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Groundwater development and management constraints in drought prone Chiredzi and Zvishavane Districts, Zimbabwe

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ABSTRACT

Communities in drought-prone areas continued to fall into new vulnerability traps due to increasing water demand and stress. The study assessed groundwater development and management constraints in the Chiredzi and Zvishavane districts of Zimbabwe. Groundwater development and management activities implemented in the study area were supported by the Government of Zimbabwe, development partners, humanitarian agencies, private sector corporate social responsibility, and individual households. Interpretivism and realism philosophical positionalities were employed in the study. Whilst interpretivism's inductive approach enabled an in-depth qualitative methodology and understanding of the groundwater constraints, the direct realism provided quantitatively driven scientific and statistical data to answer the research questions exhaustively. Quantitative data was gathered through a household questionnaire administered to randomly selected respondents. Qualitative data was gathered using focus group discussions, key informant interviews, direct field observations and measurements. Respondents to the key informant interview were drawn from district-level government officials, local authorities, traditional leaders, village pump minders and water point committee members.

Due to climate change, communities have experienced an increase in the decline in groundwater levels during the dry season evidenced by demand surpassing supply. Temperature increase and rainfall decline experienced by 97%, and 73% of respondents from Chiredzi and Zvishavane districts, respectively, resulted in increased withdrawal and reduced groundwater recharge. Participants revealed that groundwater withdrawal is on the increase while recharge is declining as evidenced by the increase in conflicts at waterpoints. The 85% coverage by low groundwater-yielding basement hydrogeological formation suggested a slight reduction in groundwater recharge due to reduced rainfall and increased community vulnerability to drought. Village Pump Minders and Water Point Committees experienced operational challenges that affected the maintenance of groundwater sources. This was mainly due to the incapacitation of local institutions in terms of financial resources, equipment, and skills. The study recommends a groundwater replenishment model to improve groundwater aquifer recharge. Strengthening of local institutions improves the management of groundwater using integrated water resources management (IWRM) framework that promotes coordination between competing uses.

Practical Implications.

Climate change and variability continued to threaten water resources, with both surface and groundwater continuing to deplete and exposing smallholder communities to water stress. Groundwater exploitation remained a huge opportunity for local communities' climate change adaptation. In Zimbabwe, most water development projects put more resources into borehole drilling to ensure the supply meets the growing demand. The institutions in place have been supporting groundwater exploitation with little attention to the sustainable management of the reserves. The practical application and implications of the study include.

- The need to promote the generation, provision, and use of groundwater information by all stakeholders. This

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ensures sustainable management of groundwater in rainfall marginal areas that depend on groundwater exploitation.
- Community-based institutions need to be capacitated in the management of groundwater to avoid maladaptation that is evidenced by declining groundwater levels.
- The study findings provide guidelines for policymakers and programme designers to apply context-specific groundwater management interventions to enhance the resilience of communities impacted by climate change-induced droughts.
- Groundwater replenishment initiatives, including infiltration and rechange promotion within the catchment, have the potential to provide multiple benefits to the ecosystems.

1. Introduction

The Intergovernmental Panel on Climate Change (IPCC) revealed that the rise in global warming levels escalates the likelihood of widespread and extreme consequential impacts (Mach et al., 2016). Climate change accounts for most of the escalating global water vulnerability, with rainfed agriculture being the most affected (Amjath-Babu et al., 2016; Filho et al., 2022). In sub-Saharan Africa, rainfed agriculture accounted for 97 % of the staple food crop production (FAO, 2022). Droughts in the sub-Saharan African region are associated chiefly with climate change. Over 184,000 Somalis migrated in 2011 to neighbouring countries due to the devastating drought in the Horn of Africa (UN Water, 2013). The Southern African Development Committee (SADC) region further recorded that more than 40 million people were at risk of starvation between 2015 and 2016 after two consecutive years of El Nino induced droughts. (Meque et al., 2021).

Climate change impacts on water resources were noted as having retrogressive impacts on achieving most water-dependent Sustainable Development Goals (FAO, 2018). Groundwater resources were identified as a pillar of support towards the attainment of SDGs 6 (clean water and sanitation), 1 (no poverty), 2 (zero hunger), 3 (good health and wellbeing), 5 (gender equality), 7 (decent work and economic growth), 10 (reduced inequality), 11 (sustainable cities and communities), and 13 (climate action) (United Nations Office for Disaster Risk Reduction, 2021; Macdonald & Edmunds, 2014). Over 70 % of the SADC region population depends on groundwater for agriculture and domestic water supply (SADC-GMI, 2019). In Zimbabwe, hand pumps dominate groundwater lifting devices at over 75 %, whilst rope and bucket, treadle pumps and submersible pumps account for less than 25 % (SADC-GMI, 2019). Most (83.82 %) rural households in Zimbabwe depend on communally owned water points (RWIMS, 2023). Hand-pumped boreholes, deep wells and submersible solar-powered boreholes account for over 90 % of water-lifting devices in Zimbabwe's rural communities. (RWIMS, 2023). Rainfall decline undermines the sustainability of groundwater resources (Chikodzi, 2013). Ecosystems that depend on groundwater are at risk from climate change and declining groundwater stocks (Majola et al., 2022). The growing water-related shocks and stressors (United Nations, 2022) outcompeted the existing water management responses (Villholth & Conti, 2019).

Globally, groundwater contributed to 33 % of the total irrigated areas (FAO, 2021). Based on the aggregation of individual countries' reports, groundwater withdrawal accounted for 820 km3 per year in 2021, indicating a 19 % increase from 2010. The global estimated annual growth rate in groundwater use is at 2.2 %. (United Nations, 2022). Groundwater, which is considered an important buffer for water supply is depleting due to intensified withdrawals and reduced recharge (United Nations Office for Disaster Risk Reduction, 2021; Villholth & Conti, 2019). Uncertainties due to the impacts of climate change and variability were noted to have undermining impacts on the replenishment of groundwater resources (United Nations, 2022). The socio-economic transformation of sub-Saharan Africa is hinged on groundwater development, which contributes to 75 % of all drinking water (Amjath-Babu et al., 2016; Nijsten et al., 2018).

Zimbabwe has different types of groundwater aquifers located in different regions, with some being of transboundary nature, including the Save Alluvial, Limpopo Basin, Tuli Karoo, Eastern Kalahari Karoo Basin, Medium Zambezi aquifer, and Nata Karoo sub-basin (Nijsten et al., 2018). However, groundwater data impediments were identified as a key challenge hindering groundwater's planning, development, management, and sustainability (IGRAC (International Groundwater Resources Assessment Centre), 2018). Over 85 % of Zimbabwe's groundwater aquifers were identified as low yielding, with 0.1 to 0.5 L per second under the extensive Basement Aquifer. Only less than 15 % of the aquifer was identified to be medium yielding (1.5 to 20 L per second) (Nijsten et al., 2018).

Based on the country's average annual precipitation of around 657 mm, Zimbabwe's surface water produced internally (11.26 km^3) is insufficient (FAO, 2019). Groundwater resources augmented the country's water supply with 6 km3 of the total Internally Renewable Water Resources per year (FAO, 2019). Groundwater management needs to be developed in response to intensified withdrawals and ensure key actions and safeguards are in place to avoid maladaptation.

1.1. Justification

Climate change and variability altered the water balance, and increased water stress for communities in dry areas, making it difficult for existing water management strategies to respond to groundwater vulnerabilities, shocks, and stressors (Filho et al., 2022; Joshua et al., 2022). The study examined climate change and variability constraints that hindered sustainable management of groundwater resources. A rise in groundwater use, the related drying up and decline in the groundwater levels were identified as key threats to ecological, social and economic development (Amjath-Babu et al., 2016; Rural Water Supply Network (RWSN), 2021; Majola et al., 2022). The study examined context-specific groundwater management requirements for areas underlain by different hydrogeological formations. Chiredzi and Zvishavane districts were therefore selected as study sites. According to the districts' livelihoods profiles, geographical location, and population dynamics, there were high levels of climate change-induced water scarcity among smallholder farmers (Government of Zimbabwe World Food Programme, 2017). This called for an in-depth analysis of underlying groundwater development constraints and management strategies in support of communities in drought-prone areas.

2. Theoretical Framework: Integrated water resources management (IWRM)

Integrated Water Resources Management Framework (IWRM) guided the study. The Global Water Partnership (2000) defined IWRM as "a process which promotes the coordinated development and management of water, land and related resources to maximize the resultant economic and social welfare equitably without compromising the sustainability of vital ecosystems." The framework recognized water as a finite resource considering threats and vulnerabilities, including climate change (Stockholm International Water Institute (SIWI) (2020)). It provides for the multi-level and multi-sectoral coordinated management mechanisms of water resources. The framework has the provision for the commodification of water resources, therefore, enabling water managers and users to attach economic value to all competing water uses. The key role played by women in the development and management of water resources was provided for in the framework.

Many countries adopted the IWRM framework based on promises for balancing the water supply and demand aspects with development and conservation needs (Manzungu & Derman, 2016). Hassing et al. (2009)

pointed out that IWRM was designed and modelled from an “on-the-ground experience of practitioners.“ In Zimbabwe, IWRM was introduced by the Global Water Partnership (2010) at an opportune time when Zimbabwe struggled to recover from the devastating drought of 1992 (Derman & Manzungu, 2017; Nangombe, 2015). An analysis of different scholarly views on the Zimbabwean water sector revealed that IWRM addressed some foundational challenges around institutional arrangements, including water policy formulation. The IWRM led to the formation of the 1998 Water Act, the 1998 ZINWA Act, and the 2013 National Water Policy (Government of Zimbabwe, 1998, 2002; Government of Zimbabwe, 2012).

3. Description of the study area

3.1. Study area location

Chiredzi and Zvishavane districts are in Masvingo and Midlands Provinces, respectively (Fig. 1), and both fall under the meteorological region three characterised by low rainfall and cover the bulk of Masvingo, Matabeleland South and the southern parts of Midlands province (Meteorological Services Department, 2020). All 32 wards of Chiredzi fall under the agroecological zone V, while 14 wards of Zvishavane district fall under region IV, and 5 wards fall into agroecological zone V (UNOCHA, 2012). Agroecological zones (AEZ) are defined by FAO (1976) in terms of “climate, landform, soils and or land cover, and having a specific range of potential constraints for land use.” In the case of zone IV and V, average temperatures are higher, and annual average rainfall is erratic and lower as compared to the national average (ZIMSTAT, 2019). The dependency on groundwater for socio-economic activities by communities in AEZ IV and V is much higher. Zvishavane district has a total population of 72,513, with 98.7 % of the population being rural smallholder farmers, while Chiredzi district has a population of 275,759 (ZIMSTAT, 2012a; ZIMSTAT, 2012b). The two districts are considered dry areas since they both receive erratic rainfall ranging between 450 and 600 mm during the October to March rain season. Poverty levels for the Chiredzi and Zvishavane districts were as high as 76.8 % in the targeted Mazvihwa area and 74.6 % in the Save communal areas, respectively (UNDP, 2009; Government of Zimbabwe & World Food Programme, 2017a). Zvishavane and Chiredzi district’s vulnerability to drought hazard is high, as evidenced by scoring 0.5532 and0.6505 respectively, in the mean hazard index under the Zimbabwe Resilience Building Fund’s vulnerability rating (UNDP, 2017; Zimbabwe Resilience Building Fund, 2016).

The Mazvihwa area of Zvishavane falls under the Masvingo Manicaland Middleveld Smallholder Livelihood Zone, whilst the Save area of Chiredzi is found in the Save River Valley and Ndowoyo Communal Livelihoods Zone (Government of Zimbabwe & World Food Programme, 2017). Because of their high vulnerability to climate change, the Save River Valley and Ndowoyo Communal Livelihoods Zones depend on crop and livestock production (World Food Programme, 2017). Despite responding directly to changes in precipitation, groundwater supports agricultural livelihoods (Chikodzi, 2013) and is considered as the primary water source for rural communities in dry lands (SADC-GMI, 2019). Some coping strategies by the targeted community include firewood and vegetable sales as well as handicrafts. Gold panning, animal rearing, and diaspora remittance are other livelihood strategies common in Zvishavane district. Cross-border trading is one of the activities that sustain the Save community due to its proximity to borders that include Chicualcuala/Sango for accessing Mozambique and Dite and Beitbridge for accessing South Africa.

4. Methodology

The study was guided by interpretivism philosophical positionality, which was critical for the researcher to understand and leverage the interaction with different participants in the community (Jackson, 2013). The interpretivism approach was chosen based on the differences in geographic, gender, cultural/traditional and age as diversified sources of information for groundwater development and management that required multiple data sources and datasets. Both secondary and primary data sources were utilised in answering the study questions.

Secondary data sources, including the Government of Zimbabwe’s Rural WASH Information Management System (RWIMS) database (United Nations Children’s Fund, 2021), district profiles, reports, and

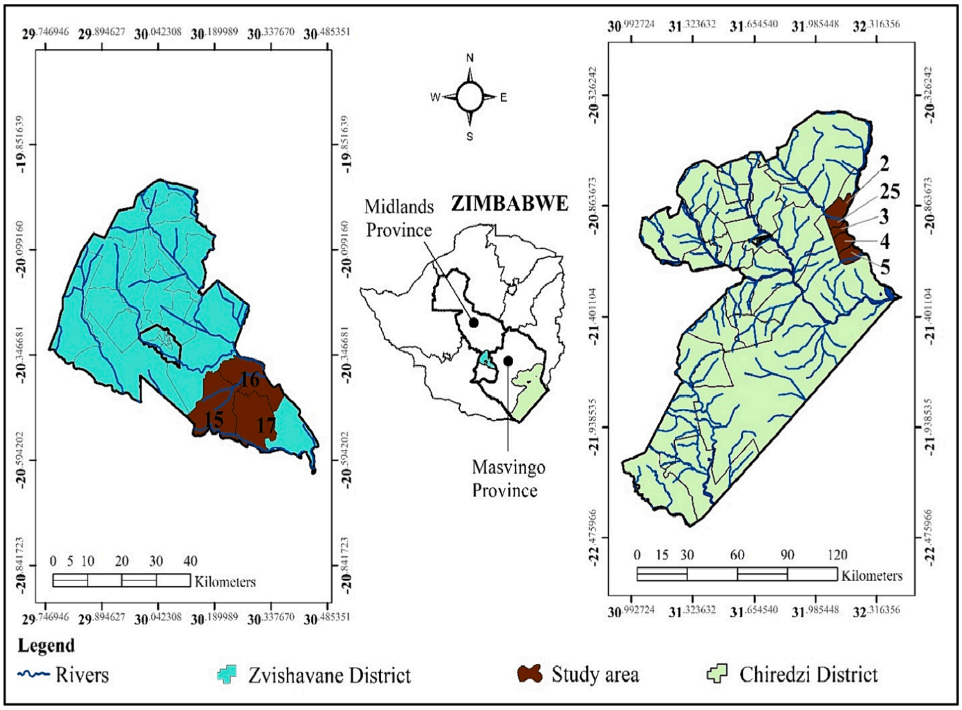


Fig. 1. Zvishavane and Chiredzi Study Area Wards. Source: Author.

strategic plans, were used as supplementary sources of information. The selection of 8 wards (Fig. 1), five being in Chiredzi (wards 2, 3, 4, 5 and 25) and three in Zvishavane (wards 15, 16, 17), was done purposively after considering the 37 wards in agroecological zone five in both districts. The selected wards have smallholder farming households that experienced climate change-induced droughts and are dependent on groundwater for adaptation.

The required data was generated using a mixed-method approach (Onwuegbuzie & Collins, 2007; Kabir, 2016). Both qualitative and quantitative methods were employed in the study to gather and triangulate information from various sources (Lapan et al., 2012). The study gathered quantitative data through household questionnaires with closed-ended questions framed around groundwater sources, use, impacts of climate and variability factors, water source vulnerability, and institutional arrangements supporting water management.

The total number of smallholder farming household population whose livelihoods were impacted by droughts and depend on groundwater (3,740 households) was first determined by collating ward and village population registers, and a 10 % sample (374 households) was randomly selected to respond to the questionnaire, allowing every household to participate in the study. A 10 % sample was chosen in line with Taherdoost (2016) and Singh & Masuku (2014), who indicated its applicability for a study population with homogenous characteristics and retaining a statistical power base. All the 374 administered questionnaires were answered (see sample questions in Fig. 2).

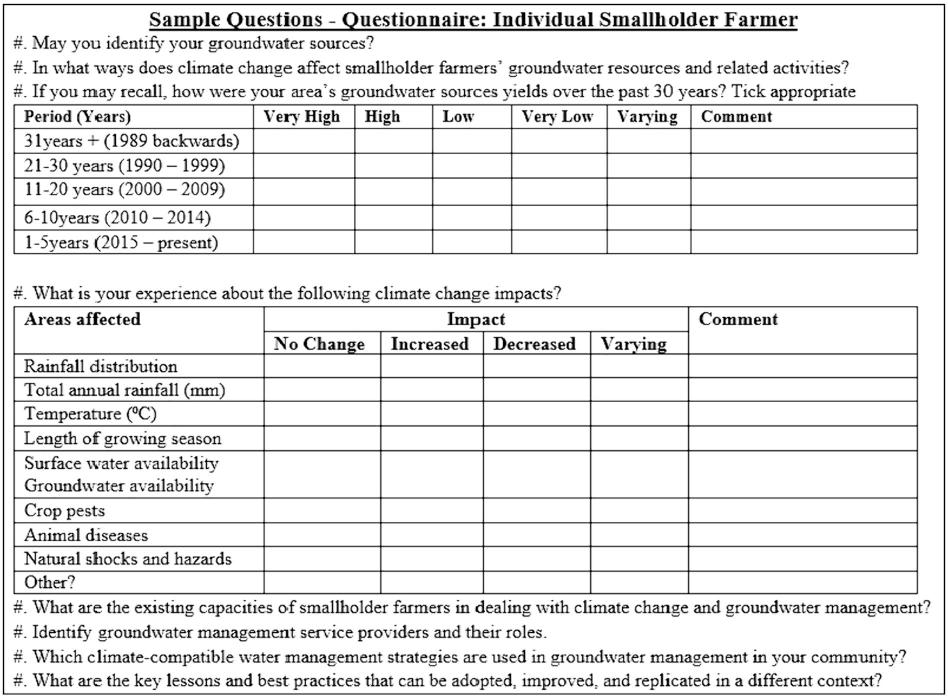
In this study, smallholder farming households' homogeneity was based on IFAD (2020) criteria for the categorization of farmers based on access to productive resources. The B category (B1 and B2) by IFAD (2020), which defines resource-constrained smallholder farming households with land and labour, although lacking or facing limitations in accessing financial resources was considered. This is the group that, if supported, can transition from poverty, food, and income insecurity, and increase food production (IFAD, 2020). The study did not consider the farmers categorised as A and C groups, which are extremely under-resourced leading to their dependence on social assistance for their survival and the more resourced successful commercial farmers, respectively (IFAD, 2020). The purposively sampled participants had those homogenous characteristics ranging from access to the same water sources, living in the same agroecological zones, similar livelihood strategies, and under the same climate characteristics.

Qualitative data was gathered using focus group discussions, direct field observation, key informant interviews and field measurements. Purposive sampling was used to select 15 key informant interview participants, 8 from Chiredzi and 7 from Zvishavane district (Table 1).

A total of 4 focus group discussions were conducted, each focus group discussion having 10 participants with a 50 % representation of both male and female participants. The selected participants' age groups were above 18 years, the age of majority for Zimbabwe. Out of the 4 focus group discussions conducted, 2 drew participants from water point committees and 2 from households that used groundwater. These participants were shared equally between Chiredzi and Zvishavane districts. Direct measurements, using PQWT exploration equipment developed by Hunan Puqi Geological Exploration Equipment Institute (n.d.), were employed in the study to determine groundwater (aquifer) productivity (O'Dochartaigh, 2019). The PQWT is an advanced machine that uses electromagnetic energy to collect sub-surface data and generate outputs about the resistivity of subsurface hydrogeological profiles (Hunan Puqi Geological Exploration Equipment Institute, n.d.). A total of 8 surface transects were conducted covering 8 wards, with 5 in Chiredzi and 3 in Zvishavane district. The PQWT exploratory equipment was used for its advantages, including high-speed reaching ten times faster in recording measurements as compared to the traditional ABEM Terrameter 300 resistivity equipment. Accurate results and good performance were key advantages attained by the machine's capability to make use of 0.001 millivolts (Mv) resolution, and the +/- 2 % equipment

Table 1
Key Informant Interviews Participants.

Participants	Chiredzi	Zvishavane	Total
Extension Officers	1	1	2
Local Authority (Rural District Council)	1	1	2
Village Pump Minders	2	2	4
Water Point Committee	2	1	3
Government department officials	1	1	2
Traditional Leaders	1	1	2
Total	**8**	**7**	**15**



Sample Questions - Questionnaire: Individual Smallholder Farmer

#. May you identify your groundwater sources?

#. In what ways does climate change affect smallholder farmers' groundwater resources and related activities?

#. If you may recall, how were your area's groundwater sources yields over the past 30 years? Tick appropriate

Period (Years)	Very High	High	Low	Very Low	Varying	Comment
31years + (1989 backwards)						
21-30 years (1990 – 1999)						
11-20 years (2000 – 2009)						
6-10years (2010 – 2014)						
1-5years (2015 – present)						

#. What is your experience about the following climate change impacts?

Areas affected	Impact				Comment
	No Change	Increased	Decreased	Varying	
Rainfall distribution					
Total annual rainfall (mm)					
Temperature (°C)					
Length of growing season					
Surface water availability Groundwater availability					
Crop pests					
Animal diseases					
Natural shocks and hazards					
Other?					

#. What are the existing capacities of smallholder farmers in dealing with climate change and groundwater management?

#. Identify groundwater management service providers and their roles.

#. Which climate-compatible water management strategies are used in groundwater management in your community?

#. What are the key lessons and best practices that can be adopted, improved, and replicated in a different context?

Fig. 2. Sample questions for the smallholder farmers questionnaire **Source**: Author.

precision (confidence level) produced accurate results.

The quantitatively gathered data from questionnaires and secondary sources were cleaned and organized before being analyzed using the Statistical Package for Social Sciences (SPSS) version 16.0, MS Office Excel 2019, and Mann Kendal Trend Test (M−K Test) XLSTAT 2021.3.1 (Addinsoft, 2022). Graphs, charts, and statistical measures were produced. Profile map analysis of the PQWT used the sub-surface colour chart and contour analysis techniques (Hunan Puqi Geological Exploration Equipment Institute, n.d.). The researcher analyzed the processed sub-surface profile map for different borehole sites established that are both perennial and intermittent in terms of water supply. This was conducted by checking the vertical axis, which indicated the profile's depth concerning the borehole's depth. The depth aspect of the profile map gave indications of the level of the water table and the water-bearing rock. The hydrogeological formation map analysis was carried out using geographical information systems-based ArcMap 10.5. Content analysis techniques were employed in analysing qualitatively gathered data from focus group discussions, direct field observations and key informant interviews to identify critical consistencies and meaning behind the data (Patton, 2002). The determination of units and key themes was carried out by identifying key phrases, keywords, and categories. Data were coded, leading to the testing of categories and sub-categories for consistency, validity, and reliability. Finally, conclusions, inferences and relationships were drawn.

The study triangulated multiple data gathered by different tools to ensure that information from local/indigenous/traditional, professional, scientific, and administrative/bureaucratic domains (Fleischman and Briske, 2016) was complementary. This helped generate a balanced conclusion on groundwater management under changing and highly variable climatic conditions (Brazier, 2018).

5. Results and discussions

5.1. *Declining groundwater under rising temperatures and declining rainfall*

Narratives of the key informant interviews and focus group discussions shared by participants from the Chiredzi and Zvishavane districts shared the same perception that temperature has been increasing over the past 30 years. Some 97 % of the sampled study population indicated that they experienced and failed to cope with the rising temperatures (Fig. 3) and (Fig. 4), as found by Defe & Matsa (2021). In connection with the rising temperatures, some 73 % of the study participants highlighted their experiences with decreasing rainfall.

The focus group discussions and key informant interview narratives of participants' lived experiences on rising temperatures were further supported by Mann-Kendall (M−K) statistical test at $\alpha = 0.05$. The statistical results from the M−K test for Chiredzi Buffalo Range (Fig. 3) and Zvishavane Brange (Fig. 4) temperature data have shown an increasing trend in temperature over the past 54 and 58 years of analysis, respectively, with both p-values < 0.001 The mean temperature for the Chiredzi district over the period analyzed using the M−K test was 30.27 degrees Celsius, while the standard deviation was 0.824.

Statistical results of the Zvishavane district also concurred with community perceptions and experiences that the temperature was increasing. Over the past 58 years, the mean temperature for the district was 27.57 degrees Celsius, with a standard deviation was 0.827. Comparing Chiredzi and Zvishavane districts against the national temperature trend confirmed smallholder farmers' perceptions and lived experiences in Chiredzi and Zvishavane. The national mean temperature was slightly lower than both districts at 26.95 degrees Celsius, and the standard deviation was 0.782. The rising temperatures noted by the study over the years from smallholder farmers' perceptions, lived experiences and statistical analysis of historic data pointed out the climate change scenario taking place and affecting communities in Chiredzi and Zvishavane districts. Brazier (2018) re-affirms Zimbabwe's rising temperature trend, and this escalated the demand for groundwater in drought-prone areas.

The study further analyzed historical rainfall data from Chiredzi district's Buffalo Range Station (Fig. 5) and Zvishavane district's Brange Station (Fig. 6) and compared the trend against the national average rainfall trend. The statistical test (*Mann- Kendall trend test*) applied was a two-tailed test with $\alpha = 0.05$ for all the districts and national level. The

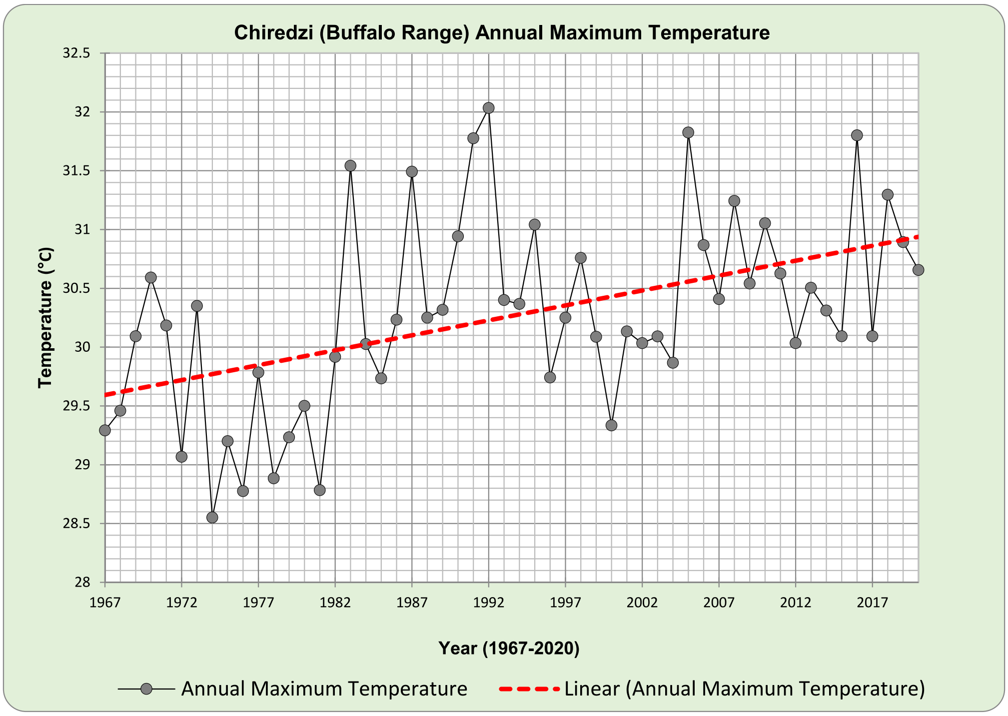


Fig. 3. Chiredzi (Buffalo Range) Annual Maximum Temperature. **Source**: Author.

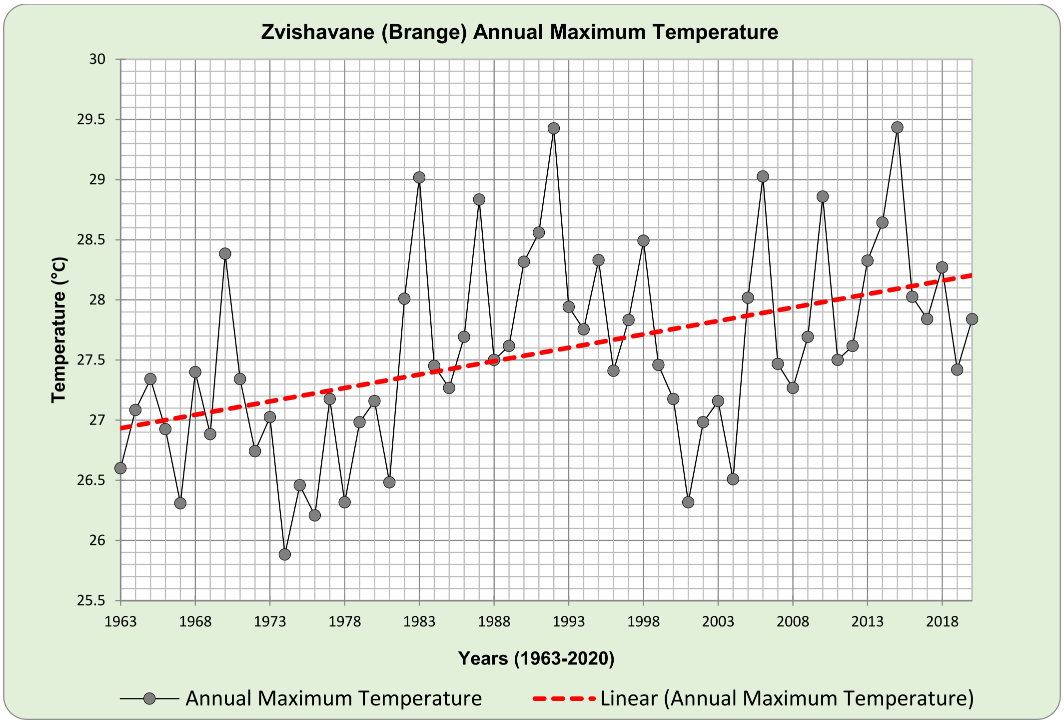


Fig. 4. Zvishavane (Brange) Annual Maximum Temperature. **Source**: Author.

statistical results from the M−K trend test for the Chiredzi district's 55 years of rainfall analysis indicated that the decline noted by smallholder farmers was not statistically significant since the p-value (0.532) was great than α (0.05).

Results from the Zvishavane district also confirmed the statistical insignificance of the smallholder farmers' declining rainfall claims. The decline in rainfall over 99 years of analysis with a p-value (0.832), which is more significant than α (0.05) concurs with findings by Mazvimavi (2010) on the interdecadal variations in Zimbabwe's rainfall. Although the study results concluded that there is an insignificant statistical decline in rainfall for both districts, the mean rainfall for Zvishavane (566.29 mm) is slightly less than that of Chiredzi (567.19 mm). The

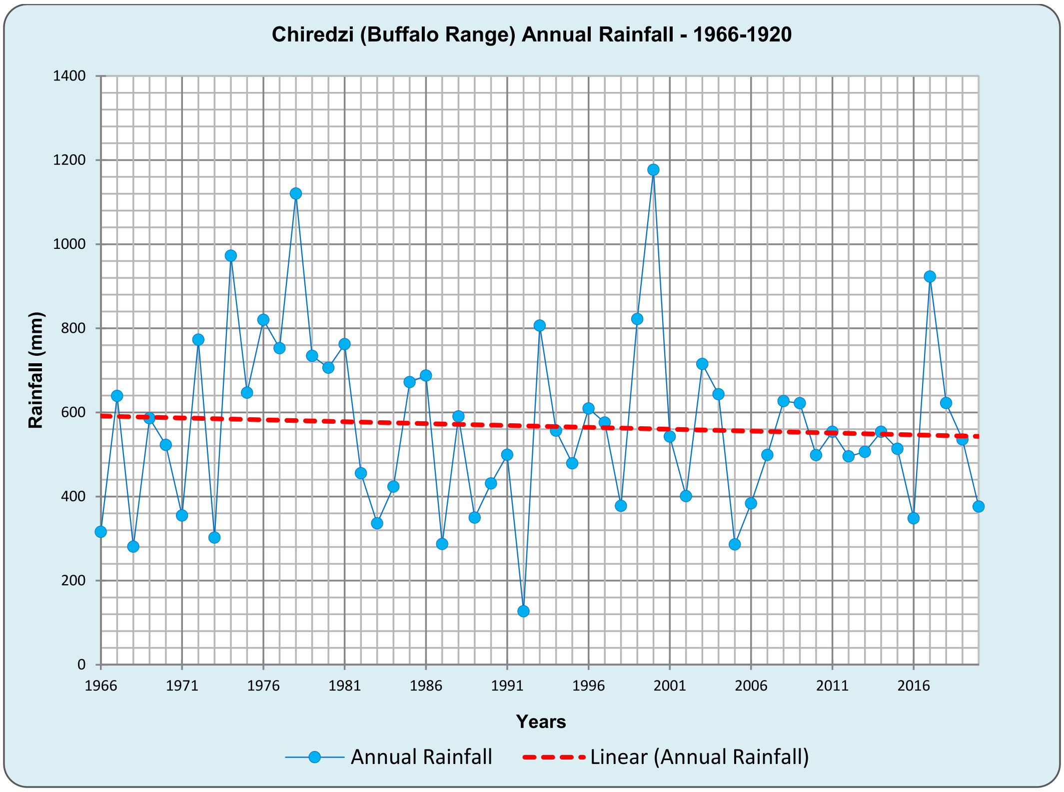


Fig. 5. Chiredzi (Buffalo Range Station) Rainfall Source: Author.

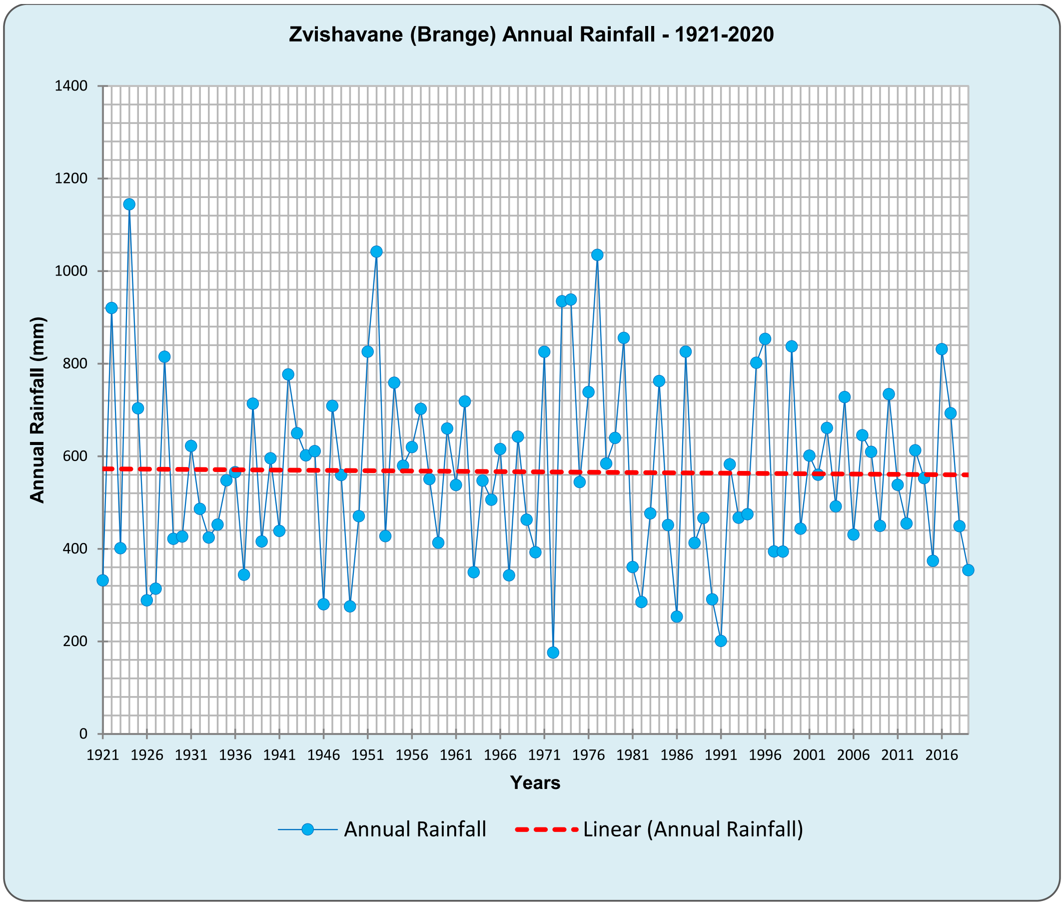


Fig. 6. Zvishavane (Brange Station) Rainfall Source: Author.

standard deviation for the Chiredzi district (209.80 mm) was higher than that of Zvishavane (197.47 mm). The results for national rainfall analyzed for 119 years indicated that the p-value (0.696) is more significant than the α (0.05), which revealed no trend in the series.

The national decline in rainfall over the period was not statistically significant. Despite an agreement on the statistical insignificance in rainfall decline for the Chiredzi district, Zvishavane district and the national level, the general trend concurred with the smallholder farmers' perceptions that rainfall was declining at a marginal scale. The results confirmed the marginal rainfall decline as the interdecadal, interannual and inter-seasonal variations (Mazvimavi, 2010). Decreasing rainfall amounts may indicate a decline in areas of high and medium groundwater potential (Kanema & Gumindoga, 2022). As reported in the two districts, affected areas will experience an increase in irrigation, domestic and livestock water demand. The declining rainfall played an aggravating factor role in increasing water demand and stress for the drought-prone communities of Zvishavane and Chiredzi, as indicated by 97 % and 73 % of Chiredzi and Zvishavane respondents, respectively.

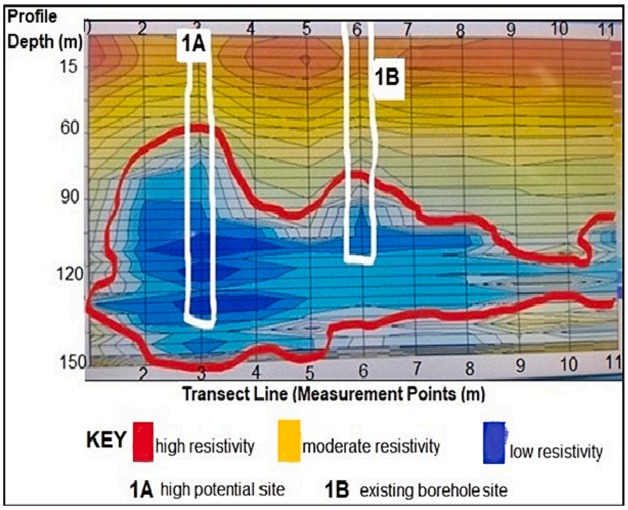


Fig. 7. Hydrogeology and groundwater aquifer for Ndali, Chiredzi district. Source: Author.

5.2. *Increase in the seasonality of groundwater sources*

Out of the study sample population, 91 % of the respondents indicated that they rely on groundwater sources (68 % boreholes and 23 % wells) for their drinking, gardening, livestock, and cleaning. Narratives from the focus group discussions with study participants revealed that the seasonality of boreholes was pronounced more in the last 20 years. Analysis of the seasonal groundwater sources reported by participants revealed that seasonality was more pronounced for boreholes less than 60 m deep, shallow wells and springs. Such groundwater sources do not tap high-yielding deep aquifers; hence these sources provide water during the rain season and they become intermittent in the dry season.

The PQWT hydrogeological measurements revealed a high-yielding deep-seated aquifer in the Chiredzi district at the Ndali borehole site (Fig. 7). In contrast, the measurements for Zvishavane at the Timba borehole (Fig. 7) highlighted a very shallow and low-yielding aquifer. The participants reported both Ndali and Timba boreholes as seasonal, prompting their hydrogeological investigations. Previous borehole drilling of 80 m at Ndali was noted to have been done at point 1B (Fig. 7). Re-investigation by hydrogeological survey revealed that the previous drilling missed a high-yielding point marked 1A (Fig. 7). Seasonality reported at the Ndali borehole was attributed to a shallow borehole depth (80 m). Options for drilling 120 m, as indicated in point 1A (Fig. 7), have the potential for increasing groundwater yield and perenniality. Borehole survey inaccuracy identified by the re-investigation was supported by Muchingami et al. (2021). The re-investigations revealed groundwater exploration challenges due to complex underlying geological formations. Fracture connectivity with the recharge source was highlighted as a determinant for basement aquifer borehole yields, especially in Zvishavane, which is part of the Great Dyke (Heymann & Kumari, 2018).

The seasonality and yield performance of the Timba borehole (Fig. 8) were further highlighted in a focus group discussion as they depended on the balance between seasonal rainfall performance and seasonal water demand.

5.3. Influence of hydrogeological formation on groundwater development and management

The study used ArcMap 10.5 to analyse and present aquifer type and groundwater potential for Chiredzi and Zvishavane districts (Fig. 9). Key informant interview narratives in Chiredzi and Zvishavane with pump minders and District Water Technicians indicated that hydrogeological formations influence groundwater development, as supported by O'Dochartaigh (2019). Chiredzi district participants revealed that boreholes in assessed wards were high yielding as confirmed by the Consolidated Sedimentary Intergranular/Fractured hydrogeology of the Save Alluvial aquifer, whose approximate yield range reach as high as 20 L per second (O'Dochartaigh, 2019). In contrast, Zvishavane district participants indicated that some areas are not encouraged for borehole drilling due to the over 80 % recorded failure rate to provide groundwater yield. The results of the hydro geophysical assessment support the views of community water users on the seasonality and low-yielding boreholes in the Zvishavane district underlain by the Basement aquifer. O'Dochartaigh (2019) and Heymann & Kumari (2018) revealed that the Basement aquifer of the Precambrian geological age is lowly fractured, and the boreholes' average yields can be as negligible as 0.1 L per second.

Hydrogeological formations that determine groundwater potential are key determinants for groundwater management as they determine fractured zones, water storage and yields for groundwater sources. Conflicts at water points were identified to be very high in Zvishavane compared to Chiredzi. At the Timba borehole, water conflicts were reported to increase where the community queued for water, due to low groundwater recovery. The narratives from the focus group discussions and key informant interviews highlighted those conflicts increased during the peak dry season. This is the period when most surface water points and shallow wells dry up. Nijsten et al. (2018) revealed that around 85 % of groundwater sources are low yielding (0.1 to 0.5 L per second). This proportion indicates the area covered by the low-yielding Basement aquifer (brown colour) in Zimbabwe [see Fig. 9] (Ó Dochartaigh, 2019).

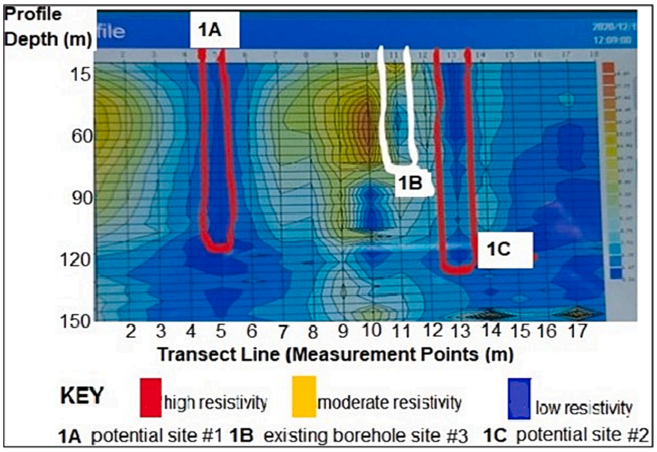


Fig. 8. Timba borehole hydrogeology & groundwater aquifer, Zvishavane. Source: Author.

5.4. Gaps in local institutional arrangements and capacity for groundwater management

5.4.1. Operational and maintenance capacity challenges by water point committees (WPC)

Eighty percent of the study participants highlighted that groundwater sources they depended on were communally managed. Water point committees were identified as responsible for the day-to-day management of communally owned water infrastructure. Members of the water point committee indicated that they were responsible for sanitation, reporting faults, monitoring usage, and coordinating the usage of water from their locally managed sources. Water point committee training was identified by focus group discussions and key informant interview participants as critical in enhancing community ownership of infrastructure, coordination of groundwater source maintenance, solving water conflicts, transparent mobilization and management of water point fund. Boora et al (2016) supported this view and emphasize that the sustainability of communally owed water points is based on strong local management structures. Key challenges faced by the water point committees (WPC) in Chiredzi and Zvishavane districts include skills and training gaps (Fig. 10). The proportion of the trained members of WPC was higher (78 %) in Chiredzi than in Zvishavane (66 %), which explained why Chiredzi had more (62.5 %) functional boreholes than Zvishavane (37.5 %).

Resilient water infrastructure and strong water governance mechanisms are key in strengthening water security under the changing climate, as revealed by Joshua et al. (2022). Weak local water institutional and governance arrangements were identified as factors aggravating water stress in Chiredzi and Zvishavane districts. The absence of borehole operations and maintenance registers at Timba in Zvishavane ward 17, and the insignificant borehole funds at Dendere and Ndali communities in wards 2 and 5 of Chiredzi undermined community structures' responsibility in conducting operations and maintenance for shared water points. The unavailability of groundwater yield records for all 8 wards and the absence of a water point committee constitution at the Mahlaba borehole in Zvishavane pointed to weaker local water institutional management arrangements. This view was supported by Bowora et al. (2016) and Mubaya & Mafongoya (2017), who assert that capacitating community institutions remains a key solution to the management of water points. An increase in the occurrence of conflicts at water points was revealed at Timba and Mahlaba boreholes in the Zvishavane. This provided an indication of the growing demand for groundwater as community members compete over access to borehole water.

5.4.2. Sustainability challenges for Village Pump Minders (VPM) model

Village Pump Minders (VPM) were identified as key players in technical and mechanical repairs and maintenance of borehole infrastructure in the Chiredzi and Zvishavane districts. The VPM are voluntary individuals trained by the District Development Fund (DDF) and stationed in communities providing operational and maintenance services to communally owned boreholes. The District Water Technicians (DWT) outlined the role of Water Point Committees (WPC) who report borehole faults to Village Pump Minders (VPM) for repairs. The VPM refers to the DWT for faults that require specialised equipment and skills. According to the District Water Technicians interviewed, one (1) village pump minder (VPM) is recommended by the standards to service a

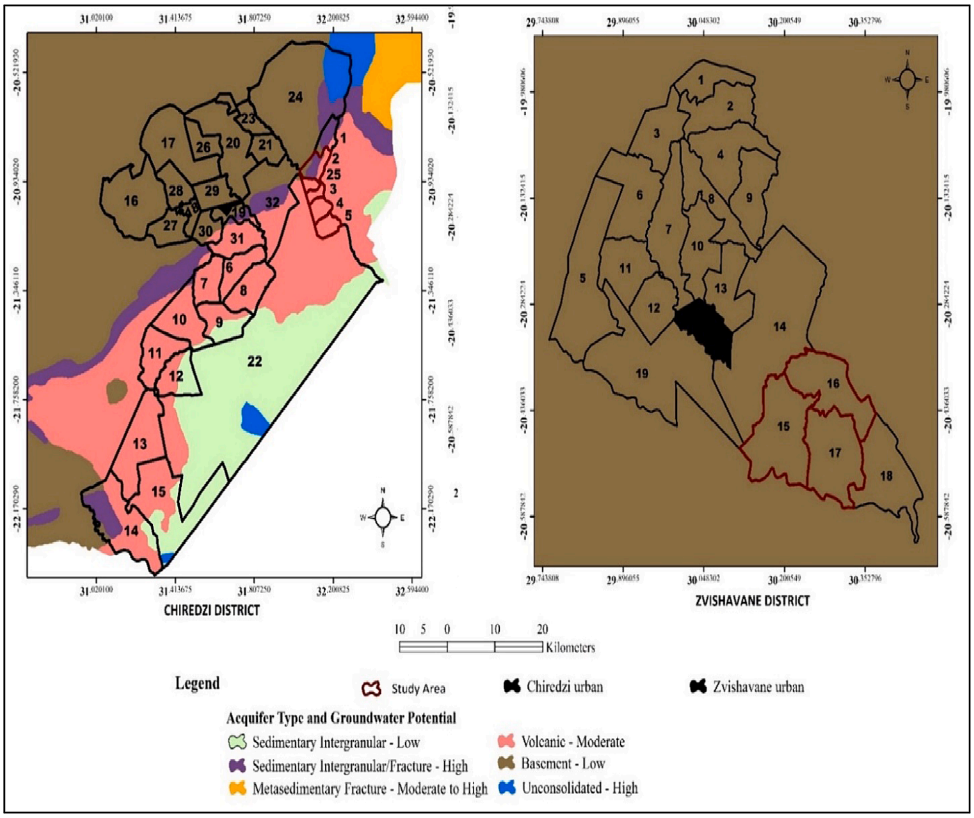


Fig. 9. Hydrogeological formation and groundwater potential for Chiredzi and Zvishavane. Source: Author.

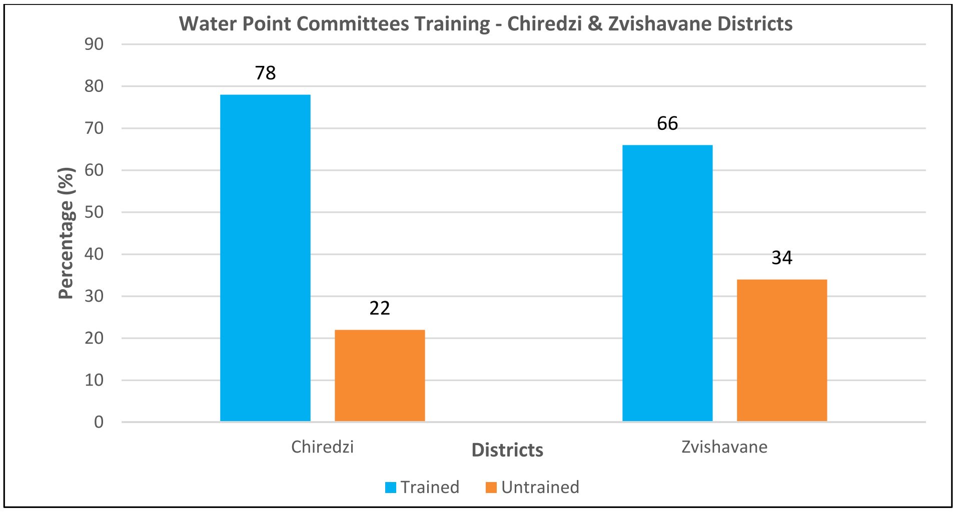


Fig. 10. Water Point Committee raining Source: Author.

maximum of ten (10) boreholes within the defined catchment area. However, the study revealed that Chiredzi district's pump minders had an average of 30 % extra burden in their borehole service and maintenance caseload. The same results further highlighted that Zvishavane pump minders had 210 % extra caseload in borehole services and maintenance (Fig. 11). Village Pump Minders (VPM) in Zvishavane district's wards 15, 16 and 17 highlighted huge caseloads in their catchment areas with 54, 46 and 42 boreholes, respectively, against the recommended standard of 10 boreholes per one VPM. High caseloads and the extensive geographic spread in the catchment area of the VPM explain the reason behind partial and non-functional boreholes constitute more than 40 % of Chiredzi and Zvishavane, collectively (RWIMS, 2021). Participants from the Focus Group Discussions revealed that some boreholes that developed minor faults were not maintained until they broke down due to a longer waiting period before the VPM attended to reported faults.

6. Conclusion

The rising atmospheric temperatures and declining rainfall reinforced each other as aggravating factors undermining sustainability in groundwater management. Weaker community arrangements and complex hydrogeological formations were identified as limitations in managing and developing groundwater in drought-prone areas. The

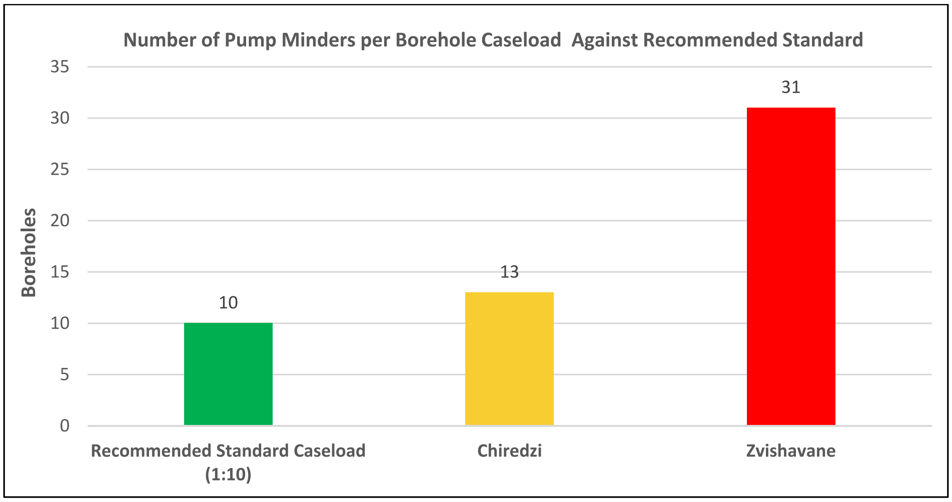


Fig. 11. Village Pump Minders Caseloads in Chiredzi & Zvishavane districts. Source: Author.

importance of groundwater in these areas cannot be overemphasized since it is the sole source of potable water. Declining groundwater levels were associated with the complex interaction of factors, including increased water demand, a negative balance between recharge and withdrawal, and existing institutional capacity gaps that undermined groundwater source operation and maintenance.

7. Recommendations

Collective efforts by a wide range of institutions are required to influence a community of practice around climate-compatible groundwater management. This will enable co-authorship, packaging, documentation, dissemination, and consumption of timely and accurate groundwater information, which is currently lacking. Based on the existing rural water infrastructure demand, the private sector has the opportunity for tapping into water development and management businesses and support communities with technologies, innovations, and social enterprises. An ecosystems-based groundwater replenishment model is required to improve groundwater storage and yields in low-yielding aquifers. The focus will also be reducing groundwater demand by encouraging utilization of other sources including rainwater harvesting. Multi-level and multi-sectoral water institutional arrangements must be strengthened to ensure that water governance, operation and maintenance functions are adequately implemented.

CRediT authorship contribution statement

Pascal Manyakaidze: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Regis Musavengane:** Conceptualization, Formal analysis, Methodology, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Mulala Simatele:** .

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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