanga province.

WP VI: Data analysis and selection of three case studies

After analysing and evaluating the data collected and the information obtained from the workshops, the findings and challenges related to the three pillars and the main phase of MAMDIWAS can be summarized as follows:

Pillar 1:

- Proven technological solutions for MIW treatment including membranes such as UF, NF, and RO are already existing.
- Installations demonstrating the successful use of treated MIW for drinking water supply are already

existing.

- Appropriate technology for treating MIW must be site-specific but neutralization, sulfate removal and membrane desalination play a key role the last especially for water reuse.
- Lack of disposal or further treatment concepts of waste products generated from improved treatment technologies such as RO/NF rejects.
- Failure of a wider implementation of existing technologies due to
    - excessive operating and investment costs, which are also caused by non-optimal treatment processes or non-optimal tuning of the treatment steps,
    - lack of coordination between the government, public sector, and local communities,
    - insufficient political pressure, lack of recommendations for action.
- Processing residues are considered as waste to be disposed of and not as potentially valuable materials, lacking technological concepts and strategies for the recovery of valuable materials.
- Conventional RO and NF cannot achieve selective recovery of valuable metals.
- Missing link of Pillar 1 to capacity building, IWRM and governance aspects of MIW.
- Missing business case models for circular economy incl. LCA.
- Security problems in abandoned mines due to illegal miners and theft of property make piloting in these mines impossible as part of a research project.
- Although there are efforts by mining companies to support its own energy supply with renewable energy, there is currently a lack of opportunities on site to operate a pilot plant with it.
- Insufficient or inadequate technical training of responsible staff and a lack of companies to maintain the systems.
- MIW treatment for water reuse could become necessary in Germany as well due to the local water scarcity that is also expected in Germany in the future.

Pillar 2:

- Although IWRM concepts are part of national water and environmental planning strategies, there are neither regulations that support and direct the implementation of IWRM concepts nor are they linked to MIW treatment.
- The IWRM approach should focus not only on impacts of MIW but also on relating it to other water pollutants. Water pollution in SA stems from various sources, including MIW emanating mainly from gold and coal mines, agricultural water with high nutrient and pesticide concentrations, sewage water overflows from WWTP, and emerging pollutants.
- MAMDIWAS requires a view on and mitigation of MIW pollution in a holistic manner and on the river (sub)catchment scale including all relevant water quality/quantity impacts and conflicts downstream for transparent water reuse options.
- There is a general lack of water quality/quantity data, especially of near real-time water quality data and information for downstream water users. No joint monitoring concept for water quality is applied on the required geographical and temporal scale.
- Lack of integration of collected data and missing information for water users.
- Potable water demand is projected to increase for households, farming (food security) and industrial use (economic development) while water quality levels and an increase in droughts due to climate change are limiting available water resources.
- Water reuse concepts and management are missing

Pillar 3:

- Although there is a profound policy and legal framework for sustainable MIW management in RSA, challenges still need a further innovative approach to improve the system.
- There are regulations gaps for different scales of water reuse (especially small and pilot projects) and stages of MIW (operation, closure, and post-closure (abandoned)
- There is a lack of trust and fruitful transparent communication channels among stakeholders.
- The broader potential that lies in treated water for SMME development (e.g., fish farming, bottled water) or for land reuse in the mining closure phase to create income opportunities in the community for transition to sustainable livelihoods and preparation for mine closure is not seen.
- There is a lack of public-private partnerships (PPP) to finance MIW treatment and rehabilitation of abandoned mines.
- Inadequate institutional arrangement for streamlining procedures, approvals, and upgrades such as SMME, innovations hub for governance, financial institutions, PPP, etc.
- The South African historical records indicate that there is poor compliance and monitoring of water quality standards.
- Lacking financial mechanisms including incentives mechanisms (at various stages of MIW management).
- There is a great need for capacity building activities in the public sector (especially among service providers and utilities) in terms of improving skills, tools, and methodologies, and establishing peer-to-peer learning collaborations.

One of the main project results of the initial phase of MAMDIWAS was the selection of the case studies for the first WASA main phase. Through several discussions within the MAMDIWAS project team and with other stakeholders, it was recognized that, contrary to initial thinking, the case study sites for the technology, IWRM and governance pillars 1, 2 and 3 need not necessarily be the same. Although the application of an appropriate technology with a technical-scale plant will have an impact on a study area, a small pilot plant will not. The same is true for the IWRM measures. Therefore, different criteria were established, for the final selection of the case studies and the pilot sites, but care was taken to ensure that they were in the same areas and as close to each other as possible. As a result, two pilot sites or case studies for each pillar are being investigated in RSA, and an additional pilot is being conducted in Germany.

Merafong area and Mogale area, both in the Gautanc province, has been selected as the area for further investigations and for the pilot and case studies in the main phase. Gautenc area is divided into two river catchment systems, the Upper-Vaal catchment in the south of Gauteng (Merafong area) and the West Marico Crocodile catchment in the north of Gauteng (Mogale area). Gauteng is the most densely populated province in the country and reported to receive up to 100% of its water through inter-basin transfer schemes. Both catchment systems provide water for irrigation purposes further downstream, with some river systems flowing into key national parks and heritage sites. The inter-basin system is a high energy demand system that also harms the environment, hence there is higher interest within Gauteng Province to reuse treated water. MIW is an alternative water source that can potentially reconcile water shortage in the area. Furthermore, there is a growing interest in small-scale farming and garden farming that rely on surface water within the Gauteng Province, consequently, proper water quality and quantity monitoring are essential for water balance and adequate water allocation.

Although the Gauteng Province does not share physical boundaries with any neighbouring country, hydrologically is connected to the river systems that flow across the South African boundaries, an example is the West Marico Crocodile catchment system that supplies water to the Limpopo River which ultimately discharges the water into countries like Mozambique and Swaziland. Historically, there have been some concerns from neighbouring countries about the water quality that flows across their boundaries from RSA, as consequence committees constituted by members from multi countries have been formed to address these challenges.

The model character of Gauteng Province will not only allow to integrate centralized and decentralised water resources management, governance strategies and measures into the IWRM approach, but also to transfer the project outcomes to other areas within the Southern African Development Community (SADC).

It is indicated at Gauteng Province, that several of the mines that are currently in operation will be closing within a five to fifteen years period. There is a transition from a mining-based society to a post-mining society within Gauteng Province. Several key steps involved in the transition are:

1. Reclamation and restoration: Reclaimed and restored mine sites can be used for a range of purposes, including agriculture, residential, commercial, and industrial development.
2. Diversification of the economy: Diversifying the economy away from a reliance on mining is essential for a sustainable post-mining society. This can involve investing in new industries such as renewable energy, technology, and tourism.
3. Skilling and reskilling the workforce: Training and upskilling the workforce to meet the demands of new industries is crucial for a successful transition to a post-mining society. This can involve vocational training, apprenticeships, and retraining programs.
4. Community engagement: Engaging with local communities is essential for a successful transition to a post-mining society. This can involve communities in decision-making processes, providing support for local economic development, and ensuring equitable distribution of benefits from post-mining activities.
5. Environmental protection: Ensuring the protection of the environment is crucial for a successful transition to a post-mining society. This can involve implementing effective environmental management systems, monitoring, and managing the impacts of post-mining activities, and restoring degraded environments.

The two local municipalities of Merafong City and Mogale City are part of the Guateng City Region's western development corridor, which is focused on mining, tourism, agriculture, and creating a green and blue economy. The West Rand District is the most sparsely populated part of Gauteng and accounts for 6% of the total Gauteng population (15.81 million). Both are experiencing a decline in population due to the declining mining sector and the accompanying economic decline and resulting low quality of life. The factors leading to the migration of people to other communities in search of better opportunities and a higher quality of life. The farming and informal settlement communities in Mogale City are highly dependent on the water supply from the mines. Unlike most communities served by Rand Water, it is inevitable that with the impending closure of the mines, human welfare, productive agriculture, and environmental sustainability will be severely impacted. In Mogale City, the impoverishment of communities dependent on the Wonderfonteinspruit, which flows through the habitat of 400,000 or more people on its way to the Vaal, is not foreseeable until water quality is good enough for food, vegetation, livestock, and irrigation. The environmental challenges also make for a bleak prognosis for the future, especially for poor, vulnerable communities. The river system and wetlands, as natural water sponges, are serverely polluted. MIW seepage into clean water is a serious problem as it affects streams in the river basin. Re-mining and poorly managed open cast mining activities contribute to the environmental decline.

The case studies selected for Pillar 2 are typical - one rural and one urban - for MIW environments and communities in RSA, and, in particular, the mining hub of Gauteng Province (see Figure 4). The Black Reef case study area, which drains into the Eastern Crocodile River basin, is located in a rural part of the Mogale area near Krugersdorp. The headwaters are heavily impacted by MIW, which has caused the death of wildlife downstream and hence the closure of a National Park, which negatively impacts the local economy. In addition, local farmers and villages cannot rely on secure water resources. The Merafong case study area, which drains into the Vaal River, is located in the sub-urban western Johannesburg region. Here, large scale mines dominate the local economy. They are currently downsizing staff, expecting high social impacts in the region. With these case study sites also international transboundary effects are considered. In case of i) Black Reef, the Eastern Crocodile River flows via Komati River to Mozambique, and in case of ii) Merafong, the Vaal River flows via the Orange River to Namibia. Both experience high MIW impacts in the study areas, which have high impacts on the environment and anthropogenic water uses downstream.

In total, six of the stakeholders (including RAG from Germany) agreed to provide a pilot site for MIW treatment in Pillar 1. Although all pilot sites are suitable for the demonstrations planned in the main phase, the core team decided to select two pilot sites for gold mining, offered by Sibanye Stillwater in Gautenc Province and one by RAG in Germany. The decision was made on the basis of the list of criteria (see section on WP II) on the one hand, but also in order to involve the mining companies with the pilot sites, whose commitment is necessary for the later implementation. The respective two pilot sites are "Driefontein South" in the Merafong area (pilot site 1 in Figure 4) and "Cooke 3" (pilot site 2 in Figure 4) in the Mogale area and close to Black Reef.

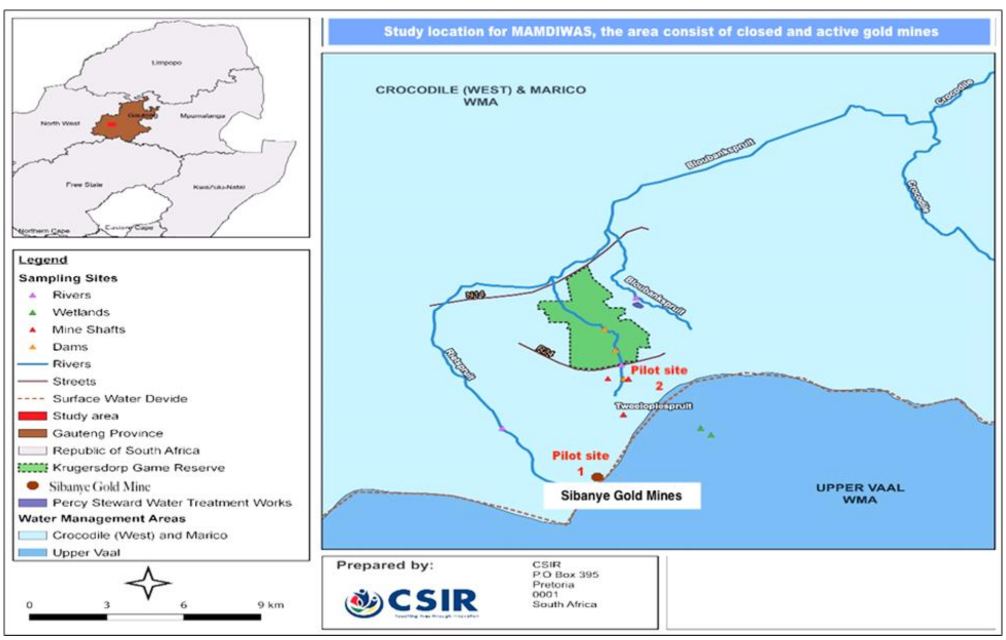


Figure 4: *Gauteng Province with pilot sites.*

Based on a brief assessment of the socio-economic situation and stakeholders, Driefontein in the Merafong City community and Wonderfontein/Lancaster in the Mogale City community and beeing close to the Black Reef area have been selected for Pillar 3. Table 2 shows all in RSA selected sites demonstrating the strong overlap.

Table 2: *Selected sites in RSA with respect to the research pillars*

Pillar	Site 1 in Merafong area	Site 2 in Mogale area
1	Sibanye Gold Mine: Driefontein South	Sibanye Gold Mine: Cook 3
2	Merafong area (Vaal River catchment)	Black Reef (Eastern Crocodile River basin)
3	Driefontein community	Wonderfontein/Lancaster community

WP VII: The main phase's strategy, concept, and work plan.

An important goal of WP VII was to attract mining companies to participate in the main phase. Indeed, two large companies were recruited, one German and one from the RSA (see list of LOI in Appendix 7.8). In addition, several other companies and stakeholders have sent their LOI to participate in the main phase. The successful stakeholder engagement in the initial phase of the project has enabled a holistic co-design approach involving cross-sectoral stakeholders in the development of the strategy and concept for the main phase. The ideas that shaped the concepts for moving forward and identifying focus areas were consolidated mainly through the input of the two workshops. The following conclusions for the main phase could be drawn from WP III, IV, and V:

Pillar 1:

- Further research is needed on process intensification and integration using membrane technologies to recover water and materials for further use. Process intensification means optimizing processes that have already been investigated and proven as potentially suitable but have nevertheless not become established in order to increase their efficiency and effectiveness.
- There is a need for smart integration of individual processes into an optimal overall process to leverage synergy effects that significantly increase the overall attractiveness of a technical implementation of MIW treatment.
- Alternative technologies for metal recovery such as modified NF need to be investigated and adapted.
- For safety reasons, pilot studies are not conducted in abandoned mines. However, piloting should be planned in such a way that the results are transferable.
- Due to the lack of on-site possibilities to operate a pilot plant with renewable energies, this topic is only treated theoretically.
- Neutralization, sulfate removal and membrane desalination will play a significant role in the technical concept.
- The piloting in RSA will be preceded by a piloting phase in Germany to test the technical concept at a representative German mine and to optimize the pilot plant.

Pillar 2:

- Further research on the occurrence and fate of MIW in the aquatic system is needed. In order to be able to classify the share of MIW in the overall pollution, it is necessary to survey relevant hydrological parameters, determine the total pollution load, and identify possible pollution sources.
- Continuous measurements of the input of MIW in terms of quantity and changes in concentration over time are required to determine the fate of the substances in the water body such as dilution, accumulation in sediment and effects downstream.
- There is a need to integrate future climate projections into IWRM, as due to climate change water levels have become more variable.

- An assessment of the eco- and human toxicity of the surface waters into which MIW is discharged is needed, as water is often used downstream for purposes such as irrigation and drinking water.
- Integration of collected water quality data and sampling campaigns (bioassays, inorganic targets, non-target) is needed to close the gap of missing information for downstream water reuse.
- Due to the country's water scarcity, ongoing pollution, increasing water demand and the future uncertainty of water supply due to climate change, reuse of MIW is needed to be seen as the "next reservoir" to increase water security.
- MIW reuse is a key issue for the MAMDIWAS main phase.
- National and international transboundary impacts need to be considered as MIW causes environmental and societal burdens downstream.
- IWRM (Pillar 2) and governance (Pillar 3) need to be interlinked to increase water security in RSA.

Pillar 3:

- A suitable use of reclaimed and restored mine sites has to be identified that is based on the needs of surrounding communities, such as agriculture, residential, commercial, and industrial development.
- Strategies to diversify the economy away from a reliance on mining are essential for a sustainable post-mining society. This can involve investing in new industries such as renewable energy, technology, and tourism.
- Training and upskilling the workforce to meet the demands of new industries is crucial for a successful transition to a post-mining society. This can involve vocational training, apprenticeships, and retraining programs.
- Involving local communities is critical to a successful transition to a post-mining society. This can involve communities in decision-making processes, support local economic development, and ensure equitable distribution of benefits from post-mining activities.
- Ensuring the protection of the environment is crucial for a successful transition to a post-mining society. This can involve implementing effective environmental management systems, monitoring, and managing the impacts of post-mining activities, and restoring degraded environments.
- Reviewing national and local regulatory frameworks and investigating and clarifying legal issues related to the work of CMAs are necessary to address existing gaps that could hinder the implementation of mine water management projects.
- Establishing strong co-development partnerships between African and European partners and ensuring recommendations for regulatory frameworks are co-created.
- Capacity building measures must be taken to provide adequate training for staff responsible for treatment and maintenance.
- Promoting peer-to-peer learning collaborations is necessary to ensure that water operators and water associations can share knowledge and skills and learn from each other in cross-sectoral areas such as water supply maintenance, water quality monitoring, and regulatory enforcement.
- Long-term management of mine water infrastructure requires close collaboration between mining companies, regulators, investors, spatial planners, and local communities. This is essential for repurposing former mining sites and identifying the most sustainable future uses of land and treated water to maximize socioeconomic development. Therefore, one task is to promote strategic partnerships to overcome the lack of funding and capacity.

In addition to the conclusions within the three pillars, we have identified the following **overarching topics** which have to be considered when developing the concept for the main phase:

- The economic and ecological aspects of reusing the water and recyclables have been identified as additional important research or development fields for the MAMDIWAS main phase. The underlying question is how best to use the recycled water to produce high value products (e.g., fish farming or bottled water).
- Furthermore, the extent to which recycling of valuable materials is worthwhile from an ecological (life cycle analysis) and economic (business models) perspective must be clarified
- There is a strong need to establish a communication platform for stakeholders to open the channels of dialogue and collaboration.
- There is a need to engage the community and the local stakeholders as early as possible on the overall phase of the project.
- There is a need to explore public-private partnerships to finance MIW treatment projects, especially in abandoned mines and in higher environmental liabilities areas. The option should include the development of a business model for MIW management, based on the recovery and reuse of valuable products from mining wastewater.

The work plan for the main phase which is based on the listed conclusions is described in detail in chapter 4 of this report.

4. MAMDIWAS main phase's strategy, concept, and work plan

4.1. Research approach

The MAMDIWAS research approach is based on the strong belief that only a strong interlocking of technological innovations, integrated water resources management as well as governance and regulatory framework aspects, can reduce barriers with regard to the implementation and acceptance of MIW treatment and thus improve water security in RSA.

The breakdown of the initial phase work packages into the three pillars was, from the point of view of the project consortium, an essential prerequisite for success and has decisively increased the attractiveness of the project idea for the stakeholders, since it could be shown that it is precisely the combination of these three Pillars that has a strong leverage effect for the implementation of mine water treatment projects. Therefore, it was decided to stick to the original structuring also in the main phase concept (see Chapters 4.3, 4.4, 4.5).

An important objective of the concept is to interlink all Pillars and to use each other's results to contribute to the holistic approach of MAMDIWAS. An MIW specific IWRM approach will be adopted to consider local conditions. This includes a screening of pollutants entering the aquatic environment and their subsequent fate. Further on, detailed sampling campaigns will be conducted to assess the load and variability of inorganic pollutants from MIW in surface waters and sediment. In order to evaluate the impact of the MIW, novel ecotoxicity sensors will be applied as well as human toxicity assays. Another important IWRM task is the analysis of water uses to quantify the reuse potential of MIW adequately treated for this purpose (link to Pillar 1). As potential MIW re-use needs to factor in social and governance aspects, it will be a joint approach of Pillar 2 and Pillar 3. The approach for Pillar 3 is to conduct a "State of the Art" analysis on the existing policies and regulations and the extent to which these measures have been implemented and the gaps identified. This will be recommended through regular consultation, assessment, and in-depth analysis. This approach aims to ensure that sustainable strategies and innovative solutions are embedded in local, provincial, and national policies. By identifying gaps in existing policies and regulations, identifying local needs, and drawing lessons from all Pillars, the goal is to create synergies between incumbent providers and water operators in Europe and their South African counterparts. Pillar 3, through the Urban Living Lab approach, also emphasizes the importance of involving all the relevant stakeholders from the public sector, private sector, civil society, and academia from the onset through the establishment of co-production partnerships. Community participation and stakeholder consultations will be conducted throughout the project from early stages. Pillar 3 aims to recommend a strategic plan for community skills development and integrated income generating interventions for the local communities with special consideration to the post-mining phase.

MAMDIWAS will be consulted through GWOPA's[6] online community and membership in the wastewater and sanitation community of practice since the associated project partner UN-Habitat[7] (see Chapter 4.2) is a member of GWOPA. The secretariat of GWOPA could also support in identification of water operator partnerships (WOPs) around participating utilities and prospective mentor utilities around the world working on MIW.

As capacity building, training, technology, and knowledge transfer are critical components for sustainable development and progress, the MAMDIWAS main phase concept will dedicate a separate work package to these aspects. By investing in these areas, societies can unlock their full potential, enhance human capabilities, promote innovation, and address complex challenges more effectively. Empowered individuals, equipped with the right skills, knowledge, and resources, can drive positive change, foster inclusive growth, and create a brighter future for themselves and future generations. The aim of this part of the concept is to train both academic and industrial professionals who can help build local capacity and promote entrepreneurship in response to the needs of RSA communities. The idea behind this is that it will create network structures between research and industry, including the important promotion of membrane-based technologies. GWOPA will also provide co-development, peer learning, knowledge exchange and sharing.

Already in the first main phase of MAMDIWAS important tasks and measures for the later second phase which is dedicated to the implementation in practice shall be tackled in order to set the course for the success of the overall project at an early stage.

The project outcomes will be disseminated, strengthening capacity, knowledge, and skills, especially to service providers and water operators. This will be one of the important elements for monitoring and evaluation sustainability. Project results will also be disseminated by the GWOPA network.

[6] The Global Water Operator Partnership Alliance (GWOPA) is a global network that promotes and facilitates water operator partnerships (WOPs) to improve water and sanitation services worldwide. It was launched in 2009 as an initiative of UN-Habitat, the United Nations Human Settlements Programme. The primary goal of GWOPA is to enhance the capacity and performance of water and sanitation operators through partnerships and knowledge exchange. WOPs involve collaboration between water and sanitation service providers, with one operator assisting another to address specific challenges, improve operational efficiency, and enhance service delivery. GWOPA serves as a platform for sharing best practices, experiences, and expertise among water operators, utilities, and stakeholders. It provides guidance, tools, and resources for establishing and implementing WOPs, including capacity building programs, training workshops, and networking opportunities. The alliance also advocates for the importance of effective water governance and supports the implementation of the Sustainable Development Goals (SDGs) related to water and sanitation.

[7] UN-Habitat is the United Nations program responsible for promoting sustainable urbanization and addressing urban challenges around the world. It works towards achieving inclusive, resilient, and sustainable cities and communities. UN-Habitat collaborates with numerous institutions, centers, and organizations globally to support its mission.

4.2. MAMDIWAS main phase project consortium

In order to achieve all the objectives of the first phase of MAMDIWAS, it is planned to enlarge the original project consortium. Each of the three pillars now has a German and a South African scientific partner, listed in Table 3. This allocation also ensures that the three doctoral students (see Chapter 4.6) have one scientific supervisor in Germany and one in South Africa.

Table 3: *List of the scientific core project consortium and allocation to the Pillars*

Pillar	German Partner	RSA Partner
1	University of Duisburg-Essen (UDE) / Centre for Water and Environmental Research (ZWU)	University of South Africa (UNISA)
2	IWW Rheinisch-Westfälisches Institut für Wasserforschung gGmbH	Stellenbosch University (SUN)
3	UN-Habitat Collaborating Center at Wuppertal Institute	University of The Witwatersrand Johannesburg

The Wuppertal Institute for Climate, Environment, and Energy, being a research institution based in Germany that focuses on sustainability research and policy advice, is a new partner in the consortium. It collaborates with various organizations and entities, including the United Nations Human Settlements Programme (UN-Habitat) which is one of the associated partners in MAMDIWAS.

In addition, several South African and German companies will participate in the project, with the partners receiving project funding also being part of the core project consortium (Surflay Nanotec GmbH, Blue-Foot Membranes GmbH, Inatec GmbH). All other partners will take on various tasks in the project as associated partners, as described in the LOIs listed in Appendix 7.8. Most of these partners will support the capacity building measures described in Chapter 4.6.

4.3. Pillar 1: Technological innovations for active mine water treatment

Based on the results, findings and challenges for Pillar 1 which are summarized in section „WP VI: Data analysis and selection of three case studies" an innovative and cost-effective solution for MIW active treatment that is transferable to as many mine sites as possible. The concept focuses on improving the existing cascade concept, which is a widely used approach for MIW treatment: Neutralization, sulfate removal and membrane desalination will play a key role, the last especially for water reuse. The basic features of the cascade process are reproduced and considerably intensified by integrating new membrane-based technologies (anaerobic bioreactor (anMBR) for sulfate reduction, membrane contactor for concentrating and harvesting H_2S, backwashable capillary NF (cNF) for sulfate removal and desalination), optimizing the operational conditions and modifying/adapting membrane materials. Smaller amounts of sludge should be produced more sustainably by precipitation either with the H_2S produced in the process or with waste products from other industries/processes. The precipitates should be of saleable quality (e.g., metal sulfides, $CaCO_3$), in contrast to the unusable poor quality gypsum slurries produced by conventional treatment.

Initially, the mentioned processes will be intensified individually before their integration into an overall process is investigated. Lab and pilot scale investigations will be performed whereby pilot plants will be designed and built in both Germany (membrane plants) and RSA (precipitation reactors), commissioned, and operated/optimized with synthetic and most importantly with real MIW in both countries. Pilot sites are offered in Germany by RAG (coal mine) and in RSA by Sibanye-Stillwater (gold mine) After final optimization, the German pilot plants will be transferred to RSA and combined with the RSA pilot plants to establish the complete process scheme in a demonstration plant which will be operated at the pilot sites in RSA.

NF is expected to have a significant impact on the project outcomes. Firstly, NF can be effectively utilized for sulfate retention and partial desalination. This means that the permeate produced by NF is of satisfactory quality and can be employed for various reuse options, including drinking water applications. NF membranes typically exhibit higher permeate flux rates at the same or even lower trans-membrane pressure compared to RO membranes. This means that they allow for a faster flow of water through the membrane, resulting in higher productivity and throughput. The high flux rates of NF membranes contribute to their energy efficiency and cost-effectiveness. NF membranes operate at lower pressures compared to RO membranes. This lower operating pressure requirement reduces the energy consumption and associated costs of the water treatment system. It also extends the lifespan of the membrane by reducing fouling and minimizing membrane stress. NF is already applied in a wide range of water treatment processes such as industrial wastewater treatment, drinking water production, selective ion removal, colour and organic matter removal, and process water purification. This highlights the versatility and reliability of NF in generating water suitable for different purposes. Moreover, there is potential to enhance the ion selectivity of NF by modifying the NF membrane. By doing so, the improved task-specific NF membrane could facilitate the recovery of valuable metals from the MIW. This presents an exciting opportunity to integrate NF into other process concepts, particularly for non-acidic MIW treatment. The modified NF membrane would exhibit enhanced selectivity, enabling the selective separation and recovery of metals, contributing to resource conservation, and promoting a more sustainable approach to MIW treatment.

The concept highlights the advancement of capillary nanofiltration (cNF) and discontinuous recirculation (CC) for the treatment of MIW. cNF are designed to be chemically and thermally stable, allowing them to withstand harsh operating conditions and various chemical cleaning regimes. cNF has the notable advantage of backwashability, i.e., the ability to perform a backwash operation The backwash process involves reversing the direction of flow across the membrane, dislodging, and removing accumulated particles, debris, and fouling materials from the membrane surface. This cleaning mechanism helps to restore the membrane's permeability and efficiency, ensuring consistent and optimal performance. Such back-washing is not possible with conventional state-of-the-art flat-sheet NF membranes in spiral-wound modules. Initial tests by our research group using cNF for sulfate removal showed that even sulfate deposits can be removed by backwashing, making these membranes particularly suitable for this application. By effectively removing fouling and particulate deposits, backwashing enhances flux recovery, allowing for sustained and efficient operation of the membrane. The backwashability of cNF membranes further on helps to minimize the need for frequent chemical cleaning. As a result, the frequency of more intensive chemical cleaning procedures, which require the use of cleaning agents, can be reduced. This leads to cost savings, lower chemical consumption, and less downtime for cleaning operations. In addition, this reduces the risk of irreversible damage to the membrane surface. This prolongs the membrane's operational life, resulting in cost savings by minimizing the need for frequent membrane replacement. The backwashability of cNF membranes also offers operational flexibility in terms of system design and configuration. It allows for the integration of backwash cycles into the overall process design, ensuring efficient and continuous operation.

To increase the flexibility of the desalination stage, to make it less site-specific and to be able to adapt it very easily to different MIW feedwater qualities CC is also part of the concept. CC is an innovative operational mode usable for RO (already commercialized) and NF (still under research) that offers several advantages compared to conventional continuous mode operation. In CC, the concentrate stream from the RO/NF system is recirculated back to the feed side, creating a closed loop. CC configuration provides better control over system parameters such as pressure, flow rates, and concentrate recirculation allowing for stable and consistent performance. By optimizing these parameters, CC can achieve higher water recovery while maintaining the desired water quality and consuming less energy, making the process more cost-effective and environmentally friendly. The increased recovery rate is particularly beneficial in water-scarce regions or for applications where maximizing water utilization is crucial. CC also mitigates fouling and scaling issues commonly encountered in continuous systems. The recirculation of concentrate within the closed circuit helps to reduce the concentration polarization effect and minimize the deposition of scaling and fouling agents on the membrane surface. This leads to improved membrane performance and prolonged membrane lifespan, reducing maintenance requirements and enhancing system reliability. Additionally, CC systems are adaptable to varying feedwater conditions and can accommodate fluctuations in water quality, feed flow rates, and operating pressures. This adaptability enhances the system's resilience and makes it especially suitable for MIW treatment. The combination of reduced energy consumption, increased recovery rates, and reduced fouling leads to significant cost savings with CC.

The combination of cNF membranes and CC brings further advantages, as backflushing steps can be integrated into the operating cycles, further optimizing the use of resources, and increasing system performance. There are however research needs and areas of focus in CCNF with cNF which will be addressed in MAMDIWAS. Research is, for example, needed to develop and optimize cNF membranes specifically designed for CCNF applications. This includes exploring different membrane materials, surface modifications, and pore structures to enhance selectivity, permeability, and fouling resistance. Improving the overall performance and durability of cNF membranes will contribute to more efficient CCNF systems. Research is also required to optimize the design and operation of CCNF systems. This includes investigating the impact of various operating parameters such as pressure, flow rates, and backwash cycles on system performance and energy efficiency. The development of effective control strategies and optimization algorithms will help to ensure stable and efficient operation of CCNF systems, including effective strategies to prevent fouling. Exploring advanced cleaning techniques, such as backwashing, chemical cleaning, and physical cleaning methods, will help maintain long-term performance and extend the lifespan of cNF membranes. Scaling up CCNF systems from lab-scale to pilot-scale or full-scale is another research need. Investigating the challenges associated with system integration, process control, and optimizing the performance of larger CCNF installations is crucial for practical implementation. Understanding the scalability and feasibility of CCNF systems is essential for their successful adoption in MIW treatment applications.

As mentioned earlier, another approach to the concept is to optimize the ion selectivity of NF for metal recovery from MIW. By improving the selectivity of NF membranes, it becomes possible to selectively separate and recover valuable metals. This not only helps reduce the environmental impact of MSW, but also provides opportunities for resource recovery and reuse. To improve the ion selectivity of NF membranes for metal recovery, several aspects related to material design and surface modification techniques can be considered. MAMDIWAS is investigating the development of layer-by-layer (LBL) assembly techniques using different polyelectrolytes and other nanomaterials as building blocks to fabricate composite membranes with precise control over layer composition, thickness, and morphology. Specific functional groups, or selective nanoparticles will be integrated into the membrane matrix to improve metal ion partitioning and, hence, permeation selectivity. For this purpose, different deposition methods will be investigated to optimize the layer formation and to tune the thickness of the selective layers. The effects of deposition parameters such as deposition time, concentration, pH, and solvent composition on membrane performance are evaluated, and the incorporation of selective functional groups, ion-specific ligands, or chelating agents into the LBL layers to increase affinity for target metal ions is investigated. Additional surface modification techniques, such as polymer coating or surface grafting, to adjust the surface charge of the membrane and optimize the electrostatic interactions between the membrane and the metal ions, as well as the effects of surface charge density, polarity, and distribution on partitioning and selectivity, will be investigated. Such modifications, with overall neutral building blocks, will also be explored to make the outer surface of the selective NF layer fouling resistant. Strategies to improve selectivity and achieve sequential or simultaneous separation of target metal ions from complex mixtures with different task-specific NF membranes, as well as the competitive adsorption, complexation, and coordination behaviour of different metal ions within the modified membranes will also be investigated. The long-term stability and durability of LBL membranes for metal recovery applications will be evaluated by examining factors such as fouling resistance, chemical stability, mechanical integrity, and the effect of repeated cycling on membrane performance and selectivity. Strategies will be developed to improve membrane lifetime and maintain consistent separation performance over time. Finally, a techno-economic evaluation of the cost effectiveness and economic viability of membrane modification processes for metal recovery will be conducted, considering factors such as material cost, scalability, energy requirements, waste management, and the value of recovered metals.

Many MIW have such high sulfate concentrations that they are unusable for direct desalination. In these cases, further sulfate removal must be provided prior to RO/NF. Anaerobic biological sulfate removal is particularly suitable for this step. The anaerobic environment promotes the growth of specific microbial communities that can convert sulfate into sulfide ions or depending on pH to H_2S, which can be used for sulfidic metal precipitation prior to biological sulfate removal. In this way, on the one hand, higher-quality and more saleable metal sulfides are produced and, on the other hand, potentially toxic metals are removed for the subsequent biological process. Biological sulfate removal is already state of the art in industrial wastewater treatment, but not the use of an anaerobic membrane bioreactor (anMBR). AnMBRs employ membranes to separate the treated wastewater from the biomass and other suspended solids in the bioreactor. The membranes act as a physical barrier, allowing for the retention of biomass while allowing treated water to pass through. This ensures high-quality effluent for further NF/RO processes and enables the concentration and retention of biomass within the bioreactor for efficient sulfate reduction. AnMBRs for sulfate removal and H_2S production would offer an environmentally friendly and cost-effective approach to sulfate removal and can be integrated into existing wastewater treatment processes.

The MAMDIWAS concept is to improve the efficiency, stability, and practical application of this process specifically for MIW treatment by using a special, backwashable MBR system. This will result in lower likelihood of the expected strong membrane blockage and thus allow a less extensive clarification as pre-treatment. Understanding the microbial community dynamics and metabolic pathways involved in biological sulfate removal is crucial. Further research is needed to identify and characterize sulfate-reducing bacteria (SRB) and other microorganisms responsible for sulfate conversion to sulfide. Elucidating their metabolic activity, interactions, and responses to different environmental conditions can help optimize process performance. Further research is required to optimize the design and configuration of anMBRs for biological sulfate removal. This includes investigating factors such as hydraulic retention time, sludge retention time, kind of carbon and energy source, and organic loading rates to enhance the conversion efficiency of sulfate to H_2S. Exploring innovative reactor designs, such as hybrid systems or biofilm-based configurations, can offer advantages in terms of biomass retention and reactor stability. Developing advanced process control and monitoring strategies is essential for maintaining stable and efficient operation. Thus, research is needed to identify appropriate process control parameters, sensor technologies, and monitoring techniques for tracking sulfate and sulfide concentrations, pH, redox potential, and other relevant parameters. Implementing real-time monitoring and control systems can help optimize process conditions and prevent process failures.

H_2S harvesting will be innovatively done by membrane contactors which is cheaper and simpler than the chemical method used so far. The membrane contactor foreseen in the concept is a specialized device designed for gas exchange applications in various industries. It utilizes a microporous hollowfibre to facilitate efficient mass transfer between a liquid and a gas phase. The contactor can be used for both degassing (removal of dissolved gases from a liquid) and gas transfer (addition of gases to a liquid). It is commonly employed in applications such as deaeration of water, carbonation, oxygen removal, nitrogenation, pH control, and gas transfer in bioreactors. The contactor is compatible with a wide range of liquids, including aqueous solutions, organic solvents, and process fluids. It can handle different gas types, including oxygen, carbon dioxide, nitrogen, hydrogen, and various volatile organic compounds. To date, the contactor has not been used for the recovery of H_2S from anaerobic sulfate removal, which requires addressing various aspects of the technology, process optimization, and system integration.

The individual processes are to be integrated into one overall process concept taking advantage of synergies. Replacing UF/RO which are used as state of the art with the less energy-intensive combination of MF/NF is expected to save operating costs. The process scheme shown in Figure 5 will be investigated in RSA with real water after all German pilot plants have been transported to RSA and combined with the RSA pilot plants to form a demonstration plant. To facilitate the transfer of the process scheme to other sites and for later process control, process modelling based on the experimental results including water quality simulation (use of PHREEQC) is part of the concept.

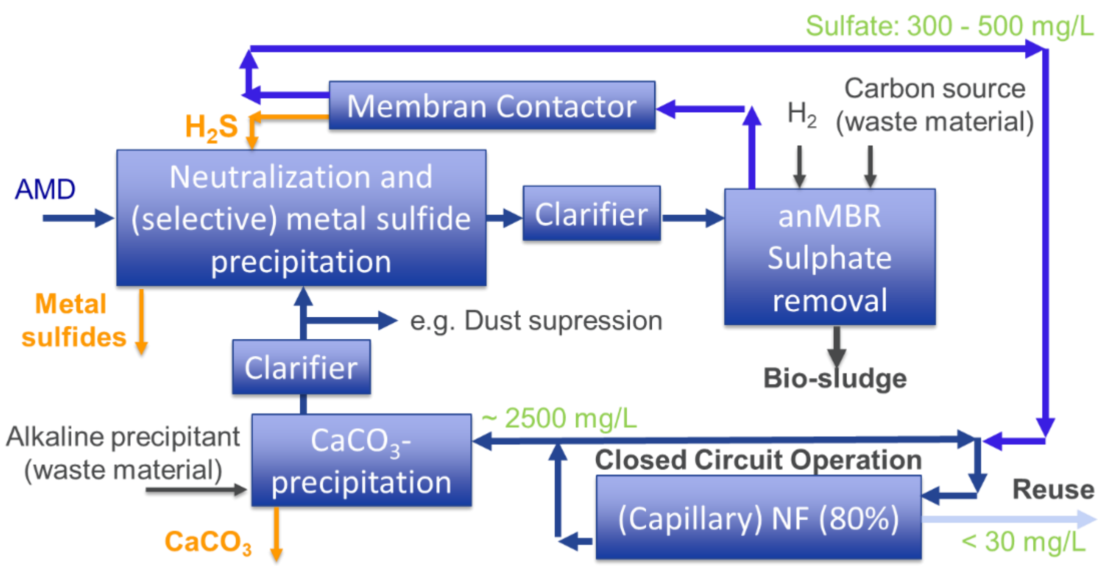


Figure 5: *Process concept for AMD treatment based on innovative membrane processes.*

The self-produced H_2S is used for sulfide precipitation prior to the anMBR to reduce the concentration of metals, which might be toxic to the sulfate reducing microorganisms and to recycle valuable metal-sulfides. Since the biological sulfate removal is not able to reduce the sulfate concentration to levels below 300 mg/L, post-treatment by NF is applied to produce water with at least drinking water quality. Being particle-free, the anMBR effluent can be processed directly with NF without any further treatment. The NF concentrate is returned to the sulfide precipitation tank after an alkaline decarbonization step. After this the concentrate can be used to neutralize MIW/AMD in the sulfide precipitation tank. By this recirculation an overall recovery of > 90% is expected. A part of the NF concentrate might be required to discharge to avoid concentrating of monovalent ions in the loop, but whether this is required and how much is to discharge is not clear yet as NF also allows monovalent ions to pass. Finally, the NF permeate could also be further desalinated by a low pressure and high recovery RO to produce high quality desalinated water for further needs (e.g., boiling water, H_2-Electrolysis). However, as this is state of the art, it is not part of the concept.

Although the HDS (high-density sludge) process has long been state of the art in the treatment of MIW, there is a great need for research in this area, both for metal precipitation and neutralization, as part of the intended process integration. Precipitation of sulfidic metals with H_2S involves several critical aspects to optimize the efficiency, effectiveness, and environmental impact of the process. Here are some key areas that need further investigation:

- Kinetics and mechanisms of metal precipitation: Investigation of the effects of various parameters such as pH, temperature, H_2S dosage, mixing intensity, and residence time on the precipitation efficiency and the quality of the formed metal sulfides.
- Sludge settling and thickening: Investigation of the impact of factors such as sludge particle size distribution, polymer addition, flocculation strategies, and sludge rheology on settling characteristics and thickening performance.
- Sludge dewatering and moisture reduction: Investigation of different dewatering techniques, such as filtration, centrifugation, and thermal drying, and evaluation of their effectiveness in achieving high solids content in the dewatered sludge while minimizing water content.
- Sludge stability and long-term storage: Investigation of stabilization techniques such as pH adjustment, oxidation, encapsulation, and the use of binders or additives to mitigate potential environmental risks during sludge storage and disposal.
- Metal recovery from HDS: Exploration of different extraction techniques, such as leaching, solvent extraction, and precipitation, to recover metals from the sludge and evaluate the economic feasibility of metal recovery processes.
- Environmental impacts and residuals management: Evaluation of the fate and behaviour of residual sulfides, residual metals, and other constituents in the sludge during disposal, and investigate approaches for their safe management and potential resource recovery.
- Process optimization and scale-up: Investigation of the effects of process parameters, reactor design, feedwater quality, and optimization algorithms on process performance and develop strategies for effective scale-up from laboratory to industrial scale.
- Techno-economic analysis: Evaluation of cost-effectiveness and economic viability of the high-density sludge process by considering factors such as capital and operational costs, energy consumption, chemical usage, sludge disposal, and potential revenue streams from metal recovery.
- Monitoring and control: Exploration of real-time monitoring techniques, automated control systems, and data analytics to optimize process performance, reduce variability, and enhance process stability.

Neutralization of AMD using alkaline waste products is a promising approach to mitigating this issue, but there are also some open research topics.

- Identifying suitable alkaline wastes: Many types of alkaline waste exist, but not all of them are suitable for use in neutralizing AMD. Research is needed to identify which types of waste are most effective, while also considering factors such as cost, availability, and the potential for secondary pollution.
- Optimization of the treatment method: Improving the speed of the treatment process, minimizing the amount of waste required, and maximizing the longevity of the treatment effect.

The final aspect of the Pillar 1 approach is to conduct a complete evaluation of the entire process through a comprehensive life cycle and cost analysis (LCCA) with the goal of developing a treatment process for MIW that is not only effective, but also economically viable and sustainable and can contribute to a circular economy. Stakeholders with a business-experience background will be involved. This analysis will consider various aspects (also including those from Pillar 2 and 3), such as the management of residuals from the treatment process, potential for the recycling of by-products, and prospects for marketing saleable products resulting from the process. In terms of residuals management, the research will investigate methods for handling the residual waste produced during the neutralization process. Strategies will be explored to minimize waste generation, maximize recycling, and ensure safe disposal. This includes assessing opportunities for creating saleable products from the process waste, which could provide a potential revenue stream to offset treatment costs. Moreover, the research will examine the potential for reusing treated MIW in other applications, such as irrigation, industrial use, or even reintroduction into the local watershed, once the water quality has been sufficiently improved. In addition, the cost analysis will include not only the direct costs associated with the treatment process but also indirect costs and benefits, such as environmental benefits and potential revenue from recycled or saleable products. This will allow for a more comprehensive understanding of the overall economic feasibility of the process. The analysis will be carried out on a technical-scale unit to simulate real-world application of the process. This will provide valuable insights into the scalability and practical application of the process on a larger, industrial scale. Furthermore, the analysis will consider the potential for using renewable energy sources to operate the treatment plant. This aspect of the research acknowledges the increasing need for energy-efficient and sustainable operations within industry and aligns the process with broader goals of reducing carbon emissions and environmental impact.

4.4. Pillar 2: Integrated Water Resources Management (IWRM) strategy

Based on the results, findings and challenges for Pillar 2 which are summarized in section „WP VI: Data analysis and selection of three case studies" the concept for Pillar 2 aims to develop an IWRM approach for MIW in the Gauteng Province. The approach includes conducting a baseline water quality assessment, determining the fate of pollutants from MIW, evaluating toxicological impacts, analysing options for water reuse, and ensuring community acceptance of management strategies. This approach finally targets to mitigate environmental risks, protect public health, and promote sustainable water management practices. The respective concept is divided into three tasks to evaluate the impact of MIW on local water resources and the MIW reuse potential. The tasks are strongly linked to Pillar 1 and 3.

As a basis and starting point for further investigation, the exact water quantities, qualities, and pollution levels in two case study areas Black Reef (Crocodile River basin, Vaal basin) and Merafong (Upper Vaal catchment, Crocodile River basin, both located in the Gauteng Province), are to be investigated in the first year. This will include a setup of a database and a GIS system (shared with Pillar 3) for the mapping of potential pollution sources. Based on the flow network and potential pollution sources a sampling campaign plan will be developed. Two sampling campaigns will be conducted (low flow and normal conditions) to identify sensitive areas within both sub-catchments. Further, runoff and water availability - including future projections - will be analysed, as due to climate change water levels have become highly variable and droughts are occurring more often. On the one hand, this influences MIW dilution and fate; on the other hand, it will also increase the need for MIW re-use (link to Pillar 3).

The next step is the investigation of the fate and toxicological impacts of MIW. Based on the catchment analyses and screening on water quantity, quality and pollution levels, a monitoring and sampling plan for pollutants from MIW, such as metals and other inorganic compounds will be installed before and after the inflow of MIW. Additionally, the MIW itself will be monitored as well as runoff further downstream to consider persistence and dilution. In order to analyse the resuspension potential and fate of MIW pollutants, sediment samples will be analysed as well. Further, the impact of MIW on the environment will be assessed by applying novel ecotoxicity sensors, which will provide matching long term time series data to MIW inflow. Specifically, the flow rate and composition of MIW will be of interest, as they can have massive impacts on tolerable thresholds for the environment. Statistical analysis will be used to define those thresholds based on MIW characteristics and the applied ecotoxicological sensors. Human toxicity assays will be applied as well to evaluate the potential impact of the MIW downstream, where it is often used for drinking water or irrigation purposes. In case of missing correlation between MIW and toxicity, further organic non-target screening as well as microbiological analysis will be conducted to identify the potential sources of toxicity.

After receiving the potential water qualities from treated MIW from Pillar 1, fit for purpose re-use potentials will be evaluated. On the one hand, joint stakeholder workshops with Pillar 3 are foreseen to assess the need, acceptance, and legal opportunities of MIW re-use; on the other hand, specific MIW reuse types will be investigated. This includes drinking water (sold as bottles, provided per pipes/truck to local municipalities), agriculture (irrigation, livestock, hydroponics), and industrial uses (process water for SMME, cooling water for energy production). This task will assess the required water quality standards of each re-use option and link them to the various treated MIW qualities from Pillar 1. Based on this task, the opportunities for local communities, farmers, and mining companies to benefit from re-use and to mitigate water scarcity will be investigated.

This holistic strategy will ensure that the point of focus is not only limited to MIW treatment solutions but to evaluate the impact of MIW on the environment and water reuse in the context of other occurring pollutants.

4.5. Pillar 3: Effective governance mechanisms and regulatory frameworks

Based on the results, findings, and challenges for Pillar 3 which are summarized in section „WP VI: Data analysis and selection of three case studies“ the concept for Pillar 3 aims to develop recommendations for regulatory framework and test sustainable and integrated MIW management measures and solution through participatory small-scale demonstration activities. It is envisioned, that Pillar 3 is divided into four tasks namely, i) analysis of the operating environment ii) establishment of co-production partnerships, iii) development of recommendations for governance, policy, and regulation, and iv) co-developing of small-scale demonstration actions.

Through the analysis of the operating environment, Pillar 3 will review national, provincial, and local regulatory frameworks as well as the Mogale City Local Municipality Integrated Development Plan and the Merafong City Local Municipality Integrated Development Plan. This analysis will aim to identify and address any existing gaps that may hinder the implementation of mine water management projects, especially on reclaimed water issues related to community development and income generation enhancement. A socio-economic mapping analysis will also be carried out to identify settlement patterns and geography, land-use, demographics, and other socio-economic factors. Given that the project will require multi-stakeholder involvement and close cooperation between mining companies, regulators, investors, land use planners and local communities, Pillar 3 will establish co-production partnerships creating strong partnerships between African and European partners. A policy and society working group will be formed to open channels and dialogues ensuring government and private actions address the public needs and there is adequate engagement with communities, political leaders, and other relevant stakeholders. With the analysis of the operating environment serving as context, and the establishment of co-production partnerships starting to pave the way for multi-stakeholder involvement, Pillar 3 will then develop recommendations for governance, policy, and regulation. The recommendations will be based on the findings from Pillars 1, 2 and 3 and will form the basis of the co-developed demonstration actions in the Urban Living Labs (see Footnote 4).

Mining in South Africa has resulted in challenges of a national extent, in particular that of the plight of mining-based communities where mines have closed or are to close in the next five to fifteen years. This is a problem that dominates in Gauteng especially in the mining areas in Merafong City and Mogale City. The socio-economic characterization conducted in the initial MAMDIWAS phase highlights the opportunities of potentially income-generating interventions for a successful transition of affected communities to sustainable livelihoods after mine closure by linking them to the challenges posed by MIW, considering gaps in the legal and strategic frameworks as they relate to community and environmental impacts. In this context, the MAMDIWAS main phase concept envisions co-developing small-scale demonstration actions focused on the productive use of water and complementary services through the Urban Living Lab approach and the “Renewable Energy, Nutrition, Environment, Water and Waste (RENEWW)” innovation zone approach (see Footnote 3).

Three main components will be explored in MAMDIWAS main phase to co-develop the small-scale demonstration activities: the water component, the agricultural component, and the energy component. These are each considered on the basis of the primary elements, the newly available water source, i.e., reclaimed water, and the land reclaimed for agriculture through mine closure. Supporting elements include the opportunities for SMME development and the prioritization of renewable/alternative energy highlighted in the spatial development framework plans. A net zero waste to energy element can be factored in to achieve a closed loop intervention cycle.

The water component contemplates the opportunities created by water purified using the technology developed in Pillar 1 that is suitable for human consumption and potable water needs. The treated water could open a supply chain that includes a community based SMME for bottling water and other bottled products, targeting distribution to small spazas (informal microenterprises) in the pilot community to meet community needs. External distribution could target commercial demand in the value chain.

In the agricultural component, based on the available reclaimed land for re-use purposes and available treated MIW, key urban agriculture activities would be supported from which food hubs and spazas that would then provide food security to the community with urban farming, edible crops, aquaponics, animal farming for meat, eggs, and dairy products. A small-scale food canning industry for the external supply chain through the community based SMMEs could also emerge from this.

The energy component is primarily renewable or alternative energy, preferably using waste products. This would be, for example, a combination of solar energy and biogas production from elephant grass grown on the reclaimed land, complemented by waste recycling using the waste generated from the above-mentioned activities for food production as well as organic municipal waste for mixed energy use to achieve a net zero waste in a closed loop. Spaza and the external commercial supply chain can also be used here as part of the community based SMME.

Community stakeholder participation is sought from the outset through communication platforms (see also Chapter 4.6). This is critical to ensure good governance and sustainable solutions that give communities a sense of ownership. This will facilitate interaction with all stakeholders and provide an opportunity for potential project partners to share experiences and receive or provide guidance on relevant policies, regulations, technologies, business approaches, operations, and implementation processes that will ensure long-term sustainability. To this end, in addition to existing project partners, other stakeholders will be invited to attend: Community leaders/agencies/stakeholders, non-governmental organizations, faith-based organizations, governments (local, provincial, and national), and government agencies and councils.

4.6. Capacity building, training, transfer of technology and knowledge

One important part of the concept is to supervise a total of three doctoral students on a bi-national basis. In the so-called "sandwich model", they are supervised by a German (home) and an RSA professor (host country), accompanied by longer research stays in both countries. The German home university finally awards the doctoral degree. A second part is the technical education by promoting cooperation between German and RSA SMEs. Therefore, a total of three technicians from RSA SMME engineering companies will be invited for a three-week skills-upgrading advanced course for the operation of MBR, CCNF and membrane contactors. Another part is peer learning and knowledge transfer through the promotion of collaborations and public-private partnerships to address the problem of skills shortages in the public sector. At the same time, pioneers such as political actors in the communities should be identified and involved. This is intended to have a greater impact in addressing water security issues. As part of this task, peer learning collaborations between water operators and water associations will be established and promoted. Through GWOPA's existing platform, peer support partnerships will be mobilized between providers and operators under the MAMDIWAS project and established providers and operators in Europe, to further strengthen partnerships between African and European stakeholders.

Business promotion measures are also part of the concept. An RSA membrane society based on the model of the DGMT German Society for Membrane Technology will be founded by RSA partners and supported by the German partners during the project runtime. Within this framework of this new network, a cooperation platform with German and RSA companies is to be established. The founders will initially be the MAMDIWAS partners. The first task of the platform will be a technology needs assessment with the three steps 1. identification and prioritization of mitigation and adaptation technologies for MIW treatment, 2. identification and analysis of barriers to successful deployment and diffusion of prioritized technologies, including enabling environments and finally 3. the preparation of technology action plans, i.e., medium- or long-term plans to support the implementation of the identified technologies, based on the knowledge gained in the previous two steps.

As an important measure for knowledge transfer and community participation a communication platform will be established ensuring transparency among the key stakeholders and project partners throughout the project (see also Chpater 4.5). Engagement and communications among the key players will also be promoted by the Urban Living Lab approach and RENEWW zone intervention.

4.7. Implementation needs

In the first main phase of MAMDIWAS, critical tasks and measures for the subsequent implementation phase are addressed. This proactive approach aims to establish the foundation for the project's success from an early stage. By tackling important tasks and measures during the first phase, the project team can set the course for a smooth and effective implementation phase. This strategic planning ensures that the necessary groundwork is laid, enabling a successful execution of the overall project objectives. By addressing key elements early on, the project can maximize its potential for success and achieve the desired outcomes in a timely and efficient manner. Respective measures and tasks are:

- Establish a robust monitoring and evaluation framework to track the project progress, outcomes, and respective impacts on the implementation phase.
- In-depth evaluation of the effectiveness and efficiency of the 1st main phase demonstration activities and identification of any areas that require further refinement or improvement.
- Engage relevant stakeholders, such as government agencies, industry partners, local communities, and academic institutions for the implementation phase.
- Promote further collaborations and partnerships with other organizations or entities that have a shared interest in addressing MIW treatment, IWRM, governance and capacity building measures.
- Encourage a culture of continuous learning and adaptation throughout the project and fostering an environment where lessons learned inform future actions and decision-making.
- Continous sharing of knowledge, best practices, and lessons learned with relevant stakeholders, both locally and internationally by utilizing various communication channels, such as reports, conferences, workshops, online platforms, and networks such as GWOPA, to disseminate project results and promote broader adoption of successful measures.
- Consider long-term sustainability and operation of the implemented measures.
- Continually identify mechanisms for funding, maintenance, and ongoing support to ensure the continued effectiveness of the technologies, IWRM approach, governance mechanisms, and capacity building measures.
- Identify options for upscaling to reach a wider area or audience

4.8. Establishment of the strategy, concept, and work plan for the 2nd main phase

In order to enable the smoothest possible transition from the first to the second main phase of MAMDIWAS, the strategy, concept, and work plan for the implementation of MAMDIWAS in practice should already be drawn up in the first main phase. This approach has already proven successful for the transition from the initial phase to the demonstration phase.

5. Expected benefit and usability of the results

The control and treatment of MIW is considered one of the greatest environmental challenges facing the mining industry worldwide. The total cost resulting from current and future obligations to remove MIW and treat MIW -contaminated water is estimated at US$100 billion worldwide. In RSA alone, the treatment of MIW seeping from abandoned mines into drinking water costs approximately US$1 billion. The ongoing environmental damage caused by mining and the associated problems of water resource management, capacity development, governance and financing are not only an issue in southern Africa, but also in Germany. The market for technical solutions for MIW treatment promises a large growth potential.

A special focus of MAMDIWAS is the development of strategies to build capacities and to control wastewater treatment and discharge as well as waste management, whereby the circular economy is to be promoted at the local level. This opens up direct economic opportunities for German and South African companies, manufacturers, and suppliers of technical and chemical components (membranes and membrane plants, antiscalants, associated measurement and control technology) to offer technically optimized and approvable technologies and components on the market on a larger scale and to benefit from the improved competitiveness of German technology resulting from the project.

The results of the initial phase were to be used primarily to prepare conceptually for the main phase of the overall project and to establish a functioning network of the stakeholders involved. Although the essential work in MAMDIWAS is thus to be carried out only in the main phase applied for, great successes in the utilization of results could already be achieved in the initial phase. For example, the initial phase of MAMDIWAS has shown that there are numerous stakeholders involved in almost all aspects of MIW. However, knowledge about that is fragmented and not contextualized, and there is a lack of trust and fruitful communication channels among stakeholders, even as they recognize the importance of open discussions to address the MIW challenges. Promoting transparency and communication platforms began in the initial stages with a comprehensive stakeholder involvement through site visits, roundtable discussions, and workshops. The outcomes of these discussions indicated that there are meaningful collaborations that can be built among various stakeholders within MAMDIWAS, based on the values of transparent governance, transfer of knowledge and capacity building. Communications platforms with different objectives can thus significantly strengthen partnerships and relationships between key stakeholders. In the main phase, several platforms such as an RSA membrane society, a company platform and a capacity building platform shall be initiated and established. One of the main tasks of the platforms would also be to ensure that proper consultations are carried out with the communities during the main phase of the project, and to develop channels for unified communication between the affected communities, local authorities, and the private sector.

In addition, the already established cooperation structures can be used for further research collaborations and the promotion of young scientists through joint exchange programs. For example, binational supervision of doctoral students in a so-called "sandwich model" is planned during the main phase. Students will be supervised by a German (home) and an RSA (host) professor accompanied by longer research stays in both countries.

The research partners have disseminated some of the results in teaching to students. For example, a lecture hour on mine water treatment was included in the Water Treatment lecture in the MTW3 course at UDE. A poster on the objectives of MAMDIWAS is planned at kassel23, a German conference on mine water and salt production water with an international character. In addition, the results will be used to submit a research and development project on mine water treatment for application to the Willy Hager Foundation.

No other progress in the area of the project by other agencies became known during the implementation of the project.

6. On the use of the grant

The use of the grant and the results achieved are described in detail and transparently in the report preceding this chapter. All project work performed was necessary and appropriate in this regard. In addition to the contents, the most important items of the numerical evidence are presented below.

- Employment of a MAMDIWAS coordinator at the University of Duisburg-Essen with knowledge of the mining situation in SA and a technical background with regard to wastewater treatment technologies (60% position)
- Personnel costs at IWW
- Conducting of two large two-day stakeholder workshops in SA:
    - workshop 1 in Johannesburg (May 2022) (Avianto Hotel)
    - workshop 2 in Stellenbosch (January 2023) (Devon Valley Hotel)

  At both venues, we covered an overnight stay for all invited stakeholders and all costs during the workshops including room rental, lunches, and dinners. For workshop 2 we additionally covered travel costs for

  a. stakeholders from SA (local flights, additional accommodation prior and after the workshop)
  b. stakeholders from Germany (representatives from RAG) (international flights, additional accommodation prior and after the workshop)
- Research stays of German partners in SA and SA partners in Germany (travel costs):
    - April 2022: representatives of IWW and UN-Habitat in SA (site visits, discussion with MAMDIWAS partners and stakeholders)
    - November 2023: representative of UNISA at UDE in Germany (site visits, discussion with MAMDIWAS partners and stakeholders, participation in an international conference on membrane technologies in Aachen)
- Consumables for the analysis of water samples at IWW (taken in SA in June 2022) and for membrane experiments at UDE

7. Appendices

7.1. Stakeholders and local experts

***Table 4**: List of stakeholders that were consulted during the initial phase*

No.	Institute name	Country	Type of institute
1	BNAQUA Solutions	South Africa	SMME
2	Council of Science and Industrial Research (CSIR)	South Africa	Scientific and Industrial Research
3	Council for Geoscience (CGS)	South Africa	National Science Council
4	Department of Water and Sanitation (DWS)	South Africa	Government department
5	Eskom	South Africa	SOE for power generation, Coal mine operator
6	Sasol	South Africa	Chemicals and energy company
7	Johannesburg Water	South Africa	Municipal entity
8	MINTEK	South Africa	National Science Research
9	ROC Technology	South Africa	Industrial waste management
10	Sibanye Stillwater	South Africa	Mining Company
11	Strategic Water Partners Network	South Africa	Water use partner association
12	SALGA	South Africa	Public entity for local government
13	Virtual Consulting Engineers	South Africa	Professional project management consultancy
14	Water Research Commission (WRC)	South Africa	Scientific and sustainability advisors
15	RAG Aktiengesellschaft	Germany	Mining Company/ Mining Water Management
16	Tshwane University of Technology	South Africa	University
17	3M	Germany	Membrane production company
18	Wuppertal institute	Germany	Research Institute
19	Umweltbundesamt	Germany	State Entity

***Table 5**: List of the local experts that were consulted during the initial phase of the project*

Institutions/Individuals	Members	Role	Contacts
Mintek	Dr. Keneiloe Sikhwivhilu	Principal Scientist: Nanotechnology	keneiloes@mintek.co.za
	Dr. Mpfunzeni Raphulu	Principal Scientist: Catalysis	mpfunzenir@mintek.co.za
Sibanye Stillwater	Mr. Quinton Paulse	MIW Treatment Specialist	quinton.paulse@sibanyestillwater.com
	Mr. André Laubscher	Water Conservation Specialist	Andre.Laubscher@sibanyestillwater.com
	Mr. Thabileng Mothabi	Superintendent: Sustainability Specialist	Thabileng.Mothabi@sibanyestillwater.com
Water Research Commission (WRC)	Dr. Mandla Msibi	Director of WRC	mandlam@wrc.org.za

Institutions/Individuals	Members	Role	Contacts
Council Of Science & Industrial Research (CSIR)	Dr. Jeffrey Baloyi	Senior Researcher for Water & Wastewater management.	SBaloyi1@csir.co.za
	Mr. Bashan Govender	Head of Impact Catalyst & Member of MWCB.	bashangov@gmail.com
Johannesburg Water	Dr. Zahkhele Khuzwayo	Head of Innovation & Technology	zakhele.khuzwayo@jwater.co.za
Eskom	Mr. Nandha Govender	Head of Sustainable Mine Water Management	govendna@eskom.co.za
	Ms. Anesh Surendra	Power Generation Department	surenda@eskom.co.za
	Ms. Felicia Sono	Environmental Department	sonof@eskom.co.za
Strategic Water Partners Network	Ms Michele Proude	Coordinator	michelle.proude@thenbf.co.za
ROC Technology	Prof. Jannie Maree	SMME/Mine Water Treatment	maree.jannie@gmail.com
Tshwane University of Technology	Prof. Christian Wolkersdorfer	International Mine Water Association (President)	christian@wolkersdorfer.info
Individual	Dr. Gerhard Gericke	Mine Water Expect & Former Eskom member	083 270 1630
iWater Solutions	Prof. Esta van Heerden	SMME/Biological processes for MIW	esta@iwatersolutions.co.za
Strategic advisory and support service	Alex Bhiman	Consultant	lxbhiman@gmail.com
Federation for a sustainable environment	Mariette Liefferink	CEO	mariette@pea.org.za

7.2. Project activities to survey stakeholder engagement and collect the necessary data for WPs III, IV, V, VI and VII

Table 6: *Activities in the initial phase*

Nature of activities	Location	Responsible participants	Date	Purpose
Site visit & round table discussion	Mintek Randburg (Johannesberg), SA	Mintek, UNISA, UDE, IWW and UN-Habitat	05.04.2022	Local Scientists consultation
Round table discussion	UNISA Florida Campus, Johannesburg, SA	Sibanye Stillwater, UNISA, UDE, IWW and UN-Habitat	05.04.2022	Local gold mine consultation
Site visit & round table discussion	WRC Offices, Pretoria, SA	WRC, UNISA, UDE, IWW and UN-Habitat	06.04.2022	Water Research Commission consultation
Site visit & round table discussion	CSIR facilities, Pretoria, SA	Mine Water Coordinating Body (MWCB), UNISA, UDE, IWW and UN-Habitat	06.04.2022	Mine water experts' consultation
Site visit & round table discussion	CSIR facilities, Pretoria, SA	CSIR, UNISA, UDE, IWW and UN-Habitat	06.04.2022	Local Scientists consultation
Round table discussion	UNISA Florida Campus, Johannesburg, SA	Johannesburg Water, UNISA, UDE, IWW and UN-Habitat	06.04.2022	Water use authority consultation
Virtual meeting	UNISA Florida Campus, Johannesburg, SA	Strategic Water Partners, Eskom, UNISA, UDE, IWW and UN-Habitat	06.04.2022	Major water user stakeholder consultation
Site visit	ROC Technology facilities, Johannesburg, SA	ROC Technology UNISA, UDE, IWW and UN-Habitat	07.04.2022	Local experts' consultation
Round table discussion	Stellenbosch University, western cape, SA	SUN, UNISA, UDE, IWW and UN-Habitat.	08.04.2022	Academia consultation
Site visit	CSIR facilities, Pretoria, SA	BNAQUA Solutions, UNISA, UDE, IWW and UN-Habitat.	30.05.2022	MIW pilot plant review
Workshop	Avianto Hotels, Johannesburg, SA	Multidisciplinary Stakeholders, 18 Institutions and 55 participants	01 & 02.06.2022	Presentations and roundtable discussions
Site visit	Sibanye Stillwater Mine facilities, Johannesburg, SA	Sibanye Stillwater, UNISA, UDE, IWW and UN-Habitat.	02.06.2022	MIW treatment plant review
Site visit	Johannesburg water facilities, Johannesburg, SA	Johannesburg Water, UNISA, UDE, IWW and UN-Habitat	03.06.2022	Domestic wastewater treatment plant review

Nature of activities	Location	Responsible participants	Date	Purpose
Site visit & roundtable discussions	Mintek, Johannesburg, SA	Mintek Biotechnology Division, UNISA and UDE	15.06.2022	Sulphate reduction bioreactor (pilot plant) review and local scientists' consultation
Site visit	Wuppertal, Germany	3M, UDE and UNISA	22.11.2022	Membrane production and testing.
Conference	Aachen, Germany	UDE, UNISA and conference attendees	25.11.2022	Presentations on mine water treatment technologies
Site visit and round table discussions	Wuppertal Institute, Berlin, Germany	UDE, IWW and UNISA	28.11.2022	Presentation on Living Lab concept.
Site visit and round table discussions	Umweltbundes-amt Berlin, Germany	UDE, IWW and UNISA	29.11.2022	MAMDIWAS introduction
Site visit (fieldwork)	CSIR, Westrand, SA	CSIR, UDE, IWW and UNISA	20.01.2023	AMD decant at Black reef cooke 5 (Western basin)
Virtual meeting	Zoom	Eskom, UDE, IWW, SUN, UN-Habitat and UNISA	20.01.2023	Further discussions on case study location and pilot sites
Site visit	Sibanye gold mines (Driefontein shaft 1, Klof shaft 1 and Cooke 4), Carletonvile, SA	Sibanye Stillwater, UDE, IWW, UN-habitat, Wuppertal Institute and UNISA	23.01.2023	Mine water treatment and reuse projects (AMD treatment plants)
Roundtable discussions	GCRO, Wits University, Braamfontein, Johannesburg, SA	GCRO, UDE, IWW, UN-habitat, Wuppertal Institute and UNISA	23.01.2023	Regional water use challenges and opportunities
Workshop	Devon Valley Hotels, Stellenbosch, SA	Multidisciplinary Stakeholders, 20 Institutions and 45 participants	26 & 27.01. 2023	Presentations and roundtable discussions

7.3. Report on stakeholder discussions

Table 7: *Stakeholder engagement report*

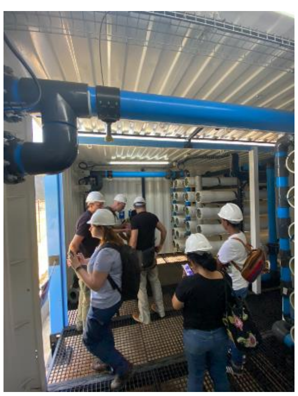
Stakeholder	Engagement method	Engagement summary	Key outcomes
MINTEK	Site visit & round table discussion	MINTEK works on R&D supported by Govt. of SA on several water management, reuse, and treatment options relevant to MIW. The institution has a long history of dealing with challenges as a result of mine water contaminants. The Biotechnology Division has developed bioreactors pilot plants to mitigate mine water issues while the Advanced Material Division mainly focuses on membrane technology piloting.	• Committed to participate in the upcoming workshop events. • They were able to show us some of their laboratories where membrane products are developed. • They have shown a key interest in the Pillar number one of the projects
Sibanye Stillwater (mining company)	Round table discussion	Company formed in 2013, quickly growing in SA and internationally. The main operations within the country are Pt & Au mines. The sources for MIW are groundwater & surface water, systems are in place to mitigate the negative impact on the environment, but challenges still persist. These include difficulties to reduce sulphate to desired concentration & issues around monitoring water quality.	• Shown an interest to participate in the upcoming workshops. • An opportunity exists to explore the possibility to recover valuable metals from mine wastewater. • Opportunity to look at groundwater models & mine closure legal framework.
Water Research Commission (WRC)	Site visit & round table discussion	WRC directly reports to DWS, leads the main water and sanitation research projects within SA. They outsource the laboratory work and focus on the research. Currently working with various organizations to look into microplastic pollutants and groundwater management in some parts of the country.	• Keen to participate in the upcoming workshops. • Opportunity to drive the local economy through mine water recovery and reuse. • Use science to improve the quality of sanitation services.
Mine Water Coordinating Body (MWCB)	Site visit & round table discussion	Falls under SWPN, as a sub-set to consider social, economic, environmentally sustainable closures of coal mines and ensure that water-related activities work to the benefit of communities. Impact Catalyst housed by CSIR and Eskom. Ongoing projects include, irrigation using mine water & Wheat crops plantation in the area of Emalahleni (Tungela).	• Keen to assist identify pilot sites for MAMDIWAS • Committed to participate in the upcoming workshops. • Willing to introduce coal mining partners to the project.
Counsel of Science and Industrial Research (CSIR)	Site visits & round table discussion	Divisions that deal with water management: Hydrological Science, Wastewater Infrastructure & Wastewater Analysis Technologies are available but often challenging to commercialize. Require economic feasibility studies, marketing, and business models. Projects underway include, RO coated by magnesite-TR level 7. Main challenges include brine management & inefficient iron content in Au-mines.	• Committed to participate in the upcoming workshops. • CSIR can help localize technologies, e.g., those developed in Germany. • Provides access to facilities and pilot sites for trials and testing

Stakeholder	Engagement method	Engagement summary	Key outcomes
Johannesburg Water	Round table discussion	Is a Water user authority that plays a vital role on the water supply chain. Activities include water supply & treatment. Many partnerships are already established with all relevant agencies (WRC, CSIR, academic institutions).	• Advice to work within pre-existing networks. Avoid duplication of efforts, we need to focus on how to fill gaps and add value. • Interest in being an active partner, not just to give away data and information, but to benefit from it
Mine water expect & Former Eskom stuff (Dr. Gerhard Gericke)	Round table discussion	Gave us insights into Eskom previous projects: Biotechnology treatment, freeze crystallization & Gypsum production in mine water treatment process. Not all effluents are acidic, some are neutral. Main challenges include Groundwater monitoring among others. Issues of water and air quality beyond plant closure. Cost of treatment vs. paying the fines. Regulation does not come down hard enough on polluters.	• Possibility for Eskom to put in funding should be explored. • Coaltech 2020 is a key stakeholder that funds projects similar to MAMDIWAS– exploring synergies. • Project should consider distinct types of treatment, not just membranes
Strategic Water Partners Network	Virtual meeting	Established in 2014 with a view to get businesses onboard with government policies. Led by Eskom as strategic water user partner. Utilizes many technologies, very dependent on local conditions. Much still needs to be done to enable reuse of treated wastewater in power stations aiming to have power stations with zero liquid discharge systems, tech to address this closed system water challenges are still under development.	• Committed to play a vital role in the upcoming workshops. • Polluter pays principle should be more strongly enforced. • Transfer of experience from Germany can add value, particularly in relation to post-closure Trust Fund set-up.
Mine Water Treatment Specialist (Prof. Jannie Meree)	Site Visit in the ROC Technology facilities.	Operates a freezing crystallization pilot plant to dilute and purify the brines coming from wastewater plants.	• He is in the process of becoming UNISA staff, meaning that he will become part of the core team in the project.
SUN; Prof. Eugene Cloete, Vice-Chancellor & Department of Process Engineering	Round table discussion	Project approach should be to work “from the bottom up” and first look at geohydrology models, attempting to avoid MIW in the first place. If MIW occurs, then look at treatment. DWS is discouraging use of large-scale brine ponds. Job creation is coming up as a key objective and driver in choice of methods during mine closure	• SUN can help explore co-funding from various sources (such as Department of Science and Research and the Technology and Innovation Agency) for the South African partners, incl. by leveraging several key networks

Stakeholder	Engagement method	Engagement summary	Key outcomes
Mintek 2nd Visit	Round table discussion and lab visit	The main topic was Mintek's water research project "cloSURE" located in Witbank (Mpumalanga province), famous for extensive coal mining activities. The cloSURE project is planned to be a demonstration plant of 50 000 L/d integrated with crop trials, currently funded by CoalTech and various mining companies in the region. A biotechnology lab was visited which displayed various lab scale MIW treatment pilot plants using biological processes.	• The cloSURE project was proposed as a potential pilot site for the MAMDIWAS. project. • Mintek will work on the first stage treatment of coal MIW using biological methods. • MAMDIWAS could explore the use of membrane technology to further treat the water from biological steps.
3M	Site visit	Valuable lessons for novel materials for membranes production and testing.	• There is a possibility of 3M providing for testing and demonstration in the MAMDIWAS.
Aachener Membran Kolloquium	Conference	MAMDIWAS was introduced to a multi-sectoral audience which included academia, tech innovation companies, research institutes to mention few.	• The conference gave us an insight on the current challenges and opportunities associated with MIW treatment.

Table 8: *Impressions/photos from site visists, round table visits and discussions*


18th Aachener Membran




TALBOT


TALBOT

7.4. Results of river water analysis

Table 9: *Substances and their concentration ranges found in Crocodile River, Gauteng Province*

Parameter	Classification	Derived concentration range (ng/L)
2-Aminobenzimidazole	Industrial chemicals	<100
Acesulfam	Sweetener	<100
ciclovir	Pharma (Virostatics)	<100
Diatrizoate	Contrast media	100-1000
Atenolol	Pharma (Beta blocker)	<100
Atrazine	Herbicide	<100
Atrazine, Desethyl-	Metabolite Atrazine	<100
Atrazine, Desisopropyl-	Metabolite Atrazine	<100
Azithromycin	Pharma (Antibiotics)	>1000
Bentazon	Herbicide	<100
Benzotriazol, 1H	Corrosion inhibitor	<100
Benzotriazol, 4/5-Methyl-1H-	Metabolite Benzotriazol, 1H	100-1000
Benzoylecgonine	Metabolite Cocaine	<100
Bezafibrat	Pharma	100-1000
Bisoprolol	Pharma (Beta blocker)	<100
Bromacil	Herbicide	<100
Carbamazepin	Pharma (Anti convulsant)	<100
10,11-Dihydro-10,11-Dihydroxy-Carbamazepin	Metabolite Carbamazepine	>1000
Cetirizin	Pharma (Anti histamines)	100-1000
Chlorothalonil-Met M12 (R417888)	Metabolite Chlorothalonil	<100
Ciprofloxacin	Pharma (Antibiotics)	<100
Clarithromycin	Pharma (Antibiotics)	100-1000
Coffein	Alkaloid	<100
Diclofenac	Pharma (Analgetics)	100-1000
Dinoterb	Herbicide	<100
Diuron	Herbicide	<100
Gabapentin	Pharma (Anti convulsant)	100-1000
Gabapentin-lactam	Metabolite Gabapentin	100-1000
Hydrochlorothiazide	Pharma (Diuretics)	<100
Imidacloprid	Insecticide	100-1000
Indometacin	Pharma (Antirheumatics)	<100
Iohexol	Contrast media	100-1000
Iomeprol	Contrast media	100-1000
Irbesartan	Pharma (Antihypertensives)	<100
Lamotrigin	Pharma (Anti convulsant)	>1000
Linuron	Herbicide	<100
Losartan	Pharma (Antihypertensives)	100-1000
Metalaxyl	Fungicide	<100
Metalaxyl-Met CGA62826	Metabolite Metalaxyl	<100
4-Acetamidoantipyrin (4-AAA)	Metabolite Metamizol	<100
4-Formylaminoanitpyrin (4-FAA)	Metabolite Metamizol	<100
Metolachlor, S-	Herbicide	<100
Metolachlor, S-, Met CGA368208	Metabolite S-Metolachlor	<100
Metolachlor, S-, Met ESA CGA380168	Metabolite S-Metolachlor	100-1000
Metoprolol acid	Metabolite Metoprolol/Atenolol	100-1000

Parameter	Classification	Derived concentration range (ng/L)
Oxazepam	Pharma (Sedatives)	100-1000
Phenazon	Pharma (Analgetics)	<100
Propiconazole	Fungicide	<100
Propranolol	Pharma (Beta blocker)	<100
Ritalinic acid	Metabolite Ritalin	<100
Saccharin	Sweetener	<100
Simazin	Herbicide	<100
Sitagliptin	Pharma (Antidiabetics)	<100
Sucralose	Sweetener	>1000
Sulfamethoxazole	Pharma (Antibiotics)	100-1000
N4-Acetyl-Sulfamethoxazole	Metabolite Sulfamethoxazole	<100
Tebuconazole	Fungicide	<100
Telmisartan	Pharma (Antihypertensives)	>1000
Terbuthylazine	Herbicide	100-1000
Terbuthylazin, Desethyl-	Metabolite Terbuthylazine	<100
Terbutryn	Herbicide	<100
Tetraethylenglycoldimethylether	Industrial chemicals	<100
Tonalid	Fragrances	<100
Trimethoprim	Pharma (Antibiotics)	100-1000
Valsartan	Pharma (Antihypertensives)	100-1000
Valsartan acid	Metabolite Valsartan	>1000
Venlafaxin	Pharma (Antidepressants)	100-1000
2-Mesitylensulfonsäure	Sulfonic acid	>1000
Amisulprid	Pharma (Neuroleptics)	100-1000
Erythromycin, Anhydro-	Metabolite Erythromycin	100-1000
Fluconazol	Pharmaka (Antifungals)	>1000
Sulpirid	Pharma (Neuroleptics)	>1000
Trifloxystrobin	Fungicide	>1000
Trifloxystrobin CGA 321113	Metabolite Trifloxystrobin	>1000
Amitriptyline	Pharma (Antidepressants)	100-1000
Atrazine, Hydroxy-	Metabolite Atrazine	100-1000
Climbazole	Pharma (Antifungals)	100-1000
Codeine	Pharma (Opioids)	100-1000
Ofloxacin	Pharma (Antibiotics)	100-1000
Oxcarbazepine	Pharma (Anti convulsant)	100-1000
Sulfapyridine	Pharma (Anti inflammatory)	100-1000
Terbuthylazine-2-hydroxy	Metabolite Terbuthylazine	<100
Tolfenamic acid	Pharma (Analgetics)	100-1000
Vildagliptin	Pharma (Antidiabetics)	<100
Lycorine	Alkaloid	>1000
Carbendazim	Fungicide	100-1000
Diazinon	Insecticide	100-1000

7.5. Short report on Workshop I

Workshop I was held at Avianto Hotels in Johannesburg between the 1st and 2nd of June 2022. A total of 55 participants from diverse groups, sectors, and levels of society (see **Figure 6**). The key stakeholders included government agencies and departments, the industrial sector (mining), SMEs, water-use associations, civil society leaders, IWRM professionals, academics, and research institutions. The total number of organisations that participated was 18, coming from South Africa and Germany attended the workshop.

The goal of the workshop was on the one hand side to present the objectives of MAMADIWAS to the multidiscipline consortium in South Africa but on the other hand side to learn from the stakeholders about the local state of the art with respect to the three Pillars of MAMDIWAS, and the main challenges. Thus, the first day was filled with a total of 12 presentations by the South African colleagues. Two presentations were given by SMME representatives, (ROC Technologies, BNAqua). The involvement of SMEs in MAMDIWAS was seen by the core team as a win-win situation: SMEs gain access to resources and expertise to drive their innovations, while research institutes and universities benefit from the practical experience and expertise of SMEs. In the view of the core team, this helps to strengthen the innovative power and competitiveness of SMEs and to promote scientific progress.

Then, on the second day, intensive group work was conducted in breakout sessions with all stakeholders to identify problems and find solutions that affect all relevant sectors of society, such as local clean water needs, waste disposal options, potential renewable energy sources, and treatment methods currently in use.

The workshop ended with a positive conclusion and an appreciation of the commitment and openness that all participants contributed to the workshop. The African side emphasized the importance of such workshops and stakeholder discussions with the participation and facilitation of the German partners. Several times it was mentioned that such a meeting had not taken place before and that the next workshop in a short time distance would be very important to take advantage of the moment that has been created. The German side was able to gain a broader understanding of the challenges in treating and managing MIW in South Africa. The workshop succeeded in breaking down complex issues into a series of questions for which practical answers can be found in the main project. Critical discussions centred on the optimization and application of MIW treatment technologies, the management of mine waste to protect water resources from pollution and recovery of valuable products for a circular economy, and the assessment of the barriers posed by the regulatory framework for mine water monitoring. In addition, the focus was on integration and open communication between water user consortia to build bridges between groups (hierarchical and functional) in all sectors of society (private, public, and community). It was shown that already multiple AMD treatment technologies have been tested in RSA, whereof few are still in operation. Hence, the MAMDIWAS approach to considering technology, IWRM and governance simultaneously seems well suited to deal with existing implementation gaps.

Figure 6: *Group photograph of workshop attendees on day 1 (1st June 2022)*

7.6. Short report on Workshop II

Workshop II was held at Aviato Hotels in Stellenbosch on the 26th and 27th of January 2023. Stakeholders present at Workshop I and those identified during the initial phase of MAMDIWAS were invited to this workshop. The goal was to gather stakeholder feedback on the results of the first phase of the project up to that point, to discuss further requirements, research needs, and challenges from a South African perspective, and finally to identify locations for the case studies and pilot projects (pilot trials, catchment area, living lab options) and ask for possible participation and integration into the main phase concept.

The 2nd workshop attracted 45 attendees coming from 20 multidiscipline-consortium institutions (Germany and South Africa), this included first-time attendees which further broadened the MAMDIWAS consortium from workshop I.

The structure of Workshop II was like that of Workshop I. Day 1 was dedicated to the presentation of the results achieved so far, but also included presentations from institutions that were not present during Workshop I, allowing a better insight into existing efforts and approaches to address MIW challenges. The presentations were divided into three sessions (MAMDIWAS's three Pillars), with four presentations for each Pillar coming from both South African and German stakeholders. For the reasons mentioned above, two presentations were again given by SMME representatives (Water 4 All, iWater solutions). Some highlighting messages from the workshop include the lessons shared by the RAG Foundation (Germany) on how they have been addressing the coal mining legacy over the years, as well as the funding models that sustain the foundation. Day 2 of the workshop was initiated with a presentation from the MAMDIWAS core team which outlined key components for the main phase, this was done as feedback from inputs that were made during the first workshop, as well as for opening the platform for further contributions from associated partners. The subsequent agenda was a breakaway session for every Pillar to allow more detailed planning and ideas sharing for each Pillar.

The outcomes of Workshop II were consolidating the strategic plan for the MAMDIWAS's main phase, including assembling the main and associated partners that will work on each Pillar of the three Pillars and the final selection of suitable locations for case studies and piloting sites. In addition, numerous stakeholders pledged their interest in the main phase of MAMDIWAS, committing to contribute through financial contributions, providing piloting sites and laboratory facilities, personnel training and community engagements. These commitments were communicated to submit letters of interest (LOIs) following the date of Workshop II. Workshop II was closed on a higher note with a conclusion that the core team of MAMDIWAS will draft a proposal for the main phase utilising the contributions that were made in the two workshops and circulate the proposal draft to all partners for approval or adjustments where necessary. The pictures below were taken during workshop II, at Aviato Hotels, Stellenbosch.

Figure 7: *Photographs taken during workshop II (26th and 27th January 2023)*

7.7. List of studied references

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7.8. List of submitted letters of interest (LOIs)

By the deadline of the report (31.05.2023), ten LOIs have been submitted. Additional LOIs have been committed (e.g., Mintek) and are to be sent by the time the main phase application is submitted.:

Table 10: *Submitted LOIs*

Company/Organisation	Country	Sector
Sibanye Stillwater	South Africa	Mining Company
Sasol	South Africa	Chemicals and energy company
ROC	South Africa	SMME/Mine Water Treatment
RAG Aktiengesellschaft	Germany	Mining Company/ Mining Water Management
Johannesburg Water	South Africa	Water and Wastewater Company
iWater solutions	South Africa	SMME/Biological processes for MIW
Eskom	South Africa	SOE for power generation, Coal mine operator
Council of Science and Industrial Research (CSIR)	South Africa	Scientific and Industrial Research
BNAqua	South Africa	SMME/ Mine Water Treatment
3M	Germany	Membrane production company

Prof. Dr.-Ing. Stefan Panglisch
Universität Duisburg-Essen (UDE)
Mechanische Verfahrenstechnik / Wassertechnik & Zentrum für Wasser- und Umweltforschung (ZWU)
Lotharstraße 1
47057 Duisburg

Letter of Intent

May 2023

Support of the BMBF WASA project proposal "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" as an associated partner.

Dear Prof. Panglisch,

We are pleased to hear that you are planning to submit the project proposal with the title "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" to the German Federal Ministry of Education and Research (BMBF) within the call "Water security in Africa (WASA); Main Phase".

We learned about your project during the stakeholder workshops in June 2022 and January 2023 you organized during the initial phase of MAMDIWAS. We as a mining company are very interested in questions regarding integrated regional water management, which contributes to the health and prosperity of a catchment while creating economic opportunities with the application of water treatment strategies and technologies.

Sibanye-Stillwater will support the project, in case of approval by the BMBF, and our internal approval processes. Our project support will be in the form of:

- provision of a pilot site for treatment of AMD waters; support with pilot plant experiments within reason
- provision of a pilot site to demonstrate peri-urban RENEWW zone through urban living lab for community to undertake income-generating activities; transformation from a mining to a post-mining city/region
- access to surface facilities of water treatment systems / to lab facilities
- provision of water analysis data from different sources, samples and of other information (e.g. location maps) after the completion of a reciprocal NDA
- participation in the socio-economic and community engagement activities at the project site
- support in the areas of dissemination of results and transfer potential
- participation in the steering committee of the network
- participation in network events and workshops; if applicable, participation through lectures (e.g. in the context of events for young scientists)

I wish you success with your application and will be happy to answer any questions or provide further information. Should you have any queries, please feel free to contact the Sibanye-Stillwater project lead, Quinton Paulse, via e-mail: quinton.paulse@sibanyestillwater.com

Yours sincerely,

Signed by:Frik du Preez
Signed at:2023-05-29 10:57:20 +02:00
Reason:I approve this document

Mr. Frik du Preez
Vice President: Environment Southern Africa Region
Sibanye-Stillwater

INNOVATION COMMITMENT ACCOUNTABILITY RESPECT ENABLING SAFETY

Prof. Dr.-Ing. Stefan Panglisch
Universität Duisburg-Essen (UDE)
Mechanische Verfahrenstechnik/Wassertechnik
Lotharstraße 1
DUISBURG
47057

Date:
18 May 2023

Enquiries:
Tel.: +27 11 629 5028

Dear Prof. Dr.-Ing. Stefan Panglisch

Letter of intent

Support of the BMBF WASA project proposal "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" as an associated partner

Eskom Research, Testing, and Development (RT&D) is pleased to hear that the Universität Duisburg-Essen (UDE) is planning to submit the project proposal with the title "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" to the German Federal Ministry of Education and Research (BMBF) within the call "Water security in Africa (WASA); Main Phase".

RT&D learnt about the project during the stakeholder workshops in June 2022 and January 2023, which were organised by the UDE during the initial phase of MAMDIWAS. The keen interest of Eskom RT&D is in water and energy security and sustainable mine water management, with a focus on the treatment of mine water for recovery and recovery on Eskom sites.

Furthermore, Eskom RT&D would like to pledge its support for the project and would be interested in actively contributing through the following areas:

- Provision of water analysis data from different sources, of samples, and of other information (for example, location maps),subject to RT&D`s data release process.
- Participation in the socio-economic and community engagement activities at the project site
- Support in the areas of dissemination of results and transfer potentials subject to RT&D`s data release process.
- Participation in the steering committee of the network
- Participation in network events and workshops; if applicable, participation through lectures (for example, in the context of events for young scientists)
- Scientific exchange and the sharing of organisational knowledge on water treatment

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15.05.2023

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Prof. Dr.-Ing. Stefan Panglisch
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47057 Duisburg

Letter of Intent

Support of the BMBF WASA project proposal "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" as an associated partner.

Dear Prof. Panglisch,

we are pleased to hear that you are planning to submit the project proposal with the title "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" to the German Federal Ministry of Education and Research (BMBF) within the call "Water security in Africa (WASA); Main Phase".

We have learned about your project during the stakeholder workshops in June 2022 and January 2023 you organized during the initial phase of MAMDIWAS. We as a company are very interested in questions regarding to removal of Hydrogen Sulfide (H_2S) as a dissolved gas from water.

3M's Separation and Purification Sciences Division with its main membrane production in Wuppertal-Germany produces microporous synthetic membranes in different shapes for a wide range of applications. An important specialty is the Liqui-Cel product line that is dedicated to gas exchange from or into liquids.

We would like to pledge our support for the project. In case of approval, we would be happy to actively contribute through:

- provision of membrane contactor modules of different size for lab and for pilot plant operation; support for pilot plant design and evaluation of results
- provision of training opportunities for students and staff exchange
- support in the areas of dissemination of results and transfer potentials
- participation in the steering committee of the network
- participation in network events and workshops; if applicable, participation through lectures (e.g. in the context of events for young scientists)

I wish you success with your application and will be happy to answer any questions or provide further information.

Yours sincerly

Norbert Selzer
Market and Application Development Manager EMEA
3M Deutschland GmbH
Separation and Purification Sciences Division

MAMDIWAS

CSIR
Touching lives through innovation

CSIR Smart Places

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03 May 2023

Prof. Dr.-Ing. Stefan Panglisch
Universität Duisburg-Essen (UDE)
Mechanische Verfahrenstechnik / Wassertechnik & Zentrum für Wasser- und Umweltforschung (ZWU)
Lotharstraße 1
47057 Duisburg

Re: Support of the BMBF WASA project proposal "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" as an associated partner.

Dear Prof. Panglisch,

We are pleased to hear that you are planning to submit the project proposal with the title "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" to the German Federal Ministry of Education and Research (BMBF) within the call "Water security in Africa (WASA); Main Phase".

We have learned about your project during the stakeholder workshops in June 2022 and January 2023 you organized during the initial phase of MAMDIWAS.

In case of this project approval, CSIR Water Centre would be happy to actively contribute through:

- provision of a pilot site for treatment of AMD waters; support with pilot plant experiments
- access to surface facilities of water treatment systems / to lab facilities
- provision of water analysis data from different sources, of samples and of other information (e.g. location maps)
- performing water analysis for physical parameters and/or pilot experiments
- provision of training opportunities for students and staff exchange
- provision of capacity building through trainings, peer to peer learning and collaboration with water operators related to wastewater management during mining and post mining phase
- participation in the socio-economic and community engagement activities at the project site
- support in the areas of dissemination of results and transfer potentials;
- participation in the steering committee of the network
- participation in network events and workshops; if applicable, participation through lectures (e.g. in the context of events for young scientists)

We wish you success with your application and will be happy to answer any questions or provide further information.
Yours sincerely,

Dr Ryneth Mbhele (Ph.D)
Research Group Leader, Smart Water and Wastewater Infrastructure Research
Tel: 082 721 3318
Email: rmbhele@csir.co.za
Signature:

MAMDIWAS

iWATER

Prof. Dr.-Ing. Stefan Panglisch
Universität Duisburg-Essen (UDE)
Mechanische Verfahrenstechnik / Wassertechnik & Zentrum für Wasser- und Umweltforschung (ZWU)
Lotharstraße 1
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Bloemfontein, 3 April 2023

Letter of Intent

Support of the BMBF WASA project proposal "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" as an associated partner.

Dear Prof. Panglisch,

We are pleased to hear that you are planning to submit the project proposal with the title "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" to the German Federal Ministry of Education and Research (BMBF) within the call "Water security in Africa (WASA); Main Phase".

We have learned about your project during the stakeholder workshop in January 2023 you organized during the initial phase of MAMDIWAS. We as a company are very interested in questions regarding bioremediation of mining influenced water such as mineral, metal and acid/alkaline mine drainages.

iWater (Pty) Ltd is a dynamic technology company focused on the management of metabolic microbial dynamics (i.e. bacterial systems), which represents the new wave associated with the treatment of pollutants. The company's vision is to use scientific knowledge to restore/clean-up natural resources for future generations.

The core competence of iWater is environmental remediation with an emphasis on the integration of biological and novel chemical solutions, which are much underutilized in the South African context. iWater already has a prominent client base and are leading effective solution development for mining and industrial clients. The team has several years of research, as well as on-site implementation experience.

We would like to pledge our support for the project,

In case of approval, we would be happy to actively contribute through:

- performing water analysis for a range of parameters associated with mine influenced water and we have the laboratory facilities to do development work that defines site pilot experiments;
- we do have clients and site access to several sites that have acid and alkaline drainage water, especially associated with gold and coal mining, but also copper mining groups, where field work, samples and pilot sites can be completed;
- we also have local preferred service providing agreements for specific filters and physical components for certain treatment aspects that the group could evaluate before selecting larger expenses for site work;
- we have a data base and can add the water analysis data from different sources, of samples and of other information (e.g. location maps);
- we would be open to host collaborators and provide training opportunities for students;
- provision of capacity building through trainings, peer to peer learning and collaboration with water operators related to wastewater management during mining and post mining phase;
- support in the areas of dissemination of results and transfer potentials;
- participation in the steering committee of the network;
- participation in network events and workshops; if applicable, participation through lectures (e.g. in the context of events for young scientists).

I wish you success with your application and will be happy to answer any questions or provide further information.

Yours sincerely

Professor Esta van Heerden and Team - Lead Scientist and CEO of iWater Pty Ltd, as well as Extraordinary Professor at North West University in the Centre for Water Sciences and Management.

RAG Aktiengesellschaft • Postfach • 45058 Essen

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Ihre Zeichen	Ihre Nachricht vom	Unsere Zeichen	Telefon/Durchwahl	Datum
		VV/Dr. Drobniewski	0201 378-6000	21.03.2023

Letter of Intent zum Projektvorhaben „MAMDIWAS"

Sehr geehrter Herr Professor Panglisch,

mit großem Interesse haben wir von Ihrem Projektvorhaben „MAMDIWAS: Membrane-based decentralized reclamation of acid mine drainage for improvement of water security and mitigation of environmental impacts in Southern Africa" gehört, das als Gemeinschaftsprojekt mit UN Habitat, den Universitäten Duisburg-Essen, South Africa, Stellenbosch und Pretoria sowie mehreren Industriepartnern durchgeführt werden soll.

Die RAG Aktiengesellschaft übernimmt langfristig Verantwortung in den Steinkohlebergbauregionen in Nordrhein-Westfalen und im Saarland. Mit der Bearbeitung der sogenannten Ewigkeitsaufgaben trägt die RAG in diesen Regionen dazu bei, den Wasserhaushalt dort unter und über Tage zu regulieren. Dazu gehört das Management des Grundwassers, das aus den ehemaligen Bergwerken als sogenanntes Grubenwasser abgepumpt und sofern notwendig vor Einleitung in die Vorflut aufbereitet wird, und die Grundwasserreinigung an einigen ehemaligen Betriebsstandorten.

Aufgrund unserer langjährigen Expertise im Umgang mit Grund- und Grubenwasser möchten wir das Projekt MAMDIWAS sehr gerne unterstützen. Sollte der Projektantrag des Konsortiums angenommen werden, so werden wir uns am Projekt in folgenden Bereichen aktiv einbringen:

- Bereitstellung von Informationen, Karten, Laboranalysen, Proben, etc.
- Zugang zu übertägigen Anlagen der zentralen Wasserhaltungen
- Unterstützung bei Technikumsversuchen auf den übertägigen Anlagen der zentralen Wasserhaltungen
- Mitarbeit im Projektkonsortium und Teilnahme an den Projektbesprechungen

Sehr gerne treten wir dem Projektkonsortium bei und freuen uns über den wichtigen Beitrag, den das Projekt Sicherung der Wasserversorgung und der Verminderung der Umweltauswirkungen im südlichen Afrika hervorbringen kann.

Mit freundlichen Grüßen und Glück auf

RAG Aktiengesellschaft

ppa. [signature] ppa. [signature]

RAG Aktiengesellschaft
Im Welterbe 10
45141 Essen
Telefon: 0201 378-0
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Vorsitzender des Aufsichtsrates:
Bernd Tönjes

Vorstand:
Peter Schrimpf, Vors.
Michael Kalthoff

Sitz der Gesellschaft: Essen
Registergericht:
Amtsgericht Essen
Handelsregister HRB 28810

22003-8

28 Keramiek Street
Clayville, Olifantsfontein
Cell: 076 751 6271
maree.jannie@gmail.com
1 March 2023

Prof. Dr.-Ing. Stefan Panglisch, Universität Duisburg-Essen (UDE)
Mechanische Verfahrenstechnik / Wassertechnik & Zentrum für Wasser- und Umweltforschung (ZWU), Lotharstraße 1, 47057 Duisburg

Letter of Intent

Support of the BMBF WASA project proposal "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" as an associated partner.

Dear Prof. Panglisch,

ROC WATER TECHNOLOGIES is pleased to hear that you are planning to submit the project proposal with the title "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" to the German Federal Ministry of Education and Research (BMBF) within the call "Water security in Africa (WASA); Main Phase".
ROC Water Technologies (Pty) Ltd (ROC) and its associates have developed and patented a unique mine water treatment system that allows recovery of drinking water and saleable products from acid and neutral mine water with the aim to meet zero waste disposal.

Clients: Kwezela Colliery, where a Ph.D. student focus is on pigment recovery from iron in acid mine water. The value of pigment will cover the cost of treatment; A-Thermal Retort Technologies, where the focus is on the treatment of highly saline water (150 g/L TDS) for the recovery of clean water, sodium sulphate and sodium chloride; Innovation Hub; Department of Trade and Industry; Water Research Commission; Consolidated Wire Industries,

Collaborators: UNISA, University of Limpopo, University of Pretoria, Tshwane University of Technology and Walter Sisulu University.

MAMDIWAS' holistic, multidisciplinary and multisectoral approach, which combines advanced membrane technology, integrated water resources management and urban water governance, will open up options for water reuse and recycling of materials.

In case of approval, we would be happy to actively contribute through the following activities:

- Provision of lab space for performing lab experiments.
- Provision of capacity building through trainings, peer to peer learning and collaboration with Water Operators related to wastewater management during mining and post mining phase
- participation in the steering committee of the network
- participation in network events and workshops; if applicable, participation through lectures (e.g. in the context of events for young scientists)

I wish you success with your application and will be happy to answer any questions or provide further information.

J P Maree
Director at ROC Water Technologies and Professor at UNISA
maree.jannie@gmail.com and mareejp@unisa.ac.za; Cell: 076 751 6271

Directors: Dr JP Maree, Mr T Mtombeni

13 April 2023

Prof. Dr.-Ing. Stefan Panglisch
Universität Duisburg-Essen (UDE)
Mechanische Verfahrenstechnik / Wassertechnik & Zentrum für Wasser- und Umweltforschung (ZWU)
Lotharstraße 1
47057 Duisburg

RE: Support of the BMBF WASA project proposal "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" as an associated partner.

Dear Prof. Panglisch,

We are pleased to hear that you are planning to submit the project proposal with the title "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" to the German Federal Ministry of Education and Research (BMBF) within the call "Water security in Africa (WASA); Main Phase".

We have learned about your project during the stakeholder workshops in June 2022 and January 2023 you organized during the initial phase of MAMDIWAS.

If this project be selected, Sasol Research and Technology would like to contribute through active participation such as:

- support in the areas of dissemination of results and transfer potentials.
- participation in the steering committee of the network
- participation in network events and workshops; if applicable, participation through lectures (e.g., in the context of events for young scientists)
- reviewing of proposals, technical reports, and articles generated from the project
- knowledge sharing based on full-scale plants experience (generic)

I wish you success with your application and will be happy to answer any questions or provide further information.

Signed by: Jenny Huang
Signed at:2023-04-13 09:14:09 +02:00
Reason:I approve

Yours sincerely

Jenny Huang (Ph.D.)
Technology Manager: Coal & Environmental Research
Energy Operations & Technology
Research & Technology
Tel: 016 960 7830/+27 82 805 6664
Email: Jenny.huang@sasol.com

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Johannesburg Water

Prof. Dr.-Ing. Stefan Panglisch
Universität Duisburg-Essen (UDE)
Mechanische Verfahrenstechnik / Wassertechnik & Zentrum für Wasser- und Umweltforschung (ZWU)
Lotharstraße 1
47057 Duisburg

Johannesburg Water
City of Johannesburg
24 May 2023

Letter of Intent

Support of the BMBF WASA project proposal "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" as an associated partner.

Dear Prof. Panglisch,

Johannesburg Water is pleased to hear that you are planning to submit the project proposal with the title "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" to the German Federal Ministry of Education and Research (BMBF) within the call "Water security in Africa (WASA); Main Phase".

We have learned about your project during the stakeholder workshops in June 2022 and January 2023 you organized during the initial phase of MAMDIWAS. We as Johannesburg Water are very interested in questions regarding efficient use of technology in treatment of mine waste amongst other things

Johannesburg Water would like to pledge our support for the project,

In case of approval, we would be happy to actively contribute through:

- provision of a pilot site for treatment of AMD waters; support with pilot plant experiments
- provision of a pilot site to demonstrate peri urban RENEWW zone through urban living lab for community to undertake income generating activities; transformation from a mining to a post mining city/region
- access to surface facilities of water treatment systems
- participation in the socio-economic and community engagement activities at the project site
- participation in the steering committee of the network
- participation in network events and workshops

I wish you success with your application and will be happy to answer any questions or provide further information.

Yours sincerely

Dr Zakhele Khuzwayo
Manager: Innovation and Technology

BNAQUA solutions

Prof. Dr.-Ing. Stefan Panglisch
Universität Duisburg-Essen (UDE)
Mechanische Verfahrenstechnik / Wassertechnik & Zentrum für Wasser- und Umweltforschung (ZWU)
Lotharstraße 1
47057 Duisburg

Pretoria: 19th May 2023

Letter of Intent

Support of the BMBF WASA project proposal "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" as an associated partner.

Dear Prof. Panglisch,

we are pleased to hear that you are planning to submit the project proposal with the title "MAMDIWAS: Making mining influenced water a driver of change for improving water security in South Africa" to the German Federal Ministry of Education and Research (BMBF) within the call "Water security in Africa (WASA); Main Phase".

We have learned about your project during the stakeholder workshops in June 2022 and January 2023 you organized during the initial phase of MAMDIWAS. We as a research company are very interested in questions regarding our pre-treatment of the mine impacted water. metallurgical slag in order to reduce heavy metals and increase pH.

BN-Aqua Solutions would like to pledge our support for the project,

In case of approval, we would be happy to actively contribute through:

- Pre-treatment of mine impacted water using our metallurgical slag, which is a waste product.
- provision of a pilot site for treatment of AMD waters; support with pilot plant experiments
- provision of water analysis data from different sources, of samples and of other information (e.g. location maps)
- performing water analysis for all the compounds a per the SANS 241.
- provision of training opportunities for students and staff exchange
- provision of capacity building through trainings, peer to peer learning and collaboration with water operators related to wastewater management during mining and post mining phase
- participation in the socio-economic and community engagement activities at the project site
- participation in the steering committee of the network
- participation in network events and workshops; if applicable, participation through lectures (e.g. in the context of events for young scientists)

I wish you success with your application and will be happy to answer any questions or provide further information.

Yours sincerely

BNAQUA solutions

B.