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Article

Decentralized sanitation alternatives in cities of the global south—A case of constructed wetlands in Bulawayo, Zimbabwe

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Abstract: Constructed wetlands have emerged as a sustainable alternative for decentralized wastewater treatment in developing countries which face challenges with urbanization and deteriorating infrastructure. This paper discusses the key factors affecting the implementation of constructed wetlands in developing countries. A case study research design was adopted, which focused on Bulawayo, Zimbabwe. A mixed-method approach was adopted for the study. Spatial analysis was conducted to identify potential sites for constructed wetlands in the city of Bulawayo. Semi structured interviews were conducted, with relevant stakeholders, such as town planners, civil engineers, NGO representatives, community leaders, and quantity surveyors. The findings reveal that political reforms, public acceptance, land availability, and funding are crucial for the successful implementation of constructed wetlands. Additionally, four sites were identified as the most favorable preliminary locations for these systems. The paper captures all the key factors relevant to the implementation of constructed wetlands (CWs) with a closer look at policy and the role it plays in the adoption of decentralized wastewater treatment systems. Formulating policy around the decentralized sanitation systems was considered imperative to the success of the systems whether in implementation or in operation. The paper adds to knowledge in the subject of sustainable wastewater treatment alternatives for developing countries. However, further research can be conducted with a different methodology to ascertain the applicability of the systems in developing urban cities considering other important aspects in the implementation of wastewater treatment systems.

Keywords: wastewater treatment; decentralized sanitation; constructed wetlands; sustainable; global south

1. Introduction

According to the United Nations World Water Development Report (2024), an estimated 842,000 deaths happen yearly due to a lack of access to safe drinking water, hand-washing facilities, and sanitation. This because discharge of raw wastewater results in the contamination of surface water bodies and groundwater aquifers (Jamwal et al., 2021). Conventional wastewater treatment technologies have been widely adopted as the wastewater treatment systems in most nations, however, most developing nations have difficulties in operating and maintaining the systems due to the chemical, skill, and energy-intensive nature of the systems (Ferreira et al., 2021). According to Oladoja (2017), the inadequate gross national product of many developing countries has led to a decline in investments in social infrastructure. This has resulted in a shortage of funding for the development, operation, and maintenance of wastewater treatment technologies, particularly in regions with limited resources. As a result, the risk of exposure to unsafe water and unsanitary conditions is widespread.

Throughout the latter part of the 19th century, various initiatives were launched to address the widespread water and sanitation issues faced around the world (Kazora and Mourad, 2018). According to Oladoja (2017), the very first program was known as the International Drinking Water Supply and Sanitation Decade (1981–1990). This aimed to provide everyone with access to clean water and sanitation facilities by 31 December 1990. Following this, the Safe Water 2000 program was introduced, with the goal of providing universal water and sanitation by 31 December 2000. Currently, the sustainable development goal (SDG goal 6) which came in effect in 2015 is targeting water and sanitation for all individuals by 31 December 2025.

To address this issue, low-cost technologies like decentralized wastewater treatment systems have been at the forefront of sanitation in developing countries (Chirisa et al., 2017). According to Starkl et al. (2013), decentralized wastewater management involves utilizing all available treatment and disposal technologies. Its objective is to match the appropriate technologies with the identified treatment and disposal requirements while also considering future growth and meeting current needs. Thus, by utilizing a decentralized wastewater treatment system, individuals can enjoy several benefits such as cost savings, while protecting the homeowner's investment (Oladoja, 2017). Additionally, it promotes superior water shed management and is an appropriate solution for low-density communities (Oliveira et al., 2021). Furthermore, according to Muduli et al. (2022), it offers a viable alternative for different site conditions and furnishes effective resolutions for ecologically sensitive areas. Progress in managing on-site decentralized treatment methods as an appropriate technology for domestic wastewater treatment has been steadily growing the past few years, and treatment methods like constructed wetlands in particular have stood out (Jamwal et al., 2021). For instance, constructed wetlands as decentralized sanitation alternatives provide a solution to sanitation problems faced by developing urban cities (Datta et al., 2021; Jamwal et al., 2021; Kilingo et al., 2022; Muduli et al., 2022). Furthermore, the expense associated with constructed wetlands (CWs) for treating wastewater in Africa is approximately $5 for every individual, while the cost of mechanical wastewater treatment such as activated sludge systems amounts to around $50 per person (Hassan et al., 2021). Therefore, to this end, the paper presents the key factors that affect the implementation of decentralized wastewater treatment systems in developing countries and constructed wetlands in particular. This paper is based on the recognition that the traditional centralized wastewater management systems have not been able to provide sustainable outcomes with regard to social, economic, and environmental concerns. Understanding the factors contributing to the successful and sustainable implementation of such systems can help policymakers and relevant stakeholders in developing countries adopt appropriate sanitation strategies to address their prevalent sanitation challenges. The paper therefore starts with an introduction, followed by a background to the study concept. A brief literature review is presented outlining urban wastewater management in Zimbabwe, and the methodology adopted in the paper follows immediately after this. The following section presents the results and discussion, and a framework that captures all the vital factors for the implementation of constructed wetlands is presented. The penultimate section presents the practical and policy implications of the paper. The paper ends with concluding remarks on the aspects presented in the study.

2. Background

Constructed wetlands are widely recognized as a sustainable decentralized wastewater treatment system, moreover, the interest in wetlands began as early as the 1950s (Vymaza, 2022). This was when Käthe Seidel conducted the first experiments at the Max Planck Institute in Plön, Germany to investigate the possibility of using wetland plants for wastewater treatment. Seidel conducted various experiments on the treatment of phenol wastewaters, dairy wastewaters, and livestock wastewater. She primarily carried out these experiments in constructed wetlands with either horizontal (HF CWs) or vertical (VF CWs) subsurface flow. The first fully constructed wetland with free water surface (FWS) was later constructed in the Netherlands in 1967 (Vymaza, 2022). By definition constructed wetlands are artificial systems intentionally built to harness the natural processes of wetland plants, soil, and microbial communities for the purpose of treating wastewater in a regulated setting (Wang et al., 2017).

According to Hassan et al. (2021),constructed wetlands are identifiable by their shallow water depth and very sluggish water flow. The lengthy retention time associated with the slow water flow aids in the settling of sediment and enhances the interaction between the wastewater and the various elements of the wetland (Verlicchi et al., 2013). CWs can be classified into free water surface constructed wetland systems (FWSCWs) and subsurface flow constructed wetland systems (SFCWs) (Aydın Temel et al., 2018). According to Shingare et al. (2017), although these two categories are distinct, they can be combined to create hybrid systems. Subsurface constructed wetlands can subsequently be categorized as either horizontal subsurface constructed wetlands (HSFCW) or vertical subsurface constructed wetlands (VSFCW) (Vymaza, 2022). According to Hassan et al. (2021), when it comes to selecting the type of flow in a constructed wetland, local regulations and bylaws play a crucial role. For example, some areas have strict laws that prohibit surface flow, which means that designers must opt for vertical flow in these cases. The efficiency of constructed wetlands (CW) is influenced by various factors such as climate conditions, weather patterns, geographical location, characteristics of wastewater and runoff, and seasonal variations (Andreo-Martínez et al., 2017). According to EPA (2006), the overall aim of designing constructed wetlands is to replicate the functions of natural wetlands, while ensuring that the system is optimized to improve the quality of wastewater.

The three most important components of CWs are the plants, media, and the microbial community operating in the wetland of which plants play a crucial role in enhancing the treatment efficiency of the system. According to Aydın Temel et al. (2018), constructed wetlands (CWs) utilize specific plant species' phytoremediation capacity, in conjunction with physical screening and sedimentation of suspended solids. By providing a range of functions such as nutrient uptake, oxygenation, filtration, habitat, and aesthetics, plants help to create a sustainable and resilient ecosystem (Pinninti et al., 2021). The medium also serves several crucial functions in constructed wetlands, providing a supportive environment for the plants and beneficial bacteria to grow and facilitating the removal of pollutants from the water passing through the wetland (Lai et al., 2021). Finally, according to Salgado et al. (2018); Valipour and Ahn (2016), the diverse functions of microbial communities in constructed wetlands include organic matter decomposition, nutrient cycling, pathogen removal, removal of contaminants, and promotion of plant growth, all of which are crucial for effective water treatment and pollution control. Constructed wetlands offer a steady reduction of organic matter and TSS; in the long term, it can be over 97%, COD removal of over 70%, TN removal of 50%, and TP removal of over 70% (Lai et al., 2021).

According to Ferreira et al. (2021); Oliveira et al. (2021) CWs play several essential roles, such as enhancing wastewater quality through adsorption or degradation, recycling nutrients, managing floodwaters by creating surface runoff and storm rainfall storage. The advantages of CWs are: (i) an eco-friendly approach that receives public approval (ii) cost-effectiveness when compared to other remediation methods (iii) wetlands promoting treated water reuse (iv) high flexibility in landscape design that fosters wildlife and organism habitats, and (v) low maintenance and operational expenses (Ayaz et al., 2015; Hassan et al., 2021). Moreover, wetlands offer a range of values, including the provision of recreational spaces and opportunities for research and education(Andreo-Martínez et al., 2017). Carneiro et al. (2022), suggests that constructed wetlands (CWs) offer numerous benefits, nevertheless, there are also several drawbacks that need to be considered. One of the setbacks is that CWs have low tolerance for near-complete drying conditions (Kilingo et al., 2022). Moreover, Hassan et al. (2021) states that the effectiveness of treatment in CWs may be inconsistent compared to other wastewater treatment methods, and hence they may not be suitable for treating discharge that must meet specific standards. Constructed wetlands also require large land areas compared to other methods of remediation (Oliveira et al., 2021).

One of the main issues of constructed wetlands when it comes to their maintenance is the residual sludge. According to Obeidat et al. (2024) residual sludge, also known as biosolids, can accumulate in the wetland substrate over time, and to maintain the efficiency of the wetland system, this sludge must be periodically managed. Management typically involves regularly removing the accumulated sludge from the wetland bed to prevent clogging and ensure optimal treatment performance (Ji et al., 2023). Saeed et al. (2022) posits that the extracted sludge is then subjected to additional treatment processes, such as composting, digestion, or drying, to stabilize and reduce its volume before final disposal or reuse. Depending on its composition and regulatory requirements, the treated residual sludge can be disposed of in landfills, used as a soil amendment in agriculture, or processed into other beneficial products (Obeidat et al., 2024).

2.1. Urban wastewater management in Zimbabwe

The planning, development, and operations of wastewater management in any country are usually governed by several pieces of legislation, policies, national strategies, and frameworks. **Figure 1** below shows the Zimbabwe water and sanitation coordination structure.

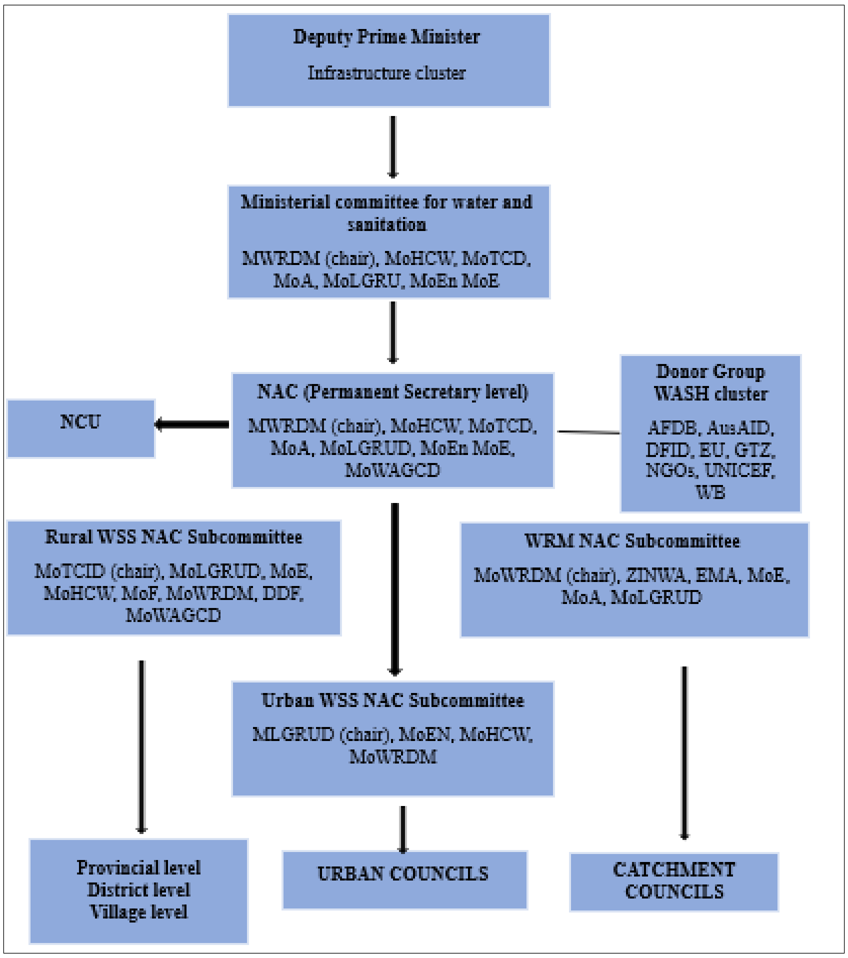

Figure 1. Entities governing water and wastewater management practices in Zimbabwe.

Source: CSO and UNICEF (2011).

Like any other country, Zimbabwe has legislative frameworks governing waste and wastewater management. Nhapi and Gijzen (2002)stated that the Environmental Management Act Chapter 20.27 of 2002 attempted to bring the wastewater regulations under one governing framework. This included the Public Health Act, the Natural Resources Act (Chapter 20, page13), the Water Act (Chapter 20, page24), the Water Pollution Control Act (1976), and the Urban Councils Act (Chapter 29, page15). According to Thebe and Mangore (2014), the Water and Sanitation Sector Council outlined the key government institutions for water and wastewater management. These include the Ministries of Water Resources, Health and Child Welfare, Transport and Infrastructural Development, Environment and Natural Resource Management, Energy, and the Ministry of Women Affairs, Gender, and Community Development. In 2007 the government gazetted the Environmental Management (Effluent and Solid Waste Disposal) Regulations, also known as the Statutory Instrument 6 of 2007 of the Environmental Management Act, to try and add more stringent rules to combat pollution from waste and wastewater.

2.2. Effluent regulations

Effluent regulations govern the discharge of effluent. Countries' regulatory bodies set the effluent discharge limit into rivers and other water bodies. Capodaglio et al. (2017); Chinyama et al. (2016) define the effluent standard as the concentration of pollutants in parts per million for wastewater discharged either through public or privately owned treatment plants. The released effluent quality is paramount to any country's public health concerns, as effluents sometimes contain pathogens and pollutants that can harm the ordinary person and the environment if not treated properly (Mutengu et al., 2007). Zimbabwe's effluent regulations were promulgated in 2000 in the Statutory Instrument (SI) 274 of 2000, also known as the Waste and Effluent Disposal (Regulations) of 2000. Sometimes the effluent standards can be proclaimed for a specific area. An example would be the latest Statutory Instrument in effluent control, which is the SI 132 of 2020 Epworth By -laws (Water Pollution and Trade Effluent Control). **Table 1** shows selected effluent discharge standards in Zimbabwe.

Table 1. Selected effluent discharge standard in Zimbabwe.

Parameter	Normal standard
BOD, mg/L	≤ 30
COD, mg/L	≤ 60
Conductivity (μS/cm)	≤ 1000
DO% saturation	≤ 60
ORP	≤ 10
PH	6–9
Temperature deg/C	≤ 35
TSS mg/L	≤ 25
Total Heavy Metals mg/L	≤ 2.0

Source: SI 174 of 2000.

In their review Nhapi and Gijzen (2002) mention that the main effluent parameters, TSS, PH, and BOD, must be at the required limit for the effluent to be regarded as safe for discharge. As the SI 174 of 2000 states, Total Suspended Solids must be equal to or below 25 mg/L, pH must be neutral between 6–9, and the Biological Oxygen Demand must be similar to or less than 30 ml/L for the safe, legal disposal of treated effluent. The municipality of Bulawayo is currently not meeting these discharge standards. According to ESMP (2015), only 30% of the 80ML of wastewater produced per day by the city, is finding its way into treatment facilities, and the remaining 70% is being discharged into rivers and streams. This means that the effluent has very high concentrations of pollutants.

Zimbabwean law states that all households are compelled to have acceptable sanitation before occupation (Urban Councils Act Chapter 29:15; Regional and Town Planning Act Chapter 29:6). Nevertheless, the challenge remaining is that the infrastructure is centralized, and maintenance failure by municipalities means there is system failure also. Therefore, the wastewater being channelled away from the households is not getting adequate treatment before disposal (Nhapi and Gijzen, 2002).

The problem with the policies and the legislative frameworks is that they are gazetted to regulate what is there already. Therefore, they do not inspire innovative thinking and new ways to tackle problems associated with the current wastewater management practices. According to Thebe and Mangore (2014), policy inconsistencies in the Zimbabwean wastewater management regulations mean there is a need to develop new guidelines that focus on wastewater use and treatment on-site to ensure adequate regulation or enforcement of standards. Chirisa et al. (2017) mention that to fully adopt decentralized wastewater systems in Zimbabwe, a review of the policy is needed, and it should be complemented by wastewater reuse guidelines, water use reduction, and pollution control and preventive measures.

3. Materials and methods

A case study research design in the City of Bulawayo and a mixed method research approach was adopted. The researchers adopted the spatial and qualitative approaches in an attempt to fulfil the research objectives. The feasibility of adoption of the constructed wetland in the city of Bulawayo is heavily dependent upon the relationship between the people and things around them. Therefore, this is the spatial aspect where the researcher is studying the environmental setting in which the study takes place. GIS was used for spatial analysis of the suitability of constructed wetlands in the city, and 4 data points were mapped out, one in the north and one in the south, one in the east, and one in the west. The researcher obtained data for mapping through the city of Bulawayo council (BCC). This included the land use data, sewer reticulation data, the slope, and streams data for mapping the proposed preliminary locations. The researcher did not consider other things like the population density around the proposed constructed wetlands locations because the main aim was to provide evidence that there is undeveloped land with no development plans, yet which is practical for positioning the constructed wetlands taking into consideration its location and physical traits. The mapping analysis was done using the QGIS (Quantum Geographic Information System.) software.

Furthermore, the authors attempted to explore the key factors in the implementation of constructed wetlands as decentralized wastewater treatment systems by interviewing stakeholders in wastewater treatment. According to Price et al. (2015, p. 146), an interview guide is a set of questions and prompts designed to elicit information from participants that will help achieve the research objectives. The interview guide is helpful for obtaining detailed information about the topic being studied. The researcher therefore used semi structured interviews to gather qualitative information about the study. The interview guide questions were designed in simple English and were separated into two sections. The first section required general demographic information about the participant’s profession and years of experience. The second section focused on the research details and included ten questions designed to achieve the study’s objectives. Ten interviews were conducted for this study from the beginning of November 2022 to the middle of December 2022. The interviewing continued until a saturation point was reached at ten interviews where no new information and themes emerged. This approach helped to increase the credibility and dependability of the data by ensuring that they were representative of the research population. Prior to the commencement of each interview, the participants were requested to complete a consent form. This provided them with details regarding the research and the process of the interview, including its duration and the fact that the discussion would be recorded. Additionally, the form outlined the confidentiality terms and made it clear that participation was entirely voluntary and that the participants could withdraw from the study at any time. By signing the consent form, participants demonstrated their willingness to be recorded and confirmed their ability to participate.

The recordings from the interviews were transcribed and the transcripts were analyzed using the Qualcoder (QualCoder is an open-source software for qualitative data analysis.) software. The approach to the analysis was based on grounded theory. This is a structured method that follows inductive logic, where researchers gather recurring ideas, concepts, or elements that emerge throughout the research process (Noble and Mitchell, 2016). The research also followed a specific methodology for coding, which was comprised of three distinct levels. Firstly, an open coding process was conducted for each transcript to identify concepts related to the adoption of constructed wetlands as decentralized sanitation alternatives. Secondly, axial coding was employed to connect the open codes based on the themes identified. Finally, the selective coding process involved integrating the themes to establish the main themes, and to identify the systematic connection between the different type of categories. The results obtained were presented in the form of file heat maps, tables, graphs, and diagrams. Top of Form.

Area of study

The study focuses on Bulawayo, Zimbabwe's second-largest city. According to the 2022 census, Bulawayo has an estimated population of about 655,675 people. The city includes 129,123 properties, which collectively generate around 80 million litres of wastewater daily that need treatment. Regarding sanitation, all high-density areas are fully connected to the waterborne sewerage system. In contrast, low and medium-density areas have only partial connections. Some neighborhoods in these lower-density areas rely on septic tanks instead. Approximately 15% of the population relies on onsite sanitation. However, a significant challenge still in the city is sewerage blockages, which pose health risks and hazards to the community. These blockages are primarily due to aging pipelines, improper disposal of solid waste in manholes, and insufficient water supply during water crises (ESMP, 2015). **Figure 2** below shows the sewer reticulation map of Bulawayo, the area of study.

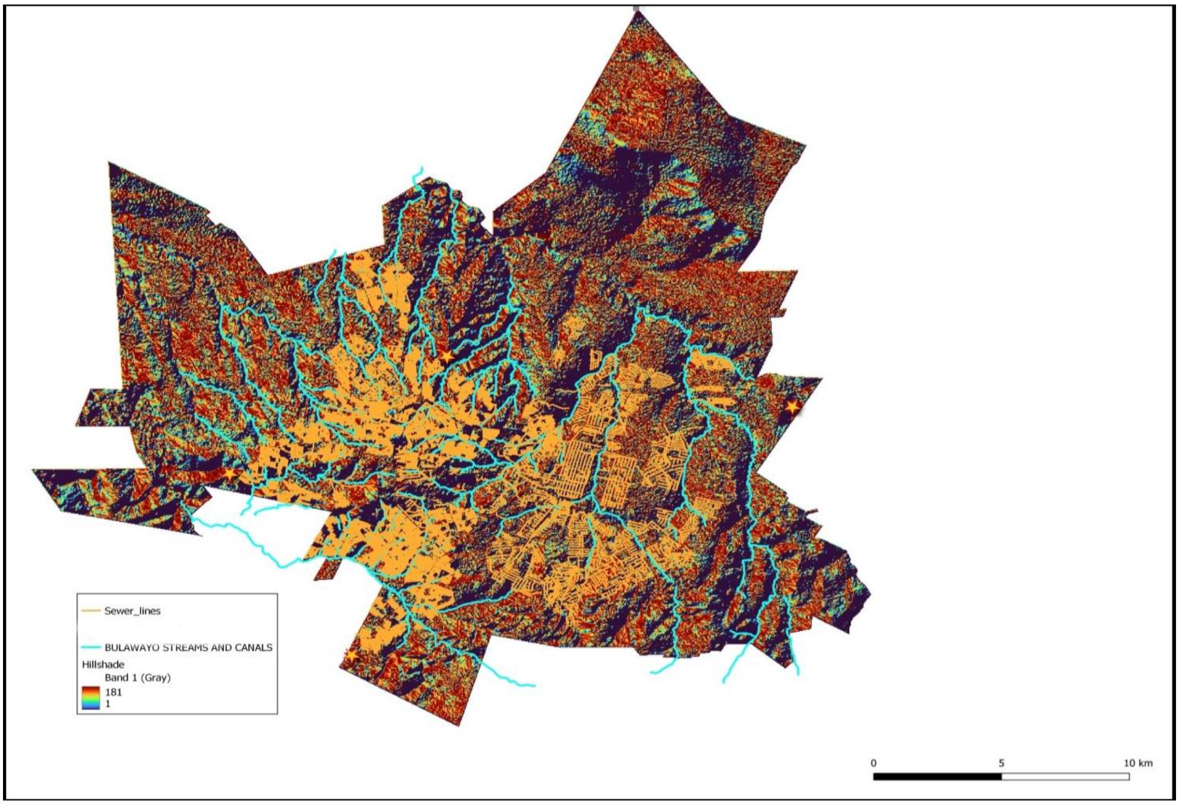

Figure 2. Bulawayo sewer reticulation map (Sources: Author).

4. Results and discussion

A spatial analysis was done on the city Bulawayo in an effort to propose preliminary sites suitable for the constructed wetlands. The main issues of concern for the siting of the constructed wetlands were the topography, proximity to existing infrastructure and development plans. For the qualitative data from the interviews, transcribed files were coded, and a file heat map was produced which shows the participants and the questions they were being asked. The ten interviewees as seen in the diagram were two town planners, one quantity surveyor (two-part interview), two NGO representatives, one Government official, two engineers and two community representatives. **Figure 3** shows the interviewees file heatmap.

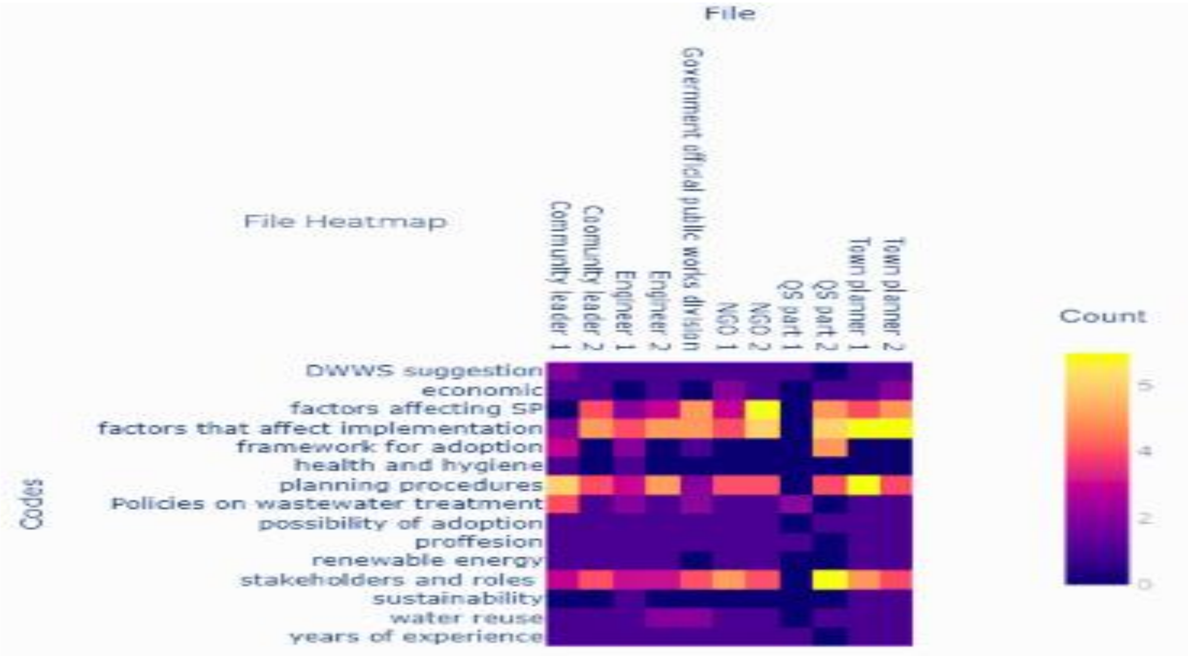

Figure 3. Interviewees file heat map.

4.1. Key criteria in the implementation of constructed wetlands as decentralized sanitation systems

Based on the coded data the following premises were established with regard to the factors that are vital for the implementation of constructed wetlands as decentralized wastewater treatment systems. A further analysis was done to present the factors in two categories either as challenges or enablers. A summary of the key findings is provided in **Figure 4**.

The figure shows two central themes. These are the challenges in implementation of the constructed wetlands and the perceived promoters or accelerators of the implementation of the systems. It is important to note that the stakeholders have different perspectives, which is reflected in their responses. For example, community leaders and NGO representatives tend to focus on local acceptance, while engineers and government officials tend to focus on technical and regulatory issues. Town planners tend to focus on land use and population growth, and QS's tend to focus on issues of funding. The factors are discussed below in detail.

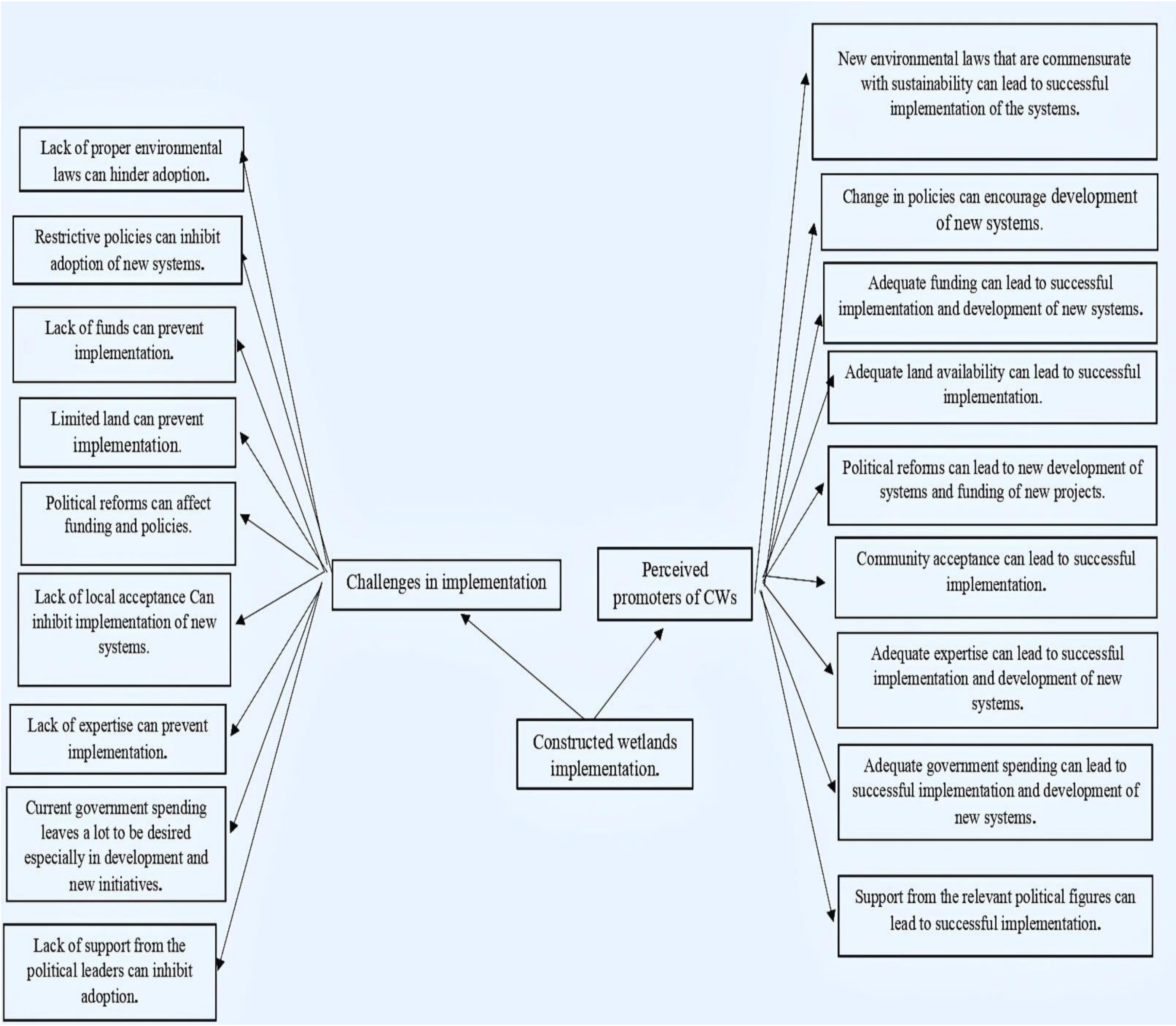

Figure 4. Summary of key ideas and themes of the analysis carried out in Qualcoder 3.2.

4.1.1. Government policies, regulations and environmental laws

Several participants mentioned the importance of government policies and regulations in shaping the implementation of decentralized technologies in wastewater treatment. Some participants noted that certain policies may inhibit adoption of these systems, suggesting that government policies should be reviewed and potentially changed to facilitate implementation. According to one of the civil engineers "Policy dictates how wastewater is treated in the sense that it governs or directs the municipality to follow the proper channels in treating wastewater, stricter regulations will mean that not any treatment is appropriate to be adopted as the wastewater treatment by the city that's why the city is using the common conventional system". Chirisa et al. (2017) note the same, stating that without legislation or policy guiding the operations of decentralized technologies, it becomes difficult to implement or sometimes convince the masses that the systems work. This will also weaken the political support for change, nevertheless, reforming the water and environmental guidelines is critical before any implementation can be done. According to Nhapi and Gijzen (2002), it is imperative for any country that the ministries governing water and wastewater management have practice guidelines in place before its adoption. This will ensure that the agencies responsible for environmental protection have statutes in place that will regulate the extent of decentralization. The interviewees also agreed, with one of the engineers stating, "Policies can be redrafted in the city or the country at large to inform the adoption of better treatments system in this case, the decentralized wastewater systems we are talking about".

The participants also mentioned the importance of environmental laws that are commensurate with the new sustainability mandate from entities like the UN in advocating for the implementation of CWs. According to Bernal et al. (2012), there is a unique overtone for decentralization, considering that notable effluent pollution challenges due to inefficient treatment in water sources are generally associated with centralized systems. In the case of Bulawayo, one of the community leaders concerned said, ". In our area, there have been numerous sewage outbreaks, highlighting the urgent need for a more environmentally friendly wastewater management system. Perhaps we can explore this decentralized option to address this pressing issue" Therefore, this can be an incentive towards the motivation to adopt the systems.

4.1.2. Land availability

The availability of land for the implementation of constructed wetlands was mentioned by several participants. For instance, town planners noted that constructed wetlands take up a lot of land and this could be a challenge in densely populated areas. However, one of the town planners in response to this notion made by his counterpart mentioned that "In Bulawayo, it's evident that we still have vast expanses of undeveloped land. This suggests that there is ample opportunity for further urban development including these other sewerage options". This discussion considered other decentralized wastewater systems which take up less space compared to constructed wetlands. However, Nivala et al. (2018), state that the land required is determined by the size of the system which in turn depends on factors such as expected volume and quality of wastewater, and the treatment goals. Therefore, to implement decentralized wastewater treatment schemes successfully, it is necessary to integrate water resource planning with urban planning based on spatial and geographical distribution and land use (Leigh and Lee, 2019) Besides the above mentioned, one of the municipality engineers also mentioned the importance of the land characteristics, citing that constructed wetlands require a site with suitable soil conditions and adequate drainage. Nivala et al. (2018) further state that the slope and topography of the land where the constructed wetland is sited can a play a big part in the design and effectiveness of the system.

4.1.3. Demography

Population size and growth were also mentioned by several participants as key factors affecting implementation. Some participants noted that an increasing population can lead to overloading of existing sewer systems, which in turn can drive the need for new systems. According to one of the town planners, "From 2012 to 2022, we observed an annual population change of 0.20% in Bulawayo. This data sheds light on the gradual but consistent shifts in our population dynamics over the past decade which can be one of the major reasons why our sewer systems are now constantly collapsing, they are strained". Other participants argued that a large population density will make it hard for the implementation of the systems as there will be no land for their development. According to Bernal et al. (2012), issues such as growth rate, size, density, and population distribution are integral to any project for urban water management. In the case of decentralization, population size and distribution are particularly important because they are the key aspects for of good planning in relation to the extent of decentralization and the number of systems required (Leigh and Lee, 2019).

4.1.4. Aging infrastructure

Several participants mentioned the need to replace aging sewer systems as a key factor driving implementation of CWs in a positive way. The participants in the discussion specifically highlighted that the sewer reticulation system in the city of Bulawayo is in a state of disrepair and urgently needs to be replaced. One of the engineers, in support of the decentralized systems mentioned that, "Yes, I do think the systems can offer a better way of managing wastewater as compared to the current system, which is failing at an alarming rate considering the sewer outbursts that the council has to attend per week especially in our western suburbs". In this regard, they suggested that alternative systems such as constructed wetlands could be a promising solution to address the issue, as revamping the system would require funding which the city does not have at the moment. A study by Pinninti et al. (2021) echoed the same sentiments, saying that, in actuality the costs of revamping aging conventional systems in developing countries are one of the drivers for adopting decentralized wastewater treatment systems. From a technical perspective, decentralization is therefore becoming increasingly important as a potential solution to address issues related to aging infrastructure, sustainability, and adaptability to fluctuations in demand, such as those caused by urban growth or renewable energy (Manny et al., 2022).

4.1.5. Technical expertise

The availability of technical expertise in design and operation of the CWs was mentioned by one of the participants as being imperative in the implementation of constructed wetlands. According to the Bulawayo City Council Quantity Surveyor "Proper technical expertise is needed on all stages, from designing, installation, operation and maintenance so as to avoid system failures. Without adequate technical expertise, there is a risk that the system may not function effectively, leading to potential health and environmental risks". It is however imperative to note that this can be offset through education and training (Starkl et al., 2013). Therefore, one can argue that if the necessary expertise is available, the implementation of the systems becomes much easier.

4.1.6. Political reforms and political support

Some participants noted the importance of political reforms and support from MPs and the Ministries of Infrastructure Development and Health in shaping the implementation of the systems. Kazora and Mourad (2018) further indicate that, that implementation should be accompanied by strengthening the capabilities of institutions in the sanitation and water sectors through decentralization to ensure the sustainability of decentralized technologies. Consequently, political leaders who make investment decisions must be fully supportive of the adoption of the systems if they are to be implemented. Such decision makers may underestimate the benefits of decentralized systems, such as improving community water security and preserving ecological water flows, as these benefits can be difficult to quantify (Leigh and Lee, 2019). As a result, decision makers may not fully appreciate the potential advantages of decentralized systems, which can hinder their implementation.

4.1.7. Local acceptance

Several participants mentioned that local acceptance of the CWs is a key factor that affects implementation of constructed wetland technologies. According to Libralato et al. (2012), the most resistance to these initiatives comes from the locals, because the consensus around wastewater management is that centralization has no reason to be substituted by decentralization if it’s already working. According to one of the non-governmental representatives interviewed one of the main reasons for this is social norms and values, mentioning that, “Social values play a big part in the societies acceptance of any initiative, in any community there many different people, different cultures, different beliefs, different norms, and just different values and this can lead to difference in how they will view the project you are trying to implement”. However, it has to be noted that public acceptance is greatly influenced by the social obligation to lessen household demand and by environmental concerns. In this sense, Bernal et al. (2021) mention that acceptance of alternative wastewater systems is usually based on measurable concerns strongly affected by the perceptions of threats and public health-related problems. For the public to accept CWs, it is paramount that acceptance should be accompanied by environmental consciousness, which is also connected to environmental education, information access, and water culture (Haldar et al., 2021). In the case of Bulawayo however, one of the community leaders echoed that, “For Bulawayo it is important to note that how the project is going to benefit the stakeholders can also be an incentive for them to participate or not to participate”. This underlines the importance of stakeholder value creation in the success of a project.

4.1.8. Government spending and funding

One participant mentioned the importance of government spending in shaping the implementation of constructed wetlands as decentralized schemes. The participant’s argued that, whilst constructed wetlands are cheaper compared to the conventional systems, they still do require significant costs upfront which the government does not always have. Massoud et al. (2009) echoed the same sentiments, stating that developing countries have more critical needs to attend to such as health care and food, other than revamping or adopting new wastewater treatment systems. According to a study by Nansubuga et al. (2016), the lack of investment in wastewater treatment in developing countries is a deep-rooted problem which starts with a lack of investment in research and is usually very low on the list of priorities. To change this, the governments in these countries need to implement policies that prioritize water conservation and recycling, and through this, the adoption of constructed wetlands may receive more support and funding. This will also mean that it is not only the government expending its resources on new sustainable wastewater treatment systems, but non-governmental organizations can also contribute. During the interview with government official from the Ministry of the Public Works Division, a question was raised about the budget structure of the city and how best can it address the issues concerned with wastewater infrastructure. The government official mentioned that "Certainly. In the 2022 fiscal year, the total budget allocated for Bulawayo amounted to US $106 million. Interestingly, a significant portion, US $20 million precisely, was earmarked for sewer-related infrastructure. This allocation underscores the prioritization of sanitation needs within the city. However, it's important to note that while centralized systems like these receive considerable funding, decentralized systems, although they entail expensive initial costs, can prove to be more cost-effective in the long run".

It is therefore imperative to note that funding for the development and implementation of constructed wetlands was mentioned as a key factor, and without funding, it is impossible to implement the systems. However, Nansubuga et al. (2016), state that the cost of implementing decentralized wastewater systems can be a barrier to adoption, especially in developing countries where they have more critical needs such as health care and food supply. Hence, these systems might be expensive to them. However, Jung et al. (2018) argue that this can be offset by involving international sanitation organizations to fund the systems. It is imperative to secure funding for the long-term operation of the systems for them to be sustainable.

4.2. Spatial analysis

The main issues of concern for the when conducting the mapping analysis and the siting of the constructed wetlands were the topography, proximity to existing infrastructure and development plans of the city of Bulawayo. The topography is important because we need our sites in a position of lower gradient relative to the residential homes as sewer water only flows down through a gradient. Siting CWs in a strategic position is key because wetlands are designed to take advantage of the natural features of the land and to minimize disturbance. The streams are also necessary as hydrology is a big part of the working conditions of constructed wetlands. Due to the fairly hot climate in the city of Bulawayo, the proposed type of wetland is the Vertical Subsurface Flow Constructed Wetland (VSFCW). This choice is primarily because, in this system, water remains below the surface, minimizing evaporation. Additionally, wastewater is distributed over the surface and then percolates downward through the substrate, allowing for intermittent loading and drying. This reduces the risk of anaerobic conditions that can cause odors in hot weather. **Figure 2** above in section 3.1 shows the current sewer reticulation of the city of Bulawayo. The reason for mapping the existing sewer reticulation was necessary because the proposed sites are just preliminary, and their position was supposed to cover the areas with no existing sewer reticulation. The proposed sites of the preliminary locations of the constructed wetlands are presented in **Figure 5**. The map shows the suburbs and the current residential boundaries in the city.

Figure 5. Proposed sites for the constructed wetlands.

Four sites were chosen for the preliminary implementation of constructed wetlands in Bulawayo. The first site proposed is Imvumila, between Emakhandeni and Windsor Park. The site was chosen to serve the suburbs of Windsor Park, Richmond, Richmond South, Upper Glenville, and North Trenance which have no sewer reticulation. However, it has to be noted that the residents of these suburbs are currently using septic tanks. The second proposed location is in Killarney, this site can successfully serve Killarney, Sunninghill, Glencore, and Woodville Park which are currently using septic tanks. These are the areas with no sewer reticulation in the eastern side of the city. The third proposed location is in Emganwini. The site can serve Newton West, Newton Eloana, Bellevue, and West Sommerton. It has to be noted that Emganwini has sewer reticulation, but it was chosen for the location of the constructed wetland for the suburbs mentioned because it was the nearest and best alternative with free undeveloped land. The fourth proposed location is in Pumula. This was chosen to cater for the new houses being built in Pumula east which have no sewer reticulation yet. The suggestion would be to start with the Pumula location as it has to serve a very small population compared to the other proposed sites. The proposed sites were chosen based on topography in relation to the suburbs they will be serving, the available infrastructure, and the available land with no development plans.

4.3. Policies on wastewater treatment in Zimbabwe

The study also enquired about the legislative frameworks that govern decentralized wastewater systems in Zimbabwe, and their implications on wastewater treatment approaches. Based on the responses it is clear that government policies and regulations play a significant role in determining how wastewater is treated in a city as well as the choice of treatment. The interviews also mention that compliance with these policies is crucial for ensuring that the treatment approach chosen is efficient enough to meet acceptable standards. This in turn will mean that it is not every wastewater treatment approach that is suitable for the city. However, some of the responses suggest that while there are Statutory Instruments that govern wastewater discharges, there seems to be a lack of specific policies in the city of Bulawayo and in Zimbabwe as a whole for effective wastewater management. They argued that this might be the cause of sewer related problems in the city. A review done by Chirisa et al. (2017) concluded that there is a need to review the current policies in Zimbabwe, especially the effluent standard (Statutory Instrument 174 of 2000). Moreover, the SI6 legislative tool governing wastewater management in Zimbabwe also does not encourage municipalities and industries to implement measures of effluent reduction (Manhokwe et al., 2018). This accidentally aggravates environmental pollution. The adoption of constructed wetlands can offset this; however, in Zimbabwe, the adoption of decentralized wastewater systems is still very minimal. According to Chirisa et al. (2017), this can be attributed to policy implications concerning wastewater management. The review of these policies can help not only with a better wastewater management framework but also make allowance for an uptake of new innovative wastewater treatment approaches including decentralized wastewater treatment technologies. The same sentiments were echoed by the interviewees, suggesting that clear policies on wastewater treatment can also influence the adoption of more efficient and sustainable systems. The key themes that were decoded from the interviews are tabulated below in **Table 2**.

Table 2. Themes on wastewater policies in Bulawayo.

Theme	Summary
Lack of specific policies	There might be a lack of specific policies and regulations for wastewater management in the city of Bulawayo which is hindering effective treatment of wastewater
Government policies and regulations	Government policies and regulations play a significant role in determining how wastewater is treated. Compliance with the policies is crucial for ensuring that the approach chosen is efficient and effective enough to meet acceptable standards
Alignment with development strategies	Policies for wastewater treatment should be aligned with the development strategy of the city; if the strategy is sustainability centred then policies around wastewater treatment should also be sustainability centred to enable efficient wastewater management

Formulating policy around the appropriate wastewater treatment systems is imperative to the success of the decentralized wastewater systems. Examples can be taken from the nations of India and Brazil, who successfully modelled policies around decentralized systems as acceptable technologies for wastewater treatment (Muzioreva et al., 2022). The Brazilian government gazetted the National Basic Sanitation Plan (Plansab) in 2013 which promoted investment in decentralized technologies around the country (Ferreira et al., 2021). Brunner et al. (2018) further state that in the Indian context, the National Urbanization Policy of 2008 paved the way for decentralized technologies to be adopted, with further strengthening through other initiatives such as the Integrated Urban sanitation launched in 2009, and the Clean India Mission launched in 2014. Zimbabwe can also follow in the footsteps of these nations if the implementation of constructed wetlands is to be successful.

4.4. Benefits of CWs as perceived enablers in the implementation of CWs

The interviewees were also asked about the benefits of constructed wetlands as perceived drivers in their implementation. **Figure 6** shows the frequently benefits according to the coded data, and which were water reuse, followed by sustainability issues. Constructed wetlands produce effluents of sufficient quality for reuse in recreational activities like swimming pools and sports events, discharging onto agricultural land for crop production, and augmenting freshwater sources such as rivers, lakes, ponds, and groundwater through aquifer recharge (Biswal and Balasubramanian, 2022). According to Nuamah et al. (2020), increasing the diversity of emergent plant species in constructed wetlands (CWs) has been shown to have a positive impact on reducing greenhouse gas (GHG) emissions. This is because the carbon sequestration in CW substrates can help mitigate emissions of methane (CH_4) and nitrous oxide (N_2O), which are potent GHGs. The presence of a greater variety of plant species in CWs has been associated with these emissions reductions and subsequent reductions in global warming potential (Mucha et al., 2018). The third most mentioned was economic benefits, followed by renewable energy in the form of bio-electricity from the systems. The least mentioned benefit by the interviewees was health and hygiene.

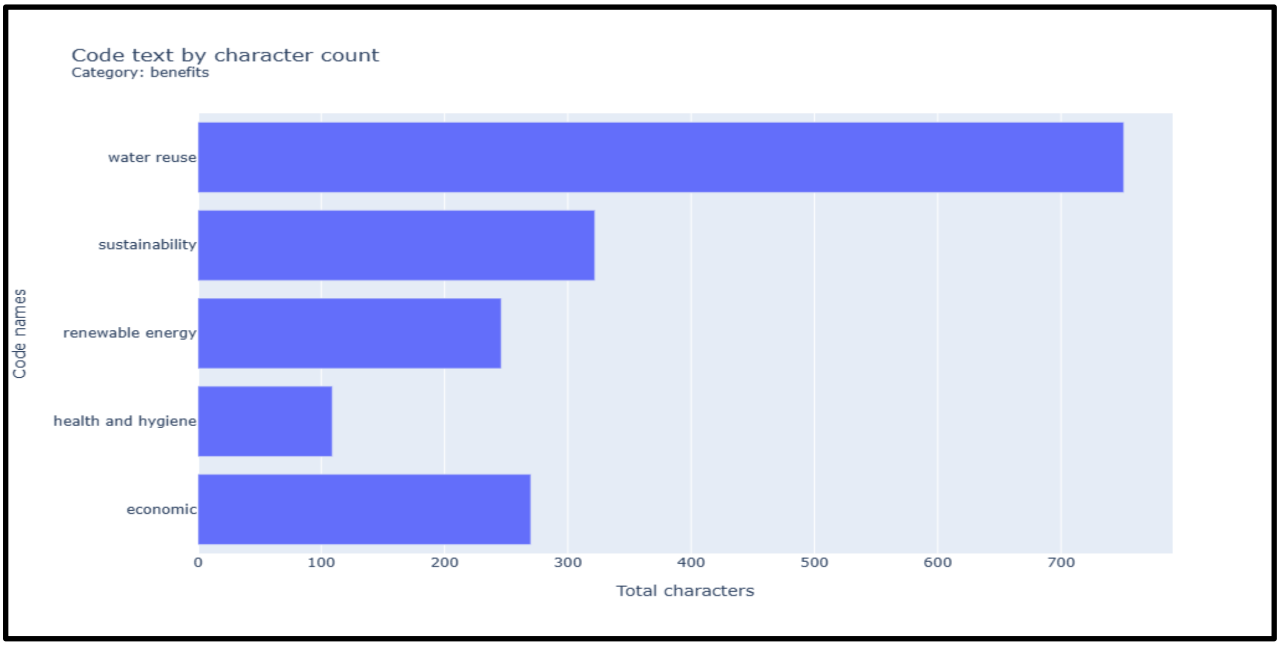

Figure 6. The most frequently mentioned benefits in the interviews.

However, it must be noted in the economic benefits category that particular responses stood out such as the creation of employment and increase in the GDP. The interviewees mentioned that the implementation of the project, can create employment for the locals especially during the check-up and maintenance stage. The increase in GDP, as explained, could result from new infrastructure being built. Some of the benefits mentioned were like those found in literature such as water reuse for parks and golf courses, aquaculture, crop irrigation and bio-electricity generation.

4.5. Practical implications of the study

The adoption of constructed wetlands can be a solution for sustainable wastewater treatment in developing countries however there needs to be clear coherent planning in the implementation of the systems. The study discussed the key criteria in the implementation of constructed wetlands, identified four preliminary sites for the systems in the city and also identified the benefits of the systems. The lessons which can be taken form the study are as follows.

1) First and foremost, there is need to change the policies and the legislative frameworks around wastewater management in the city of Bulawayo and the country if constructed wetlands wastewater treatment systems are adopted. Policies should therefore be updated and molded around sustainable wastewater management systems.
2) The second thing to note is that securing sufficient capital for the project, including long-term funding for operation and maintenance goes a long way in making the project sustainable.
3) It's important to carefully consider how constructed wetlands are sited and integrated with local infrastructure and services to maximize their benefits and minimize their costs.
4) Providing education and outreach to the community to increase understanding of the benefits of decentralized systems helps address any concerns or misconceptions about the technology. This can help with the acceptance of the systems. Conversations like these can empower citizens to act and become part of the solution and can clarify specific measures to bring about the changes they want to see. The objective should not be to impose new technologies on citizens from the top down for the sake of the greater good, but to encourage grassroots acceptance. This will in turn increase buy in and ownership of the project and enhance stakeholder value creation. It is important to craft messaging that addresses these concerns and demonstrates how embracing these alternative approaches can lead to a more sustainable society.

5. Conclusion

Constructed wetlands offer a sustainable alternative to centralized wastewater treatment systems. Developing countries have a growing problem of urbanization, which is putting a lot of strain on the already limited infrastructure. The current centralized facilities for treating wastewater suffer from a plethora of irregularities, and due to the expensive nature, developing countries cannot afford to renovate and upgrade their systems. Therefore, adopting constructed wetlands can be the solution to the sanitation challenges those developing countries face. To this end, this study has explored the key criteria vital for implementation of constructed wetlands in developing urban cities, using Bulawayo, Zimbabwe as a case study. Key factors that were identified by the interviewees include political support and political reforms which are in alignment with the sustainability development framework. One of the crucial aspects to note is that the issues are relevant for all the stakeholders involved in wastewater treatment projects. For example, community acceptance is very important in the implementation of the systems since these are community-based sanitation programmers. Additionally, four sites were identified as the most favorable preliminary locations for these systems. Moreover, policy plays a crucial part for the adoption of any initiative especially in the wastewater sector. Modelling policy around the decentralized sanitation systems is therefore imperative to the success of the systems whether in implementation or in operation. Benefits associated with constructed wetlands were also identified as perceived enablers of their implementation. The standout benefit was water reuse, highlighting the efficiency of constructed wetlands as wastewater treatment systems. According to the findings of this study, citizens recognize the challenges in the implementation of constructed wetlands, as well as what needs to be done to adopt the systems. This study has presented a framework for the factors crucial in the implementation of constructed wetlands (CWs). However, the study was limited by its exclusive use of a qualitative methodology which may restrict the generalizability of the findings to other contexts. The study’s findings are also specific to the context in which the research was conducted, limiting their relevance to other geographical or socio-economic settings. Therefore, further research can be conducted with a different methodology to ascertain the applicability of the systems in other urban settings considering other practical important aspects in the implementation of wastewater treatment systems. Additionally, future research may extend the overall findings of this study and implement them in addressing other crucial societal challenges.

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Abbreviations

AfDB	African Development Bank
AusAID	Australian Government Aid Agency
DDF	District Development Fund
EMA	Environmental Management Agency
EU	European Union

GTZ	German technical assistance
MoLGRUD	Ministry of Local Government Rural and Urban Development
MoA	Ministry of Agriculture, Mechanization and Irrigation Development
MoE	Ministry of Energy and Power Development
MoEn	Ministry of Environment and Natural Resources Development
MoF	Ministry of Finance
MoHCW	Ministry of Health and Child Welfare
MoTCID	Ministry of Transport Communication and Infrastructure Development
MoWAGCD	Ministry of Women's Affairs Gender and Community Development
MoWRDM	Ministry of Water Resources Development and Management
NAC	National Action Committee
NCU	National Coordination Unit
NGO	Nongovernmental organization
WB	World Bank
WSS	Water and sanitation sector
ZINWA	Zimbabwe National Water Authority

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