ABSTRACT

Limited understanding of the complex interactions of factors that influence the sustainability of access to improved water services poses a threat to rural livelihoods. The study assessed the complex interactions of the factors using a network approach. The assessment was to understand the complex interaction of the factors resulting from their cause-effect relationship that influence the sustainability of access to improved water services in a rural municipality of South Africa. The results highlighted that limited budget, limited or no water supply and improper operation and maintenance were critical factors resulting from the cause-effect relationship of other factors that influenced the sustainability of access to improved water services in the study area. We conclude that critical factors with a cause-effect relationship can influence the sustainability of access to improved water services. As a result, this deprives rural communities of the benefits derived from accessing improved water services. We recommend the use of the findings by the relevant authorities responsible for water services provision to inform planning, management policies to address challenges identified to contribute to sustainability of access to improved water services.

Key words | categorical factors, complex systems, Makhudutamaga Local Municipality, network approach, sustainability of water services

HIGHLIGHTS

- Understanding of complex interactions of factors is critical to ensuring sustainable access to improved water services.
- Conventional approaches do not capture the complex interactions of factors.
- It is critical to have a coherent understanding of the factors that influence sustainable access to improved water services.
- Sustainable access to improved water services is affected by the complex interactions of factors.

INTRODUCTION

The sustainability of access to improved water services provided by Improved Water Sources (IWS) (e.g. standpipes connected in the dwelling or communal standpipes) in rural communities can contribute to enhanced public health, wellbeing and livelihoods (Giné-Garriga 2015; Giné-Garriga et al. 2018; Sambo et al. 2018). However, there remains a substantial proportion of the rural population without access to improved water services (WHO/UNICEF 2019). Also, those that are reported to have access to improved water services are experiencing services...
related issues that influence access negatively (Martinez-Santos 2017). The literature reviewed indicates that the situation on the ground results from factors that are technical, social and institutional that influence the sustainability of access to improved water services, which are documented in detail by Clasen (2012), Flores Baquero et al. (2013), Kayser et al. (2013), Shaheed et al. (2014), Giné-Garriga et al. (2015), Martinez-Santos (2017) and Adams (2018).

The factors that influence the sustainability of access to improved water services are well documented in the literature. However, the compartmentalised analysis of the factors could be a contributing aspect to the reason the situation is as it is on the ground. This is because the factors have a cause-effect relationship that represents the complex interactions of the factors, as reported by Harvey & Reed (2004) and Sambo et al. (2018). The conventional approaches employed in the analysis of the factors do not capture the complex interactions resulting from their cause-effect relationship to provide a coherent understanding (Sambo 2015; Giné-Garriga et al. 2018). As a result, the understanding of the factors in how they are analysed does not yield sustainable solutions. There is a need to understand the complex interactions of the factors. Such an understanding can contribute to enhanced public health, wellbeing and livelihoods (Giné-Garriga 2015; Giné-Garriga et al. 2018; Sambo et al. 2018). It can also result in targeted interventions that include evidence-based policies and proper planning and management of improved water services to ensure sustainability. Consequently, this raises a need to explore appropriate approaches that capture and provide a coherent understanding of the complex interactions of factors that influence the sustainability of access to improved water services (Giné-Garriga et al. 2018).

There have been efforts to employ appropriate approaches with the potential to inform interventions targeted towards the attainment of universal access to improved water services. These efforts focused on addressing specific challenges related to IWS coverage, water service level and prioritisation of high-risk communities (Rietveld et al. 2008; Cohen & Sullivan 2010; Flores Baquero et al. 2015; Giné-Garriga et al. 2015; Luh et al. 2015; Giné-Garriga 2015; Sambo 2015; Kulinka et al. 2017; Molinos-Senante et al. 2019). These resulted in enhanced availability and access to up-to-date and reliable information as well as promoting dissemination and use of the information to inform evidence-based policies and proper planning and management of water services (Giné-Garriga et al. 2018). The approaches provide valuable information that contributes to the sustainability of access to improved water services. However, when the results derived from the approaches are used in isolation, they provide a somewhat compartmentalised perspective centred on specific aspects (e.g. physical accessibility or functionality) of water service provision. As a result, the approaches provide some level of understanding with regards to the sustainability of access to improved water services but do not provide a coherent understanding of the cause-effect relationship of factors that contribute to sustainability.

In an attempt to address the gap, various researchers have employed approaches that interlinked two or more categorical factors in studies that addressed issues that influenced the sustainability of access to improved water services. Categorical factors refer to factors that influence the sustainability of access to improved water services, categorised as social, environmental, institutional, economic and technical factors, explained in detail by Graciana & Nkambule (2012) and Sambo (2015). The literature reviewed indicated contradicting results in terms of main factors that influenced the sustainability of access to improved water services (Macus & Onjala 2008; Graciana & Nkambule 2012; Sambo 2015; Giné-Garriga et al. 2018; Sambo et al. 2018). For example, Macus & Onjala (2008) found that the sustainability of access to improved water services depended on economic and institutional factors. Contrary to this, Graciana & Nkambule (2012) found that economic and institutional factors were less critical than technical and social factors. The contradicting results are indicative of the fact that the sustainability of access to improved water services can be influenced by different factors depending on the situation on the ground. For example, the improved water services can fail due to a burst pipe (technical), lack of budget to buy electricity to run water pump (economical) and water pump theft (social). Therefore, the limitation of the approaches employed was that the complex interactions of the factors was not quantified. Giné-Garriga et al. (2018) proposed Object-Oriented Bayesian Networks (OOBN) as an approach to quantify the complex interactions of Water Sanitation and Hygiene (WaSH) factors. The results of the study indicated that the OOBN approach has the potential to accommodate the complex interactions of WaSH factors.
However, they concluded that there is a need to improve the model to simplify it by lowering the number of nodes (factors) of some categories without losing critical information. They also indicated that the software used requires a highly qualified person to use it, which is a major drawback. In rural municipalities where there is limited technical capacity (Sambo et al. 2018), it makes the adoption of such an approach a challenge.

It is against this background that the research finds the network analysis approach suitable to capture the complex interactions of factors that influence the sustainability of access to improved water services in rural municipalities (Sambo et al. 2018). It is its simplicity regarding data collection and analysis that makes it adaptable in a rural setup (Sambo et al. 2018). The network approach has the potential to capture the complex interactions of different and unlimited numbers of categorical factors based on their cause-effect relationship. These include but are not limited to technical, social, institutional, economic, and environmental factors (Harvey & Reed 2004; Graciana & Nkambule 2012; Fan et al. 2013; Spaling et al. 2014). The approach has been employed in different disciplines, including social sciences, management and agriculture (Wasserman & Faust 1994; Freeman 2004; Fairweather 2010; Bezuidenhout et al. 2013). However, there has been limited use of the approach in the water sector, mainly in rural water supply.

The graphical nature of the network (‘spider-web’ like) allows for easy and systematic analysis of the complex interactions of factors. The nodes in the network represent factors, and the lines represent the linkages of the factors with each other (Milojević 2014). The nodes’ size can represent the intensity of the relation of a node with other nodes (Wasserman & Faust 1994; Milojević 2014), thus allowing for quantification of the cause-effect relationship of the factors to identify critical areas to focus interventions in order to address challenges. The lines can be used to represent the direction of the linkages of nodes with other nodes. The direction of the linkages is useful in analysing the flow of the interactions leading to critical nodes in the network (Bezuidenhout et al. 2013). The closeness of the node resulting from their interactions helps in understanding their relation. The community structure approach can be used to identify thematic communities resulting from closeness of the factors to enhance understanding of the network (Bezuidenhout et al. 2013). As a result, in the context of rural water supply, this can provide a coherent understanding of the interactions of the factors that influence outcomes regarding IWS coverage and water service levels in different settings (e.g. district, municipality, community, etc.).

The study sought to addresses the gap concerning the understanding of the complex interactions of factors that influence the sustainability of access to improved water services in a rural setup. The objective of the study was to assess factors that influenced the sustainability of access to improved water services using an approach the captures their complex interactions.

**METHODS**

**Study area and research approach**

The study was conducted in Makhudutamaga Local Municipality, Limpopo Province, South Africa (24°44′5.77″S; 29°50′6.83″E). A mixed-methods approach was employed to investigate (qualitative method) and analyse (quantitative method) the factors influencing the sustainability of access to improved water services provided in the study area. Tables 1 and 2 show a summary of the research procedure employed to attain the research objective. The key informant interview method was employed as a qualitative research method to collect qualitative data on factors that influence the sustainability of access to an improved water service. The research preferred the key informant interview method because it allowed for collecting rich and reliable explanatory qualitative data, supported by Bezuidenhout et al. (2013). In this regard, semi-structured questions were formulated to collect relevant explanatory qualitative information. Semi-structured questions were preferred over close-ended questions because of their flexibility with regards to allowing for follow up questions to be asked when the interviewer did not fully comprehend the responses provided by the interviewees. The asking of follow-up questions enhanced the researcher’s understanding to contextualise the interviewees’ responses. The formulated questions were piloted with two people to ensure their relevance in collecting the required data. The
The piloting of the questions provided clarity regarding how the interviewees will understand and respond to the questions. After piloting, comments were provided by the interviewees to improve the questions to collect the relevant information in a reduced time frame. The comments were incorporated in the finalisation of the questions.

The interviewees’ sampling was purposeful because it was based on their availability and accessibility at the time of the research (Sambo et al. 2018). The researcher consulted the Sekhukhune District Municipality (SDM) to identify relevant personnel involved in the planning and managing of water services that could participate in the key informant interviews. As a result, a list of 9 (nine) personnel and their contact details (emails and mobile numbers) was provided for scheduling appointments. Email and telephone calls were used to contact the identified personnel to introduce the research and request their participation in the interviews. Consequently, appointments were secured with six (6) personnel (interviewees), due to the other three (3) identified personnel being unreachable. Due to COVID-19 regulations of 2020 at the time of the study, the research was not able to conduct physical field visits to interview water service users in the study area. This is because movement was restricted to essential services, and research was not classified as essential. Hence, the interviews were conducted telephonically with the SDM personnel.

Interviewees were sent consent forms via email to give consent to participate in the interviews as per ethical research requirements. The consent form, in addition to other things, solicited consent for the interviewees to be recorded. This was for the researcher to be able to refer to the recording when analysing the exploratory qualitative

| Stage | Description of stages | Descriptive summary of actual steps taken |
|-------|-----------------------|----------------------------------------|
| Stage 1 | Research method and type of data | – Key informant interviews were employed for data collection.  
– Qualitative explanatory data was collected. |
| Stage 2 | Data collection instrument | – Semi-structured questions were developed and piloted with two people to check for relevance.  
– After piloting, revisions were made to the questions and then finalised. |
| Stage 3 | Identification of stakeholders | – Stakeholder selection criteria were developed.  
– Stakeholders were identified from a list of personnel working at the Sekhukhune District Municipality – Infrastructure Water Services division (SDM-IWS) based on the selection criteria.  
– Interviews with identified personnel were scheduled using email and telephone. |
| Stage 4 | Data collection | – The interviews were conducted telephonically.  
– The interviews were recorded and notes made in a journal. |
| Stage 5 | Categorisation | – Statements regarding factors that affect the sustainability of access to improved water services were identified.  
– The factors were coded.  
– The coded factors were allocated to representative categories.  
– Factors were linked based on their direct cause-effect relationship using the first (1st) principle. |
| Stage 6 | Data analysis and display | – The linked factors were loaded on computer software (Pajek®) for processing.  
– The energy transformation technique was applied to the data to generate a network.  
– Centrality approaches relating to interconnectedness and closeness were applied to the network.  
– Thematic communities were identified in the network (for steps taken, see Table 2).  
– The final network was generated (see Figure 1).  
– Density visualisation was applied to the network (see Figure 2) to identify problem areas. |
information provided and not to misinterpret the information. This was critical in ensuring the validity and reliability of the data. During the interviews, semi-structured questions were asked with clarity and in a manner that was not offensive to the interviewees. In this regard, the responses provided by the interviewees were clear and addressed the questions asked. This is because the interviewees responded with an understanding of the questions asked providing relevant information. In addition to recording, the researcher also noted certain issues in a journal that were emphasised by the interviewees. This was regarded as important information to help in data analysis, especially in the identification of factors. At the end of the interviews, the interviewees were thanked for their time.

The researcher preferred to conduct physical interviews. However, telephonic interviews and interviewing six (6) people did not compromise the quality of the data collected. Interviewing more people could have led to the saturation of the qualitative explanatory information provided; this is supported by the experiences of Bezuidenhout et al. (2013) and Sambo et al. (2018). This was evident as interviewees reported similar issues during the interviews, resulting in saturation. As a result, the data collected was sufficient to conduct a detailed analysis.

The initial aim of the study was to also interview community members in the study area. However, as mentioned, due to COVID-19 regulations at the time of the study, physical field visit were not possible. Due to time constraints, and not knowing when movement would be allowed, a decision was made to only interview personnel from the SDM as they could be contacted telephonically. It is worth noting that the researcher worked in the study area for a long time conducting research. As a result, it is our view that the information provided by the interviewees represented the issues that are of concern to the communities. Therefore, the involvement of the community members could have resulted in saturation of information. However, the involvement of community members can still be explored in future research.

### Data analysis and network generation

The recordings and notes of the interviews were used as a reference to identify critical factors and their linkages. The researcher preferred using both manual and computer-assisted methods to analyse the data collected to take advantage of their strengths to produce the best results (Welsh 2002). Computer software is useful in organising and grouping extensive qualitative data according to specified categories to enable data analysis (Alhojailan 2012). This was valuable because it improved the rigour of analytical steps for validating the data and allowed for the data to be

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**Table 2** Steps employed to analyse the generated network

| Stages | Description of stage | Descriptive summary of actual steps taken |
|--------|----------------------|------------------------------------------|
| Stage 1 | Reliability and validity | – The researcher checked that the network was correctly generated.  
– An analysis of the nodes and linkages was done, including the flow of the network.  
– An independent person also checked the network (SDM Operation and maintenance manager). |
| Stage 2 | Identification of thematic communities | – Thematic communities were identified based on closely related nodes using Louvain method (Blondel et al. 2008).  
– The coherence and diversity of the nodes was analysed to validate the communities. |
| Stage 3 | Naming of the thematic communities | – The thematic communities were delineated according to the clusters.  
– Based on the coherence and diversity of the nodes, the thematic communities were named. |
| Stage 4 | Review the thematic communities | – The thematic communities were reviewed by repeating Stages 2, 3, and 4. |
| Stage 5 | Finalise thematic communities | – The thematic communities were finalised. |
analysed based on the interactions of the factors at the level of a complex system (Alhojailan 2012).

NotePad® was employed to assist with the categorisation and linking of factors. The identified factors were categorised under technical, institutional, economic, environmental, and social categories. The categorised factors were linked based on their cause-effect relationship using the first principle. The first principle referring to the linking of factors that have a direct cause-effect relationship (e.g. ‘A’ has a direct cause-effect relationship with ‘B’). For example, ‘we are unable to repair pump because we do not have spare parts’ (A); as a result, ‘broken pump’ links with the ‘unavailability of spare parts’ (B), as a result influences the sustainability of access to improved water services.

The data processed in NotePad® was exported to Pajek® (Version 5.09) (Batagelj & Mrvar 1998). Pajek® is a computer software that was employed to process the data to generate the network. The computer software is a powerful tool for processing interconnected factors to generate networks (Batagelj & Mrvar 1998; Milojević 2014). The Kamada Kawai energy transformation (Kamada & Kawai 1989) was applied to the factors to generate the network. The network was generated based on the diversity, interconnectedness, and closeness of the factors (nodes). To quantitatively analyse the generated network, the centrality approaches were applied to the network. The Degree Centrality (DC) approach determines the nodes' interconnectedness based on the direct cause-effect relationship (Zhang & Luo 2017). This allows for the identification of critical nodes in the network. The Betweenness Centrality (BC) approach determines the number of times a node lies in the shortest path between nodes (Zhang & Luo 2017). The approach allowed for the identification of nodes that influenced the flow of the network. The Closeness Centrality (CC) approach uses a score to determine the ‘closeness’ of a node to other nodes in the network (Zhang & Luo 2017). The approach allowed for the identification of nodes that influenced the whole network. For the identification of thematic communities, the Louvain method (Blondel et al. 2008), a community structure method, was applied to the network. The thematic communities were identified based on the nodes’ coherence and diversity. The density visualisation approach using VosViews® (Version 1.6.5) (Van Eck & Waltman 2010) was applied to the network to identify ‘hot’ and ‘cold’ spots (problem areas) in the network. The use of density visualisation allowed for the identification and categorisation of critical problem areas in the network.

Ethical consideration

The research was approved by the University of Kwa-Zulu Natal (UKZN) ethics office to conduct key informant interviews in the study area (Protocol reference number: HSS/0863/018D).

RESULTS

Thirty (30) different categories of factors (nodes) and seventy-two (72) direct cause-effect linkages (lines) were identified from the qualitative exploratory information collected through the key informant interviews. Figure 1 shows an energised network depicting the complex interactions of the factors that influence the sustainability of access to improved water services. The energy transformation applied to the network distributed the nodes based on their association; therefore, closely related nodes were placed close to each other. The centrality approaches were applied to the network. The DC approach created different sizes of nodes based on their interconnectedness with other nodes. Larger nodes represented critical points in the network that raised opportunities for improvements. Complementary to critical points, problem areas were identified using density visualisation of the network (see Figure 2). The red, yellow, and green colours shown in Figure 2 represent high, medium, and low-density areas, respectively. High-density areas represent critical problem areas in the network. For example, in Figure 2, the area marked (A) represents a high-density area. Furthermore, community structure method identified three (3) thematic communities (grey shaded areas) in the network (see Figure 1). The thematic communities were identified as ‘water availability,’ ‘institutional arrangements and funding’, and ‘long-term sustainability’.

The nodes representing limited budget, limited/no water supply, limited staff capacity, improper operation and maintenance (O&M), and limited specialised staff are the top five (5) critical points in the network. Limited or no water supply
referring to a situation where the water supplied is not sufficient or no water is discharged from IWS as a result of other factors. The critical points are located in areas categorised as critical problem areas based on density visualisation. For example, in Figure 2, the area marked C is a critical problem area representative of factors to do with O&M and capacity of staff responsible for O&M.

The critical problem areas are useful to bring attention to certain key nodes in the network and not just one node. However, it is important to understand the in-degree (leverage) and out-degree (KPI) the different nodes have in the network. For example, the limited budget has the highest leverage and low KPI, and limited or no water supply has the lowest leverage, but the high KPI. This means that a limited budget causes an effect to a majority of the nodes connected to it, and limited or no water is an effect of the majority of nodes connected to it. Improper O&M also has an effect on the majority of the nodes connected to it, which include limited budget, limited staff capacity, and limited specialised staff. Therefore, understanding the leverage and KPI of nodes helps to understand their role in the network.

The role of nodes in the network can be further understood using the BC and CC. This allows for a detailed analysis of the nodes and the network. Limited or no water supply has the highest BC and CC. This means that it has a strong influence on the flow of the network, and it is best placed compared to other nodes to be influenced or to influence other nodes. In this case, as shown by the red arrows in Figure 1, the flow of nodes leads to limited or no water supply, and it is influenced by most nodes. The limited budget also has high BC and DC, it influences the flow of the network as most of the nodes are influenced by it, and its influence evenly results in limited or no water supply; therefore, it is an influencer in the network. Based on this, the flow of the network is from right to left.

It is also important to understand the role of nodes in the linkage of thematic communities identified in the network. The nodes in the ‘institutional arrangements and funding’ and ‘long-term sustainability’ thematic communities are more closely related compared to those in the ‘water availability’ community. The ‘water availability’ thematic community is separated at a noticeable distance.
from the other thematic communities. However, as indicated by BC and DC, the critical node in ‘water availability’ has a strong influence on the flow of the network. This is because it is influenced by the nodes within the thematic community and in the other thematic communities. Limited or no water supply is central to the connection with other thematic communities, and limited budget is central to the linkage of ‘institutional arrangements and funding’ and ‘long-term sustainability’ thematic communities. This again indicates the importance of the two nodes in the network.

**DISCUSSION**

The network approach identified critical nodes (factors) and quantified their cause-effect relationship in influencing the sustainability of access to improved water services. This resulted in identification of critical factors that need to be address to contribute to sustainability of access to improved water services. This is important as the approach allowed for a coherent understanding of the factors. Possible interventions of the challenges identified can be proposed and implemented, resulting in sustainability. However,
proposing solutions for the identified challenges was not within the scope of this study but to demonstrate the use of the network approach in bringing a coherent understanding of the factors that influence the sustainability of access to improved water services. Therefore, having a coherent understanding is a step towards ensuring sustainability. The sub-sections below present a discussion of the critical aspects and thematic communities of the network.

**Institutional arrangements and funding**

The challenge in the ‘institutional arrangement and funding’ thematic community is the failure (delayed/abandoned) of water infrastructure projects aimed at supporting water services provision. Within the community, the challenge is due to political influence, a top-down approach, and the lack of consultation with beneficiary communities. This is because, at a political level, especially during elections, communities are promised projects that are expected to address their water challenges (Muller 2008). However, these projects can either be started and not completed or completed but with no water supply. Some projects fail because of ‘limited budget’, which is a critical factor within the ‘long-term sustainability’ thematic community and network. The factor is influenced by a poor funding model used to fund investment in the development of water infrastructure and O&M. The fact that the WSP does not collect water tariffs worsens the situation with regards to the availability of budget to fully support water service provision. The WSP depends on grants provided by the Department of Water Affairs and Sanitation (DWAS) and the Municipality Infrastructure Grant (MIG) to support water services provision. The equity-share model guides the allocation of the grants, which in most cases does not consider the situation in the communities but considers the population served by the respective municipality. This results in challenges that affect the long-term sustainability of improved water services.

**Long-term sustainability**

The limited budget allocated for investment in new water infrastructure projects and O&M is a challenge faced by the WSP within the ‘long-term sustainability’ thematic community. This has resulted in a number of challenges that compromised the sustainability of access to improved water services. The WSP operates with limited capacity to fulfil its mandate of water provision in the communities; due to that, it is short-staffed and has limited staff with specialised skills required to conduct proper O&M. This is even though the WSP through the assistance of external service providers having developed a comprehensive O&M strategy (e.g., community water supplier master plan) aligned to achieve the objective of the Water Supply Development Plan (WSDP) and IDP as well as to attain universal water access. The over-reliance on external service providers on issues to do with the development of strategies, infrastructure projects, and O&M is perhaps one of the reasons the budget allocated to the WSP is constrained. External service providers tend to take advantage of the situation and charge ‘ballooned’ fees for their services. However, because of the constrained budget, there are key vacant positions, and the focus is on recruiting general labourers that are not trained in doing the specialised work of O&M. This, as a result, has led to O&M being one of the challenges that influence access to sustained water services. Ruiters (2015) states that in a situation where the budget is constrained, O&M is sacrificed over the development of new water infrastructure projects, which is what is being done by the WSP. The combination of constrained budget and limited staff has resulted in delays in the repair, replacement, and maintenance of critical water infrastructure (e.g., broken-down/stolen electric pumps). This has contributed to communities experiencing limited/no water supply.

**Water availability**

The challenge of limited or no water supply is not only as a result of improper O&M but also to do with water availability. The fact that the study area is located within a water-scarce district with low rainfall makes it challenging for the WSP to provide water services that meet the water demand of its residents. The annual rainfall received is not sufficient to replenish surface and groundwater sources. Many boreholes have been reported to have dried-out, and dam capacities are reducing (Sambo et al. 2018; SDM 2019). Population growth that has resulted in the expansion of residential areas in the communities has made the work of the WSP challenging. It is estimated that the annual average increases in population...
and households are 1.6% and 2.0%, respectively (SDM 2020). The WSP is grappling to keep up with providing services; due to that, from 2008 to 2018, the number of households estimated to be using improved water services decreased by an annual average of 1.6% (SDM 2020). It is estimated that the combined developed and undeveloped surface and groundwater sources will not meet the water demand by 2045 (SDM 2020) - provided that there are no water infrastructure issues. However, 47% of the potential surface and groundwater sources have been developed, and the remainder is yet to be developed (SDM 2020). The interviewees indicated that the challenge is worsened by traditional authorities that do not consult them when establishing new residential areas. As a result, the new residential areas are not included in the planning of the WSP. However, the expectation once established is that the WSP should provide them with water services. This is problematic for the WSP as they are struggling to clear the water backlog, and it is increasing annually.

**CONCLUSION**

The network approach captured the complex interactions of factors that influence the sustainability of access to improved water services in a rural municipality. Critical factors that influence the sustainability of access to improved water services were identified as a result of quantifying their cause-effect relationship. Therefore, the analysis of the factors resulted in a coherent understanding of the factors, providing a clear picture of the context where factors interact to influence an outcome regarding IWS coverage and water service level. Limited budget, limited or no water supply and improper O&M are some of the critical factors that have a more significant influence on the sustainability of access to improved water services. However, most of the issues resulted from the limited budget. The identification of the critical factor allows for the development of targeted interventions that can result in the sustainability of access to improved water services. It is recommended that the relevant authorities responsible for water services provision adopt the findings of the study to inform planning and management as well as strategies and policies to contribute to the sustainability of access to improved water services and improvement of rural livelihoods.

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**DECLARATION OF INTEREST STATEMENT**

The authors do not have a conflict of interest.

**DATA**

The recordings of the key informant interviews are not available as the consent form signed by the interviewees stated that the recording would not be shared with any third party. However, the NotePad, Pajek and VosViewer data files used for analysis are available.

**DATA AVAILABILITY STATEMENT**

Data cannot be made publicly available; readers should contact the corresponding author for details.

**REFERENCES**

Adams, E. A. 2018 Intra-urban inequalities in water access among households in Malawi’s informal settlements: toward pro-poor urban water policies in Africa. *Environmental Development* 26 (2012), 34–42.

Alhojailan, M. I. 2022 Thematic analysis: a critical review of its process and evaluation. *West East Journal of Social Sciences* 1 (1), 39–47.

Batagelj, V. & Mrvar, A. 1998 Pajek – a program for large network analysis. *Connections* 21 (2), 47–57.

Bezuidenhout, C. N., Kadwa, M. & Sibomana, M. S. 2013 Using theme and domain networking approaches to understand complex agri-industrial systems a demonstration from the South African sugar industry. *Outlook on Agriculture* 42 (1), 9–16.

Blondel, V. D., Guillaume, J.-L., Lambiotte, R. & Lefebvre, E. 2008 Fast unfolding of communities in large networks. *Journal of Statistical Mechanics: Theory and Experiment* 2008 (10), P10008.
Clasen, T. F. 2012 Millennium development goals water target claim exaggerates achievement. *Tropical Medicine and International Health* **17** (10), 1178–1180.

Cohen, A. & Sullivan, C. A. 2010 Water and poverty in rural China: developing an instrument to assess the multiple dimensions of water and poverty. *Ecological Economics* **69** (3), 999–1009.

Fairweather, J. 2010 Farmer models of socio-ecologic systems: application of causal mapping across multiple locations. *Ecological Modelling* **221** (3), 555–562.

Fan, L. X., Liu, G. B., Wang, F., Geissen, V. & Ritsema, C. J. 2015 Factors affecting domestic water consumption in rural households upon access to improved water supply: insights from the Wei river basin, China. *PLoS One* **8**(8), 1–9.

Flores Baquero, O., Jiménez, A. & Pérez Foguet, A. 2015 Monitoring access to water in rural areas based on the human right to water framework: a local level case study in Nicaragua. *International Journal of Water Resources Development* **4** (29), 605–621.

Freeman, L. C. 2004 The development of social network analysis: a study in the sociology of science. *Social Networks* **2005**(27), 377–384.

Giné-Garriga, R. 2015 Monitoring Water, Sanitation and Hygiene Services: Developing Tools and Methods to Measure Sustainable Access and Practice at the Local Level. PhD in Civil Engineering thesis, University Research Institute for Sustainable Development Universitat Politècnica de Catalunya, Barcelona, Spain.

Giné-Garriga, R., Jiménez-Fernández de Palencia, A. & Pérez-Foguet, A. 2015 Water–sanitation–hygiene mapping: an improved approach for data collection at local level. *Science of The Total Environment* **463–464** (2013), 700–711.

Giné-Garriga, R., de Palencia, A. J. & Jiménez, A. 2015 Improved monitoring framework for local planning in the water, sanitation and hygiene sector: from data to decision-making. *Science of The Total Environment* **526** (2015), 204–214.

Giné-Garriga, R., Requejo, D., Molina, J. L. & Pérez-Foguet, A. 2018 A novel planning approach for the water, sanitation and hygiene (wash) sector: the use of object-oriented bayesian networks. *Environmental Modelling & Software* **103** (2018), 1–15.

Graciana, P. & Nkambule, S. 2012 Factors affecting sustainability of rural water schemes in Swaziland. *Physics and Chemistry of the Earth* **50–52** (2012), 196–2014.

Harvey, P. & Reed, R. 2004 *Rural Water Supply in Africa: Building Blocks for Hand Pump Sustainability*. Loughborough University, Water, Engineering and Development Centre, UK.

Kamada, T. & Kawai, S. 1989 An algorithm for drawing general undirected graphs. *Information Processing Letters* **31**(1), 7–15.

Kayser, G. L., Moriarty, P., Fonseca, C. & Bartram, J. 2013 Domestic water service delivery indicators and frameworks for monitoring, evaluation, policy and planning: a review. *International Journal of Environmental Research and Public Health* **10**(10), 4812–4835.

Kulinkina, A. V., Kosinski, K. C., Plummer, J. D., Durant, J. L., Bosompem, K. M., Adeji, M. N., Griffiths, J. K., Gute, D. M. & Naumova, E. N. 2017 Indicators of improved water access in the context of schistosomiasis transmission in rural eastern region, Ghana. *Science of Total Environment* **579** (1), 1745–1755.

Luh, J., Baum, R. & Bartram, J. 2013 Equity in water and sanitation: developing an index to measure progressive realization of the human right. *International Journal of Hygiene and Environmental Health* **216** (2013), 662–671.

Macus, R. R. & Onjala, J. 2008 Exit the state: decentralization and the need for local social, political, and economic considerations in water allocation in Madagascar and Kenya. *Journal of Human Development and Capabilities* **9**(1), 23–45.

Martinez-Santos, P. 2017 Does 91% of the world’s population really have ‘sustainable access to safe drinking water’? *International Journal of Water Resources Development* **33**(4), 514–533.

Milojević, S. 2014 Network analysis and indicators. In: *Measuring Scholarly Impact – Methods and Practice*, Chapter 3 (Y. Ding, R. Rousseau & D. Wolfram, eds). Springer, New York, NY, USA, pp. 57–82.

Molinos-Senante, M., Munoz, S. & Chamorro, A. 2019 Assessing the quality of service for drinking water supplies in rural settings: a synthetic index approach. *Journal of Environmental Management* **247**(2019), 613–623.

 Muller, M. 2008 Free basic water – a sustainable instrument for a sustainable future in South Africa. *Environment and Urbanization* **20**(1), 67–87.

Rietveld, L., Haarhoff, J. & Jagals, P. 2008 A tool for technical assessment of rural water supply systems in South Africa. *Physics and Chemistry of the Earth* **34**(1–2), 43–49.

Ruiter, C. 2013 Funding models for financing water infrastructure in South Africa: framework and critical analysis of alternatives. *Water SA* **39**(2), 313–326.

Sambo, D. C. 2015 *Assessment of the Performance of Small-Scale Water Infrastructure (SWI) for Multiple Uses in Nebo Plateau, Sekhukhune District, South Africa*. MSc Bioresources Systems thesis, School of Engineering University of KwaZulu Natal, Pietermaritzburg, South Africa.

Sambo, D. C., Senzanje, A. & Dhavu, K. 2018 Using network analysis to analyse the complex interaction of factors causing the failure of small-scale water infrastructure (SWI) in the rural areas of South Africa. *Water SA* **44**(3), 348–357.

SDM 2019 *Integrated development plan 2019–2020*. Available from: http://www.sckhukundistrict.gov.za/sdm-admin/documents/Final%20IDP-Budget%20Review%202019–2020.pdf (accessed 20 August 2019).

SDM 2020 *Integrated development plan 2020–2021*. Available from: http://www.sckhukundistrict.gov.za/sdm-admin/documents/2020–2021%20Final%20IDP%20Budget%20%20%20Budget%202010–2020.pdf (accessed 05 August 2020).

Shaheed, A., Orgill, J., Montgomery, M. A., Jeuland, M. A. & Brown, J. 2014 Why ‘improved’ water sources are not always safe. *Bulletin of the World Health Organization* **92**(4), 283–289.
Spaling, H., Brouwer, G. & Njoka, J. 2014 Factors affecting the sustainability of a community water supply project in Kenya. Development in Practice 24 (7), 797–811.

Van Eck, N. J. & Waltman, L. 2010 Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84 (2), 523–538.

Wasserman, S. & Faust, K. 1994 Social Network Analysis: Methods and Applications. Cambridge University Press, Cambridge, United Kingdom.

Welsh, E. 2002 Dealing with data: using nVivo in the qualitative data analysis process. Forum: Qualitative Social Research Sozialforschung 3 (2), 1–9.

WHO/UNICEF 2019 Progress on Household Drinking Water, Sanitation and Hygiene 2000–2017: Special Focus on Inequalities. Report No. N/A. WHO/UNICEF, Geneva, Switzerland.

Zhang, J. & Luo, Y. 2017 Degree centrality, betweenness centrality, and closeness centrality in social network. Advances in Intelligent Systems Research 132 (2017), 300–305.

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