Using nature-based water storage for smallholder irrigated agriculture in African drylands
Lessons from frugal innovation pilots in Mozambique and Zimbabwe

Duker, A.; Cambaza, C.; Saveca, P.; Ponguane, S.; Mawoyo, T. A.; Hulshof, M.; Nkomo, L.; Hussey, S.; van der Zaag, P.; More Authors

DOI
10.1016/j.envsci.2020.02.010

Publication date
2020

Document Version
Accepted author manuscript

Published in
Environmental Science and Policy

Citation (APA)
Duker, A., Cambaza, C., Saveca, P., Ponguane, S., Mawoyo, T. A., Hulshof, M., Nkomo, L., Hussey, S., van der Zaag, P., & More Authors (2020). Using nature-based water storage for smallholder irrigated agriculture in African drylands: Lessons from frugal innovation pilots in Mozambique and Zimbabwe. *Environmental Science and Policy*, *107*, 1-6. https://doi.org/10.1016/j.envsci.2020.02.010

published in *Environmental Science & Policy* Vol. 107, May 2020, Pages 1-6

Short communication

Using nature-based water storage for smallholder irrigated agriculture in African drylands: lessons from frugal innovation pilots in Mozambique and Zimbabwe

A. Duker[1 *], C. Cambaza[2], P. Saveca[2], S. Ponguane[2], T.A. Mawoyo[3], M. Hulshof[4], L. Nkomo[5], S. Hussey[5], B. Van der Pol[6], R. Vuik[6], T. Stigter[1] and P. van der Zaag[1, 7]

1. IHE Delft Institute for Water Education, Delft, The Netherlands
2. Instituto Superior Politécnico de Gaza, Chókwè, Mozambique
3. Department of Irrigation of the Ministry of Lands, Agriculture, Water, Climate and Rural Resettlement, Bulawayo, Zimbabwe
4. Acacia Water, Gouda, The Netherlands
5. Dabane Trust, Bulawayo, Zimbabwe
6. Practica Foundation, Papendrecht, The Netherlands
7. Delft University of Technology, Delft, The Netherlands

* corresponding author: a.duker@un-ihe.org

Highlights

- Sand river aquifers provide potential for individual family-focused solar irrigation in arid lands in Africa.
- Action research in the Limpopo basin aims to bridge the gap between hydrological theory and practical farm experience.
- Preliminary findings show that it has technical and economic potential, and requires an adaptive development approach.
- Future ambitions include enhanced monitoring of the water source and use, and technical performance of frugal innovations.
- These diverse innovations need better understanding in relation to marketing and families' livelihoods and rural networks.

Abstract

Alluvial aquifers in seasonal rivers are a yet underutilised resource in many (semi-)arid regions of Africa. These so-called sand river aquifers provide nature-based water storage within easy reach because they are shallow. They form a significant potential renewable source of water for irrigation development. Innovative approaches and solutions are needed to sustainably increase productive use of this resource to enhance rural livelihoods. The A4Labs action research explores the potential and pitfalls of introducing solutions designed for individual smallholder farmers. This entails innovation in three domains: the technology used (manually-installed shallow well-points in or next to a sand river combined with solar-powered water pumps), the arrangement (individual smallholder farmers), and the purpose (market-oriented farming). Pilots were established in the Limpopo river basin in Zimbabwe and Mozambique. Monitoring and assessment are ongoing, but preliminary findings indicate that successful adoption of the approach was not constrained by water availability. Despite the fact that these pilots were established during two subsequent drought years, there was no difficulty in accessing freshwater in sufficient quantity. Instead, successful adoption depends on previous farming experience, market access, and the possibility to grow adaptively in terms of technology, scale and financial risks. In addition, establishing an individual farm to grow cash crops requires acceptance and new skills, as irrigation for smallholder farmers in Africa has traditionally been framed as a communal activity in "collective" irrigation schemes with strong support by outside agencies, and with the well-known collective action challenges. This action research has also estimated that the potential for upscaling this innovation in the Limpopo river basin is significant.

Our innovative solution for accessing water stored in shallow alluvial aquifers can start small, is within reach of smallholder farmers (initial investment being less than US$1,000/0.2ha), and is scalable as farmers can gradually improve their system and expand. Moreover, the solution allows for the application of "adaptive development pathways" at the river-stretch scale.

Key words: frugal innovation, sand river aquifers, Africa, solar-powered irrigation development, farmer-led irrigation

1. Introduction

Sand river aquifers are unconfined alluvial groundwater systems consisting of sandy deposits in river beds of seasonal rivers in arid and semi-arid regions in Sub-Saharan Africa. They have been used by rural communities for domestic and smallholder crop production purposes for centuries (Senzanje et al, 2008; Mpala et al., 2016). More recently, farmers have been able to exploit the resources for commercial agriculture in few regions in southern Africa (Love et al., 2011). Nevertheless, these sand rivers form a yet underutilised resource with large potential for irrigation development. Water balance modelling has revealed that there is potential for an additional 5,000ha of irrigated agriculture along the Mzingwane river in Zimbabwe alone (Love et al. 2011), and at least 15,000 ha in the Lower Limpopo in Mozambique (Acacia Water, 2019). The Mzingwane is one of the most developed sand rivers in southern Zimbabwe, implying that the potential for productive use is still large along the many sand rivers in the Limpopo basin, both in Mozambique and Zimbabwe. At the same time these arid regions are facing persistent poverty and paltry contributions from unreliable agricultural production to people's livelihoods. Smallholder rain-fed agriculture is increasingly challenging because of unreliable rainfall patterns, while communal irrigation systems struggle to sustain as a result of poor access to energy and additional collective action problems (Coward, 1986; Manzungu and Van der Zaag, 1996; Bolding et al, 2003). For these reasons an action research programme (A4Labs) was started to assess why the nature-based storage capacity of sand rivers is underutilised and what could be innovative and meaningful modalities to make better use of these rivers in a sustainable way. Advancing frugal innovations for the abstraction and use of these resources can enhance resilience of smallholder irrigators who are operating in an extremely uncertain environment, in terms of climate and economic prospects. Action research was chosen to bridge a gap between hydrological findings (underutilised water stored in sand rivers in arid to semi-arid regions) and creating and capturing on-the-ground and real-time experiences in implementing innovations. It allows to draw applicable lessons and tools for practitioners and target groups, in this case farming families (Hart and Bond, 1995; Vallenga et al., 2009). Action research works through a cycle of planning, action, observation and reflection (Hopkins, 1985; Vallenga et al, 2009). This 'message from the field' forms part of the reflection step and will feed into adapted planning and action in the field. In the sections that follow, the approach adopted by the action research, preliminary achievements, lessons learned so far, and the way forward are presented and reflected on.

2. Project approach and area description

Action research approaches are common in various scientific domains, primarily applied in real-world situations (O'Brien, 2001). In this research the approach is used in an experimental set-up. The four-year A4Labs (Arid African Alluvial Aquifers Laboratories) project centres around testing labs in the Mzingwane catchment in Zimbabwe and the Lower Limpopo catchment in Mozambique. The study is an action research, or action learning, that seeks to change the status-quo, introduce innovations and involve the participants, i.e. the farmers, as project designers and co-researchers (O'Brien, 2001), and learn by doing. This change is pursued through two main pillars of the project: a focus on individual farming families, and an adaptive development avenue. The focus on individual farming originates from the observation that conventional smallholder irrigation schemes developed in the region are facing continuous challenges to sustain themselves; most if not all such schemes suffer from the "build-neglect-repair" syndrome and hence do not provide a reliable source of income (Mandri-Perrott and Bisbey, 2016). Farming families are increasingly establishing their own irrigated plots individually, and this research seeks ways to understand and contribute to their modes of operation. An adaptive approach, building on the concept of adaptive development pathways (Rietdijk et al., 2019), is chosen as it is expected to gain more sustainable results for introducing, and scaling, frugal innovations while mitigating financial, social and environmental risks. This approach is effectuated by starting small, in terms of number of farmers, pump capacity and irrigated area.

The action research is a collaboration between four types of actors: farmers at the two sites, (local and international) NGOs, (local and national) government agents, and (local and international) academics, (Table 1). These different actors meet regularly at each of the two labs, and there have been exchange visits of selected actors between the labs to facilitate the exchange of ideas and approaches.

Table 1. Type of actors involved in the A4Labs action research

Type of actor	Mozambique lab	Zimbabwe lab
Farmers	Farmers in Guijá and Chókwè	Farmers in Tshelanyemba
NGOs	Kulima, Oxfam Mozambique, PRACTICA Foundation	Dabane Trust, PRACTICA Foundation
Government agents	SDAEs[3] Guijá and Chókwè, INIR[4], ARA-SUL	Maphisa-Matobo RDC[5], DID[6]
Academics	ISPG,[1] IHE Delft, Acacia Water	NUST,[2] IHE Delft, Acacia Water

1. Instituto Superior Politécnico de Gaza; 2. National University of Science and Technology; 3. Serviços Distritais de Actividades Económicas (district services for economic activities); 4. Instituto Nacional de Irrigação (national irrigation institute); 5. Rural District Council; 6. Department of Irrigation Development.

Research methods include literature review, analysis of existing biophysical datasets, remote sensing and GIS analyses, field observations (rainfall, water levels, hydro-geological surveys), well and pump tests, modelling, crop surveys, plot monitoring, semi-structured interviews, financial analysis, and exchange visits between Zimbabwean and Mozambican partners.

Study sites

Experimental plots have been developed in two locations in the Limpopo basin:

1) Tshelanyemba community along the Shashane river in the Mzingwane catchment in southern Zimbabwe, which is a tributary to the Shashe and Limpopo river;

2) The area around Chókwè town in Chókwè and Guijá districts along the Limpopo river in southern Mozambique.

Both project sites are faced with low annual rainfall, less than 500mm/yr, with recurring dry spells. The areas have a history of rain fed farming by most families. Irrigation is applied to a limited extent in small community or privately-managed gardens in the Zimbabwean site. Near Chókwè in Mozambique there is a large irrigation system, as well as several small communal irrigation systems, and commercial irrigated farms. Table 2 presents an overview of the involved farmers at each experimental lab.

Table 2. Overview of farmers involved in the A4Labs action research

Research site	Total area (ha)	Number of farmers	Male farmers	Female farmers	Area per farmer (ha)
Zimbabwe					
Z1 ('All one')	0.5	3	3	-	0.125-0.25
Z2 ('Malaba')	1	8	3	5	0.125
Mozambique					
M1	0.2	1	1	-	0.2
M2	0.2	1	-	1	0.2
M3	0.2	1	1	-	0.2
M4	0.2	1	-	1	0.2
Total		**15**	**8**	**7**	

3. Achievements up to now

At both labs farmers were involved in several meetings with local institutions (district governments, NGOs and academics). Interested farmers were invited to develop a plan for their farm, including their own contributions to the plot. These were further worked out with project partners. The majority of farmers, 15 in total, had previous experience in irrigation (individually, in an association or in community gardens), while few had worked in rain-fed agriculture only.

Installation of abstraction and irrigation equipment

Different combinations of abstraction systems have been installed, as can be seen in Table 3. An abstraction system consists of a manually-installed wellpoint and a solar-powered pump. Different set-ups are in use to compare effectiveness and operational aspects. The first type is a wellpoint placed in the riverbed (left in Figure 1), which is most commonly used. The second type is a wellpoint positioned in the plot to be irrigated (right in Figure 1). The possibility of creating the latter depends on the local geohydrology as the saturated sand zone is at some places bordered by less permeable materials (clay, silt, hardrock), while at others a stronger connectivity occurs due to the presence of paleochannels or generally more permeable material below and on the side, as is shown in Figure 1. The number of wellpoints installed is based on the sand river characteristics and pump discharge.

Table 3. Different combinations of abstraction and irrigation technology

Research site	Solar pump		Wellpoint/source			Irrigation application method				
	SF2	GF	River bed	Field	Canal	Spray tube	Drip	Hose pipe	Mini pivot	Tank (lift)
Zimbabwe										
Z1 ('All one')	2	1	3	1	-	-	1	-	-	-
Z2 ('Malaba')	0	1	5	-	-	-	-	1	-	1
Mozambique										
M1	1	-	1	-	-	-	-	1	-	-
M2	1	-	1	-	-	1	-	-	-	-
M3	1	-	-	-	1	-	-	-	1	-
M4	1	-	-	1	-	1	-	1	-	-

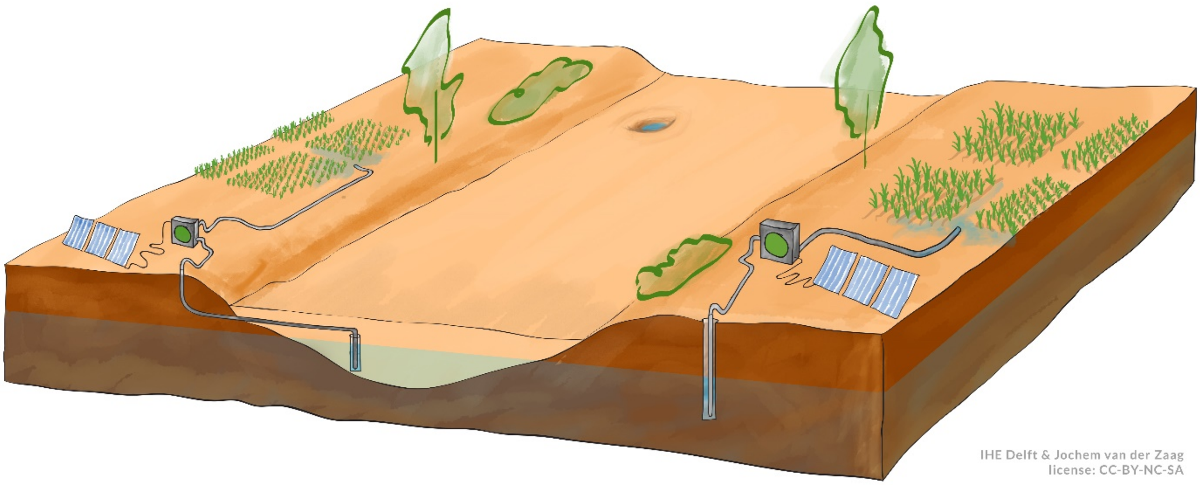

Figure 1. A 3D Cross-section of an alluvial aquifer with wellpoint abstraction systems for smallholder irrigation

Two types of solar-powered pumps have been installed for and with the farmers. The first is the SF2, which is a small and movable solar-powered pump developed by Practica and manufactured by Futurepump Ltd. It has been used in several countries around the world since 2017 but its performance in alluvial aquifers has not yet been recorded. The second pump type is the submersible Grundfos SQF2.5-2N, a Danish solar pump with a larger capacity to irrigate a larger area than the SF2. The specification for the pumps are shown in Table 4. The pumps are connected to the two different types of wellpoint systems.

Table 4. Characteristics of solar-powered pump types used

	Futurepump SF2	Grundfos SQF2.5
PV panel capacity (W)	120	1,400
Max. discharge (m^3/h)	2.3	2.9
At total head (m)	8.0	10
Max. total head (m)	15	120
Weight of pump (kg)	20	8
Weight incl. panels and suction pipe (kg)	35	110

Farmers apply different irrigation methods, of which some are completely novel for them, while others are already used in the region. This facilitates a comparison on various aspects such as labour, water flow, ease of use, acceptance, cost, and the potential for upscaling. The Mini pivot is a low-pressure application system developed by Practica to fit the variable water output of solar pumps.

Irrigated crop production and marketing

Two Mozambican farmers are well into their second season of crop production (in the wet season of 2018/19 and the dry season of 2019). They water their fields using different irrigation methods. Farmer M3 using the mini pivot started growing cash crops immediately as he was already experienced in irrigation. Farmer M4 was equipped with a hosepipe and spray-tubes and had no previous experience in irrigation and hence focused on understanding and operating the irrigation equipment and fencing in the first season. She then planted quite a large area, which resulted in crop losses as the irrigation demand surpassed the pump capacity. In the second season, she made adjustments in her operations and intercropped maize, beans and cabbage. She successfully sold beans and cabbage on the local market of the nearby village.

Two farmers in Mozambique (M1 and M2) pulled out after one season. One faced a combination of challenges, including her labour availability for full-time farming, and different expectations of the discharge of the pump compared to diesel pumps that are more commonly used in the area. The other stopped because of a land dispute. These are further discussed in the next section.

In Zimbabwe, the farmers in site Z1 are in their first productive season irrigating cash crops with drip lines. The plot size is 0.5ha, of which around 0.375ha is currently irrigated. The farmers are learning how to irrigate with the objective of future upscaling. The driplines of 3 farmers are connected with an underground manifold. A further scoping of markets and value-adding crops has been initialised. At site Z2, the eight farmers have cleared and fenced the land, while preparations for cultivating crops were still ongoing. They have developed a cropping plan.

4. Lessons learned so far

The project embraces innovation in three domains in each of which lessons have been learned:

- The application of new technology: manually-installed shallow wells in or next to a sand river combined with solar-powered pumps and different types of irrigation equipment.
- The mode of operation: focus on individual farming families as opposed to community gardens and collective irrigation systems.
- Market-oriented farming: establishing market linkages instead of merely subsistence farming.

All three elements are pivotal for evaluating the potential for future upscaling of the innovation.

Application of technology

The solar-powered pumps combined with both types of well points were found to be effective in abstracting and conveying water to the fields. Here we briefly review the experiences with the different elements applied.

Wellpoints: The manual installation of wellpoints in or close to the river bed is feasible and easy. A large amount of water is available in the dry season, and abstracted volumes can be replenished quickly again through infiltration from runoff during the following rain season (Abi, 2018; Moulahoum 2018; Moulahoum et al., 2019). Salinity levels are well suitable for irrigation purposes as measured in the Limpopo river bed (200-600 µS/cm) and in the Shashane (155 µS/cm) (Abi, 2018; Blok, 2017). The possibility of installing the wellpoint in the farmer’s field depends on the local hydrogeology and requires (local) knowledge about the groundwater systems and more labour as the water levels are relatively deeper as compared to the lower lying river beds. However, in field wellpoints significantly reduce operational costs for conveyance infrastructure, and repairs of damage due to floods, livestock or vandalism. In addition, the pipe friction losses are lower, and farmers can operate the pump easier as it is close by. Because the elevations are comparable for both types of wellpoints, the energy losses from the water level up to the field are similar. For M4 we have found that water is available from the in-field wellpoint year-round. For the Zimbabwean sites further trials will show whether there is a difference in water levels and accessibility throughout the dry season between the in-field and riverbed wellpoints.

An exchange visit between the Mozambique and Zimbabwe technical teams resulted in merging the best elements of both manual drilling techniques: the bailing technique used in Mozambique to quickly penetrate into the aquifer and the installation of a poly-pipe (PE) instead of PVC as done in Zimbabwe to create a single casing and suction pipe. This fusion of techniques resulted in a material cost reduction of 50%.

Solar pumps: The farmers consider irrigating with the solar pumps combined with either hosepipes, spray tubes or drip lines not very labour-intensive. M3 had a fuel pump before and labour contributions are similar. The SF2 solar pumps are taken to the farmers' homes in the evening with a wheelbarrow, which has not been experienced as burdensome by most, although for farmer M2 this was one of the reasons to stop. The Grundfos is not movable because of the weight and is therefore installed in a galvanised tank to avoid theft and damage. No problems have yet been encountered regarding the operation of the solar pumps. They are easy to use with one on-off switch. The SF2 is quickly affected by little shade, as opposed to the Grundfos. By positioning it well and possibly adjusting it throughout the day this is not a major concern. Experience in other countries where the SF2 pumps have been operated for a longer time, indicates that the pump demands little maintenance, and maintenance is overall easy. The Grundfos pump which has also been in use in several locations in Zimbabwe, is more difficult to repair. It is clear that if the solution will be scaled, the suppliers of these new pumps will need to provide repair services by establishing local service support facilities. The wellpoints in the river bed require a seasonal check-up after major floods in the rainy season. In case of a strong flood damaging the system, replacement is required, for which low-cost tools and skills are locally available.

The scale of irrigated farming plays a major role, in which labour, cropped area and applied technology are intertwined. For example, one of the farmers was previously irrigating with buckets and using a scoop hole in the river bed (M4). In this way it is not possible to irrigate more than approx. 100 m^2. The new pump and irrigation equipment allow for irrigating approximately 0.2 ha, which seems to be the appropriate area for one family without having to hire permanent labour. This size allows farmers to grow for subsistence farming and local sales.

Farmers' previous experience is crucial in their appreciation of the solar pump. For those who have never irrigated before or irrigated manually with buckets, such as M2, the pump results in an important improvement to their livelihood, while those who are used to fuel pumps, such as M3, are disappointed by the solar pump's relative low discharge. Irrigation application method: So far no constraints have been found with the different irrigation methods in the short time the project is running. As water is abundant and energy freely available, other aspects than water use efficiency are expected to play a role in the choice for a certain technology. Labour use has decreased compared to bucket irrigation, which enables irrigating a larger area. This effect is the largest for application methods that do not require permanent presence; such as spray, mini pivot or drip irrigation.

However, farmers face challenges in using new equipment. For example, M4 has stopped using the spray-tubes and is only using the hosepipe now, as she has more confidence in basin irrigation.

Adaptive development: Although we observe that 0.1-0.2 ha might be an appropriate farm size to start with, farmers might want to increase the cropped area, which is exemplified by the experiences of M4. She immediately started with a larger area, which could not be accommodated for by the SF2 pump with crop losses as a result. She did not get discouraged though, and grew a smaller section in the next season. For her, and others, there are several options for increasing the irrigated areas once the farmers have the means to make further investments:

- A second pump set, although this is costly. An additional wellpoint would not be needed as one wellpoint can serve multiple SF2 pumps;
- More efficient irrigation technology, i.e. drip, which will increase the water application efficiency and reduce the labour need and hence provide a potential for increasing the area and intensifying crop cultivation;
- Adding more solar panels, which enhances the discharge of the pump and prolong the daily pumping time significantly, and hence increases the total volume of water that can be abstracted on a daily basis, and it will allow for better pumping during cloudy days;
- Water storage facilities to reduce the time it takes to irrigate, especially during the beginning and end of the day when solar power is low.

Mode of operation

The Mozambican and Zimbabwean farmers have a comparable history in irrigation arrangements. We observe that both research areas have a tradition of communal irrigation development, which is embedded in local structures. Only in recent years is irrigation development for and by individual smallholder families modestly emerging, apart from very small home gardens. This thinking in collectives seems to be stronger with the involved institutions in Zimbabwe than in Mozambique, and is reflected in the way the farmers are working in the labs. In Mozambique the labs are running on their own, while in Zimbabwe they are operating, by design, as a mini scheme of 3 or 8 farmers. Hence we learn that this aspect of innovation is more difficult to achieve. Individual farming requires different skills, the ability and mind-set to take risks, and social acceptance to do things differently, both with the farmers and the implementing agencies involved. This takes time and is part of the adaptive character of the study in finding out whether the Zimbabwean farmers will appreciate working on an individual basis at a later stage, after having started in a more collective setting to share perceived risks. At field level, we have learned several lessons from the new farmers, especially from their difficulties and deliberations to get involved in the project. Firstly, they need to learn how to use the new technologies on their own. One concern encountered is that the flow of the pump is small compared to the diesel or petrol pumps that most people are familiar with. Secondly, this type of irrigated farming is, irrespective of the irrigation method, labour-demanding and farmers have to be highly motivated and prepared to work and irrigate nearly full time in their plots during the period with peak irrigation demand. This differs from the conventional irrigation practice in schemes where farmers may typically irrigate only once per week. Having full-time other jobs, or combining it with irrigating in a communal scheme has been found incompatible, as this was the main reason for farmer M2 to stop. Likewise, farmers need to take care of issues such as safe transport and storage of the pumps, and fencing, which is crucial on lands along rivers that are also used for grazing. Farmer M4 was eager to make this additional effort, while farmer M2 was not.

At national level, the irrigation departments of both Mozambique and Zimbabwe have recently started to take the 0.2 ha irrigation for individual farming families as a serious irrigation development option, which was not yet the case when the project started in 2016; in Zimbabwe individual irrigation options of 30 ha or larger were then favoured, and in Mozambique no support facility for individual irrigation farming development was available. The A4Labs experience may have assisted to bring about this change in perspective, and thus influenced the development practice.

Market-oriented farming

The adaptive approach has been found crucial in this facet of the project. Starting interventions with a focus on (staple) crops for home consumption has been one strategy to become acquainted with the farm and avoid financial risks. However, for a return on investment marketing of the produce will be necessary and most likely upscaling the irrigated area. This implies further investment in the technology and the time invested in the farm. Preliminary data from Mozambique suggest that the A4Labs combination of technologies can raise average incomes of smallholders that change from subsistence rain-fed to irrigated crop production with 725 USD/year (45,000 MT/year), assuming two seasons within a year. The return on investment time is estimated to be two to six seasons. This still needs to be further evaluated with evidence from the upcoming seasons, considering market volatility induced by economic instability, and cheap, mainly South African, imports of vegetables.

Finally, we observe that there is immense potential for solar-powered irrigation in Zimbabwe given the current economic crisis where accessing cash and fuel poses tremendous challenges. Marketing produce requires planning and collaboration geared towards the demand, while current individual farmer operations as observed in the region are driven by a volatile supply of fuel. Therefore solar-powered irrigation is a welcome innovation, despite the initial investment still being relatively high compared to small petrol pumps. In Zimbabwe, a boost in solar-powered irrigation could enhance smallholders' access to markets.

5. Future ambitions

The lessons learned are based on progress made so far and provide a meaningful mirror for the project partners and beneficiaries. The experiences in Zimbabwe and Mozambique yielded several insights and necessary adjustments for the future, both within and after the lifetime of the project.

Monitor and address technical possibilities and limitations for expansion and upscaling

At plot level, we aim to yield more findings regarding the linkages between pump capacity, irrigated area, labour use, and the potential for expansion of the farms. This includes addressing likely technical challenges such as back-ups for cloudy days, which seems a likely need, even in the dry season. Solar-charged batteries are not recommended as they face operational issues because of simultaneous pumping and charging.

At river-stretch level, we will facilitate monitoring - by the water users themselves - of water levels and the speed of replenishment. With the current use there is no competition over water among users or with the riparian vegetation along the river bank. However, this might change if the use intensifies, with more farmers copying the innovation and establishing farms.

Understand individual farming modalities within existing livelihoods

For current collaboration, and for potential new farmers in the future, we need to better consider current livelihood sources, labour availability and opportunity costs of getting involved in an unknown and unsecure project. Related, enhanced understanding of feasible financial modalities and market linkages is crucial to make any relevant and significant impact. Moreover, there may be gender-biases in these possibilities and choices, which we have not yet been able to observe. Therefore we will monitor the trajectories for returns on investment and the possibilities or limitations that these give for expansion of the area irrigated and related resources such as hiring labour and gender-related aspects. A4Labs encourages farmers to be careful in selecting crops to be irrigated; ideally the selected combination of crops is informed by commercial considerations (cash crops, market opportunity), subsistence considerations (crops that can be used both for subsistence and for sale, including fodder), and own experience and knowledge. Given the vagaries of climate and markets it is prudent for starting smallholder farmers to have a careful learning approach, as this reduces risks and enhances resilience. With the application of solar energy and an abundant water resource, we are yet to learn how crop planning on an individual basis can be optimised considering market prices, areas irrigated, irrigation priority, pump capacity, and the water-sensitivity of crops. The production of fodder in these mainly livestock-based livelihoods could be a viable alternative strategy, or even the production of raising of broiler chicken in combination with the production of the fodder they need. These choices influence to a major extent for whom this form of irrigated agriculture is accessible, and a desirable and feasible option to increase their resilience and prosperity.

6. Conclusions

Individual solar-powered irrigation is feasible through adaptive development

Preliminary findings show that individual-geared solar-powered irrigation development from shallow aquifers in ephemeral rivers has, from a technical and economic perspective, a large potential as a frugal innovation for uplifting people's livelihoods in one of the driest parts of southern Africa. Our novel efficient and frugal (because cheap and made of locally available materials) wellpoint technique was the result of Mozambican and Zimbabwean technicians combining their approaches. We conclude that abstracting and using water with the current tools is technically feasible and able to contribute to the sustenance of farming families.

We have seen that, despite turning a back to collective action challenges in communal schemes, farming on an individual basis is not a paved road to success. This is illustrated by the fact that progress in both countries is slow and two farmers in Mozambique dropped out for a combination of reasons. Furthermore, we are confronted with the observation that a certain level of dependence is unavoidable, and even necessary, in terms of maintenance and marketing strategies.

Embracing an adaptive approach has been found meaningful in several ways: start small in an area with a handful of farmers to cultivate crops they are already familiar with, then move on to new crops that are potentially marketable. The technology leaves room for upscaling in terms of irrigated area, which requires an additional but relatively small investment by the farmer.

Action-research evolves with the research context

One of the challenges we observed in action research relates to the tension between following local structures and existing practices in order to establish a project and in institutionalising change through innovations. This is experienced in both countries and specifically in Zimbabwe where is a strong tendency to establish 'individual farms' in a communal setting. Additionally, when implementing action-research, and more so in the experimental set-up that we have chosen, we need to be fully aware that an experiment is never initialised from scratch, but building on a contextualised network with existing forms of livelihoods. This has consequences for people willing to engage in a project that is new and poses risks to their current state of living. These are reasons why action research is a slow process that needs time for alliance building through understanding mutual interests and different viewpoints to finally come to strong innovative approaches. We are operating in unknown territories, which is exciting and at the same time we need to reflect on our own adaptive pathway.

Funding

This work was supported by the Directorate-General of International Cooperation (DGIS) of the Netherlands Ministry of Foreign Affairs, and the Netherlands Enterprise Agency (RVO) from the Netherlands Ministry of Economic Affairs and Climate Policy.

Credit authorship contribution statement

A. Duker: Supervision, Formal analysis, Visualization, Writing - original draft. C. Cambaza: Data curation, Resources, Investigation, Project administration. P. Saveca: Resources, Data curation, Investigation. S. Ponguane: Resources, Data curation, Investigation. T.A. Mawoyo: Methodology, Data curation. M. Hulshof: Methodology, Formal analysis, Writing - review & editing. L. Nkomo: Data curation, Resources, Investigation, Project administration. S. Hussey: Resources, Investigation, Project administration. B. Van den Pol: Methodology, Data curation, Formal analysis, Writing - review & editing. R. Vuik: Resources, Validation. T. Stigter: Methodology, Formal analysis, Writing - review & editing. P. van der Zaag: Conceptualization, Funding acquisition, Supervision, Writing - original draft.

Declaration of Competing Interest

No potential conflict of interest was reported by the authors.

Acknowledgements

We thank all participating farmers in the labs in Zimbabwe and Mozambique for sharing their knowledge, experiences and concerns, and the local authorities for supporting the field work.

References

Abi A. 2018. Assessing the groundwater dynamics, recharge and storage potential in the Limpopo river sand deposits. MSc thesis UNESCO-IHE, Delft; 99 pp.

Acacia Water, 2019. Feasibility study Irrigation Package for Sand Rivers (IPSAR). Unpublished report. Acacia Water, Gouda.

Blok T. 2017. Groundwater storage in sand rivers – A case study of Shashani, Zimbabwe. Unpublished internship report. Acacia Water, Gouda, the Netherlands.

Bolding A., Mutimba J., Van der Zaag P. 2003. *Interventions in Smallholder Agriculture.* University of Zimbabwe Publications, Harare; 345pp.

Coward E.W. 1986. Direct or indirect alternatives for irrigation investment and the creation of property. Chapter 13 in: *Irrigation Investment, Technology, and Management Strategies for Development, Easter K.W (ed.). Studies in Water Policy and Management, no.9.* Westview Press, Boulder and London.

Hart E., Bond M. 1995. *Action research for health and social care: a guide to practice.* Open University Press, Buckingham Philadelphia.

Hopkins, D. 1985. *A teacher's guide to classroom research.* Open University Press, Philadelphia.

Love D., Van der Zaag P., Uhlenbrook S, and Owen R.J.S. 2011. A water balance modelling approach to optimising the use of water resources in ephemeral sand rivers. *River Research and Applications,* 27: 908-925.

Mandri-Perrott, C., and J. Bisbey, 2016. How to develop sustainable irrigation projects with private sector participation. World Bank, Washington DC.

Manzungu, E., and P. van der Zaag (eds.), 1996. *The practice of smallholder irrigation; case studies from Zimbabwe.* University of Zimbabwe Publications, Harare; 235 pp.

Moulahoum A.W. 2018. Using Field Assessment and Numerical Modelling Tools to Optimize a Water Abstraction System in the Shashane Sand River Aquifer (Zimbabwe). MSc thesis UNESCO-IHE, Delft; 107 pp.

Moulahoum W., Stigter T., Hulshof M. 2019. Sand river aquifers as a nature-based solution of water storage for food production: the example of the Shashane River in Southwest Zimbabwe. *Geophysical Research Abstracts* Vol. 21, EGU2019-17440-1.

Mpala S.C., Gagnon A.S., Mansell M.G., Hussey S.W. 2016. The hydrology of sand rivers in Zimbabwe and the use of remote sensing to assess their level of saturation. *Physics and Chemistry of the Earth* 93: 24-36.

O'Brien, R. (2001). An Overview of the Methodological Approach of Action Research. URL: http://www.web.ca/~robrien/papers/arfinal.html (Accessed August 2019).

Rietdijk, E., J. Timmermans, J. Kwakkel and P. van der Zaag, 2019. Adaptive Development Pathways - a novel planning approach for vulnerable communities facing an uncertain future. *DeltaLinks*, July 2019; URL: http://flowsplatform.nl/#/adaptive-development-pathways---a-novel-planning-approach-for-vulnerable-communities-facing-an-uncertain-future-1562523585139 505 (Accessed September 2019).

Senzanje, A., Boelee, E., Rusere, S. 2008. Multiple use of water and water productivity of communal small dams in the Limpopo Basin, Zimbabwe. *Irrigation and Drainage Systems* 22(3), pp225-237.

Vallenga D., Grypdonck M.H.F., Hoogwerf L.J.R., and Tan F.I.Y. 2009. Action research: what, why and how? *Acta Neurologica Belgica*, 109: 81-90.