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Martin Zimmermann, Birte Boysen, Ehsan Ebrahimi, Michaela Fischer, Elmar Henzen, Johannes Hilsdorf, Jürgen Kleber, Susanne Lackner, Aydin Parsa, Karl-Ulrich Rudolph, Sebastian Schöller, Faruq Shalizi, Jochen Sinn, Jana Zinkernagel

Replication Guideline for Water Reuse in Agricultural Irrigation

Upgrading wastewater pond systems to generate irrigation water for animal fodder production using the example of Outapi, Namibia



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Herausgeber:
Institut für sozial-ökologische Forschung (ISOE) GmbH
Hamburger Allee 45
60486 Frankfurt am Main



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Abbreviations

AHP	Analytic hierarchy process
CBA	Cost-Benefit Analysis
CEO	Chief executive officer
COD	Chemical oxygen demand
EIA	Environmental Impact Assessment
EPoNa	Upgrading of wastewater ponds to generate irrigation water using the example of the Cuvelai-Etosha Basins in Namibia (Ertüchtigung von Abwasser-Ponds zur Erzeugung von Bewässerungswasser am Beispiel des Cuvelai-Etosha-Basins in Namibia)
GIZ	German Cooperation for International Cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit)
MAWF	Ministry of Agriculture, Water and Forestry
MURD	Ministry of Urban and Rural Development
OTC	Outapi Town Council
SADC	Southern African Development Community
TSS	Total suspended solids
UASB	Upflow anaerobic sludge blanket
WSP	Waste stabilization ponds
WWTP	Wastewater treatment plant
WWTPP	Wastewater treatment plant partnership

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Preface

This Replication Guideline has been developed within the research project “Upgrading of Wastewater Ponds for Irrigation Water Production using the Cuvelai-Etосha Basin in Namibia as an Example (EPoNa)”, funded by the German Federal Ministry of Education and Research (grant number 02WAV1401B). Authors from all project partners of the consortium contributed to the preparation. The Replication Guideline summarizes the results and experiences of EPoNa in the fields of technology, agriculture, ecology and governance for the transfer of knowledge to decision makers. The scientific and technical results are presented in an application-oriented manner so that they can serve as a blueprint for replication, opening up opportunities for the transfer of the EPoNa concept to other African countries. The Replication Guideline is concluded with lessons learned and success factors of the implementation process.

Vorwort

Die vorliegende Replication Guideline ist im Rahmen des vom Bundesministerium für Bildung und Forschung geförderten Projekts „Ertüchtigung von Abwasser-Ponds zur Erzeugung von Bewässerungswasser am Beispiel des Cuvelai-Etосha-Basins in Namibia (EPoNa)“ entstanden (Förderkennzeichen 02WAV1401B). Autoren aller Projektpartner des Verbunds haben an der Erstellung mitgewirkt. Die Replication Guideline fasst die Ergebnisse und Erfahrungen von EPoNa aus den Bereichen Technik, Landwirtschaft, Ökonomie und Governance für den Wissenstransfer zu Entscheidungsträgern aus der Praxis zusammen. Die wissenschaftlich-technischen Ergebnisse werden anwendungsorientiert präsentiert, sodass sie als Blaupause für die Replikation dienen können und somit Wege für den Transfer des EPoNa-Gesamtkonzeptes in andere afrikanische Länder eröffnen. Abgerundet wird die Replication Guideline mit Lessons Learnt und Success Factors des Implementierungsprozesses.

Objectives of the Replication Guideline

The replication guideline provides relevant information for the transfer of the EPoNa water reuse system to other locations. In this context, it is essential to illustrate the benefits of the system and also the disadvantages of a lack of sanitation. We can show how the EPoNa water reuse concept can improve living conditions and how it can be adapted to different framework conditions. The experiences of the Outapi Town Council (OTC) exemplarily illustrates the steps and measures taken to adapt the water reuse concept to a town's existing structures. The aims of the replication guideline therefore are:

- to provide information for the replication of the EPoNa concept in regions with similar conditions
- to support further strategic planning of a sustainable implementation of the EPoNa concept
- to support communication with partners in Namibia, Germany and other countries and
- to support internal work processes and knowledge management

1. Initial situation in Central Northern Namibia and Outapi

1.1 Water reuse applications and socio-economic aspects

In order to assess water reuse, it is necessary to link major water use patterns and water demand with potential water reuse applications. Besides the geographical and climatic situation, water use and withdrawals also depend on socio-economic aspects such as the degree of urbanization and population growth, which is why water withdrawals differ considerably. It becomes clear that particularly the distribution of water abstractions for industry and agriculture differs significantly from region to region. With regard to Africa, including both sub-Saharan and northern Africa, we can see that the agricultural sector withdraws the enormous amount of almost 90% of water. This is due to the fact that, on the one hand, less water is generally available in (semi-) arid regions through precipitation and therefore more irrigation is required, and, on the other hand, the industrial sector is not as established as in industrialized countries. The relevance of water reuse is underlined by population growth, economic development and climate change, especially in countries of the global south.

1.2 Specific problems in Northern Namibia

Around half of the Namibian population lives in the Cuvelai-Etosha Basin in central northern Namibia. For the almost one million people, water from the Kunene River on the Angolan-Namibian border is transported and distributed via a long-distance water supply system for human consumption as well as agricultural purposes. The arid region faces the following water-related problems: water scarcity, lack of irrigation water, loss of water due to evaporation in wastewater ponds and saline groundwater, poor access to tap water and sanitation services in informal settlements, poor capacities with regard to health and hygiene as well as at a technical level.

1.3 Political framework, governance and institutions

On the political level, the Ministry of Agriculture, Water and Forestry (MAWF) is responsible for the support, development, management and usage of water resources, agriculture and forests. Issues regarding water resources management in rural contexts are regulated by the Department of Water Affairs and Forestry while the subordinated Directorate of Water Supply and Sanitation Coordination coordinates the efforts of all the ministries and other stakeholders in the area of sanitation. The Ministry of Health and Social Services sets up programs for hygiene education.

Further key stakeholders in the project region are the Ministry of Urban and Rural Development (MURD), Regional Councils (RC), the Olushandja Basin Management

Committee, and the Outapi Town Council (OTC). External stakeholders may also be relevant under certain circumstances, e.g. GIZ for its involvement in (Transboundary) Basin Management Committees.

1.4 Local demand in Outapi

Outapi is located 10km south of the Angolan border. The already limited water resources in the Cuvelai-Etosha catchment area are increasingly under pressure by population growth and urbanization. According to the former CEO of Outapi, the population has been doubling in numbers roughly every 3 years. In 2011, Outapi reached a total population of 6,437, in 2018 the population came up to 11,000 inhabitants (Mwinda et al. 2018). In addition, the region is undergoing a process of rapid urbanization which leads to the fact that around 40% of the population in urban areas have no access to improved sanitation facilities (MAWF 2009). Apart from this, Northern Namibia is dependent on fodder supply from other parts of the country. This shows that the need to produce fodder crops causes a high demand for water reuse and agricultural irrigation.

1.5 Analysis of local capacities

There is a general lack of water operators and technicians in Namibia. Although management structures regarding water and sanitation do exist at the OTC (at the Departments of Technical Services as well as Environmental Health and Safety), Outapi lacks local capacities, especially on a technical level. So far, the OTC owns and operates a gravity sewer network discharging in a system of ponds (waste stabilization ponds, WSP) with a so-called “evaporation pond” as the final stage. But due to population growth and the extension of the sewer system, the ponds lack maintenance and are overloaded. This leads to an overflow of barely treated wastewater into the surrounding environment (especially during flooding in the rainy season) and a rapid fill-up with sludge.

Local and regional capacities for small-scale farming are limited. As irrigation agriculture is difficult due to the aridity of the region, traditional farming is mostly based on rainfed agriculture and the cultivation of Pearl Millet (Mahangu). Irrigation farming is only practised by few commercial farmers who cultivate crops for human consumption. Thus, fodder has to be imported from greater distances.

2. Overview of the EPoNa concept

2.1 Aim of the concept

The EPoNa concept pursues the following objectives:

- Reuse of water resources
- Reuse of nutrients
- Production of fodder crops
- Preventing uncontrolled discharge of wastewater from waste stabilization ponds into the environment
- Reduction of greenhouse gas emissions

2.2 Initial situation of the wastewater infrastructure

Since 2004, waste stabilization ponds (WSP) were constructed in Namibia. Back then, Outapi had a population of about 3,000, with 2,500 having access to sewerage services. Nowadays, houses in more developed urban districts are connected to a gravity sewer system.

The WSP system in Outapi has two parallel lines (line A and line B) with four ponds each: one primary facultative pond followed by three maturation ponds. All eight ponds have a total water surface area of 40,000m² and a total volume of 55,000m³. The final evaporation pond has a surface area of 41,000m² and a volume of 20,000m³ (Sinn and Lackner 2020).

2.3 Design and flow chart of the upgraded technology

One way of accomplishing the goals can be a purposeful upgrade of the existing WSP with other technologies. The EPoNa project compared two pre-treatment technologies: an Upstream Anaerobic Sludge Blanket (UASB) reactor and a micro sieve in order to reduce the organic and particle load (total COD and TSS) (Sinn et al. 2019).

The daily amount of wastewater for the design varied between 480 and 1,250m³/d. The UASB had a pilot scale character and a constant flow rate of 6.5m³/h for 12 hours per day was applied as a basis for the anaerobic biological process, which meant a treatment capacity of 78m³/d wastewater can be treated via this treatment process. The mechanic filtering process had a size that was able to treat the remaining wastewater of maximum 80m³/h and on average about 6m³/h were treated via this micro sieve (Sinn and Lackner 2020).

Line A was further improved by emptying, and by then removing settled solids from pond A-1. In this first pond of line A two floating baffles were also introduced to

improve the flow system and make use of the full pond volume. Furthermore, in pond A-4 a rock filter was added as a post-treatment stage in pond A-4 (see figure 1).

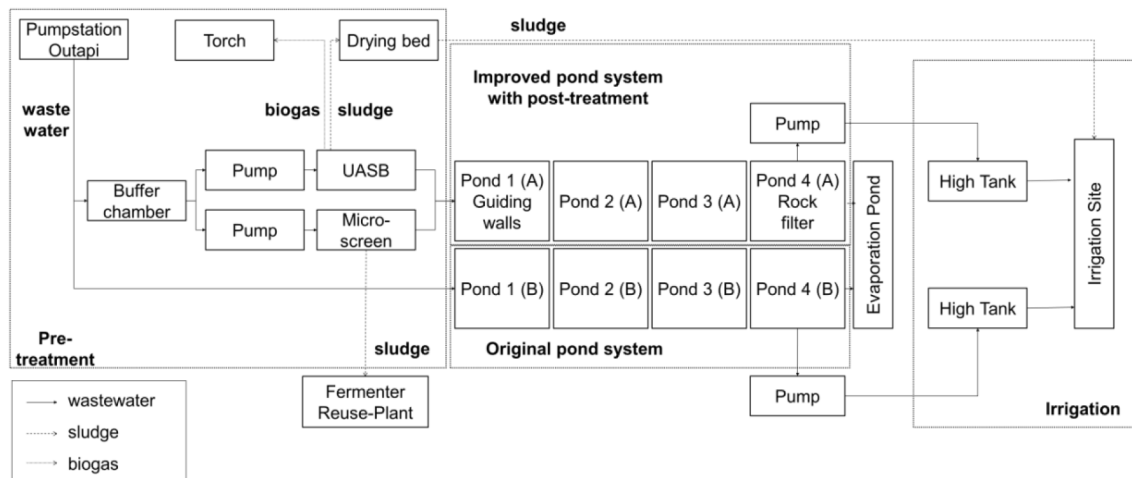


Figure 1: Flow chart of the improved waste stabilization pond system (Simm et al. 2019)

Under normal pond operation conditions, both lines A and B are completely separated from each other, with pond A-4 delivering an advanced treated effluent and pond B-4 delivering only wastewater treated by ponds in their original or even overloaded state. New pumps at the end of pond A-4 and B-4 convey the treated wastewater into high tanks.

The new pre-treatment plant consists of flow distribution valves, a manual fine screen, and a buffer chamber as well as of 2 parallel processes for COD and TSS load reduction, one biological treatment via a UASB-reactor and one mechanical filter via a micro sieve. It was examined which of those technologies is more suitable for retrofitting existent pond systems in terms of wastewater treatment for water reuse but also with regard to the possibility of further sludge treatment and disposal.

Stabilized sludge withdrawn from the UASB-reactor is directed to sludge drying beds and finally used as fertilizer in agriculture whereas raw sludge that is removed from the micro sieve is further treated in a fermenter. The fermenter is located at the Oswin O. Namakalu Sanitation and Reuse Facility in Outapi where the generated biogas is utilized in the combined heat and power unit available there. The biogas produced in the UASB-reactor is burned in a gas flare to prevent methane emissions to the environment.

2.4 Pre-treatment using UASB and micro sieve

The volumetric loading rates of the UASB are about $1,260\text{g}/(\text{m}^3\text{d})$ and $550\text{g}/(\text{m}^3\text{d})$ of total COD and TSS, respectively. Total COD and TSS are reduced through sedimentation and anaerobic digestion, and the UASB reaches reductions of 15 to 20%. After further

development of the anaerobic sludge bed, continued improvement of the performance of the UASB is expected (Sinn et al. 2019, Sinn and Lackner 2020).

The process design considered the Passavant CarbonExtract®-Process with a Noggerath® RSH-MG, which enables primary sludge generation and handling in a combined unit.¹ For standard cleaning, effluent water from pre-treatment was used to generate a forceful water-air mixture. The drum of the micro sieve was cleaned with a 2% potassium hydroxide solution at 60°C if required. During a testing phase, different flows and operation parameters of the micro sieve were examined. By using a sieve with 250 micron mesh size, the removal rates of total COD and particulate COD improved to 18% and 29%, respectively.



Figure 2: Pond A-1 and the pre-treatment plant (Photo: EPoNa joint project)

2.5 Post-treatment in wastewater ponds with a bio-percolation filter

The bio-percolation filter can be used for post-treatment within the rehabilitation and upgrading of an existing pond system, in combination with the described pre-treatment, to raise the effluent quality to a suitable level for reuse in agricultural fodder irrigation. The design philosophy of the post-treatment is to keep things as simple as possible and in line with the existing pond system. Generally, pond systems are easy to use and reliable because of their relatively simple technique (Weil et al. 2019).

¹ <https://www.aqseptence.com/app/en/solutions/carbonextract/>

Rocks can be used as a filter medium in the bio-percolation filter, hence the terms rock filter or stone filter. The water passes through the voids between the rocks in the submerged porous rock bed. For this, the ideal rock size ranges from 50 to 200mm. A larger rock size reduces the available surface area which limits the biofilm development, while smaller rocks increase the risk of clogging (Sperling et al. 2019). The filter influent can be introduced below the rock surface layer to avoid odour and insect problems. Algae and solid particles from the previous ponds percolate horizontally under gravity flow and become attached to the rocks where biologically active surfaces induce decomposition. The treatment operation of the rock filter is based completely on natural processes and depends on the loading rate, temperature, size, and shape of the rocks (Mara et al. 2001; Short 2008; Sperling et al. 2019).



Figure 3: Rock filter under construction (with visible collection pipes), the finished filter and biofilm (Photos: EPoNa joint project)

Apart from the mechanical filter effect, the biological degradation performance depends on the degree of development of the biofilm on the rock surface, which increases naturally over a period of several months. First results of the EPoNa sampling campaign show a promising increase in efficiency, especially in COD reduction. A reduction of suspended solids of more than 45% (Average January – April 2020), an improved oxygen demand and a fair reduction of pathogens (more than $4.0E+04$ for *E.coli*) demonstrate the positive effects of the filter.

Undecomposed nutrients which are discharged by the effluent can be seen as fertilizer in the irrigation water. A possible disadvantage could be the unreliability of the rock filter with regard to ammonia removal. In numerous cases, ammonia concentrations in the effluent exceed those in the influent of the rock filter (Gonzalez-Martinez et al. 2011)². If an ammonia concentration limit is given for the final effluent, aeration measures should be taken into consideration (Mara and Johnson 2005).

Based on the measuring results of the EPoNa research project in Outapi, we can conclude that for wastewater generated from small communities a rock filter is a feasible

² The ammonium nitrogen is mainly reduced by algal uptake under favourable conditions for algae (Camargo Valero und Mara 2007). Also, it is investigated that algae mineralized organic nitrogen into inorganic forms, mainly ammonia nitrogen (Khatiwada et al. 2017). Concurrent with the mentioned factors, protein and amino acids used during anaerobic biodegradation and ammonia is released. The ammonium nitrogen as the ion of ammonia used to grow microorganisms is always lower than its production (Rao et al. 2005).

natural upgrading solution for post-treatment. That kind of treated water would then be ready to be reused for agricultural irrigation.

To decrease construction costs further, the rock filter can be put inside an existing pond. The biological percolation filter can be built with locally available materials and it is even possible to utilize recycling materials from construction sites (excluding solid waste and contaminated materials).

Moreover, the bio-percolation filter is comparatively easy to operate. No chemical additives or energy (dependent on site-specific factors) are necessary. Although there are no provisions for cleaning rock filters, the estimate is that rock filters keep an acceptable performance for over 20 years. At worst, it might be necessary to remove the rock media, dredge out accumulated detritus, and replace the rock.

The cost-effectiveness in combination with the simplicity and locally available resources in some areas emphasize the high replication potential of the filter. Depending on the water application requirements, a gradual treatment extension such as UV disinfection is possible and can be added (Fuhrmann and Rudolph 2006).

2.6 Reduction of pathogens and management of microbial risk

Water treatment in WSPs is driven by natural processes such as solar radiation and sedimentation. The design of the ponds has a large impact on the efficiency of these natural processes in the removal of faecal bacteria. Often the effluent of WSPs does not comply with quality standards. The Namibian Code of Practice (DWAF, 2012) demands filtration and disinfection as part of the tertiary treatment steps for water reuse. Conventional disinfection such as chlorination however is often not effective due to high amounts of organic solids and ammonia. As a result, unrestricted irrigation is not possible. The Code of Practice was amended in 2012 to allow the irrigation of fodder crops without the requirement of disinfection in exceptional cases. If it can be proven that the irrigation water will not come into contact with humans or animals, a permit for exemption may be issued. The previous WSP in Outapi was not able to meet the WHO guidelines for safe water reuse and fodder crop irrigation. Based on the analysis of E.coli, the pathogen reduction was evaluated considering the different treatment steps. With pre-treatment and an upgrading of pond A1, a reduction of 97% (inflow – A1) was reached as compared to 91% reduction without pre-treatment. Further reductions provided by the ponds (from pond 2 to 4) were similar for both, trains A and B, with 99.8%. As for the reuse water storage tanks, concentrations of E.coli were still above the thresholds set out in the WHO guidelines (1.0E+03 MPN/100mL) in line B, and there might even be the danger of regrowth. A further reduction of pathogens is therefore required and can be attained by appropriate irrigation techniques. For instance, drip irrigation of low growing crops reduces pathogens by 2 log₁₀ units (WHO 2006) reaching values far below the threshold (Mohr et al. 2020).

2.7 Agricultural production

By the increasing frequency of droughts and decreasing rainfall, pastures become smaller and livestock grazing becomes more difficult. This creates a substantial market for fodder. Due to the lack of water, treated wastewater can be an important water source in these regions and can be used in agriculture to produce fodder. That is why we examined different scenarios including different irrigation systems, plant cultivars, and sludge usage methods.

Soil and Fertilizers

It is recommended to use a disc harrow to crush the clods as well as plant residuals to a depth of 10-20cm. The soil surface should be leveled for seedbed and installing the irrigation system. In order to efficiently provide the nutrients needed by a plant, one should first analyze the soil. If the soil contains an adequate amount of phosphorous (P) (>15ppm), potassium (K) (>100ppm), and magnesium (Mg) (>50ppm), there is no need for basic fertilization. On average, the deprivation amount of these substances comes to:

P = 30 to 40kg/ha, K = 160 to 260kg/ha, Mg = 20 to 45kg/ha, Ca = 30 to 50kg/ha.

In order to measure the nitrogen (N), N_{\min} of the soil before planting should be included. To produce a yield of 20t/ha dry matter (DM), we need approximately 160kg/ha N. For higher efficiency, it is recommended to add N fertilizer to the soil twice during the growing season.

Trial 1: Irrigation system and cultivation system

a) Irrigation System

The irrigation systems chosen are farrow, dripper and drainage pipes. We evaluated these systems based on three principles: 1. efficiency, 2. sustainability, and 3. low maintenance costs (table 1).

Table 1: Advantages and disadvantages of different irrigation systems.

	Irrigation system	Advantages	Disadvantages
1	Furrow: 40cm width, 25cm depth, distance between the furrows 1m	Little material required, easy to create	High workload for the creation of the furrows, uneven distribution of water, between the furrows a strip of only 60cm width remains as a cultivation area
2	Drainage pipe: 110mm diameter wrapped in tightly woven polyester fabric, laid in approx. 35cm deep furrows, overlapping with soil approx. 24cm, distance between the drainage pipes 1m	Good water distribution, low humidification of the soil surface, no pipes on the soil surface	Very high labor input for the installation, very high material costs, due to low water storage capacity of the pipes, frequent irrigation is required → very high labor input for irrigation, difficult to automate
3	Drip pipe: Type: Agri plas, 16mm tube diameter, drip rate 4l/h, 30cm drip distance, drip tube placed on the ground surface, distance between drip tubes 1m	No soil preparation necessary (no furrows), very even water distribution → simple and flexible to use, proven system, can be automated	High costs for the material, water pressure min. 0.5bar, drip pipes are in the stock and can hinder harvesting and maintenance work

The average daily evapotranspiration in Outapi is about 5l/m² water per day. Therefore, we will need about 50m³ of water per day to irrigate one hectare. About 470m³ of water are provided daily by EPoNa ponds A4 and B4. Regardless of rainfall, this amount of water is enough to irrigate about 9 hectares. Our experiment showed that a 30% reduction in irrigation water causes a severe drop in yield in the furrow irrigation system (figure 4).

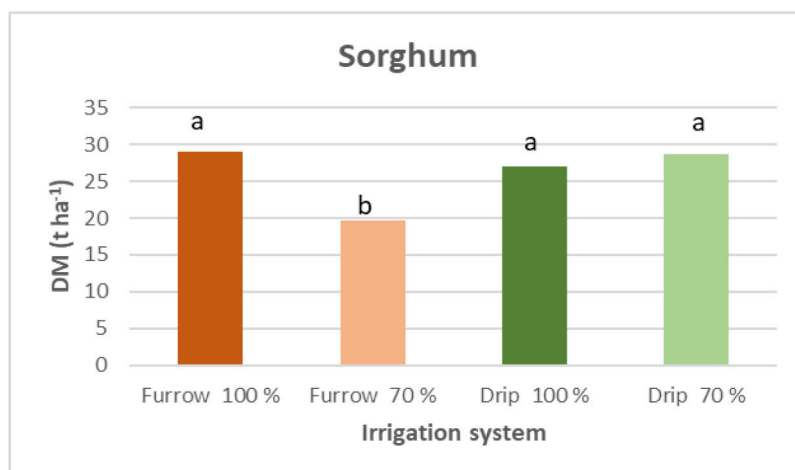


Figure 4: Dry matter (DM) yield reduction in Sorghum after applying deficit irrigation 70% of the required matter. Means followed by different letters (a, b) are significantly different ($p \leq 0.05$, Tukey test).

b) Cultivation system

Two types of fodder crops have been tested in the EPoNa project: Sorghum Bicolor and Lucerne. The amount of yield produced in each irrigation system was different. It is worth noting though that the differences between furrow irrigation and drip pipes were not significant. The table below shows the amount of yield (t/ha) produced in each irrigation system:

Table 2: Total yield (t/ha) produced in each irrigation system

	Irrigation system	Sorghum (sum of two harvests)*	Lucerne (sum of four harvests)
1	Furrow	99t/ha	20t/ha
2	Drainage pipe	123t/ha	20t/ha
3	Drip pipe	98t/ha	19t/ha

* Plant density: 55 seeds per m²

The yield is sold as air-dried bales of 10 to 20kg. In the rainy season when the prices are lower than in the dry season, each 10kg bale costs 15N\$ for Sorghum and 100N\$ for Lucerne. In general though, planting Lucerne was not successful because large parts of the seedlings were destroyed. This could have been due to the high temperature at the beginning of the growing season. Additionally, Lucerne needs proper tillage, which was not available in the region.

The first trial showed that the drip irrigation system is superior to other systems (figure 4 & table 1). Based on the results of the first trial, we designed the second trial with the aim of using sludge and different water form pond A4 and B4. In the second trial, we just used the drip irrigation system and Sorghum.

Trial 2: Sludge application and water quality

Sludge reuse

Each year, a large amount of sludge settles in the ponds. The use of this sludge can improve the soil and provide some of the nutrients needed by the crop. The sludge should be composted before application. The rest of the nutrients needed by the Sorghum should be provided through chemical fertilization. Applying 10 to 15t/ha of sludge can improve soil organic matter, physical texture, and provide some of the nutrients needed by the crop. If the sludge has more than 0.5% P and 0.2% Mg, fertilizer is not needed to supply P and Mg. Sludge improves soil conditions, increases soil organic matter, and can retain water for a longer period of time.

Table 3: Total yield (t/ha) produced in each fertilizer and water quality

	Water quality	Fertilizer	Yield (t/ha)*
1	A4	Sludge + Chemical fertilizer	77
2		Chemical fertilizer	68
3	B4	Sludge + Chemical fertilizer	70
4		Chemical fertilizer	71
5	Tap water	Sludge + Chemical fertilizer	81
6		Chemical fertilizer	69

* Means are NOT significantly different ($p \leq 0.05$, Tukey test). Plant density: 9 seeds per m^2

Based on the results of the two trials, it is recommended to cultivate Sorghum Bicolor with drip irrigation for the production of fodder in Outapi. A combination of sewage sludge and chemical fertilizer should be used for fertilization.

3. Planning, operation and sustainability

3.1 Work packages and time schedule

The project management is recommended to delegate several tasks to operational services in collaboration with an engineering consultant who shall be assisting to the project management during the entire implementation cycle. Alternatively, the project management may decide to carry out planning stages autonomously. Depending on the tender obligations of the project management, the selection of a consultant may take up to six months. It is assumed that in parallel to that, the project management enters into an agreement with operational services for subsequent collaboration.

Once the financial planning and water reuse concept has been approved by the management, the foremost step before starting any further planning activities is to secure the planning criteria. Existing information should be screened and complemented by survey campaigns (terrain, flows, social and financial scope and development). Depending on the quality of the existing information this task may take up to three months.

Parallel to securing the planning criteria, the operational services engage in scheduling the emptying of the ponds. This may require additional materials. It is assumed that the emptying of the ponds and the completion of the planning tasks proposed by the consultant will take place simultaneously.

It is assumed that from this stage onwards the project management is going to rely on the assistance of an engineering consultant. The latter is supposed to take charge of all relevant design phases with a particular focus on conceptual and preliminary designs and subsequent detailed elaborations. Tender documentation will be another one of his tasks. Parallel to these activities, an Environmental Impact Assessment (EIA) and further geotechnical investigations may take place. The completion of this task package may take up to ten months.

As soon as a tender documentation is available, a contractor may be hired. Depending on the project management's tender obligations, this process may take anything between 3–12 months including tender evaluation and contractual negotiations.

Finding a contractor and starting construction activities are ventures that depend largely on the season (rainfall) and the availability on the market. It is important to choose a reliable contractor and to await site clearance and the availability of material in order to enable the contractor and site supervision to provide an ongoing service. This subtask may take up to four months. Once works are launched on a pre-empted pond series, completion of preliminary reception of works may be reached within 6 months' time. Thus, one may assume that 12 months suffice for the task to be completed within the time span between contraction and reception. Once reception has

Table 5: Overview of personnel required for the operation and maintenance of the treatment blocks

Block	Activity	Frequency	HR requirement
Pumping system	Inspection of operational condition of suction chambers, pumps, pressure mains, valves, switchboards, automation, sensors, lightning protection	Weekly	Semi-skilled labor
Channel/Weir	Visual inspection and cleansing	Daily	Semi-skilled labor
Manhole	Visual inspection of lid and interior and cleansing	Weekly	Semi-skilled labor
Ladder	Visual inspection of steps and corrosive protection	Monthly	Semi-skilled labor
Structure	Visual inspection of surface, cleansing of platforms, basins, flumes and grids	Weekly	Semi-skilled labor
Shut-off device	Visual and functional check on seal/power, cleansing and greasing of impulsion	Weekly	Skilled labor
Flushing device	Functional check of units and cleansing	Weekly	Semi-skilled labor
Retention filter	Visual inspection of inflow and outflow for debris and scour. Maintenance of vegetational cover, where appropriate backwashing and cutting or replacement of filter material	Daily	Skilled/semi-skilled labor
Pond	Visual inspection of pond aligning and dams for erosion / cracks. If applicable sealing or reinforcement of earth dams. Probing for sludge levels and desilting of ponds if applicable. For anaerobic ponds the sludge level should be below one fifth of total column	Weekly	Skilled/semi-skilled labor
Fencing and enclosure	Visual and functional inspection of gates and fences. If required cleansing, protection and greasing.	Weekly	Semi-skilled labor
Paved area and roof	Visual surface inspection, sealing cracks, removing vegetation	Weekly	Semi-skilled labor

3.2 Framing activities, capacity development and wastewater treatment plant partnership

The approach also includes the establishment of a so-called wastewater treatment plant partnership (WWTPP) which represents a regional network of different operators of wastewater treatment plants and wastewater ponds (Frick-Trzebitzky et al. 2021). The network is intended to facilitate the exchange of information and experience with regard to questions of operation and maintenance as well as the procurement of materials and spare parts. It also provides a platform for possible associations of operators for the joint operation of plants in the region, in the form of special-purpose associations or other forms of municipal cooperation.

Experiences from the EPoNa project show the necessities to create synergies. Outsourcing public responsibilities for the provision of services has also led to an outsourcing of both technology and knowledge capacities thus perpetuating low levels of institutional capacity within the municipalities, and creating a dependency on consultants. Several workshops were held in order to support the WWTPP. An overview of the activities is presented in figure 5. The partnership that had been established offered an opportunity for both formal and informal mutual learning. A great potential for developing and strengthening capacities and reducing municipal costs for wastewater treatment was identified. How this can be used will depend on the long-term commitment of town councils to collaborate for which political backing is crucial.



Figure 5: Timeline of workshops and formation of WWTPP (adapted based on Frick-Trzebitzky et al. 2021)

3.3 Ownership

In order to consolidate his ownership, the system's operator focuses on a regular exchange of information with the project and prepares joint decisions.

The plant was finally handed over to the OTC. All the information necessary to run the facilities are collected in order to support the operation.

3.4 Social-ecological impacts

It is possible that unintended effects may occur through the approach tested in the EPoNa project. Different scenarios have been discussed and interviews with local actors and experts have been executed in order to understand such possible effects (Zimmermann et al. 2021). Intended and unintended effects of pond upgrading and fodder production are presented in table 6. The results show that there are less negative/unintended effects than positive/intended effects. Furthermore, good governance and problem solving skills might help to overcome these unintended effects.

Table 6: Intended and unintended effects (based on Zimmermann et al. 2021)

Intended effects	Unintended effects
Relief of ponds and improved efficiency	Over-abundance of water in rainy season
Reduction of duct system failures	Pipe clogging of irrigation system (algae)
Reduction of the repair efforts and blockages therefore improved management of the facilities	Risk of oversupply of fodder and falling prices for fodder
New water resources and nutrients and value creation	Financial dependency between operator and farmer
Improved agricultural production, robust to climate variability and higher yields	
Less transportation effort to distribute fodder and reduction of import dependency	
Power generation	
Rural development	

Against the background of the current problems in dealing with WSP systems and water supply constraints in central northern Namibia, the study has demonstrated that an upgrade of WSP and the resulting reuse of water represent a reasonable and sustainable solution. The wastewater is not only disposed of but seen as a new water resource – thus a polluting liquid is transformed into a value benefitting people and ecosystems. In addition, the concept reveals a completely new opportunity of water reclamation and thence constitutes a major advantage for irrigation water supply and relieve of water resources.

4. Economic considerations

4.1 Investment

The direct investment costs for upgrading the wastewater pond system within the EPoNa project are estimated to amount to 15.7 million NAD (equals approx. 984,000 EUR). The investment costs are partially allocated across guiding walls, pre-treatment with the UASB, pre-treatment with the micro sieve as well as post-treatment with the rock filter, as illustrated in the table below:

*Table 7: Approximate investment in the EPoNa pond system upgrade
(1 EUR ~ 15.9 NAD)*

Est. investment expenditures 2018/19	NAD	EUR
Guiding walls	315,485	19,840
UASB pre-treatment	6,157,053	386,993
Micro sieve pre-treatment	6,841,151	429,991
Rock filter post-treatment	2,339,882	147,070
Total investment	15,653,570	983,882

In order to calculate depreciation, civil works are assumed to require replacement after 30 years, whereas mechanical works are expected to last 15 years and electrical works 10 years, before replacement investments are required. Accordingly, approximately 45% of investment expenditures are ascribed to civil works or are logically aligned (e.g. topographical and geotechnical assessments; design, approval and construction supervision), 39% are necessary for mechanical works and 16% for electrical works. The resulting annual depreciation is approx. 750,000 NAD (equals approx. 47,000 EUR).

The investment costs outlined above apply to the implementation of the pilot pond system in the context of a scientific research project. Replicating the system without the accompanying research project and pilot character can be assumed to be less expensive, especially since the construction and simultaneous operation of both UASB and micro sieve is unique to the pilot project. Additional savings can be expected because of reduced monitoring equipment and requirements. Furthermore, the investment costs will vary depending on local conditions, market prices and scale of the pond system. In a scenario analysis, the expenses that are specific to the research character of the pilot system and the investment costs for replicating the pond system with comparable characteristics were estimated and compared. The first option is the one described above and includes all accrued costs. In option 2, costs for UASB and

micro sieve are divided, and research specific costs are no longer included. Option 3 considers the upgrade of both pond lines with either UASB or micro sieve without research cost and introduces lessons learned and further improvements. For example, the investments without UASB would amount to roughly one third less (approx. 600,000 EUR). Further details can be found in the final project report.

4.2 Operation and maintenance costs and revenues

The upgrade of the sewage treatment ponds within the EPoNa project entails additional operation and maintenance costs for the operation of coarse bar, UASB, micro sieve and rock filter as well as general purpose expenses (e.g. ablution building). These additional expenses comprise salaries for additional staff (guard), electricity costs, consumables (e.g. chemicals, process water), repairs and maintenance as well as monitoring. Estimated annual expenses for the first operative year of the pond system are illustrated below:

Table 8: Approximate operative expenditures in the first year of operation (1 EUR ~ 15.9 NAD)

Est. operative expenditures 2019/20	NAD	EUR
Labor	60,000	3,771
Power	58,250	3,661
Consumables	31,310	1,968
Repairs and maintenance	445,838	28,023
Monitoring	150,000	9,428
Total operative expenditures	745,398	46,851

Analogous to investment cost, the additional costs for operation and maintenance as outlined above apply to the implementation of the pilot pond system in the context of a scientific research project. Replicating the system without the accompanying research project and pilot character can be assumed to be less expensive, especially since the simultaneous operation of both UASB and micro sieve is unique to the pilot project. Depending on the current HR situation it might be necessary to hire an additional technician which would increase operational expenses. Savings can be expected from decreased monitoring requirements. By deducting operational expenses that are specific to the research character of the pilot system, operation and maintenance costs for replicating the pond system with comparable characteristics are calculated and done in a separate analysis as described above.

Additional revenues are generated through the potential sale of produced irrigation water to agricultural sites. The sludge produced from the micro sieve is being transferred to a fermenter (located at the Oswin O. Namakalu Sanitation and Reuse Facility in Outapi) where electricity is generated from it which is a potential source of revenue or reduction of electricity cost. Furthermore, the upgrade prevents future penalty payments due to overflowing of the evaporation pond.

4.3 Cost-benefit analysis

The Cost-Benefit Analysis (CBA) is an approach to systematically evaluate the desirability of a project. To do so, a monetary value is assigned to all inputs and outputs into a system and so it can be determined whether there is an overall positive or negative system outcome. The CBA can be expressed in different ways, for example, the internal rate of return, the net present value and the cost-benefit ratio (Europäische Kommission 2003).

The wastewater treatment plant's CBA is conducted based on the changes in operation and maintenance costs, plus necessary investments for the upgrade which are then compared to the possible revenues as described above. In figure 6 the required revenue per cubic meter over ten years for option 1 as well as option 2a (2x UASB) and option 2b (micro sieve) is depicted. When these revenues are generated by irrigation water, the cost of the upgrade are covered.

For a first comparison, the Outapi water tariffs can be used. The rate for a small business is 16.33 NAD per cubic meters of water which is lower than option 1 but higher than both options 2. It can also be assumed that the required revenue will continue to decrease in the third option.

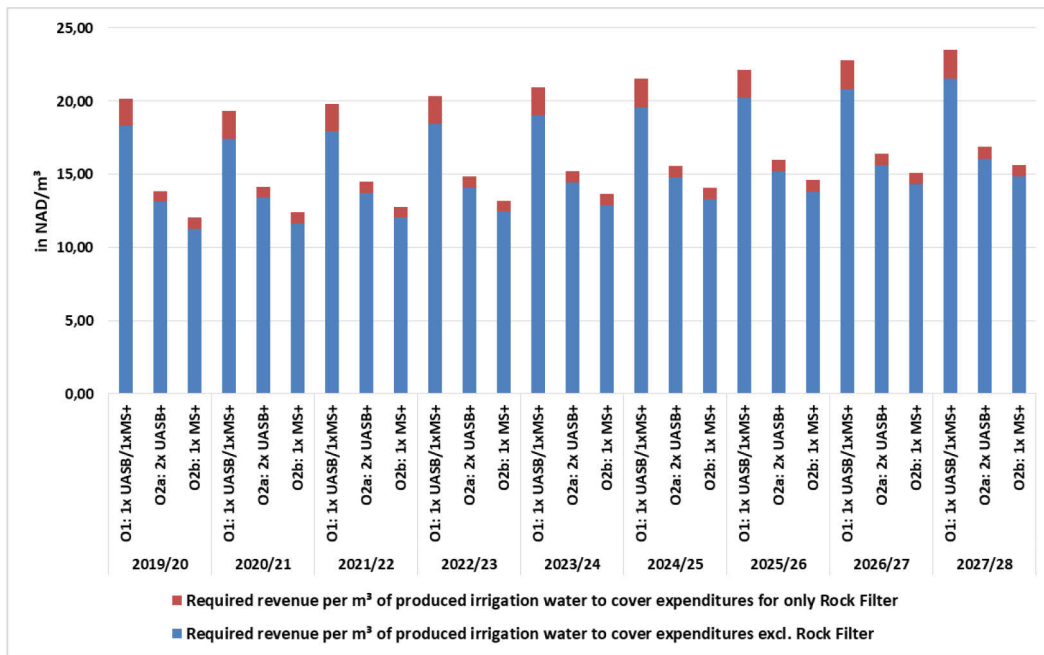


Figure 6: Required revenue per m³ irrigation water to cover pond line A upgrade expenditures

To include all economic costs and benefits regardless of the beneficiary in the CBA, shadow prices are used. When converting market prices to shadow prices, external factors such as environmental and social effects can be included. The cost of natural resources can be converted with a determined factor as well as wages and the possible reduction of methane emissions can be included in the calculation. Furthermore, aspects such as local business development are raised. Effects that can't be directly quantified or to which no monetary value can be attributed (e.g. reduced health risk, increased food security, increased attractiveness of the city in general) are described in the final project report which also goes for the final results of the described scenarios.

4.4 Financing options

When planning to replicate a system such as EPoNa, the financing of the project, with the investments as a decisive factor, is a crucial element to influence the annual capital cost. In the case of the EPoNa pilot plant, the initial investment was fully covered by a donor (German Federal Ministry of Education and Research) which, as mentioned above, is why the calculation does not include financing costs that may constitute a considerable amount.

In a replication case, these costs need to be considered according to the chosen financing option. There are multiple financing options and sources for the replication of a pond system with comparable characteristics. Some of the possibilities are:

1. Public (national, provincial, municipal) loans and grants,
2. Loans from development financing institutions, mostly from national, regional or multilateral donor banks
3. Commercial loans, private loans or
4. Combinations of the above: hybrid financing (Hilbig und Rudolph 2019).

Besides the initial financing of the project, the continuing operation and maintenance needs to be sustainable. Twinning within the realm of municipal partnerships³ such as the GWOPA⁴ or entering into partnerships with municipal operators⁵ may provide helpful consultancy during the stage of research and development. Furthermore, there are NGOs or public water enterprises willing to help free of charge.

However, in the long run, sustainable operation and maintenance needs a professional business concept. To ensure requirements for wastewater treatment and reuse can be fulfilled independently from political disruptions and budget uncertainties, an autonomous (“ring-fenced”) body can be formed. Small towns and villages can unite to establish a common ring-fenced of appropriate size, serving > 50,000 people to achieve “economy of scale”-effects in procurement and operations.

³ <https://www.adb.org/publications/water-operators-partnerships-twinning-utilities-better-services>

⁴ <https://gwopa.org/>

⁵ Kommunale Betreiber-Partnerschaften: <https://skew.engagement-global.de/aktuelle-mitteilung/betreiberplattform-kommunale-wasserunternehmen.html>

5. Transfer and dissemination

The EPoNa concept offers a high potential for transfer and implementation. First of all, the proposed infrastructure provides irrigation water and resources for agriculture while minimizing environmental impacts which benefits the need for resource efficient concepts and fodder production for livestock in northern Namibia and Sub-Saharan Africa in general. Since northern Namibia is highly dependent on fodder supply from other parts of the country, the EPoNa concept combines the advantages of local water reuse and fodder production.

5.1 Initial transfer projects

No transfer projects have been initiated yet. However, following the successful implementation of the concept in Outapi, a potential for a transfer to other cities in Namibia as well as the SADC region can be seen. The experiences gained within the EPoNa project might offer a strong incentive to initiate follow-up projects. Support for forming wastewater treatment plant partnerships was provided during five workshops (see chapter 3.3) with the aim to encourage the transfer of the project to other regions.

5.2 Suitable areas for dissemination

The transferability of water reuse systems was assessed by using transfer criteria (Juschak 2014). These criteria were used to find out to what extent countries and areas in southern Africa are suitable for a system similar to the one in Outapi. The results show that countries such as Botswana, Namibia and South Africa are most suitable. These countries reached highest scores for indicators such as literacy rate, ability to pay, government effectiveness, and ease of doing business. Further results assessing population density, the occurrence of floods, and the suitability of soil and climate for agriculture at a local level show regions that are potentially suitable for a transfer of the EPoNa concept. This regional assessment shows that towns in Namibia (Windhoek, Okahandja, Rundu), a few regions in southern Botswana (Ramatlabama, Gaborone), and substantial sections of the eastern coast of South Africa, as well as several areas in the country's interior (e.g. regions around Johannesburg and Pretoria) are suitable for the dissemination of the concept. Preconditions supporting the implementation of the EPoNa concept are introduced in chapter 5.4, table 9, success factors.

5.3 Networks and partners for dissemination

Transfer options were discussed in the project team. Regular meetings took place especially among TU Darmstadt, ISOE, Aqseptence, University Geisenheim und IEEM. Furthermore, regular exchanges between the EPoNa project team and the Namibian partners (especially OTC, MAWF) enabled rapid action with regard to changes that arose during the work process.

Platforms for promoting the EPoNa concept are at a national (e.g. Basin Management Committees, WATSAN Forum) and international level (e.g. Global Water Partnership, SADC Water Division, Sustainable Sanitation Alliance/SuSanA, Water Supply & Sanitation Collaborative Council). Moreover, the GIZ Transboundary Basin Management Committees are a good network for approaching neighboring countries.

5.4 Success factors and benefits of the approach

In general, the evaluation of the effects (see chapter 3.5) showed that the intended or positive effects clearly outweigh the unintended ones. A further scenario analysis revealed the consequences of inadequate management of the system and low fodder demand. If, independently of other factors, there is a low demand for fodder in the respective area, alternative water reuse applications have to be considered. In addition, the analysis showed that good management of such a system is of fundamental importance in order to operate the facility, protect nature and assist people.

For similar future projects, the key factors for success are (Liehr und Kluge 2018):

5. the development of trust and confidence among all involved parties,
6. the combination of technological and social innovations,
7. the promotion of capacity development and multiplication of the proposed technologies and
8. flexible thinking that is not attached to linear planning.

Furthermore, the transferability of the concept was investigated with the help of interviews. Actors and experts involved in the project and from neighboring communities mentioned the following success factors (table 9) and benefits of the approach (table 10):

Table 9: Success factors for transferability

	Criteria	Short description
Natural conditions	Water scarce region	The region experiences long periods of drought which increases the urgency to act.
	No discharge option	The absence of a river makes it even more crucial to think of alternatives for water disposal.
Demographics	Need for animal fodder = Agricultural production	Animal fodder is requested, especially during the dry season.
	Growing towns	The towns are growing and therefore also produce growing amounts of wastewater.
	Sparsely populated surroundings	Availability of land to produce agricultural goods
Structure	WWTPP	The structure of the partnership will be an advantage for those towns in the region that follow the example of Outapi.
	Successful role model	The power of a good reputation of the already existing approach in Outapi
	Ponds are ubiquitous in Namibia and developing countries.	The ponds exist in many parts of the world. They are ubiquitous in the northern part of Namibia.
	Local authorities welcome solutions.	The local authorities see the need to improve the management of wastewater.
	Skilled workers (farmers)	There are already people who practice agriculture in the region.
	Shifting focus	The focus is shifting towards water demand management, which also includes wastewater reuse.

Table 10: Benefits of the EPoNa concept

Benefits	Short description
Creating jobs	Both the technical system and the production of fodder crops will create jobs.
Less need for fertilizer	The inert sludge can be used as fertilizer and will thus decrease the costs of other fertilizers.
Ponds serve as a backup system.	The fact that the ponds will still be part of the system even after the enhancement provides a backup system in case the pre-treatment is not working.
Value creation	Currently the local authorities already have to invest money in the ponds but without any return. By implementing the approach, they are scaling up the wastewater resource by producing fodder crops instead of storing the wastewater until it is evaporated.
Avoiding environmental pollution	Because the wastewater will especially be used during the dry season, the ponds are expected to be almost empty at the beginning of the rainy season. As a result, the risk of overflowing will be minimized enormously and thus also the risk of wastewater to infiltrate into the groundwater and the Oshanas.
Low-tech approach	The benefits of a comparatively low-tech approach are lower maintenance costs as well as less required skills for maintenance.
Lower water price	The water price will be lower than tap water which makes it attractive for local farmers to engage in this approach.
Less health risks	Preventing the ponds from overflowing will also minimize the risk of local people getting in touch with contaminated water.
No need to build new ponds	Because most of the sludge does no longer enter the ponds and wastewater will be reused, building new ponds is unnecessary.
Other types of usage	Even if the production of fodder crops is not convincing, other types of usage are possible such as the irrigation of public gardens

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