Bridging Tradition and Innovation: Evaluating Water Harvesting Systems for Sustainable Agriculture in Phalaborwa's Post-Mining Landscape

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Abstract

The post-mining transition presents a critical challenge in regions where resource extraction has historically shaped local economies and landscapes. This study explores the applicability of water harvesting and conservation techniques in the Phalaborwa region of South Africa, with a focus on fostering post-mining agricultural development. Through a multi-scalar analysis incorporating geographic and environmental assessments, we evaluate the potential of various water harvesting & conservation strategies to support sustainable land use transformation. Our findings highlight the opportunities and constraints associated with implementing these techniques in a post-mining context, emphasizing the role of integrated water harvesting & conservation strategies in enhancing agricultural productivity and environmental resilience. The study contributes to the broader MineLives project by aligning with its objective of developing viable socio-ecological strategies for post-mining landscapes, providing valuable insights for policymakers and local stakeholders seeking to revitalize the region's agricultural potential.

Keywords

Water harvesting & conservation; Extractive environment; Arid/Semi-arid agriculture; Water balance

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1 / Introduction

This report is part of the *MineLives* project, a collaboration under the NWO/NRF Merian grant project titled *Longue Durée of WEF in Post-Extraction Landscapes: Learning from Gauteng and Limpopo Regions to Develop an Interdisciplinary Approach*. The project is jointly conducted by The School of Architecture and Planning at the University of the Witwatersrand, in collaboration with GCRO, Wits Mining Institute, University of Venda, Iyer Urban Design, TU Delft Faculty of Architecture and the Built Environment (research groups Delta Urbanism and History of Architecture and Urban Planning), TU Delft Faculty of Civil Engineering and Geosciences (research group Applied Geology), IHE Delft Institute for Water Education, Studio Hartzema, and UrbaniaHoeve.

This report is directly linked to the *TU Delft 2024 MDP Project*, serving as a complementary study that focuses on the water-related issues identified in the main project.

The project explores the closure of mines in South Africa through the *WEF Nexus*—an analytical framework for understanding the interconnections between water, energy, and food systems. Using this approach as a design tool, the research examines infrastructure and water systems' impact on local energy and food networks, providing a comprehensive and interdisciplinary planning strategy for post-mining landscapes. By addressing various socio-ecological perspectives, this report specifically focuses on one of the project's key study areas—the Phalaborwa mining region in South Africa—utilizing *Water Harvesting & Conservation (WH&C)* strategies to tackle future water challenges in the area.

1.1 / Brief introduction of the role of Phalaborwa as a mining town

Phalaborwa, located in South Africa's northeastern Limpopo Province within the Mopani District, is a town bordering Kruger National Park and home to Africa's widest man-made mining pit. As early as 400 AD, the Sotho people were already mining and smelting copper and iron here. Fifteen centuries later, in 1954, this land held the world's largest copper reserves, poised for extraction. Beyond copper, high-grade phosphate mined by FOSKOR was exported to Europe, and in an instant, this once-hidden red bushveld became one of the world's key mining towns.

Technology and capital transformed both the landscape and the potential of its resources. Beneath this unassuming red plain, minerals were continuously extracted and sent across the globe, while miners, their families, and opportunity-seekers settled in the area. Over half a century, the demand for water, food, and energy shifted dramatically. Today, reservoirs and ubiquitous boreholes sustain life in this arid terrain. Agriculture, too, is bound by water constraints. Whether in the intensively irrigated farmlands upstream of the Ga-Selati River to the west of Phalaborwa or the gardening agriculture in the settlements of Namakgale and Lulekani, crop irrigation depends primarily on two methods—diverting river water and extracting groundwater—both of which face serious sustainability challenges (Berbé et al., 2024).

The reality is that the mine is likely to close by the mid-21st century, fundamentally altering Phalaborwa's resourcescape, even though the resources themselves remain unchanged. This

report focuses on the critical question of Phalaborwa's survival after mining ceases—an isolated town within the vast Olifants River Basin, whose very existence is tied to the industry. Given the report's scope, the discussion will be limited to water resources: In this arid landscape, what constraints will water access face in the post-extractive period? How can new resource acquisition methods enhance water collection efficiency in a sustainable manner? And how should these methods be effectively implanted within the study area?

1.2 / Structure of this report and its connection to the former MDP report

This report is closely linked to a 2024 study on the WEF nexus in Phalaborwa's post-extractive era, conducted by the author alongside three fellow TU Delft students, D.W. Berbé, A.L. Houben, and M.E.Y. de Jonge, guided by Dr. Fransje Hooimeijer and PhD candidate Isabel Recubenis Sanchis. A significant portion of the data on local water resources and agricultural conditions is drawn from the analyses within that study, and the proposed new water collection systems built upon the post-extractive era strategies outlined in the original report.

As a more targeted and detailed investigation focused specifically on spatial design for water collection, this report aims to fill the gaps left in the implementation aspects of the parent study. However, much like the original report, this research is based on incomplete hydrological and agricultural data for the region, relying largely on semi-quantitative or qualitative analyses. Nonetheless, it presents viable strategies for enhancing water efficiency and sustainability in Phalaborwa's post-extractive future.

2 / Context

2.1 / The post-mining future of Phalaborwa

The study area of this report is located in South Africa's Limpopo Province, within the triangular region between Tzaneen, Hoedspruit, and Phalaborwa. It primarily encompasses the section of the Olifants River Basin situated between the Wolkberg Mountains and Kruger National Park. This region falls within a semi-arid climate zone, where limited rainfall is concentrated in the summer months.

Most precipitation bypasses the vast, flat plains of this area, instead accumulating in the mountainous regions near Tzaneen. Similarly, groundwater resources are largely concentrated around the escarpment near Tzaneen, while downstream groundwater availability is constrained by soil conditions. The low permeability of the soil makes it difficult for water to infiltrate deeper aquifers, leading to significant losses through evapotranspiration from shallow groundwater sources. Only a few areas near the tributaries of the Ga-Selati River exhibit higher base flows of groundwater (Berbé et al., 2024).

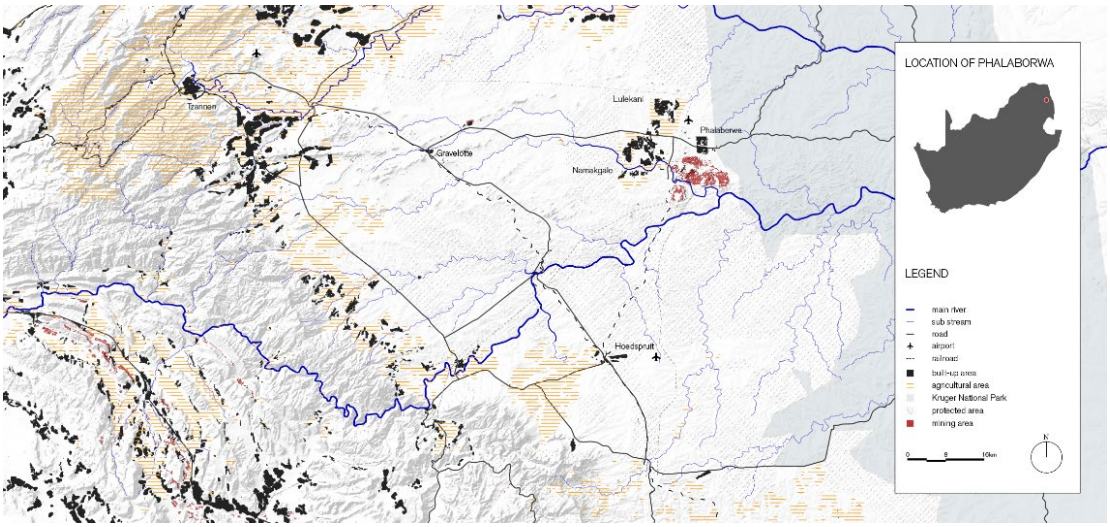

Fig. 1. Research area. (Source: Berbé et al., 2024)

According to the scenarios outlined in the parent report, the carrying capacity of the study area is insufficient to sustain the current populations of Phalaborwa and Namakgale, particularly after the closure of the mine. To address this challenge, the parent report proposed new spatial design strategies for the post-extractive era, including the establishment of decentralized agricultural zones along the Ga-Selati tributaries, sourcing water from the dolomite aquifer near Tzaneen, introducing greenhouses and gardening agriculture within Phalaborwa, and promoting extensive low-density wild farming across the Lowveld. A more detailed discussion of these strategies can be found in the original report.

However, water acquisition remains an unresolved issue. The parent report, which approaches the topic from a broader spatial scale, does not fully address the practical implementation of new water resource strategies. In reality, small-scale, decentralized improvements in water resource utilization hold just as much potential as the large-scale, long-distance water transfers proposed in the original study.

For instance, the parent report highlights rooftop rainwater harvesting as a viable method to reduce rainwater loss through evapotranspiration. However, its discussion is limited to rooftops as collection surfaces—an area that represents only a small fraction of the entire study region. A far greater water harvesting potential lies hidden in settlement roads, within agricultural patches along the Ga-Selati River, and across the vast Lowveld plains. These overlooked opportunities form the core focus of this report.

2.2 / Local water & food problem

According to the water balance calculations from the parent report for the B72D catchment—encompassing much of the Lower Olifants region—significant and persistent water deficits are observed throughout the year, except in spring. The majority of rainfall is lost to evapotranspiration.

The striking red and yellow hues of the land serve as a constant reminder of its extreme aridity.

However, the region's annual precipitation of approximately 500 mm—comparable to that of Cape Town—does not fully align with its drought-prone appearance (Open Data Portal – CCTE GIS, 2024). The issue lies not in the total amount of rainfall but in its fate: due to extremely low soil infiltration capacity and high evapotranspiration rates, much of the precipitation is unable to be retained within the catchment area.

Data from the parent report indicates that the Lower Olifants region contains nearly 12,000 hectares of formally designated irrigated farmland and an additional 8,500 hectares of uncontrolled irrigation zones. Even when considering only the formally designated farmland, agricultural water consumption accounts for 61% of total water demand. This water primarily comes from dam reservoirs and boreholes, the former exacerbating evaporation losses, while the latter depletes groundwater reserves that cannot be replenished quickly.

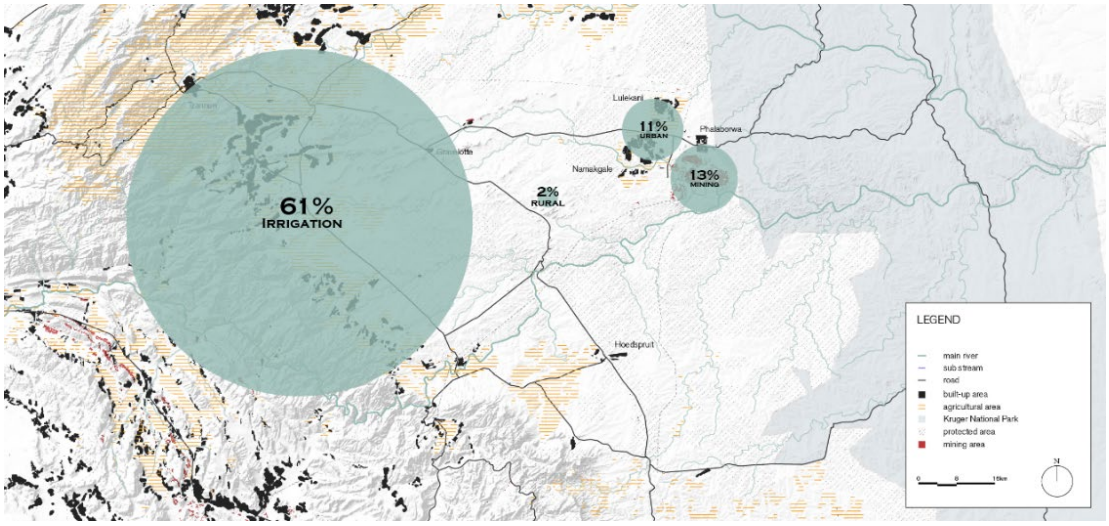

Fig. 2. 2011 Lower Olifants water balance. (Source: Author, Data source: Berbé et al., 2024)

The primary causes of this issue are the region's high temperatures and low soil permeability. The rainy season coincides with periods of intense heat, leading to rapid evaporation of exposed rainfall before it can infiltrate the ground. Additionally, the low permeability of the soil prevents water from percolating into deeper layers, limiting groundwater recharge and further exacerbating water loss through evapotranspiration.

Given the envisioned agricultural expansion to enhance local food self-sufficiency, there is an urgent need for a more efficient and sustainable water acquisition strategy to address the existing water balance deficit.

3 / Theoretical framework

3.1 / WH&C approach

Rainwater harvesting is widely used around the world for domestic and agricultural purposes. However, in South Africa, the adoption of such practices remains relatively low (Denison & Wotshela, 2009). Improving the efficiency of rainwater collection is an appropriate water utilization

strategy for Phalaborwa and surrounding areas, as the region experiences a moderate amount of rainfall. However, due to high temperatures and soil conditions, the utilization rate of this rainfall is very low (Berbé et al., 2024).

Beyond the rooftop rainwater harvesting strategies discussed in the parent report, low-cost, large-scale rainwater collection strategies that involve capturing rainwater through soil or the construction of collection and storage areas are gaining popularity worldwide. This is especially true in countries that are primarily arid or semi-arid, where such strategies are increasingly being advocated (Mutunga, 1999).

The concepts of water conservation (WC) and water harvesting (WH) are often used within the context of soil and water management to describe two distinct methods of collecting rainwater. These concepts are frequently used interchangeably in practice. According to a report submitted to the South African Water Research Commission (WRC), the following definitions are used to specify the distinct roles of WH and WC (Denison & Wotshela, 2012):

Water Harvesting: Water harvesting can be defined as the process of concentrating runoff from a larger catchment area to be used for crop production in a smaller target area. This process may occur naturally or artificially. The collected runoff water is either directly applied to an adjacent agricultural field (i.e. stored in the soil profile) or stored in some type of on-farm storage facility for domestic use and as supplemental irrigation of crops.
Water Conservation: Water conservation, in the context of water harvesting, is defined as methods that reduce unproductive water loss from crop fields by evaporation, runoff and deep drainage.

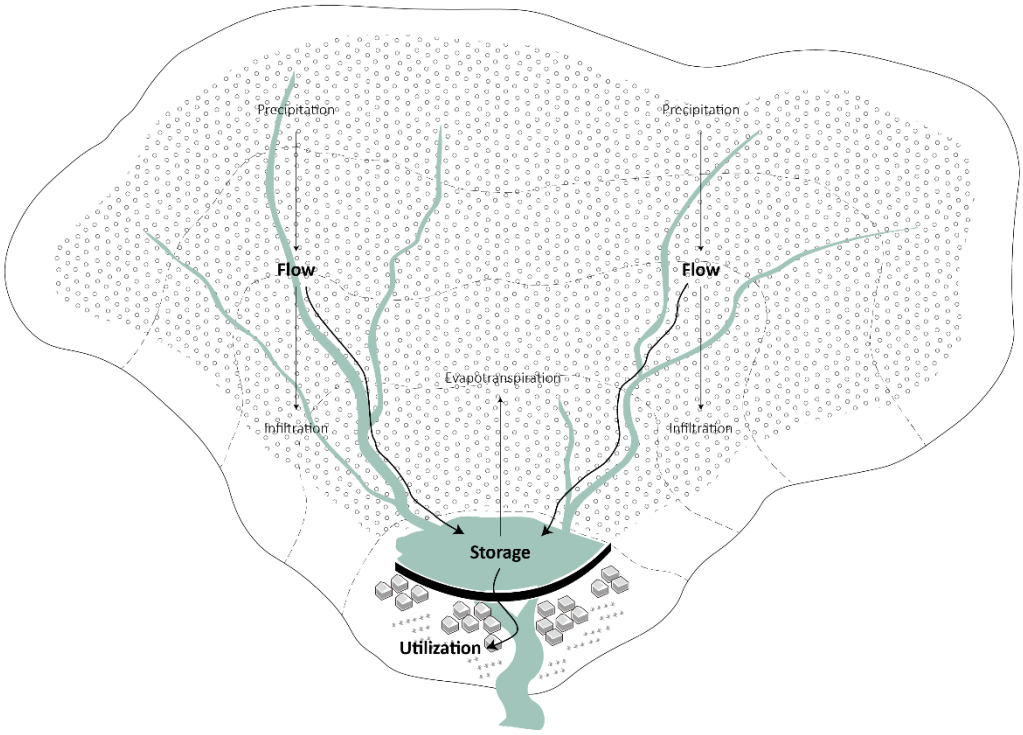

Fig. 3. Diagram of water harvesting strategy. (Drawn by Houxuan Zhang)

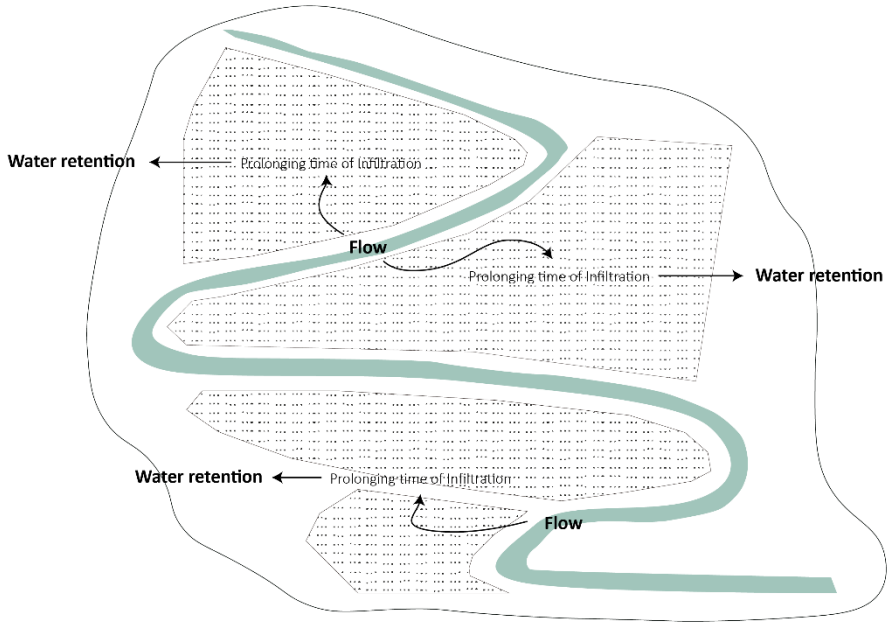

Fig. 4. Diagram of water conservation strategy. (Source: Author)

The application of WH&C (Water Harvesting and Conservation) strategies in South Africa is not entirely absent. In 2008, the Water Research Commission (WRC) conducted a nationwide study on the scope of WH&C practices across South Africa, identifying and documenting the range of practices used in the country, while delving into their origins and applications (Denison & Wotshela, 2009). More practical operation manuals have also been written for agricultural practitioners to adopt these strategies (Water Research Commission, 2015). These studies are undoubtedly insightful; however, the discussion regarding Phalaborwa remains valuable, primarily due to the region's unique post-extractive context. This context presents new challenges, as technology and investment are not gradually being introduced, but rather gradually withdrawn. Therefore, greater emphasis must be placed on how to integrate WH&C technologies in low-tech environments.

Additionally, the unique environmental conditions in Phalaborwa present new challenges, such as how to achieve the water retention required for water conservation in soils with low permeability. How can local agricultural practices and settlements of different scales be used to collect water? Which WH&C technologies are suitable for the local precipitation, temperature, and evapotranspiration conditions? This report will address these questions from the perspective of spatial design.

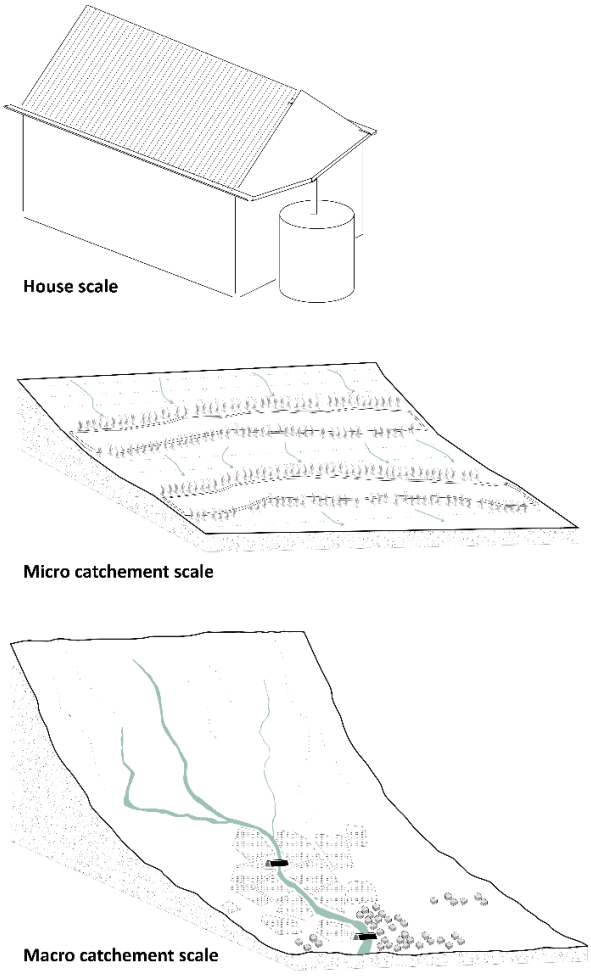

Fig. 5. Different scales of WH&C system. (Source: Author)

WH&C (Water Harvesting and Conservation) technologies generally follow a basic model of collecting rainwater over a large catchment area, channeling it into a concentrated water collection zone for utilization. While WH typically emphasizes man-made water storage facilities, WC strategies focus more on keeping precipitation on the soil as long as possible to increase water retention. This model can be implemented at different scales. For example, a rooftop rainwater harvesting system is a relatively small-scale water harvesting technology, utilizing the roof as an independent catchment area and directing water into a storage tank. On a larger scale, WH&C technologies require using the landscape and naturally existing spatial elements to guide and store rainwater. A well-known example in South Africa is the Saaidam system, which uses a low embankment surrounding a flat field in a valley to capture seasonal floodwaters, storing them for a period to promote soil water retention (Denison & Wotshela, 2009).

Based on Phalaborwa's specific situation, WH&C systems can be categorized into three scales:

House scale: Systems that collect and store water within a single residential unit or smaller scale. These systems are more feasible in urban areas where spaces are fragmented and smaller

structures can be converted into water collection facilities.

Micro-catchment scale: Systems that collect and store water within a single agricultural field. This includes individual farm plots in concentrated agricultural areas as well as gardening agriculture within urban environments.

Macro-catchment scale: Systems that collect and store water across an entire agricultural area or small-scale river catchment. This includes systems that utilize whole agricultural regions or surrounding areas, such as those used in wild farming.

3.2 / Low-tech knowledge approach – learning from indigenous knowledge

Low-tech (or Lo-tech) is described as a simple, unsophisticated, uncomplicated, and primitive technology. It uses traditional or non-mechanical technology, such as crafts and tools. It is usually related to sustainable, adaptable and resilient technologies that are born out of necessity, and considered as the opposite of high-tech, which is advanced and complicated and considered as also problematic and expensive nowadays. (Watson, 2019) Low-tech knowledge is not necessarily indigenous, however, many of them generated from vernacular production and livelihood.

The number of resources a region can acquire is not solely determined by the resources it possesses but also by the technology available to access those resources. This is particularly evident in Phalaborwa's water resource access history. Currently, Phalaborwa's reliance on river and groundwater resources has been made possible through the extensive development of boreholes and dams, but this process is unsustainable.

In the case of Phalaborwa, the introduction of technology has given residents better access to resources, but it has also impacted on the sustainability of these resources. Specifically, boreholes have provided access to groundwater, but the natural replenishment rate of groundwater is far slower than the rate at which people are extracting it. As a result, the region's water balance has been disrupted.

Although there is no inherent logical connection, lower-tech water resource collection methods tend to be more environmentally sustainable. These methods follow the natural water cycle in the environment and often utilize parts of the natural water cycle to collect and store water. It is important to note that WH&C strategies that rely on natural processes benefit the local water balance because these processes depend on soil or natural terrain structures to store rainwater. The stored rainwater cannot be fully utilized by human activities. Instead, some of the water will seep into the soil, run off the surface, or contribute to local lakes, thus becoming part of the local water inflow and helping to reduce the water balance deficit.

Therefore, the research strategy in this report is to gather existing low-tech WH&C methods in South Africa (many of which are considered indigenous techniques) and use these as a basis to analyze and discuss the feasibility of adopting these technologies in Phalaborwa, given the region's existing ecological, social, technological, and spatial contexts.

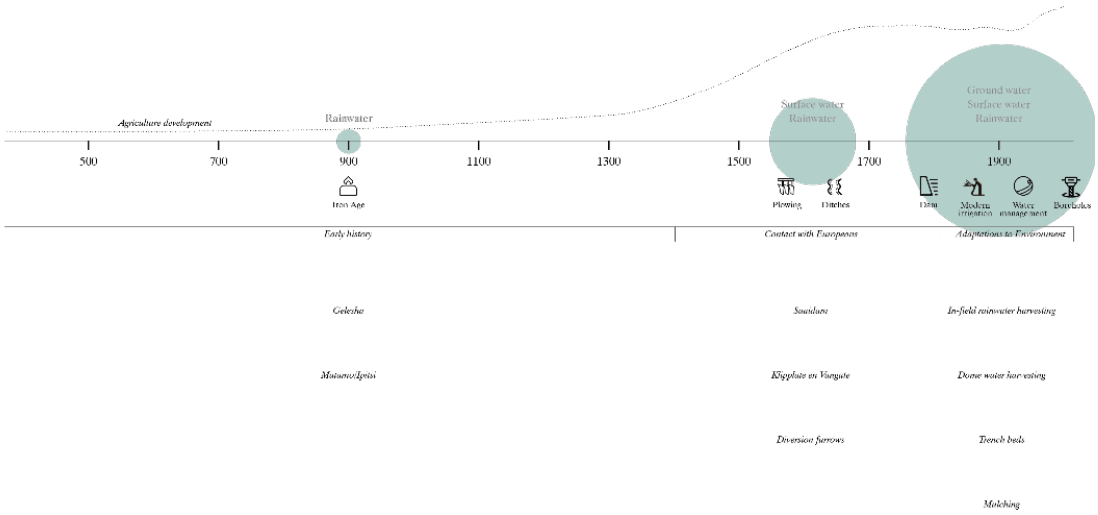

Fig. 6. Historical timeline of water harvesting technics in South Africa. (Source: Author)

4 / WH&C practice in South Africa

4.1 / Description of WH&C practice

A 2008 study supported by the Water Research Commission (WRC) collected 12 existing WH&C methods in South Africa, many of which are indigenous solutions or hybrid approaches combining external influences and local knowledge. The description of these techniques and their implementation locations were thoroughly documented in this study. Considering that the research combined a literature review, extensive interviews with rural development and agricultural support organizations, as well as field surveys, this list can be considered comprehensive. This report will build on this list, selecting strategies that are suitable for the Phalaborwa context, and will specifically discuss the feasibility of implementing these strategies in the Phalaborwa environment (Denison & Wotshela, 2012).

	WHC Practice	Description	Purpose	Origins
1	*Gelesha*	Conservation	Cropping	Indigenous
2	*Matamo/Ipitsi*	Water harvesting to home pond	Multiple use	Indigenous
3	*Saaidam*	Floodwater	Cropping	Indigenised
4	*Klipplate en Vangate*	Water harvesting to storage tanks	Multiple use	Indigenised
5	Terracing	Conservation	Cropping	Indigenised
6	Contouring	Conservation	Cropping	Indigenised
7	*Ploegvore* (pitting)	Micro	Grazing	Indigenised
8	Dome water harvesting	Water harvesting to storage tanks	Multiple use	Contemporary
9	In-field rainwater harvesting	Micro	Cropping	Contemporary
10	Trench beds	Conservation	Cropping	Contemporary
11	Diversion furrows	Macro	Cropping	Contemporary
12	Mulching	Conservation	Cropping	Contemporary

Table. 1. List of water harvesting and conservation practices in South Africa (Source: Denison & Wotshela, 2012)

The report has simplified the description of the 12 strategies from the original study and has recorded them as follows:

Gelesha – A traditional Xhosa practice involving mid-winter soil tilling to enhance water infiltration and prevent evaporation.
Matamo/Ipitsi – Small homestead ponds designed to capture rainwater for multiple uses, including irrigation and livestock watering.
Saaidam – A floodwater harvesting system used in commercial farming, diverting peak floods into planting basins.
Klipplate en Vangate – A method using hardened surfaces to collect runoff and channel it into underground storage for human and livestock use.
Terracing – The construction of stone or soil terraces on slopes to reduce runoff, prevent erosion, and retain moisture for crops.
Contouring – Creating contour ridges to slow down surface water flow, helping infiltration and reducing soil erosion.
Ploegvore (Pitting) – Shallow pits dug in arid regions to trap rainwater and improve vegetation growth, especially for grazing.
Dome Water Harvesting – Collecting runoff from granite domes into storage reservoirs for community water supply.
In-field Rainwater Harvesting – Capturing rainwater directly in planting
Trench Beds – Digging deep, compost-filled trenches to retain moisture and improve soil fertility

for vegetable gardening.
Diversion Furrows – Large-scale channels diverting water from streams or hillsides to irrigate cropland.
Mulching – Spreading organic material like straw or leaves over the soil surface to reduce evaporation, improve infiltration, and protect crops

4.2 / Preliminary applicability assessment of WH&C practice in Phalaborwa

The 12 WH&C strategies included in the previous study were collected from across South Africa. However, low-tech WH&C strategies are more closely connected to the local environment and natural water cycles, and therefore have specific requirements for local soil, climate, and topography. A technology described as indigenous needs to be transferred and implemented in another area with a more cautious approach. This is not only due to differences in environmental conditions, but also because local social conditions, agricultural systems, and technical capabilities will affect the efficiency of these strategies. Therefore, a preliminary applicability analysis is necessary. This analysis will be used to confirm whether these strategies have the potential to be tested within the research area's context.

When studying the applicability and sustainability of a system related to local ecological processes and society, the Social-Ecological-Technological Systems (SETS) framework has been used to examine the impact of mining industries and surrounding environments. Environmental impacts are described as the potential relationship between technology and local social-ecological-technical systems. This analytical framework can be seen as an evaluation tool for the impact of knowledge production on the local area (Nilsson et al., 2021). In the 2021 study by Nilsson, Avango, and Rosqvist, eight universal components were used to structure the analysis approach:

(1) abiotic environment; (2) biodiversity and ecosystems (3) technical artefacts; (4) institutions; (5) markets; (6) knowledge; (7) social networks and demography; and (8) actors and agency.

In the case of Phalaborwa, we focus more on the technological aspects related to the local environment and agricultural culture, such as institutions and market-related management factors, which are excluded because they fall outside the scope of this report and the mother report, which focus on physical feasibility rather than institutional feasibility. Combining the SETS research framework and the focus of this study, the 12 technologies were evaluated based on the following concerns: Ecological, Social, and Technological.

Ecological: This primarily concerns the assessment of the WH&C systems on the non-biological environment (including climate conditions such as temperature, rainfall, and evapotranspiration) and agricultural ecosystems within the study area.
Social: In agriculture, this focuses on local traditional agricultural cultures, staple crops, and agricultural knowledge, in addition to considering non-agricultural population structures and labor habits.
Technological: This mainly concerns the technical and cost conditions required to implement and

maintain the systems described.

In the analysis, the study provides a basic evaluation conclusion on the feasibility of each WH&C strategy in a particular aspect. Apart from the straightforward categories of feasible and infeasible, those that may be used locally but are less efficient in water collection due to certain limitations in comparison to their efficiency in the original location will be rated as **Less efficient**. Strategies that cannot be implemented due to local technological or ecological limitations but could be adapted to local conditions with changes in implementation steps will be rated as **Need Modification**. Strategies that cannot be given a definitive answer due to limitations in this study's field or data gaps will be rated as **Debatable**. The results of the analysis are as follows:

	ECOLOGICAL APPLIABILITY	SOCIAL APPLIABILITY	TECHNICAL APPLIABILITY	ASSESSMENT DESCRIPTION
Gelesha	+	+	***	**E:** The example is in a more precipitated area; however, it is recorded that it is also used in Limpopo Province. **S:** Only works for summer crops but matches local agricultural system. **T:** Traditionally it is done by cows and ploughing but could also be done by machinery.
Stone terracing	-	-	-	**E:** It requires higher precipitation and alluvial soil to collect the sediments, however, could be used as a rain collection method. Also, it can be used only in the mountain area. **S:** It is managed by the group as family. Requires more labor work to be done. **T:** Requires large number of stones to actually do the job.
Homestead Ponds	*	+	***	**E:** It requires higher precipitation and alluvial soil to actually collect the sediments, however, could be used as a rain collection method. **S:** Considering the water gather ability, the homestead ponds could only gather water enough for an individual garden for 5 months. **T:** Hand dig, however, it is more important to think about the water gathering area instead of water storage pond itself, filtering as well.

Contouring	*	+	+	**E:** Planting grass to encourage water flow to the water storage or cultivation area could be possible, however, it requires certain topographic change to make it happen. **S:** It suits the requirement of local agriculture. **T:** Maintenance needs to be discussed.
Saaidam	*	**	***	**E:** The climate matches. However, this sophisticated and large-scale system needs suitable flat land with deep alluvial soils, maybe only Rhodic Nitisol matches. Besides, the products are limited to lucerne for animal husbandry. **S:** Requires certain management method to apply in such large-scale agriculture. **T:** Requires relatively high investment and maintenance cost.
Klipplaate en vanggate	+	+	***	**E:** The climate matches. It requires a compact surface to gather water. Might be able to find in urban areas. **S:** Can be utilized in any water needed area with harden surface. **T:** Finding/creating the compact surface would be crucial.
Ploegrove	+	**	**	**E:** The climate and soil matches. **S:** It is only used to provide suitable land for animal husbandry. It could be used in wild-farming area, however, hard to find if it is efficient. **T:** Certain technics to create pitting need to be imported.
Granite dome harvesting	-	+	+	**E:** Such granite dome do not exist in Phalaborwa area. High evaporation also makes any water harvesting method with open water storage impractical. **S:** Public water gathering might fit the smaller settlement in rural areas. **T:** Low expected investment and maintenance cost. However, water pollution might be a problem.

In-field rainwater harvesting	+	+	**	**E:** It is being experimented in free state and eastern cape. **S:** Higher labor participation is required, but it could be solved with migration in the strategy. **T:** No-till cultivation method needs to be imported.
Trench bed gardening	-	**	+	**E:** It required more precipitation to be functional. **S:** Could be used in a small-scale farming system. But it should apply in a family structured farming system. **T:** Abandoned metal or crops could be used as materials.
* Less efficient ** Debatable *** Need modification				

Table. 2. SETS assessment of WH&C strategies (Made by Houxuan Zhang)

It should be clarified that the report only provides a preliminary analysis of the listed WH&C technologies based on the SETS framework. A deeper, more nuanced evaluation of the feasibility of implementing these strategies remains an area that this report does not cover. This report only uses the SETS framework as a preliminary tool to assess whether the WH&C strategies have initial feasibility within the scope of the study. The actual application of these strategies and their further impacts on the local SETS framework would require more in-depth analysis in future research.

Based on the above analysis, the study identifies four strategies that show potential for experimental implementation within the scope of the research:

- Contouring **(E: Less efficient, S: Yes, T: Yes)**
- Klipplaate en vanggate & Syenite intrusion **(E: Yes, S: Yes, T: Need modification)**
- In-field rainwater harvesting **(E: Yes, S: Yes, T: Debatable)**
- Ploegvore **(E: Yes, S: Debatable, T: Debatable)**

The study will analyze each of these four strategies in terms of their suitable implementation scale within the research scope, the changes they would bring to the spatial structure within the implementation area, and the significance of their implementation in relation to the overall strategy proposed in the main report.

5 / Experimenting WH&C practices in Phalaborwa

5.1 / Discussion on scales of WH&C practices

Before discussing the spatial experimentation of the aforementioned WH&C systems in the study area, it is essential to determine the appropriate scale for implementing each system. This study categorizes local design scales into three types: House scale, Micro scale, and Macro scale.

Among these, house-scale applications primarily involve rooftop rainwater harvesting, which has already been assessed for feasibility in the main report. The four WH&C strategies examined in this study correspond to the following suitable scales:

	APPLIED SCALE	EXPLANATION
Contouring	Macro	Contouring involves transforming single or multiple agricultural plots into grass-covered planting zones, affecting an entire agricultural production area. Its impact aligns more closely with a macro-scale agricultural landscape.
Klipplaate en vanggate	Micro	Since Klipplaate en vanggate requires non-exposed water storage infrastructure, its current applications are mostly limited to individual house yards. However, with greater investment, replicating this structure as modular units to expand the catchment area is feasible.
In-field rainwater harvesting	Micro	This method is currently restricted to single agricultural plots and, due to its high labor requirements, is not well suited for larger-scale agricultural systems.
Ploegvore	Macro	The low-intervention nature and long-term environmental transformation process make this strategy more suitable for large-scale implementation.

Table. 3. WH&C system in different scales (Made by Houxuan Zhang)

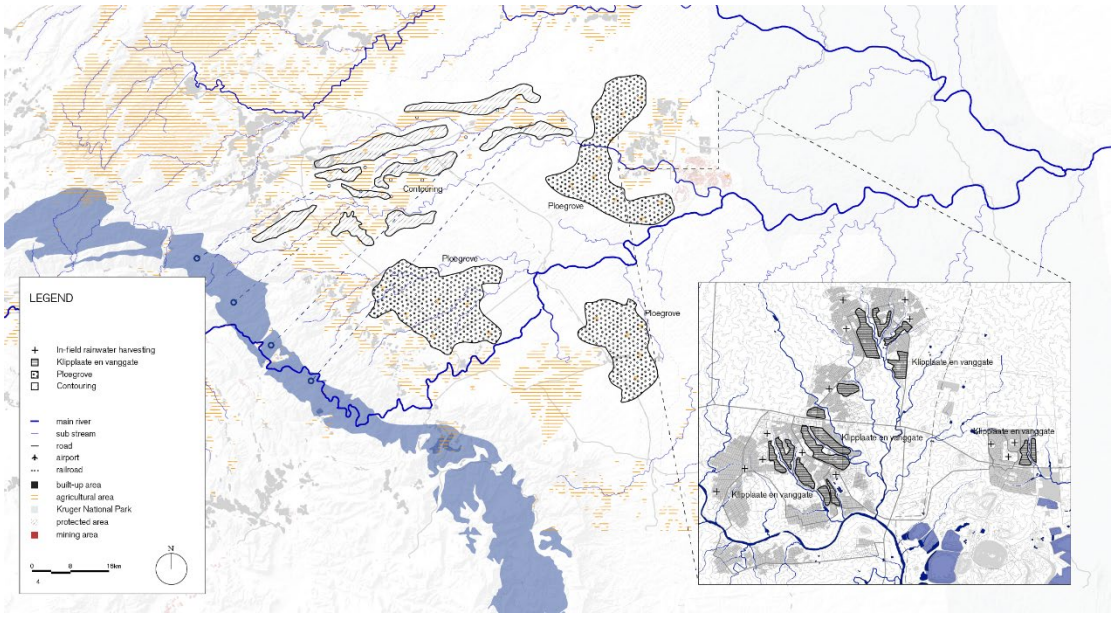

Fig. 8. WH&C system in different scales (Drawn by Houxuan Zhang)

5.2 / Experimenting in Macroscale agriculture

5.2.1 / Contouring (E: Less efficient, S: Yes, T: Yes)

Contouring is commonly used in rainfed farming, primarily as a soil conservation technique. However, its ability to enhance soil infiltration makes it valuable as a potential Water Harvesting & Conservation (WH&C) strategy for the study area.

Contouring refers to an agricultural structure where crops are planted in strip formations along contour lines. The land between these strips is usually left unplanted, serving as a rainwater collection area rather than a direct utilization area. By incorporating grasses or shrubs between the strips, rainwater retention on the crop soil is prolonged, thereby increasing infiltration rates. Additionally, the harvested grasses can be used as fodder to support livestock farming, ultimately improving the region's livestock carrying capacity.

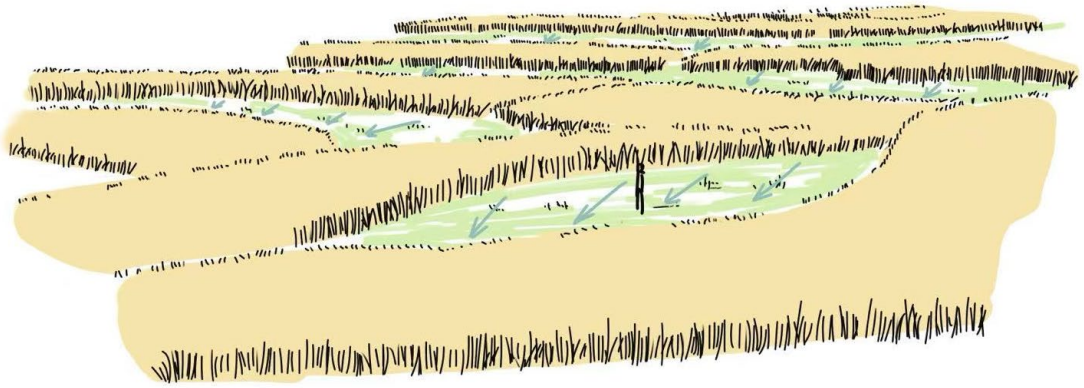

Fig. 8. Contouring system (Drawn by Houxuan Zhang)

This technique has been described as widely present in both commercial and smallholder farming across South Africa (Denison & Wotshela, 2012). However, its use has not been observed in the agriculture of the study area. This may be due to the fact that large-scale farms near Tzaneen employ simpler structures to accommodate mechanized agriculture, while subsistence farms near Phalaborwa are too small and located on relatively flat terrain, making it difficult to implement contouring practices.

Nevertheless, given the simplicity and adaptability of this strategy, contouring still holds significant potential in the region, particularly in the context of the agricultural expansion plans outlined in the main report for areas near the Ga-Selati River tributaries, where the valley slopes provide suitable terrain.

To test the spatial applicability of this approach, a selected agricultural site near a Ga-Selati tributary was analyzed. In its current state, rainwater rapidly drains from higher-elevation agricultural patches into nearby river channels, leading to water loss. The introduction of two levels of contouring-based shrub and grass buffer zones along the river and between farmlands is expected to slow down surface runoff and enhance soil infiltration. Even if these buffer zones are not strictly aligned with contour lines, a more structured spatial layout would still allow room for mechanized and automated farming processes.

Fig. 9. Spatial experiment of contouring system (Drawn by Houxuan Zhang)

5.3 / Experimenting in Microscale agriculture

5.3.1 / Klipplaate en vanggate (E: Yes, S: Yes, T: Need modification)

Klipplaate en vanggate is considered a classic and ancient water harvesting method, first appearing in the late 19th century. The most typical structures of this type take advantage of naturally formed hardened and impermeable surfaces, which are further cleaned and compacted to serve as rainwater collection surfaces. The collected water is then channeled through a structured profile into underground storage tanks, minimizing evaporation losses.

Historically, this system primarily relied on naturally occurring compacted calcrete surfaces. However, modern adaptations increasingly utilize artificially constructed cement surfaces to maximize surface runoff.

One of the key advantages of this WH&C system is its structural flexibility. The catchment area can be any hard surface with low permeability, and such surfaces are widely present in Phalaborwa's urban settlements. This system can be seen as a scaled-up extension of rooftop rainwater harvesting, as both share similar components— a hard-surfaced collection area (rooftops/cement or natural rock surfaces) and a storage unit (water tanks/underground reservoirs).The direct implication for local WH&C strategies is: Beyond rooftops, which existing hard surfaces in Phalaborwa can be repurposed for rainwater harvesting? How should rainwater harvesting systems be designed and implemented around these surfaces?

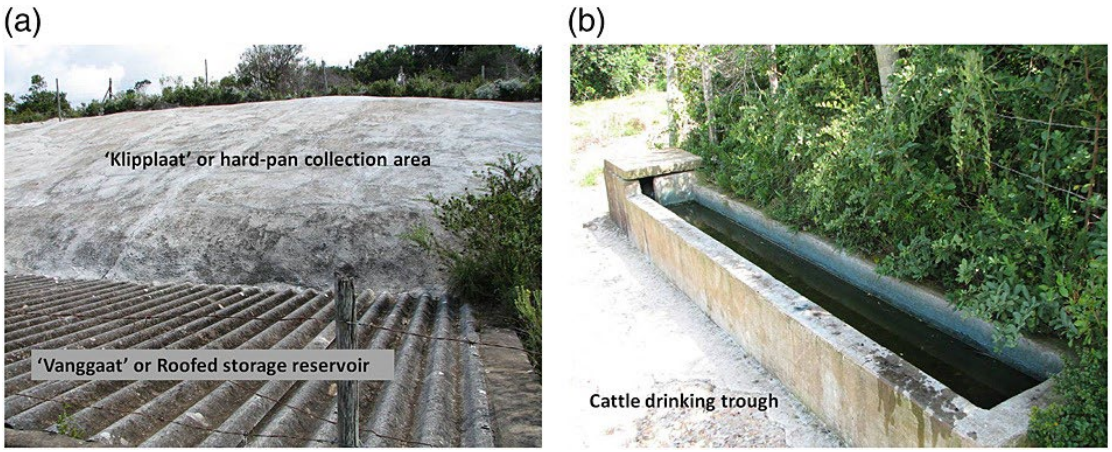

Fig. 10. Klipplaate en vanggate (Source: Denison & Wotshela, 2012)

In the study area, one possible approach is to identify similar naturally formed low-permeability surfaces. However, a more efficient method is to directly utilize existing built-up low-permeability surfaces within urban areas. Naturally occurring low-permeability surfaces are relatively rare, whereas in human-made environments, such surfaces are far more common. In Phalaborwa's urban areas, most streets and house yards have significantly lower permeability than typical natural ground surfaces, making them highly promising for rainwater harvesting.

This study selects a site in the northern part of Namakgale Township for a design experiment. Rooftops have already been incorporated in the parent report as part of a rainwater harvesting system, as they provide cleaner surfaces for collecting water intended for domestic use. Meanwhile, house yards, which cover a larger area, can be utilized as part of an agricultural

rainwater collection system.

Rainwater will be directed through drainage channels along the streets, following the natural topography toward the lowest point of the neighborhood, a seasonal river channel. At the outermost edge of this river channel, two water storage strips will be constructed.

A semi-underground rainwater collection facility, designed to leverage the natural undulations of the terrain, shows significant potential. However, the degree of isolation between the storage facility and the local soil remains a subject of discussion, as the specific soil infiltration rate and water retention capacity of the area are still unclear. According to the conclusions from the parent report, the soil in this area has a significantly lower water retention capacity compared to Tzaneen and Ga-Selati. However, the possibility of utilizing the soil for some level of water storage cannot be ruled out.

Beyond the storage strips, two agricultural strips will be established closer to the river channel to make full use of the stored water resources.

Fig. 11. Spatial experiment of Klipplaate en vanggate (Drawn by Houxuan Zhang)

The issue with widespread use of hard surfaces in urban areas for water collection is that pollution caused by rainwater flowing over these surfaces is relatively difficult to control. However, it is possible to maintain a certain level of surface cleanliness to reduce contamination of the rainwater resources, ensuring the water quality meets agricultural needs. With appropriate management strategies, this system could also serve as a driving force for local residents to

engage in public cleanliness activities. Furthermore, the water storage facilities could be designed with structures that promote the settling or purification of the collected water, further ensuring the cleanliness of the stored rainwater resources.

5.3.2 / In-field rainwater harvesting (E: Yes, S: Yes, T: Debatable)

In-field rainwater harvesting is not an indigenous WH&C technology. It originated around the year 2000 in South African WH&C practices and has been proven to be practical and valuable in 42 village household farms in the Thaba Nchu area of the Free State. The success of this method suggests that it can be replicated in similar ecological contexts across other parts of South Africa (Denison & Wotshela, 2012). Even though it is modern agricultural technology, it aligns with the characteristics of low-tech systems. The structure consists of two distinct parts, one of which is the main planting surface, utilizing no-till technology to facilitate the lateral movement of collected precipitation in the region. The collected rainwater is directed into a storage area, which is a man-made depression, roughly one meter in width. This depression is filled with a certain amount of mulch, which can be made from crop roots or stems, as well as discarded plastic, stones, or other materials to reduce the evaporation of the stored water.

The application of this technology in the study area is primarily focused on small-scale, individually managed agricultural regions, as it is less adaptable to large-scale mechanized farming. However, in the gardening agriculture within Phalaborwa, this technology has greater potential. The practice of this system in other areas has demonstrated effective rainwater collection, though whether this system can provide long-term water supply for agriculture remains a subject of discussion. One possible improvement is to increase the soil infiltration rate in the storage area. The no-till technique in the planting area reduces the evaporation loss of water stored in the lower layers of soil, making soil-based water storage feasible. However, the ability of this system to provide year-round water supply for the area is still questionable. Nevertheless, even if it cannot entirely replace external water sources, this system can still enhance the agricultural system's ability to utilize rainfall.

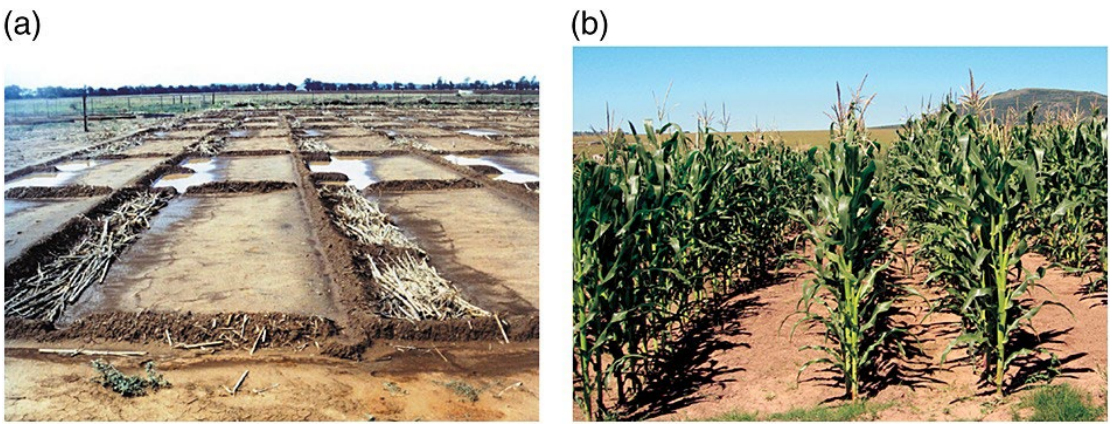

Fig. 12. In-field rainwater harvesting (Source: Denison & Wotshela, 2012)

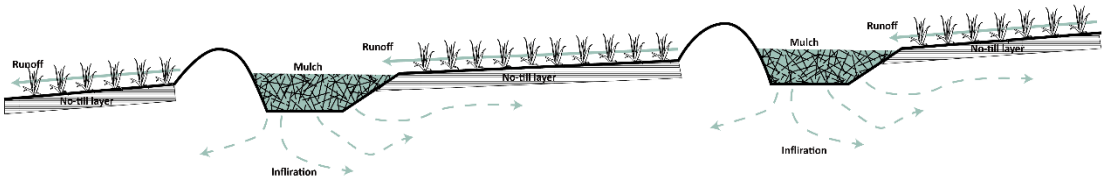

Fig. 13. Spatial structure of In-field rainwater harvesting (Drawn by Houxuan Zhang)

Another issue that needs to be discussed is that the no-till planting technique is not a familiar agricultural practice in the region. Therefore, proper agricultural technical guidance is also necessary. In implementing this technology in the study area, the dissemination of agricultural knowledge and techniques will need to be further researched and developed.

5.4 / Experimenting in Wildlife farming

5.4.1 / Ploegvore (E: Yes, S: Debatable, T: Debatable)

Ploegvore is an indigenous WH&C technique that originated in Africa, although its use is not widespread in South Africa. This technique involves digging shallow pits or strip-like depressions in the land in natural arrangements to capture water in the soil, thereby promoting agricultural development or protecting ecosystems. It is commonly used in pastureland ecological restoration strategies, with the goal of transforming vast, sparsely vegetated, arid areas into regions with greater grazing potential, ultimately enhancing the carrying capacity of the environment. However, this technique has high soil requirements, and past cases have used a special double-bladed plough to dig these shallow pits, preventing excessive soil compaction and preserving the water capture function.

This technique could serve as a precursor to the wildlife farming included in the main report, enhancing the carrying capacity of the region's vast wilderness. In a land restoration program in the Northern Cape, it was recorded that within 15 years, the carrying capacity for livestock nearly doubled (Denison & Wotshela, 2012). However, due to the limited focus on wildlife farming in the main report for this region, this report does not continue to discuss it further under this scheme.

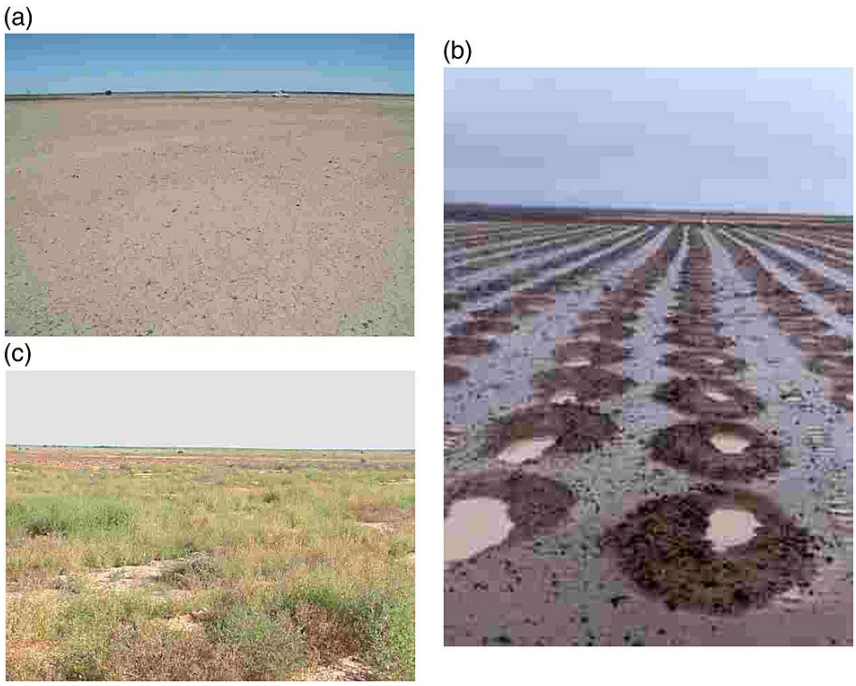

Fig. 14. Ploegvore (Source: Denison & Wotshela, 2012)

6 / Discussion

6.1 / The role of WH&C in the water-related strategy of main report

This report is directly linked to the water issues addressed in the main report. On a macro scale, WH&C strategies have the potential to reduce evapotranspiration of precipitation, thus enabling more local water collection, which can make the region's water balance more sustainable. In practical terms, WH&C strategies enhance the local water system's carrying capacity for agriculture, providing greater possibilities for local farming. Low-tech systems also reduce the risk of water harvesting systems becoming unusable in the post-extractive period, due to reduced investment, unaffordable maintenance costs, or the withdrawal of technical personnel.

In summary, the practices outlined in this report have the potential to improve precipitation utilization efficiency in the region. However, much of the low-tech WH&C strategies' water collection capabilities are still constrained by local precipitation amounts, rainfall patterns, evapotranspiration, soil permeability, and available space. Therefore, the WH&C systems discussed in this report are not expected to provide complete self-sufficiency in water resources. The use of the Malmani dolomites aquifer, as mentioned in the main report, remains the primary solution to addressing the region's water resource issues. However, the WH&C technologies mentioned here aim to improve the sustainability of the water cycle in the study area from a more dispersed and small-scale perspective, aligning with the spatial strategy proposed in the main report, which calls for decentralization and small-scale solutions.

The limitation of this report lies in the lack of exploration of these technologies' feasibility from a management perspective, as well as the absence of further research on their usability. While WH&C strategies provide feasible options for improving the sustainability and security of the water

system in the study area, significant challenges remain.

6.2 / The role of WH&C in local WEF nexus

The WEF (Water-Energy-Food) Nexus is used in the main report to address sustainability challenges in Phalaborwa and its surrounding areas and to discuss potential future developments for the region. Water, as a key resource, is closely linked to food and energy, especially in the context of agriculture. Most of the WH&C strategies mentioned in the report are directly related to agricultural systems, with the rainwater resources provided being directly applied to associated agricultural production systems. As stated in the agricultural chapter of the main report, irrigation water for agriculture in semi-arid regions is directly linked to local agricultural strategies. By introducing WH&C strategies, this report increases the availability of water resources for agriculture, thus enhancing the region's potential for achieving food self-sufficiency through agricultural production.

Certain WH&C strategies, such as Ploegvore and Contouring, also could improve the soil. Another limitation faced by agriculture in the area is that most of the soil does not have enough water retention or nutrients to support agricultural or livestock development. However, WH&C offers the possibility of improving the soil at low cost through natural processes.

In terms of energy, this report is not closely linked to the photovoltaic systems or solar intermittent spring systems proposed in the main report. However, the low-tech approach indirectly reduces the energy consumption required for water resource acquisition, thereby contributing to addressing the region's energy challenges.

6.3 / Future research and further steps

Two critical questions in advancing WH&C technologies in the study area are: Which existing WH&C technologies are suitable for experimentation and further promotion in this region? What challenges do these technologies face in practice, and what adjustments are necessary to address these challenges? This report provides recommendations for future research based on these questions, supporting other researchers in addressing the research gaps identified in this study.

All WH&C technologies examined in this study originate from South Africa and are largely based on research conducted in 2008 by the WRC, which focused on existing WH&C technologies in the country. However, this scope is clearly incomplete. The diversity of South Africa’s climate, natural environment, and ecosystems means that many WH&C technologies listed in this study are not suitable for implementation in the study area and have been filtered out. Additionally, WH&C technologies developed in East and West African countries—regions with environmental conditions more similar to the study area—were not included in this research. Future studies should explore a wider range of WH&C technologies and assess their feasibility for local implementation.

This study primarily focuses on the preliminary selection of WH&C systems using the SETS

framework and on spatial applications. However, research on the applicability of these systems within the existing local context remains limited. Evaluating soil conditions, climate, and environmental ecology is a prerequisite for conducting WH&C experiments in the area. Small-scale pilot projects may provide valuable supporting information for these discussions. Ultimately, pilot projects can serve as proof of feasibility and as a foundation for knowledge dissemination, facilitating further advancements.

7 / Conclusions

This study underscores the significance of water harvesting and conservation techniques in facilitating agricultural revitalization in post-mining landscapes, particularly in Phalaborwa. By employing scale analysis and environmental assessments, we have demonstrated the feasibility of adaptive water management strategies that align with the region's hydrological characteristics and socio-economic needs. Key findings suggest that integrated approaches, incorporating both traditional and modern conservation practices, can mitigate water scarcity challenges and foster long-term agricultural sustainability.

The conclusions drawn from this research align with the broader objectives of the MineLives project, which seeks to develop resilient socio-ecological frameworks for post-mining communities. Our findings contribute to this vision by providing practical guidance on water resource utilization, ensuring that agricultural development is both ecologically sound and economically viable. Moving forward, further engagement with local stakeholders and continued monitoring of water resource interventions will be essential to refining these strategies and ensuring their long-term success in transforming post-mining landscapes into sustainable agricultural hubs.

8 / Reference

- Berbé, D. W., Houben, A. L., de Jonge, M. E. Y., & Zhang, H. (2024). *WEF Nexus Phalaborwa: Multidisciplinary project (MDP) – Student report*. Delft University of Technology. http://resolver.tudelft.nl/uuid:c4545c19-463b-464b-9aa7-037bce6f7ed8
- Open Data Portal – CCTE GIS. (2024). *Rainfall Data 2000 to 2024*. Retrieved March 23, 2025, from https://odp-cctegis.opendata.arcgis.com/content/143a4af6c0f842e2adb6580b540b7cfa/about
- Denison, J., & Wotshela, L. (2009). *Indigenous water harvesting and conservation practices: Historical context, cases and implications : report to the Water Research Commission*. Water Research Commission.
- Mutunga, K. (1999). *Water Conservation, Harvesting and Management (WCHM)—Kenyan Experience*.
- Denison, J. A., & Wotshela, L. (2012). *AN OVERVIEW OF INDIGENOUS, INDIGENISED AND CONTEMPORARY WATER HARVESTING AND CONSERVATION PRACTICES IN SOUTH AFRICA - Denison—2012—Irrigation and Drainage—Wiley Online Library*. https://onlinelibrary.wiley.com/doi/full/10.1002/ird.1689
- Water Research Commission. (2015). *Rainwater harvesting and conservation for cropland*

and rangeland productivity (Technical Brief No. 1775/1/14). Water Research Commission. http://www.wrc.org.za

- Nilsson, A. E., Avango, D., & Rosqvist, G. (2021). Social-ecological-technological systems consequences of mining: An analytical framework for more holistic impact assessments. *The Extractive Industries and Society*, *8*(4), 101011. https://doi.org/10.1016/j.exis.2021.101011
- Everson, C. S., & Dladla, R. (2011). *Sustainable techniques and practices for water harvesting and conservation and their effective application in resource-poor agricultural production through participatory adaptive research*. Water Research Commission.
- Watson, J. (2019). *Lo-TEK: Design by radical indigenism*. Thames & Hudson.