Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2020.25545

جمعية علوم وتقنية المياه
Water Sciences and Technology Association

A practical step towards sustainability: decentralised wastewater management in Oman

Mohamed Nasser Al-Rawahi[a,b,*], Mi-Yong Lee[b], Jan Friesen[c], Ganbaatar Khurelbaatar[b], Roland Mueller[b]

[a]*The Institute of Advanced Technology Integration (IATI), The Research Council of Oman (TRC), P.O. Box: 92, Postal Code: 123, Al Khoud, Muscat, Sultanate of Oman, Tel. +968 99 34 91 51; email: mohammed.alrawahi@trc.gov.om (M.N. Al-Rawahi)*
[b]*Centre for Environmental Biotechnology (UBZ), Helmholtz Centre for Environmental Research UFZ, Leipzig, Germany*
[c]*Department Catchment Hydrology, Helmholtz Centre for Environmental Research UFZ, Leipzig, Germany*

ABSTRACT

Oman has undergone major transformations during the past few decades, which have resulted in growing water scarcity and an increase in the domestic wastewater production. To align with UN Sustainable Development Goal (SDG) number 6: "Ensure availability and sustainable management of water and sanitation for all", the government spending on wastewater services dramatically increased over the past two decades aiming to extend sanitation services all over Oman. However, the expansion of the wastewater infrastructure will have to address the conditions of rural and suburban settlements in order to reduce network and pumping requirements and the risk of technical failure to the minimum and to ensure cost efficiency. To achieve this goal, a pilot project has been set up to develop an integrated system solution for decentralised wastewater management in Oman. The main objective of the project is to establish a research, demonstration and training facility aiming at developing, promoting and facilitating the implementation of sustainable and effective sewage and reuse management solutions for suburban and rural communities in Oman. The procedure applied for designing the facility was comprised of two parts; the comparative analysis, which gathers forms and ranks information into a knowledge basis, on which the designer can make a decision and the engineering design process. With the geographic information system (GIS)-based assessment tool assessment of local lowest-cost wastewater solutions (ALLOWS) the project compares different scenarios for regional wastewater management options. ALLOWS features two main components: (1) Spatial analysis, and (2) cost assessment using net present value calculation for different scenarios for a lifetime of 80 years. In a case study, different sanitation scenarios were developed for Al Mizarih village, near Qurayyat, Oman. This preliminary assessment indicates that under current conditions a solution on household level is the most cost-effective option. However, semi- and decentralised scenarios gain in cost-effectiveness, when future population growth and settlement patterns are anticipated in the analysis.

Keywords: GIS-based assessment, ALLOWS, rural, sewage, suburban, wastewater management

1. Introduction

Oman experienced fast economic growth and demographic change over the past two decades causing more stress on its limited water resources. In 2015, the population reached about 4.2 million with 56% Omanis and 44% expatriates. As a result, the national demand for water already exceeds annually recharged resources by 316 million m^3/year (Al-Barwani 2016). Furthermore, by the year 2040, the total population is projected to increase by 2.4 million National Centre for Statistics and Information's (NCSI, 2015). Consequently, sewage production will also further increase as a result of population growth. However, improper sewage treatment can affect groundwater quality if undesired

* Corresponding author.

Presented at the 13th Gulf Water Conference – Water in the GCC: Challenges and Innovative Solutions. 12–14 March 2019, Kuwait

substances infiltrate into the aquifers and can thus result in serious pollution, which might cause adverse effects on human health and the environment. Possible groundwater pollution from sewage effluent has already been observed in Oman (Al-Bahry et al., 2014). Such pollution can result from leaking septic systems on household level or from the improper operation and maintenance (O&M) of sewage treatment plants (STPs) and improper sewage treatment and quality of treated effluents (Baawain et al., 2014).

In 2015, the Ministry of Regional Municipalities and Water Resources (MRMWR) signed an agreement with Oman Wastewater Services Company, SAOC (Haya Water) on managing, operating and maintaining sewage facilities of the ministry across the entire country, except for the Dhofar governorate. Subsequently, MRMWR has already transferred 63 STPs connected to sewer and treated effluent networks with a total length of about 750 km in various governorates to Haya Water (Haya Water, 2016). In 2016 Haya Water has floated a consultancy service tender to update its sewage management master plan and to include the additional nine governorates in the Sultanate in its master plan (ZAWYA, 2016). However, the introduction of new sewage infrastructure in remote rural and suburban settlements faces several major challenges, most importantly, capital cost, regulatory, planning, and technical bottlenecks as well as citizens' concerns over adverse effects from STPs. To overcome these bottlenecks and to ensure countrywide acceptance of new sewage infrastructure as well as the safe and sustainable treatment and reuse schemes, exceptional efforts are required to focus on:

- Cost-efficiency and reliability of treatment technologies under Omani conditions
- Ensuring adequate skills of operations and maintenance personnel responsible for different STP types in remote areas
- Involving rural and suburban communities and homeowners in the planning for sewage treatment and reuse infrastructure. Experiences in several countries (UN, 2017) have shown that engaging national sectors and stakeholders is a prerequisite for a sustainable sewage management system
- Promoting sewage treatment and reuse as essential themes for the future of Oman
- Improving the image and acceptance of sewage treatment and reuse for all Omani citizens and residents
- And finally, sewage management is a task of national interest

A collaborative discussion between The Research Council of Oman (TRC), Haya Water and the Helmholtz Centre for Environmental Research (UFZ, Germany), has been set up to develop an integrated system solution for decentralised approaches to sewage management in suburban and rural areas of Oman. It has been agreed that the above challenges require a multifunctional facility that provides the environment for technology testing, certification, and development, research on resource recovery and reuse, as well as outreach to the general public and capacity building all provided at one location.

1.1. Traditional sewer extension approach vs. integrated management approach

Sewage treatment management can be designed specifically to fit local sanitation needs for individual homes and rural communities. For remote areas and especially in mountainous areas and in urban areas where existing infrastructure inhibits extension (re-densification), local sewage treatment systems provide economic benefits, due to the reduction of pumping and network requirements, as well as ecological benefits from water reuse and groundwater protection. To realize these benefits, Haya Water aims at an integrated approach, which can effectively combine safe and economical treatment for different types of settlements, ranging from villages to cities and provide treated effluent and nutrients for reuse.

Integrated sewage treatment and reuse is defined as the collection, treatment, and reuse (or disposal) of sewage in the most cost-efficient and beneficial manner in the local context. In an integrated approach growing rural and suburban areas without sewage infrastructure as well as re-densifying urban areas where spatial limitations inhibit the growth of the existing centralized infrastructure can be

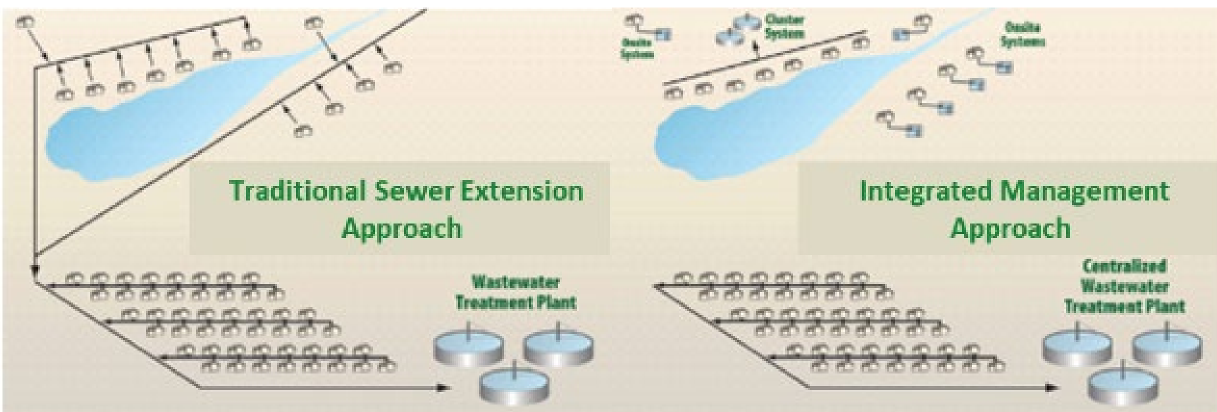

Fig. 1. Traditional sewer extension and integrated management approach that uses a variety of system scales to provide treatment that matches the context (WERF, 2010).

served at relatively low cost. For remote locations, the costs associated with the sewer construction (between the village and the closest STP) can become prohibitive, particularly in mountainous landscapes. Integrated sewage management provides local communities with additional benefits in the form of locally available water, nutrients and organic resources for reuse and improved sanitary and environmental conditions. Integrated solutions focus on cost-efficiency by designing treatment systems specifically to fit local sanitation needs for individual homes and rural communities thus combining small and large infrastructure.

1.2. Key components of an integrated management approach

Integrated wastewater treatment and reuse systems, independently of the technical solution selected, are all constituted of the following components:

- *A sewage collection system* that conveys sewage from its point of origin to its place of treatment. In integrated solutions, it is usually expected that the network length between household connections is as short as possible either and preferably gravity-fed to reduce operation and maintenance cost (OMC).
- *A sewage treatment system* that removes pollutants to a level determined by regulation. It usually includes, at least, a primary and secondary treatment step. A wide range of technologies is available to perform at any treatment level. Typically, national regulations pre-select some technologies that can be used to meet the level of treatment based on the given local context (population connected, sewage quality, reuse purpose, etc.). However, the one sewage treatment technology that would fit all possible contexts does not exist till now. Each technology has advantages and limitations and one of the main challenges for sewage infrastructure planners is identifying a technical solution that is best under given local constraints.
- *A reuse or disposal solution* that allows safe discharge of the treated effluent. Controlled reuse of treated effluent provides additional benefits (irrigation and fertilization of agricultural fields, landscaping, soil restoration, etc.). When reuse is not feasible, the safe disposal of treated effluent is required, e.g. controlled discharge or managed aquifers recharge.
- *An O&M framework* so that O&M tasks are regularly carried out to ensure that the treatment systems meet regulatory requirements throughout their operational life. For remote locations, O&M requirements are key criteria in the choice of the treatment technology to be installed. Most important is to ensure, that O&M is being performed properly for all sizes of treatment plants. In many countries, this is ensured by certifying O&M companies and the platform is designed to enable Haya Water to conduct certified training for O&M personnel.
- *Governance* that ensures regular monitoring of STPs and proper performance of O&M contractors. Also, general regulations regarding the set of treatment technologies that can be implemented in Oman as well as requirements for reuse and discharge need to be determined and monitored.

1.3. Why we need research and testing facility?

Innovative sewage product designers and manufacturers have begun developing technologies to treat and reuse water while keeping it onsite. This type of decentralized treatment and reuse offers a solution that is sustainable, efficient, cost-effective, and highly practical. For a particular location and specific effluent quality and in the absence of a technology certification procedure, it is usually difficult to select the most appropriate technology from among the set of available technologies. Factors like cost, efficiency, site requirements as well as sustainability criteria such as robustness and O&M requirements and their interdependencies are involved in the decision-making process. However, selecting the most appropriate technology might be difficult for decision-makers in administrations, government, and engineering companies as they may not possess comprehensive knowledge of their individual features. It is also important to acquire the experience with their O&M in order to be familiar with these technologies and be able to choose from the extensive range of commercially available technologies before the implementation in a specific location. This is particularly the case for technologies applied in more remote areas with unique challenges.

In addition, it is obligatory for all sewage treatment systems operated in Oman to meet the Omani treatment, reuse and disposal standards. However, such obligation does not secure the required treatment efficiency, stability, ease of O&M nor a wide range of important technological features (robustness, behavior under Omani climate conditions, tolerance to shock loads, sludge generation, etc.). Therefore, the proposed research and testing facility is planned to be a world-class infrastructure, enabling Oman to get to the next level of wastewater management. It will create new and singular opportunities for improving sewage management in Oman at all scales in particular by introducing cost-effective sanitation systems for rural remote areas, by providing a training center for technical training, thus securing best O&M skills, and by increasing the range of beneficial reuse of treated effluents.

2. Methodology

2.1. Design of research and testing facility for decentralised wastewater

A comparative analysis was carried out to gathering and comparing information, experiences, and conclusions from existing research and testing sites, which are similarly designed to fulfill one or more of the research objectives. Four different sites were chosen on the basis of their primary driver or purpose, which closely matched a study objective. These sites are listed below, with their corresponding primary objective;

- The UFZ Eco-technology Research Facility at Langenreichenbach (LRB). Langenreichenbach, Germany.
- The BDZ Decentralised Sewage Treatment Training and Demonstration Centre (BDZ) - Training and Demonstration. Leipzig, Germany.
- The SMART Project Research, Demonstration and Training Facility, Fuheis, Jordan.

- The PIA Testing Institute for Wastewater Technology GmbH – Testing and Certification. Aachen, Germany.

2.2. Creating sanitation scenarios

The assessment of local lowest-cost wastewater solutions (ALLOWS) tool (Manfred van Afferden et al., 2015) has been used to create sanitation scenarios for rural regions in Oman. The methodology has two general components:

- Spatial analysis methodology
- Cost assessment methodology

The methodology enables wastewater asset planners to plan different sewage management scenarios in a spatially explicit way using geographic information system (GIS) and technical drawing software (e.g. ArcGIS, AutoCAD) and compare the costs of the different scenarios on the basis of a dynamic cost comparison methodology using standard software (e.g. MS Excel, Python, R, Matlab). To be able to exercise this methodology on a case study (e.g. a specific village), a set of spatial and cost data are required. Depending on the envisioned level of detail, additional data regarding building regulations and standards should be used. Fig. 2 shows the required input data, the spatial analysis and the cost assessment workflow in general.

3. Results

3.1. Multi-functional national platform

An area of 6,000 m^2 has been allocated within Haya Water premises, at Al Ansab STP, for establishing this platform. To serve its purpose, the proposed platform is conceived as a facility that accommodates the major sewage and reuse stakeholder groups in Oman. This allows the pursuit of specific objectives in the area of integrated sewage management and will create new collaboration opportunities and synergies. Thus, the platform provides a holistic environment for testing and certification and technology development, embedded in a park-like landscape citing the cultural and natural heritage of Oman that will appeal to visitors and stakeholders. The platform also includes infrastructure for technical training, research, demonstration, capacity development, all designed specifically for the Omani context. In addition, the platform activities and services will have the potential to extend to the GCC region and beyond so as to open new market opportunities for Oman.

3.2. Designing options

Three different designs are prepared for the proposed "National Platform for Advanced Integration of Water Reclamation and Resource Recovery Technologies", with a particular and in-depth focus on the components and technical details of the facility. Key components of each design are also presented to show how they satisfy the facility's objectives and activities.

3.3. Main features and benefits

The potential applications of the platform will include the following facilities and benefits:

- *Facilities for testing and certification of sewage and sludge treatment/stabilization technologies (box concept)*: These important facilities will help Haya Water and other sewage service providers in their evaluation and pre-selection of sewage treatment systems that are most reliable, effective and sustainable under Omani conditions (technology selection and adaptation). This infrastructure will serve as a condenser in order to enhance collaboration between industry, academia, and policymakers.
- *Facilities for technology development and adaptation*: These facilities - technical hall and workshop, mixing and dosing station to produce different sewage qualities and field laboratories combined with the existing Haya laboratories - will help in transferring new research outcomes to concrete applications or sewage treatment products ready for commercialization. These products are expected to be cutting-edge innovative, cost-effective and simple-to-operate. Furthermore, they are expected to provide essential and forward-looking sewage services such as provision of treated effluent for reuse from different sewage qualities, reduction of local side-effects (e.g. odor) to acceptable levels, effective removal of pathogens and micro-pollutants, nutrient (phosphorus) and organic carbon recovery, production of bio-energy and energy-self-sufficient treatment, etc. These facilities will be designed to play a pivotal role in promoting spin-offs in the sewage treatment and resource recovery sectors thus contributing to job creation, in-country value creation, and sustainable economic growth.
- *Facilities for applied research on reuse*: To increase the opportunities for successful applied research and training of graduate, postgraduate, and postdoctoral researchers in agricultural irrigation using treated effluent qualities. Such facilities will also support policymakers in revising and where necessary amending existing legal provisions and standards to ensure safe reuse and economic feasibility of Omani sewage infrastructure and management.
- *Environment for capacity development and technical training*: The platform is designed to provide a variety of capacity building infrastructure, in particular, a water reclamation and management learning path, media-equipped classrooms, and exhibition and demonstration facilities,

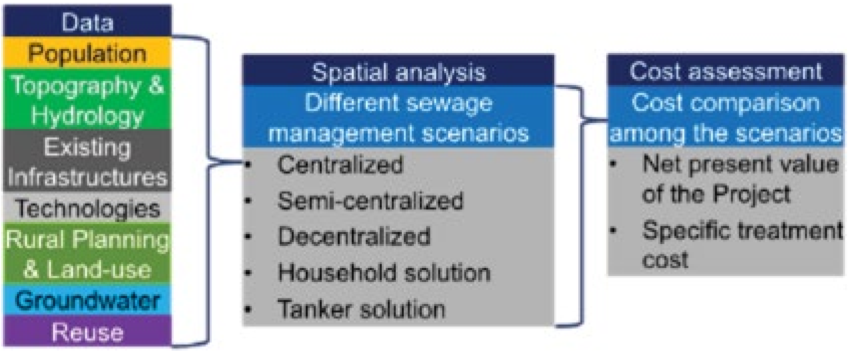

Fig. 2. ALLOWS 3-step process: (1) General data collection, (2) Spatial analysis and (3) Cost assessment.

to conduct capacity building programs for technical staff, graduates and school students in order to enhance practical, technical and scientific knowledge about and overall acceptance of sewage infrastructure and related topics, e.g. water reuse and water saving, environmental protection and sustainability of water resources.

- *Demonstration of different sewage treatment technologies in operation (demonstration plots)*: Demonstration does not focus on specific technologies, but on a long-term operation, treatment efficiency and stability, and hence on the appropriateness of investment, resources, capacities, and framework conditions. Through the demonstration projects and subsequent seminars, conferences etc., decision-makers will be informed about the advantages and challenges of different treatment technologies and management options. Bottlenecks and weaknesses of the existing regulatory and legal frameworks become apparent and indicate the improvement of framework conditions. This will also help in conducting education and outreach activities in order to contribute to the strategic social involvement objectives of Haya Water.

3.4. Technical key features proposed for the national platform

- *Concrete cased testing boxes (plug and play)*: Eight closable and partly extendable testing boxes (2 × 30 m², 6 × 20 m²) fitted with an array of inlet and outlet pipes, in addition to monitoring and control devices allowing for testing, certification, and researching the housed technology unit. Boxes are designed with removable internal and external walls allowing customizing the box volume and to ease and increase the safety of technology installation.
- *Open testing boxes*: Two boxes of designated open areas for the testing, certification, and research of containerized, modular or 'package STPs' using identical operational infrastructure to the closed testing boxes.
- *Primary sewage* distribution system: Sewage line fitted with pumps, dosing, and control systems providing sewage to the open and closed testing boxes.
- *Mixing and dosing station with secondary artificial sewage distribution line*: Infrastructure allowing for the distribution of artificial sewage to the testing boxes.
- *Combined office and meeting space*: Designated space and equipment for staff operating/ researching at the platform, in addition to facilities dedicated to hosting meetings and conventions.
- *Technical hall*: The technical hall, also connected to the real and artificial sewage distribution systems, allows for the development of technologies via lab experiments, research, and development of bioprocesses and biotechnology in addition to providing technical infrastructure for conducting training programs.
- *Media-equipped education and training room*: Designated space for the technical training of target groups (engineers, O&M technicians, farmers, scientists, and students).
- *SCADA*: A system to control, monitor and operate the platform systems which also provides a human-machine

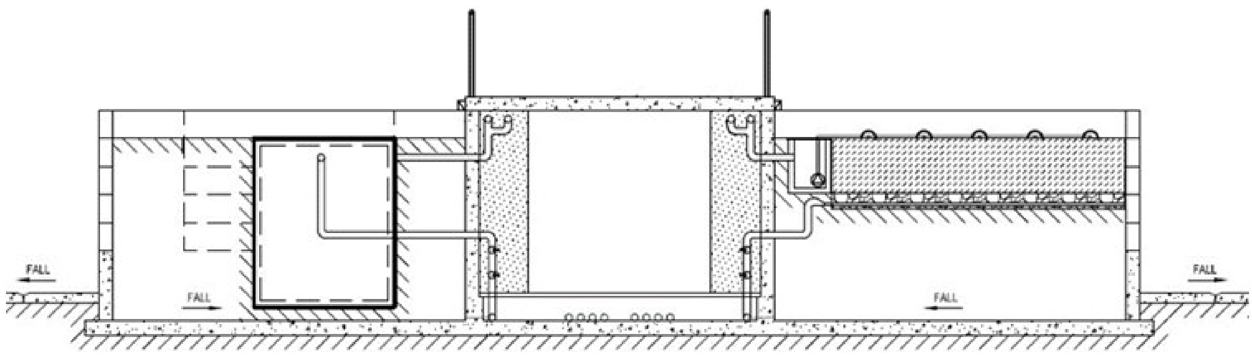

Fig. 3. Cross section of the box and corridor concept (Wetzlar, 2017).

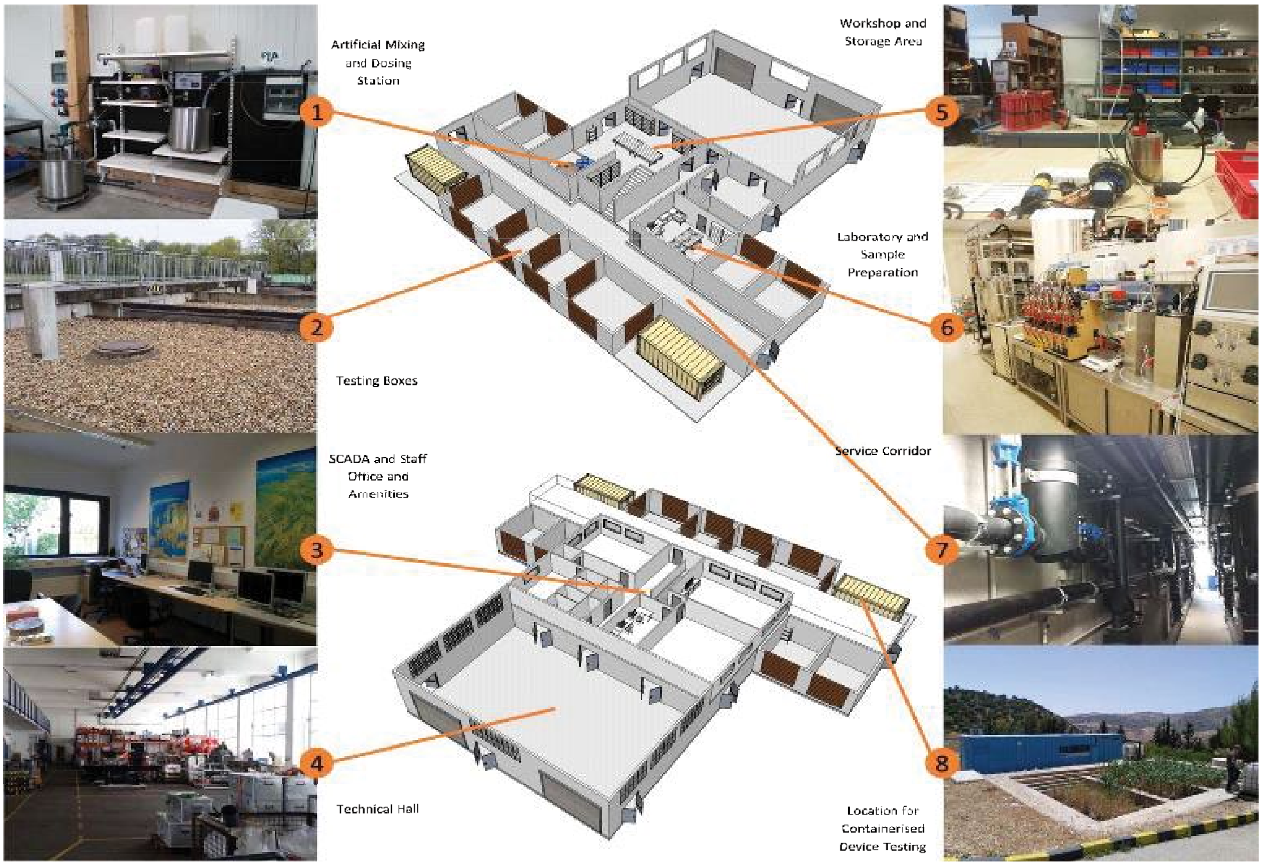

Fig. 4. Preliminary 3D overview indicating technical key features of the Platform. A multi-functional Design Option has 8 testing boxes, 2 containers connections, artificial sewage dosing unit, samples preparation room, offices, training room, big technical hall, workshop, sewage and reuse storage room (Wetzlar, 2017).

interface, allowing staff to access and visualize data onsite or remotely.

- *Auto-sampling*: Auto-samplers are proposed to be installed for all test boxes to improve sampling flexibility, provide automated data entry and to prevent sample degradation.
- *Service Corridor*: An air-conditioned corridor housing the two distribution lines, operational and maintenance equipment and distribution, 'Switch Area'. The corridor is proposed to include a false floor and air-conditioning to facilitate a comfortable, easy to access and safe working environment for operators, scientist, and visitors.
- *Collection Tanks*: for numerous treated, untreated, and artificial sewage supply.

3.5. Integrated management scenarios: Al Mizarih case study

Different sanitation management scenarios have been designed for Al Mizarih village as a case study:

- *Centralized scenario*: Sewer system with a conveyance of the sewage to the central STP
- *Semi-centralized scenario*: Sewer system connected to a local STP in Al Mizarih
- *Decentralised scenario*: Reduced sewer network, six small STPs and household STPs
- *Only single household solution*: Household STPs
- *Disposal via vacuum tankers*: All households are serviced by tankers

3.6. Spatial analysis

The first step of the spatial analysis involves data processing. Despite bringing the data into a uniform format, spatial resolution, as well as a uniform projection, different processing steps have to be computed based on the input data. For Al Mizarih we started with satellite images and some basic information, namely the population size of about 2,000 inhabitants. Fig. 5 shows a high-resolution satellite image of Al Mizarih that shows the close vicinity of the settlement to the Daykah dam and a map inlay that visualizes the surrounding region including the distance to the next largest city, Qurayyat. In Fig. 6, the main data layers namely: the digital elevation model (DEM), as well as the buildings and roads are depicted.

Figs. 7 and 8 depict processed data based on the DEM and the buildings. For Al Mizarih the populated area has an elevation range of about 90–160 m a.m.s.l and about 437 buildings. Fig. 7 shows the hydrological Wadi network as well as the micro-catchments based on the natural flow direction that enables planners to divide settlements into suburbs that can be connected to a treatment unit based

Fig. 5

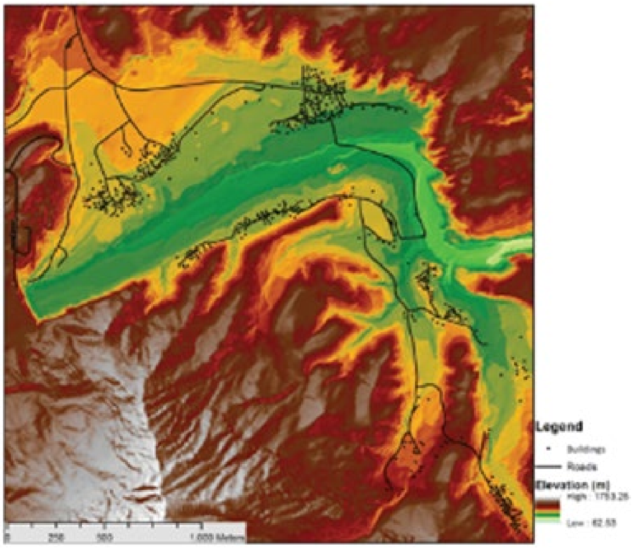

Fig. 6

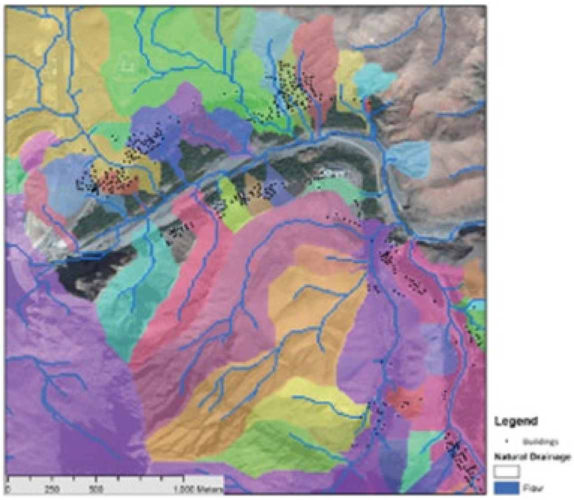

Fig. 7

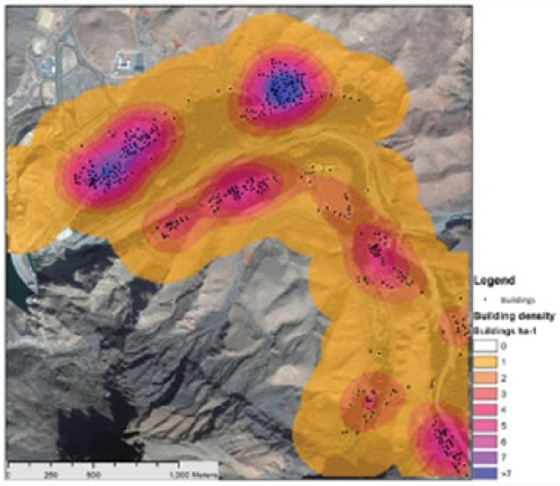

Fig. 8

on gravity flow rather than on pumping. In the case of Al Mizarih, however, it is obvious that the village is divided by a large Wadi bed which also means that the buildings along the Wadi bed are separated into many small catchments. A separation into small clusters that can have a pure gravity based network, therefore, is difficult. Therefore, the demand for pump stations will accordingly increase in this particular case. Fig. 6 shows a density map that was processed using the individual buildings. The building density allows analyses such as building density vs. network length and is a tool to cluster the settlement into treatment units.

Following the data processing, the sewer design is the next step. The sewer network is designed according to the German guideline ATV-A 200 using technical drawing software (e.g. AutoCAD Civil 3D). The elevation data requires some network assumptions that are listed below:

Horizontal alignment of the sewer network:

- Roads used as a potential route for sewer network
- The maximum distance between manholes: 60 m
- Wadi: Special sewer structure to cross Wadi
- Water consumption ca. 150 L/d

Vertical alignment of the sewer network:

- Minimum slope: 0.5%
- Maximum slope: 12%
- Minimum cover: 0.8 m
- Depth ≥5 m: pump station

3.7. Sewer network (AutoCAD)

The sewer network is designed using AUTOCAD civil 3 d (2011) pipe network creation tool. First, the pipe properties for the gravity and pressurized pipes are defined in accordance with the German norm DWA-A 139. Then the manhole properties are defined according to DWA-A 139. Based on the preliminary data for water consumption in Al-Mizarih, the DIN 200 concrete pipe is selected as the minimum diameter pipeline. Following the set up the assumptions for the vertical alignment (e. g. min. and max. slope) is set as a rule for the network creation tool. The tool then enables to create sewer network by converting the horizontal alignment (in this case the roads as the potential route) into the sewer network. The pump stations are placed on the sewer line when the depth of the sewer line reached 5 m. The pump stations are designed according to the German guideline ATV-DVWK-A 134. Depending on the elevation the pressurized pipelines were designed manually.

In a first step, a sewer network is designed that is connected to all households (Fig. 9). Based on this, the centralized scenario is designed that connects the settlement to the next available treatment plant. In the case of Al Mirazih this is the STPs in Qurayyat (Fig. 10), meaning the wastewater will be conveyed by 30 km long combined (gravity and pressurized) sewer line and 6 pump stations to the STP in Qurayyat. In the semi-centralized scenario all households are considered to be connected as well, however, a 2,000 person equivalent (PE) STP within the settlement is planned (Fig. 11). The construction and O&M of the sewer network and pump station are cost-intensive factors. Therefore, in the decentralised scenario, the sewer network and pump stations are minimized by creating clusters depending on the density of the buildings (Fig. 12). The correlation between the density of the town and the specific sewer network length is analyzed as it is shown in Fig. 13. The specific sewer length (m per household or m per capita) increases in low-density areas, whereas the opposite occurs in the higher populated area. Based on this analysis, the sewer network is then minimized, leaving the building in low-density areas out and serving only the building in high-density areas (Fig. 14). Then the pump stations are replaced with STPs (size of 150–500 PE). The remaining buildings are considered to have their own single household solutions (6 PE STPs). The next scenario is the single household solution, meaning that all buildings are considered to have their own small STPs (6 PE). The last scenario is the tanker solution, where the entire buildings are considered having storage tanks and serviced by tankers.

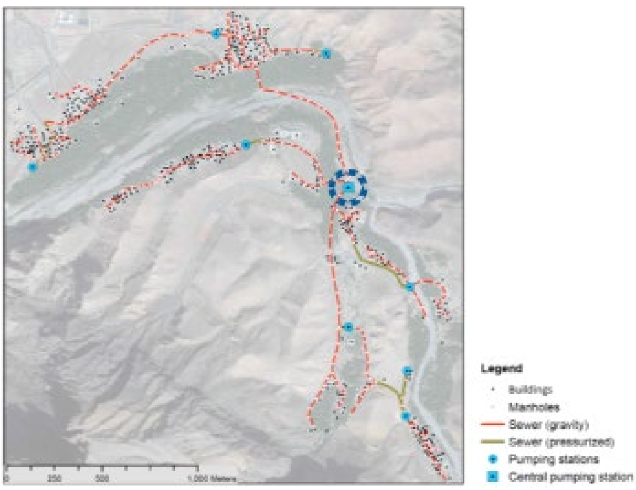

Fig. 9

Fig. 10

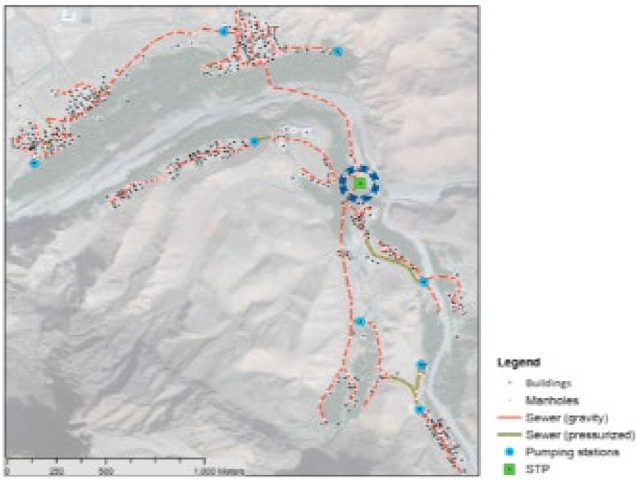

Fig. 11

3.8. Cost assessment

Following the spatial analysis, the spatial data for each scenario is extracted for the cost assessment. The cost assessment is carried out in accordance with the German guidelines for the application of dynamic cost comparison calculations. The methodology allows to add the different types of costs (investment cost (IC), reinvestment cost (RIC), and O&M cost) in order to find the net present value of the project over the analysis period.

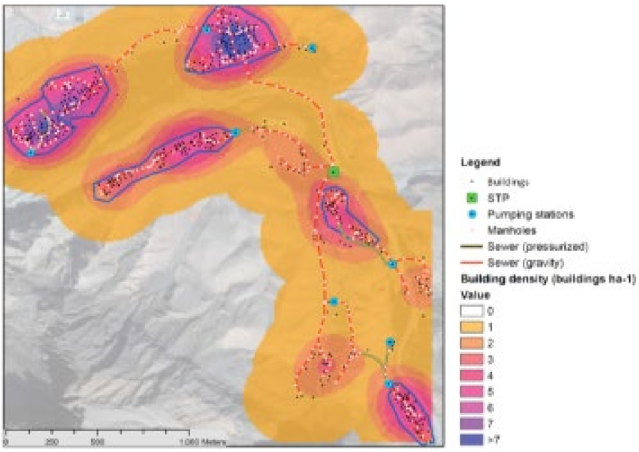

Fig. 12

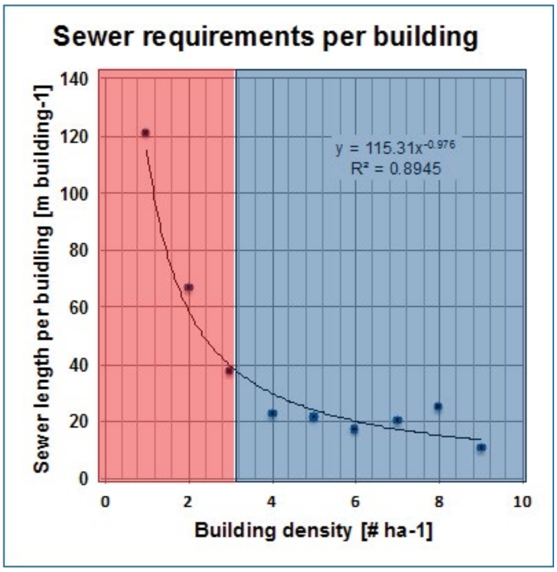

Fig. 13

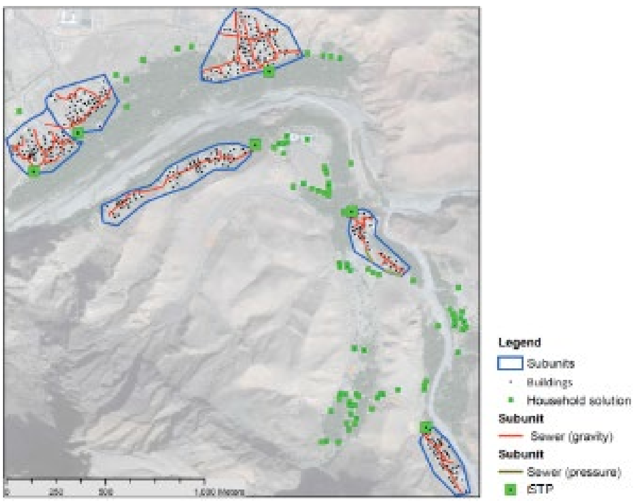

Fig. 14

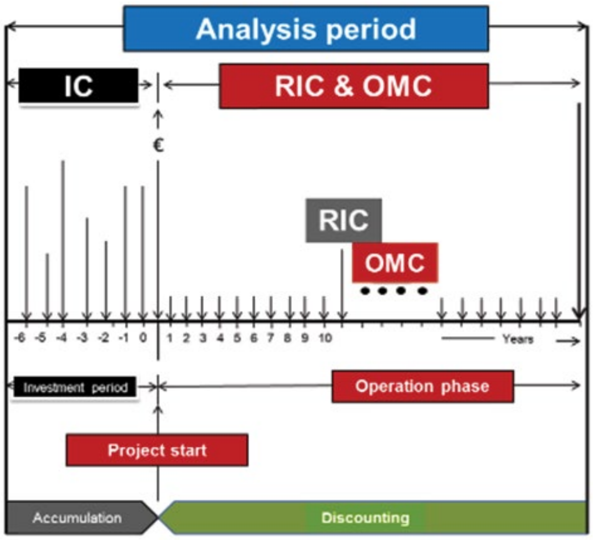

Fig. 15

Then the stations were designed according to the German guideline ATV-DVWK-A 134.

The IC includes the cost of construction, planning, and other costs (such as land price, contingency etc.). This is then calculated at the beginning of the project (present). The RIC is the cost spent for routine renovation and replacement (e.g. a pump is replaced every 5 to 8 years). The OMC is the annual cost for energy consumption, maintenance work, salary etc. The latter cost (RIC and OMC) are calculated for the future and converted in present values. There are two important aspects of the cost assessment, the analysis period and discount factor. Both are used for estimating the present values of the cost, which arises in the future.

The analysis period depends on the lifetime of the individual infrastructures such as STPs and sewer network. For example, the lifetime of sewer network is assumed to be 80 years while package STPs are often planned to last for 40 years and household STPs only 25 years. In the case of Al Mizarih, the period is chosen as 80 years in order to appreciate the lifetime of the sewer network, which is the most influential cost factor. The discount factor is basically the interest rate and is used for determining the present value of the future cost. This depends on the prognoses economic analysis and varies mostly between 3%–7%.

4. Conclusion

Innovative sewage product designers and manufacturers have begun developing technologies to treat and reuse water while keeping it onsite. This type of decentralised treatment and reuse offers a solution that is sustainable, efficient, cost-effective, and highly practical. However, improper treatment before water reuse can create public health issues. This study outlines the plan for setting up and operating the national platform for advanced integration of water reclamation and resource recovery technologies. The main purpose of this platform is to develop, promote and facilitate the implementation of sustainable and effective sewage and

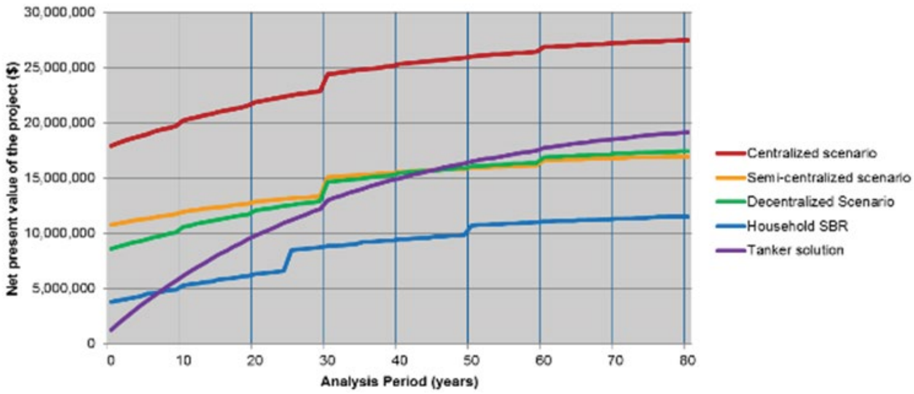

Fig. 16. Net present value of the different scenarios over the 80 years of analysis period. The preliminary assessment shows that the household solution might be an attractive option. However, it has to be mentioned, that future development of the town is not considered at this stage. Under growing population, the semi-centralized and decentralised scenarios might become attractive.

reuse management solutions for suburban and rural communities in Oman. The proposed designs have been postulated to integrate the various yet essential multi-functional activities concerned with the development of adequate and context-specific sewage management options. For example, testing and certification activities are designed for technology selection and adaptation to the Omani conditions and regulations, while training activities shall be designed for long-term sustainable development that will gradually and consistently add value to the local communities by building the capacity of local human capital. In addition, the platform will also provide space for a variety of research programs on different sewage treatment technologies and agricultural reuse in order to contribute towards strategic investment objectives of Haya Water and to play a leading role in further developing in-country value. The GIS-based decision support tool (ALLOWS) enables applying scenario analysis by comparing the total value project lifecycle of different sanitation management options.

References

Al-Bahry, S.N., Ibrahim Y. Mahmoud, Al-Musharafi, S.K., Al-Gharibi, I.S., Al-Harthy, N.K., Al-Zadjali, H.A., (2014), Microbial and Chemical Pollution of Water-wells Relative to Sewage effluents in Oman Journal of Sustainability, Energy and the Environment, 1(1), pp. 35–56.

Al-Barwani, A., (2016), Water Resources in Oman Assessment, Challenges and Management Practices. International Water Conference 2016, Water Resources in the Arid area: The way forward, Sultan Qaboos University, Muscat, Oman.

Baawain, M.S., Al-Omairi, A., Choudri, B.S., (2014), Characterization of domestic wastewater treatment in Oman from three different regions and current implications of treated effluents, Environmental Monitoring and Assessment, 186(5), pp. 2701–2716.

Haya Water, (2016), The Reuse of Treated Effluent. International Water Conference 2016, Water Resources in the Arid area: The way forward. Sultan Qaboos University, Muscat, Oman.

Manfred van Afferden, Jaime A. Cardona, Mi-Yong Lee, Ali Subah, Roland A. Müller., (2015), A new approach to implementing decentralised wastewater treatment concepts, Water Science and Technology, 72 (11), pp. 1923–1930; doi: 10.2166/wst.2015.393.

NCSI, (2015), The National Centre for Statistics and Information's: Report titled 'Population Projection in Sultanate of Oman 2015–2040: Available at: https://www.ncsi.gov.om/Elibrary/LibraryContentDoc/ben_population%20projections%20In%20Sultanate%20of%20Oman_fa17fe2c-34fe-4d6b-93fd-1f7746e7b23e.pdf.

UN, (2017), The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource, Paris, ISBN 978-92-3-100201-4: Available at: http://unesdoc.unesco.org/images/0024/002471/247153e.pdf.

Wetzlar, N.R., (2017), Design of research and testing facility for decentralised wastewater management technologies in Muscat, Oman, MSc Thesis, Institute for Technology and Resources Management in the Tropics and Subtropics (ITT), Cologne University of Applied Science; Helmhotz Centre for Environmental Research, 135 pp.

WERF, (2010), Decentralized Water Resources: Answers to the Most Frequently Asked Questions, A Guide to Research and Products from the Decentralized Water Resources Collaborative, Water Environment Research Foundation, 635 Slaters Lane, Suite G-110. Alexandria, VA 22314-1177: http://www.thegrandvision.org/local/upload/file/DEC3R08bweb.pdf.pdf.

Zawya, Thomson Reuters (2016), Oman's Haya tenders wastewater master plan consultancy: Available at: https://www.zawya.com/mena/en/story/Omans_Haya_tenders_wastewater_masterplan_consultancy-ZAWYA20161221094659/.