Geophysical investigation of dambo groundwater reserves as sustainable irrigation water sources: case of Linthipe sub-basin

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ABSTRACT

The geophysical investigation of dambo groundwater reserves using electrical resistivity methods was conducted in Linthipe 4B sub basin in Central region of Malawi. With the increasing over-utilization of shallow wells in dabmos for smallholder irrigation, this study was carried out to investigate whether dambo groundwater reserves could serve as sustainable irrigation water sources and to examine the aquifer characteristics in Linthipe sub basin. Vertical Electrical Sounding (VES) points were established in the basin using the Schlumberger configuration array. Data was analysed using IPI2win and Surfer software applications. Contrary to other commercial software applications which are costly for government departments when analysing geophysical data, partial curve matching and one dimensional (1-D) computer iteration techniques were used to interpret the VES curves and the pseudo-cross section resistivity profiles due to their simplicity and cost-effectiveness. The study has revealed that the aquifer properties in the basin are exceptionally variable in terms of state of weathering, depth, thickness, lithology, aquifer recharge configuration, geologic material and hydraulic gradients. These variations showed that the shallow wells in the basin have significant fractures suggesting high water potential for climate smart irrigation usage in the study area. The potential groundwater zones for climate smart irrigated farming were detected at VES 1, 2, 3, 4, 5 and 6 noted by low aquifer resistivity with high values of aquifer thickness. However, VES points, 7, 8 and 9 were likely to be zones of low water bearing potential because they had high values of aquifer resistivity with low aquifer thickness. The findings also validated the effectiveness, timeliness, and efficiency of using vertical electrical resistivity technique in exploring groundwater for irrigation. The results from this study have highlighted that feasible shallow well depth for a sustainable irrigation system is a function of geologic resistance and aquifer thickness when the geologic material has low resistance and broader thickness. This study noted that knowledge of aquifer recharge rates in dabmos is required in order to effectively control abstraction rates for sustainable irrigation in basins. There is a need to promote the usage of geophysical studies, reforestation, river basin management trainings and aquifer recharge technologies in exploring sites for shallow well development for irrigation. The study further recommends the usage of geographical information systems (GIS) and Artificial Intelligence (AI) in improving the results of groundwater monitoring studies in Malawi.

1. Introduction

The availability of subsurface water in terms of quantity, quality and accessibility plays a very important role in agricultural development in Malawi. In arid and semi-arid areas, surface water is increasingly becoming scarce due to climate change regimes and pollution resulting in the over-exploitation of ground water. Pavelic et al. (2012) highlights that poor river basin management, rapid population growth, poor agricultural practices and weak institutional frameworks are contributing to the degradation of water resources in Malawi. Just like in Ghana, where most smallholder farmers use groundwater for high value horticultural crops (Andah, 1993), in Malawi, most smallholder farmers use shallow to medium wells to irrigate their small farms for vegetables, maize and beans. However, in most farms, these wells are ineffective as they dry out

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without satisfying the crop water requirements. Furthermore, discharge rates are mostly greater than recharge rates as most farmers do not understand irrigation scheduling specifically when irrigating from wells. This reduces the yields and subsequently leads to uneconomical livelihoods amongst most people in rural areas who depend on irrigation. Bera et al. (2020) accounts that groundwater has become a resource that is influencing irrigated agriculture activities and ecological balance management. Burke and Villholth (2007) observed that small-scale irrigation using shallow wells is very important to most smallholder farmers in Africa. This suggests that a threat to these shallow wells through poor siting and drilling could be detrimental to the dependents of these resources. Sambo (2014) agree with Kossamu et al. (2012) that most wetlands in Malawi are being over-exploited resulting in shallow wells drying up and crop yield losses.

There is still low knowledge on the characteristics on dambo hydrology amongst smallholder farmers (Heyden and New, 2003). This often leads to the drilling of very shallow or deep wells which frequently dry leading to the reduction in area of farming. Besides, the drilling of these wells does not require any data collection about the geology of the area or expertise. This challenges farmers when they encounter hard terrains during drilling. Asserted that groundwater assessment in hard rock landscapes is problematic and costly as it requires a lot of resources. A good understanding therefore of the hydrogeology of an area becomes domineering as the availability of water in the aquifer depends on the thickness of the geological layers in the ground. The controlled drilling of wells along the rivers is very crucial in the sustainability of water resources in any catchment area. Gomez and Fuentes (2010) discussed that geophysical analysis of land is essential in exploring and managing groundwater in a basin. If unchecked, the uncontrolled drilling of wells without proper guidelines and surveys would lead to the reduced recharge and increased discharge in a catchment resulting in hydrological droughts. Hasianiaina et al. (2010) argued that groundwater assessments are intensely required in order to develop sustainable plans for managing water resources.

The proper understanding of geological formation is crucial in determining the drilling of wells for irrigation. Most farmers use local methods such as dowsing in exploring where to drill wells. However, the local methods are ineffective, inefficient, not scientific, probable and sketchy. Telford et al. (1990) proposed the use of electrical resistivity methods which are simple to use, cost effective and detailed in revealing sub surface geological characteristics in exploring sustainable groundwater sources for sustainable irrigation. The usage of these geophysical methods in groundwater exploration is becoming common due to its higher efficiencies (Metwaly et al., 2009). Ojojina (2014) and Oyedele and Olayinka (2012) recommended the use of Vertical Electrical Sounding (VES) method in exploring groundwater due to its simplicity. Nejad et al. (2011) used the VES with the Schlumberger array to identify potential groundwater zones in Iran. Shishaye and Abd (2016) used the same approach as Zeru et al. (2015) to examine aquifer characteristics in Haramaya University campus. Kumar and Swathi (2014) employed the VES Schlumberger array method to investigate the depth and thickness of subsurface geologic layers in Prakasam district. The common border line from these studies is that electrical methods have the ability to correlate resistivity and geologic properties hence appropriate for groundwater exploration. Kumar et al. (2016) supported the assertion of Nagarajan and Singh (2009) that mapping of groundwater potential zones using geophysical means is crucial in the management of water resources.

Being the first of its kind in applying geophysical methods in irrigation studies, this study was aimed to investigate dambo groundwater reserves as sustainable irrigation water sources in Linthipe 4B sub basin. Specifically, this research was also conducted to examine the aquifer characteristics of the sub basin.  

2. Materials and methods 

2.1. Study area description 

The Linthipe sub basin lies in the plateau-highland area hence groundwater potential is relatively low but enough for domestic supply and any other related activities that need reasonable amount of water. The basin area is 11600 km². The main economic activity in the basin is cultivation of crops such as maize, tomatoes, cabbage and onions under small scale irrigation that use shallow wells. Figure 1 shows the location of the Linthipe River sub basin.

2.2. Methodology 

A desk study of the study area was carried out to determine the surrounding characteristics of the area. Existing borehole data of the surrounding area were collected and studied for general overview of their status, the drilling depth, water table and other aquifer parameters. This was done due to the availability of data in water district offices. Data

Figure 1. (a) Map of Malawi (b) Linthipe 4B river sub-basin.
triangulation involved a comprehensive geophysical field surveys to understand the hydrogeological configuration and groundwater resources of the area. Used the electrical resistivity method, a Syscal Resistivity Meter was employed with the Schlumberger electrode configuration for depth probe (DP) and Wenner electrode configuration for Constant Separation Traverse (CST). Data analysis was done using Microsoft Excel, Surfer 12 and IPI2Win software applications. These applications were used due to their simplicity, availability and reliability in analyzing geological data in contrast to traditional methods and commercial applications which in most cases are inefficient, time consuming laborious and costly respectively, hence feasible for under-funded departments. In this electrical resistivity method, current is introduced from the resistivity meter into the sub-surface through the current wires and current electrodes which are spread laterally into the subsurface. As current pass through different subsurface formations and structures, the average apparent resistivity is observed through the potential electrodes and is displayed on the monitor of the meter. This method helps to determine the number of geo-electric layers (n), aquifer depth (d), and aquifer thickness (h). During this study, lateral CST lines were constructed to establish hydrogeological pseudo section.

3. Results and discussions

The elevation of the basin ranges from 2109 m to 483 m above mean sea level (Figure 2). Figure 3 shows the slope configuration of the basin which indicates that the area is dominated by flat land (0–4.4%).

Figure 2(c) highlights that the basin is characterized by quaternary alluvial aquifer in the lower part of the basin. This area is close to the lake and serves as a potential water bearing zone. This result agrees with the finding of Mussa et al. (2020) that established that water bearing zones are likely to be in areas with gentle slopes. The middle section of the basin is pigeonholed by fractured basement aquifer and the south western part of the basin is dominated by weathered basement aquifer. The topography of the area suggests that the main source of recharge in weathered basement aquifer is rainfall whereas fractured basement aquifer is recharged by both rainfall and groundwater from the weathered basement and finally quaternary alluvial aquifer gets its contribution from fractured basement aquifer and rainfall. The lower VES points were located in a location with alluvial aquifer that is continually under recharge. Moreover, the area is equally close to the lake. Therefore, the undulating topography in the basin regulates availability and the level of water in the shallow wells. Liu et al. (2010) highlighted that there is a direct relationship between the amount of rainfall and groundwater levels such that an increase in rainfall depth increases groundwater level and vice versa. This explains why the lower aquifer has a good supply of water potential for irrigation in the basin. Edet (2016) noted that shallow aquifer recharges are normally due to the contribution from rainfall and infiltration from rivers. Figure 2(d) shows the location of the VES points that were carried out in the basin. Table 1 exhibits the respective apparent resistivity, aquifer depth and thickness of the VES in the study area.

Table 1 and Figure 3(a) indicate that VES 1 consists of 3 layers. The first layer has a resistivity of 21.3 Ωm with a thickness of 1.09 m at the depth of 2.83 m. The second layer has a resistivity of 882 Ωm with a thickness of 1.74 m. The second layer is under laid by a third layer with a resistivity of 11.6 Ωm. Figure 3(a) shows a characteristic of p-type curves where low resistive layers exist within a high resistive layer suggestive the availability of an unconfined aquifer where shallow wells are generally found. VES 1 is located in alluvial deposits area which is an indication that water could be found at a shallow depth. Rusinga (2002) reported that fractured zones normally have low resistivity values and this indicates the presence of ground water. The low resistivity in the first layer is a clear indication that water could be reaped at a depth of 2.83 m. Similar trend is shown in Figure 3(c) for VES 3.

VES 2 as seen in Figure 3(b) also has 3 layers. The first layer has a resistivity of 134 Ωm with a thickness of 2.31 m at the depth of 2.31 m. The second layer has a resistivity of 18.4 Ωm with a thickness of 1.88 m. The third layer has a resistivity of 146 Ωm which shows a layer with saturated sand and gravel. The lowest resistivity value in the second layer could be an indication of an alluvial aquifer at the depth of 4.2 m. The high resistivity in the first layer could be due to the unsaturated soil conditions since electrical resistivity decreases with an increase in

![Figure 2](image-url). (a) Digital Elevation Model (DEM); (b) Slopes (%); (c) Aquifer characterization (d) Vertical Electrical Soundings (VES) in Linthipe 4B sub-basin.
Figure 3. Resistivity curves: (a) VES 1 (b) VES 2 (c) VES 3 (d) VES 4 (e) VES 5 (f) VES 6 (g) VES 7 (h) VES 8 (i) VES 9.

Table 1. Summary of apparent resistivity, thickness and aquifer depths at VES stations.

| VES | $\rho_1$ (Ωm) | $\rho_2$ (Ωm) | $\rho_3$ (Ωm) | $\rho_4$ (Ωm) | $\rho_5$ (Ωm) | $h_1$(m) | $h_2$(m) | $h_3$(m) | $h_4$(m) | $h_5$(m) | Aquifer depth (m) | $\varepsilon$ (%) |
|-----|----------------|----------------|----------------|----------------|----------------|----------|----------|----------|----------|----------|-------------------|------------------|
| 1   | 21.3           | 882            | 11.6           | -              | -              | 1.09     | 1.74     | -        | -        | -        | 2.83              | 14.9             |
| 2   | 134            | 18.4           | 146            | -              | -              | 2.31     | 1.88     | -        | -        | -        | 4.2               | 6.89             |
| 3   | 87.4           | 202            | 2.81           | -              | -              | 2.73     | 28.2     | -        | -        | -        | 30.9              | 6.78             |
| 4   | 238            | 79.9           | 366            | 16.9           | -              | 2.1      | 2.28     | 4.03     | -        | -        | 8.42              | 2.61             |
| 5   | 144            | 23.7           | 276            | 17.8           | 10628          | 1.92     | 1.67     | 5.47     | 15.3     | -        | 24.3              | 6.33             |
| 6   | 177            | 62.5           | 320            | -              | -              | 1.33     | 11.4     | -        | -        | -        | 12.7              | 4.6              |
| 7   | 104            | 53             | 279            | -              | -              | 2.46     | 8.64     | -        | -        | -        | 11.1              | 3.97             |
| 8   | 143            | 10.7           | 1585           | -              | -              | 12.5     | 16.3     | -        | -        | -        | 28.8              | 6.91             |
| 9   | 170            | 44             | 449            | 36.1           | 4681           | 4.08     | 3.43     | 7.38     | 15.1     | -        | 30                | 5.93             |
saturation (Munoz-Castelblanco et al., 2012). Figure 3(d) shows the apparent resistivity curve model for VES 4 with four layers and resistivity varying from 16.9 Ωm to 366 Ωm. The low resistivity between the first and the third layer indicates the possibility of a fracture. The third layer with a resistivity of 366 Ωm with a thickness of 4.03 m at the depth of 8.42 m is the fresh basement. The fourth layer with a resistivity value of 16.9 Ωm indicates also a fracture beneath the fresh basement. The fracture in the second layer could be a source of groundwater at the depth of 4.39 m. Figure 3(e) shows that VES 5 is made up of five layers with resistivity ranging from 17.8 to 10628 Ωm with thickness ranging from 1.67 to 15.3 m. The first layer has a resistivity of 144 Ωm with thickness of 1.92 m indicating the top soil. The second layer has a resistivity of 23.7 Ωm with a thickness of 1.67 m at the depth of 3.58. The third layer with a resistivity of 276 Ωm with a thickness of 5.47 at the depth of 9.06 m, is slightly weathered, and the fourth layer with a resistivity value of 17.8 Ωm with a thickness of 15.3 m at the depth of 24.3 m. The fifth layer with a resistivity of 10628 m is the fresh basement. This layer suggests a bed rock due to its high resistivity value. Hamza et al. (2011) found that deep bed rocks of Precambrian basement are generally indicated by very high resistivity values. The aquifer could be located in the fracture with the lowest resistivity of 17.8 Ωm, which is the highly weathered layer with depth of about 24.3 m. The types of soil at this point consist of clay, lateritic sandstones and the fresh basement.

VES 6 (Figure 3f) revealed three layers in the subsurface layer. The topsoil has a resistivity of 177 Ωm and thickness of 1.33 m whereas the second layer which is 11.4 thick has a resistivity of 62.5 m. The third layer with a resistivity of 320 Ωm is the Fresh basement. The low resistivity value in the second layer is an indication of a permeable aquifer. This could be a potential zone for borehole drilling at the depth of 12.7 m. This finding agrees with Obiora and Onwuka (2005) who found out that using VES, sustainable water sources can be determined based on its depth to water table, aquifer thickness and geologic subsurface material.

The subsurface structure at VES 7 (Figure 3g) indicated three layers with apparent resistivity ranging from 104 to 279 Ωm with thickness ranging from 2.46 to 8.64 m. The results revealed that the upper layer has a resistivity of 104 Ωm and is 2.46 m thick. The second layer is 8.64 m thick at the depth of 11.1 m with a resistivity of 53 Ωm. The third layer with a resistivity of 279 Ωm is the Fresh basement. The highly weathered layer in the second layer could be a potential zone for groundwater storage at the depth of 11.1 m.

The subsurface of VES 8 as shown in Figure 3(h) is made of three layers with resistivity ranging from 10.7 to 1585 Ωm with thickness ranging from 12.5 to 16.3 m. The first layer has a resistivity of 143 Ωm with thickness of 12.5 m indicating the top soil. The second layer with a resistivity of 10.7 Ωm with a thickness of 16.3 m, is taken as highly weathered. The third layer with a resistivity of 1585 Ωm is the fresh basement. The fracture in the second layer could be identified as high potential zone for groundwater at the depth of 28.8 m. Figure 3(i) shows that VES 9 consisted five layers. Apparent resistivity values ranges between 36.1 and 4681 Ωm. The first layer has a resistivity of 170 Ωm and thickness of 4.08 m and is underlain by a second layer of 3.43 thick, has a resistivity of 44 Ωm. Beneath is a slightly weathered layer with a resistivity of 449 Ωm with a thickness of 7.38 m. The fourth layer is highly weathered by virtue of its low resistivity of 36.1 with a thickness of 15.1 at the depth of 30 m. The fifth layer with a resistivity of 4681 Ωm is the fresh basement. Groundwater is expected to be accumulated in this zone. The resistivity of VES 8 es is a high potential zone for groundwater development. The soil consists of clay, sand and gravel saturated and fresh basement. VES points 6–9 are within the weathered basement complex aquifer which is a plateau area. The findings indicate that this area is dominated by clays. These aquifers are therefore low yielding and require a good determination in order to determine water availability and usability. When sited wrongly, the potential wells could dry up since the recharge rates of these aquifers are very low and not very deep to provide sufficient holding capacity. This concurs with Hassan et al. (2017) who noted that the thickness and the depth of an aquifer is very important in determining whether it can be used for agriculture or other domestic purposes.

Figures 4(a–f) present the pseudo-sections of the apparent resistivity of selected VES points in the three aquifer types in the sub-basin. VES 1 and 2 are in the lower aquifer, VES 2 and 4 are in the middle aquifer and VES 8 and 9 are in the upper aquifer.

The pseudo-section VES 1 (Figure 4(a)) mirrors the apparent resistivity configuration with respect to electrode spacing (AB/2). The resistivity values increased from 21.3 to 882 Ωm then decreased again to 11.6 Ωm. The lower resistivity values suggested coarse grained sized soil type. The increase in the resistivity values could be due to the influence of a bed rock signifying a shallow aquifer presence at VES 1. The pseudo-section VES 2 (Figure 4(b)) reveals the presence of a shallow well as the resistivity values decreased significantly from 134 to 18.4 Ωm. This decrease revealed the presence of an aquifer at a depth of 4.2 m. As suggested by Ahmed (2005), areas with low resistivity and high values of aquifer thickness represent areas of high potential groundwater exploration. This makes VES 1 and 2 highly potential areas for irrigation development. Furthermore, VES points 1 and 2 are within quaternary alluvium aquifer which is a high yielding aquifer located on gentle slopes and store significant water potential for irrigation in the basin. The depth of the aquifers presents an opportunity for low head, high discharge solar based pumping in the basin. VES 1 and 2 are also located at the lowest point of the basin. This feature makes these areas to be recharged by upland aquifiers making water supply sustainable in such areas.

The pseudo-section VES 4 (Figure 4(c)) revealed the presence of a confined aquifer at that point due to the constant variation in the resistivity values. Lower resistivity areas are composed of weathered materials whilst higher resistivity values suggested a bed rock. Ndlovu et al. (2010) observed that the fluctuating levels of resistivity values indicate the presence of fractures in the geological materials suggesting the occurrence of groundwater. This finding corroborates earlier observations of Weaver et al. (1992) who asserted that weathered geologic materials favorably increase porosity resulting in the occurrence of ground water in such regions. The availability of water in these aquifers is generally small and at greater depths feasible for climate-smart irrigation systems such as drip irrigation. The pseudo cross-section VES 6 (Figure 4(d)) resistivity pinpointed that the area was comprised of weathered geological materials hence a zone of weathered aquifer. This finding relates with the assertion of Sikandar et al. (2010) who established that higher resistivity normally indicates the presence of bed rock. The region is predominantly fractured as indicated by the consistent low resistivity values. This suggests a water bearing zone along the pseudo-section. This aligns with the observation of Muchingamia et al. (2012) that low resistivity values in a sub-surface geologic material foretell groundwater availability.

Figure 4(d) and 4(e) highlight the pseudo-section resistivity dispersal of VES 8 and VES 9. The gentle slopes of the area indicated that the geologic materials of the area were due to the action of weathering. Kumar and Swathi (2014) agree that when the geologic material is weathered or fractured, in relation to its thickness and resistivity configuration, groundwater occurrence is highly probable in such regions. The geologic structure of these areas suggested fractured materials hence an indication of the availability of groundwater. This concurs with the observation of Rai et al. (2013) that formations with clear fractures provide good quantities of groundwater. Smith-Carrington and Chilton (1983) also supports this finding and observes that the type of geologic material determines sufficient water storage.

Figures 5 and 6 present the aquifer depth configuration and potential dambo land for irrigation in the basin respectively. Figure 2(b) and Figure 5 revealed that VES points 3–5 are located on steep slopes suggesting that the aquifer nature of this area is discontinuous. The steep slopes result in large hydraulic gradients thereby increasing discharge of groundwater into downstream aquifers i.e. alluvial aquifers. The effective depth of the shallow wells is therefore correlated to the topography.
of an area in relation to the geologic materials available in that area. This finding settles well with the study of Stella et al. (2011) that found that the topography of an area plays a major role in determining effective groundwater sources.

Shallow wells may be dug to a minimum depth of 5 m in alluvial aquifers while boreholes may be dug from 18 to 30 m in fractured and weathered basement complex to provide irrigation water to smallholder farms utilizing climate smart irrigation systems in dambo areas. The potential groundwater zones for climate smart irrigated farming were detected at VES 1, 2, 3, 4, 5 and 6 noted by low aquifer resistivity with high values of aquifer thickness. However, VES points, 7, 8 and 9 were likely to be zones of low water bearing potential because they had high values of aquifer resistivity with low aquifer thickness. High resistivity values indicate low porosity resulting in limited flow of water hence areas of low water bearing potential. This observation is not dissimilar to that of Joshua et al. (2011) and Omosuyi et al. (2008) that observed that areas with very high apparent resistivity values are likely to be areas of low porosity with limited groundwater potential for socioeconomic development activities.

As seen in Figure 6, Linthipe 4B has a lot of dambos where irrigation using shallow wells is practiced. Proper management of these dambo shallow wells for irrigation is therefore imperative in order to prevent the degradation of these water sources. There is a need to guide on the proper depths to drill, amount of ground water to abstract and size of pump to use. Omosuyi and Osogbile (2012) supports Aladejana et al. (2020) that shallow wells are very vulnerable to degradation due to human activities hence require proper management. Kossam et al. (2012) noted that building capacity of rural communities is essential in sustainable management of natural resources. The findings second the assertion and add that smallholder farmers need to be trained and guided when utilizing dambo water sources from siting shallow well sources, drilling and irrigation scheduling in order to sustainably use the dambo reserves for irrigation.

Even though this study has found that the usage of VES is easy to use, practical and offer reliable results in exploring shallow well reserves for smallholder irrigation development, soft computing applications in groundwater studies would equally offer the accuracy of these results. This observation presages the finding of Djurovic et al. (2015) that soft computing applications such as Artificial Neural Networks (ANN) can improve the accuracy of groundwater management studies. Different studies (Rajaee et al., 2019; Razavi-Termeh et al., 2019; Shekhar and Pandey, 2014; Virupaksha and Lokesh, 2019; Yeh et al., 2016) have further concurred that geographical information systems (GIS) and ANN improve the accuracy of groundwater management.

**Figure 4.** Pseudosections: (a) VES 1 (b) VES 2 (c) VES 4 (d) VES 6 (e) VES 8 (f) VES 9.
Figure 5. Aquifer depth configuration in the basin.

Figure 6. (a) Potential irrigable areas in the dambo (b) Aquifer depth profile in Linthipe 4B basin.
4. Conclusion

The objective of this study was to investigate whether dambo groundwater reserves could serve as sustainable irrigation water sources and to examine the aquifer characteristics in Linthipe 4B sub basin using vertical electrical soundings. The findings revealed that the aquifer properties in the basin are exceptionally variable in terms of states of weathering, depth, thickness, lithology, aquifer recharge configuration, geologic material and hydraulic gradients. The results showed that the shallow wells in the basin have significant fractures suggesting high water potential for climate smart irrigation usage in the study area. The geophysical configuration of the basin shows that on average, a minimum depth of 30 m is feasible for wells for climate smart irrigation in the dambos in the river basin. There is a need to balance the discharge-recharge relationship in the sub-basin to sustain the shallow well development for irrigation development.

Due to the unavailability and inadequacy of geophysical data to dependably guide the management of shallow wells for sustainable irrigation, the findings from this study may be used as a guide for groundwater abstraction and watershed management. Capacity building in the farmers practicing irrigation within the dambos was done to upscale their management of the groundwater resources through proper guidance of drilling wells and determining the depth in relation to their area under irrigation and crop water requirements. Furthermore, this study has found that knowledge of aquifer recharge rates in dambos is required in order to effectively control abstraction rates for sustainable irrigation in basins. This would also avoid the depletion of the water resource in the dambos where smallholder irrigation is increasingly being practiced.

This study recommends the usage of geophysical studies in exploring sites for shallow well development for irrigation, frequent river basin management trainings to farmers when there is a need to develop an area for irrigation within the dambo area. It also recommends afforestation and aquifer recharge technologies to ensure management of groundwater in the study area. In order to improve ground water monitoring and modelling, soft computing techniques such as remote sensing and geographic information systems (GIS), Machine Learning (ML) and Artificial Neural Networks (ANN) need to be explored in future research in the basins in Malawi.

Declarations

Author contribution statement

Sylvester Richard Chikabvumbwa: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Davis Sibale: Analyzed and interpreted the data; Wrote the paper.

Rayman Marne: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Sylvester William Chisale, Lackson Chishanu: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Data availability statement

Data associated with this study has been deposited at Data in Brief under the accession number Linthipe_Data.

Declaration of interests statement

The authors declare no conflict of interest.
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