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Perceptions on irrigation water supply and utilisation by smallholder agricultural enterprises in Vhembe district of Limpopo Province, South Africa

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Abstract. The study investigated perceptions on irrigation water supply and utilisation by Smallholder Agricultural Enterprises (SHAES) in the Vhembe District of Limpopo Province. More (55.4%) SHAES depended on surface water as the main source for irrigation. Surface water supply was ranked moderate in the majority of SHAES, both for summer (58.6%) and winter (69.7%) irrigation and was regarded as always available (51.3%). Groundwater was the main source in 44.2% of SHAES and was ranked very high for summer (55.7%) and winter (34.4%) irrigation. Groundwater was perceived to have the advantage of being always available in 83.6% of SHAES while 64.9% complained about higher pumping costs. One in three (33.9%) SHAES revealed they irrigated two to four times a day while one in five (18.7%) irrigated once every eight to 14 days. The mean amount of water used to irrigate was estimated at $5\,300,88\text{ l} \pm 20\,762,91\text{ l}$. Almost two in three (62.6%) SHAES experienced competition for water. Statistically, significant association was observed between the main source for irrigation and monthly income ($\chi^2(1) = 7.10$, $p < 0.013$) after the Bonferroni adjustment. It was determined that 51.3% of SHAES with income $\leq$ R5000/month used surface water as the main source for irrigation compared to 69.6% with income $>$ R5000/month.

Keywords. Surface water, Groundwater, Irrigation

1. Introduction

While the global supply of available freshwater is more than adequate to meet all current and future water demands, its spatial and temporal distributions are not. As a result of the skewed spatial and temporal distribution of the freshwater resources, there are many regions where water resources are inadequate to meet requirements (Cosgrove and Loucks 2015) while other regions are oversupplied (Tshikolomo, Walker, and Nesamvuni 2013). Adequacy of water supply remains critical for human life and livelihoods (Nnaji and Banigo 2018; Ritchie 2017).

Agriculture consumes the largest quantity of water in the world with some countries allocating around two-thirds of their water to this sector. Agriculture water requirements must be supplied in a context of declining availability due to environmental awareness, population growth and economic development (Iglesias and Garrote 2015). The purpose of this study was to investigate the irrigation water supply and utilisation in SHAEs with a focus on the Vhembe District of Limpopo Province.

2. Methodology

2.1. Description of the study area

The study was carried out in Vhembe District Municipality of Limpopo Province, South Africa. The specific areas were Madimbo Corridor in Musina and Mutale Valley in Thulamela Local Municipality. The study was carried out in Vhembe District Municipality of Limpopo Province, South Africa. The specific areas were Madimbo Corridor in Musina and Mutale Valley in Thulamela Local Municipality. The two areas were categorized as independent smallholder agricultural enterprises (SHAE) each with a private water supply in the case of Madimbo and as irrigated smallholders which are served by communal water supply infrastructure in the case of Mutale. The two areas of Madimbo corridor and upper Mutale valley irrigation schemes constitute a total of more than 2270 ha of production area.

2.2. Sampling procedure

Stratified random sampling was used to obtain a representative sample of villages and households for interview (Leedy et al. 2005) with the target population being women and youth SHAEs. A two-stage random sampling process was conducted using the *SURVEYSELECT* procedure of SAS. The *PROC SUREVEYSELECT* allowed for probability-based random sampling where sampling in a category or class depended on the number of units within that class. The sampling was regarded as appropriate for handling selection bias. The total number of SHAEs sampled were two hundred and ninety-four (N=294). The sample was comprised of 71 youths aged 18 to 35 (56 females and 15 males) and 223 women of whom 153 were adults (36-59 years) and 70 pensioners (≥ 60 years old).

2.3. Data collection

A semi-structured household questionnaire was used to survey with an emphasis on women and youth SHAE. The total number of SHAE interviewed were two hundred and ninety-four (N=294) with a response rate of 75 per cent. The sample was comprised of 71 youths aged 18 to 35 years old (56 females and 15 males) and 223 women of whom 153 were adults (36-59 years) and 70 pensioners (≥ 60 years old).

2.4. Data analysis

The Statistical Package for the Social Sciences (SPSS) version 22 was used to analyse quantitative data. Descriptive statistics included frequency tables and measures of central tendency. Inferential statistics were in the form of chi-square analyses, which assessed the association between major demographic variables (gender, age, education, and income) and vegetable/ field crop production, water resources and governance. (Fischer Exact tests were interpreted in cases where the assumptions for chi-square analysis had been violated.) A Bonferroni adjustment was made to prevent a type I error, therefore significance was considered when $p < 0.013$. Qualitative data were analysed using MS Excel, themes for each question were created according to participants' responses and each response was coded accordingly.

3. Results and Discussions

3.1. Irrigation water sources

Knowledge of sources of irrigation water used in SHAEs was regarded as important. Despite the utilisation of both surface and groundwater sources (Qureshi 2018), the scarcity of the resource continued to adversely affect agricultural production, especially in arid and semi-arid areas (Abdelkhalik et al. 2020). As evident from the survey (Table 1), more SHAEs (55.4%) depended on surface water as their main source for irrigation compared to those who relied on groundwater (44.2%). For SHAE who used groundwater, the mean groundwater level was reportedly $42.03\text{m} \pm 18,10\text{m}$ with a minimum of 10.00m and a maximum of 90.00m with 77.9% of them claiming to have conducted pumping tests for their boreholes. The cost of pumping irrigation water has been an important consideration when choosing a water source and tended to be higher for groundwater compared to that for surface water. For groundwater, pumping costs would be lesser for boreholes with water obtained at shallower levels compared to those where water was obtainable from deeper levels.

Table 1. Sources of irrigation water for Smallholder Agricultural Enterprises in Vhembe District, Limpopo Province (Source: Own Survey)

Water source	Frequency	Per cent
Source 1 (main source)		
Surface water	163	55.4
Groundwater	130	44.2
Missing (System)	1	0.3
Total	294	100.0
Source 2 (complementary source)		
Surface water	4	1.4
Groundwater	15	5.1
Missing (System)	275	93.5
Total	294	100.0

Although fewer responses were recorded, groundwater tended to be relatively more important in the study area as a complementary source of irrigation water compared to surface water. The 6.5 per cent of SHAE who responded to the second complementary source of water gave an impression that there was hardly any significant complementary activities to source water by SHAE. It was however noted that the activity to complement surface water with groundwater was done by five per cent of the SHAE. As posited by Crouch et al. (2020), precedence is provided to human consumption when water gets scarcer in many countries. The 55.4 per cent perceived usage of surface water in comparison to the 44.2 usages of groundwater indicates the spatial geophysical environment and water access in the study area. Qureshi (2018) stated that surface water management can be improved by introducing small farm-level reservoirs to store rainfall during the high flow seasons for use in low or no flow periods. However, groundwater as a source of irrigation requires both conservation and recharge of the groundwater resources for purposes of sustainable farming (Dhawan 1991).

Conservation and recharge are necessary to prevent rapid declines in aquifer levels as that could have a negative implication for the sustainability of irrigated agriculture (Rouhi Rad,

Araya, and Zambreski 2020).

3.2. Quantity of water supplied by the sources

The SHAEs in the area under study tended to be severely constrained regarding access to water, hence knowledge of the quantity supplied has been critical. The quantity of irrigation water supplied reflected the importance of the source for the success of SHAEs (Table 2). Surface water was ranked moderate by the majority of respondents, both for summer (58.6%) and winter (69.7%) irrigation.

Table 2. Ranking of the quantity of irrigation water supply by sources in Vhembe District, Limpopo Province (Source: Own Survey)

Seasonal water supply ranking	Frequency	Per cent
Source 1 (Surface) - Summer		
Very high	24	15.8
High	25	16.4
Moderate	89	58.6
Low	12	7.9
Very low	1	.7
Missing	1	.7
Total	152	100.0
Source 1 (Surface) - Winter		
Very high	10	6.6
High	10	6.6
Moderate	106	69.7
Low	17	11.2
Very low	8	5.3
Missing	1	.7
Total	152	100.0
Source 1 (Ground) - Summer		
Very high	68	55.7
High	11	9.0
Moderate	41	33.6
Low	1	.8
Missing	1	.8
Total	122	100.0
Source 1 (Ground) - Winter		
Very high	42	34.4
High	36	29.5
Moderate	42	34.4
Low	1	.8
Missing	1	.8
Total	122	100.0

Although the study was conducted in a summer rainfall area, the ranking of irrigation water supply from surface water sources remained moderate during this season, a situation that

probably reflected the low rainfall status of the area. The retention of moderate ranking in winter was probably due to the availability of dams in which water was stored during summer rainfall season and reallocated to the dry winter season with no or very little rainfall (Keller, Sakthivadivel, and Seckle 2000). The moderate ranking of surface water supply as moderate was corroborated by investigation done by Keller, Sakthivadivel, and Seckle (2000), who reported that water was stored in dams during rainfall seasons (summer in this study) when the economic value of the resource was low and was then reallocated to times (winter) and places when and where its economic value was high.

As for groundwater, the respondents ranked it very high, both for summer (55.7%) and winter (34.4%) irrigation, with the same number (34.4%) of respondents having also ranked it moderate. Groundwater sources were perceived to be important and seemed to supply more irrigation water than surface water sources. The ranking of groundwater remained very high even by SHAEs (76.5%) who used it as their second (complimentary) source for both summer and winter. Based on the findings of this study, groundwater sources were perceived to be important sources that seemed to supply more irrigation water than surface water sources. This observation seemed in line with Nnaji and Banigo (2018) who, based on AHP method, ranked the water sources in order of preference as Ground (borehole) better than Surface (water board better than water tankers which in turn is better than streams which were also better than rainwater harvesting). The ranking of groundwater remained very high even by SHAE (76.5%) who used it as their second (complimentary) source for both summer and winter.

In a study on multi-criteria evaluation of sources for self-help domestic water supply in Nigeria, it was observed that the most important criteria which were found to affect the ranking of water sources for domestic water supply are quality, risk of contamination, sustainability, maintainability, and public acceptance (Nnaji and Banigo 2018), with most of the criteria also relevant for ranking of water sources for irrigation. Water quality aspects such as salinity and associated problems have been a major challenge for global food production (Minhas et al. 2020). As posited by Minhas et al. (2020), strategies to cope with salinity include a better understanding of the impacts of temporal and spatial dynamics of salinity on soil water balances vis-à-vis evapotranspiration (ET) and devising optimal irrigation schedules and efficient methods.

As stated by Kumarasamy et al. (2014), water quality indicators included physicochemical parameters where sodium absorption ratios (SAR—0.14 to 9.23 meq L⁻¹), sodium percentage (Na%—10.15 to 85.38 meq L⁻¹), residual sodium carbonate (RSC—0.32 to 5.64 meq L⁻¹), potential salinity (PS—0.5 to 7.1 meq L⁻¹), and permeability index (PI—12.5 to 89.7 meq L⁻¹) attested to excellent water quality for irrigation. Other than quality issues, smallholder agricultural enterprises in the area under study tended to be severely constrained regarding access to water, hence for them, the quantity supplied has been critical. Resultantly, the quantity of irrigation water supplied has reflected the importance of the source for the success of smallholder agricultural enterprises. The water sources in the study area were therefore ranked by the SHAE based on the volumes of irrigation water they supplied to the agricultural enterprises.

3.3. Advantages and disadvantages of irrigation water sources in the study area

A comprehensive discussion of the advantages and disadvantages of water sources should consider that the sources tend to be interlinked as opposed to being separate entities. Surface-water bodies often gained water from ground-water systems while also serving as sources of ground-water recharge (Winter et al. 1998).

As the development of land and water resources increased, it became apparent that the development of one water resource affected the other. Nearly all surface-water features (streams, lakes, reservoirs, wetlands, and estuaries) interact with groundwater. As part of the interactions, surface-water bodies often gained water and solutes from ground-water systems while surface-water bodies served as sources of ground-water recharge and caused changes in ground-water quality. As a result, withdrawal of water from streams tended to deplete groundwater, and conversely, abstraction of groundwater tended to deplete water in streams, lakes, or wetlands (Winter et al. 1998).

In this study surface water as the main source (source 1) was perceived by half (51.3%) of SHAEs to be always available followed by those (36.8%) who considered the source to be located at proximity. The main disadvantages were that surface water as the main source had insufficient water (39.5%) with some respondents (20.4%) bothered by the water quality (Table 3).

Table 3. Advantages and disadvantages of irrigation water sources as perceived in Smallholder Agricultural Enterprises in Vhembe District, Limpopo Province (Source: Own Survey)

Advantages and disadvantages of Source 1 water sources	Source 1 - Surface water		Source 1 - Groundwater	
	Frequency (n=152)	Per cent (of participants with surface water as source 1)	Frequency (n=122)	Per cent (of participants with groundwater as source 1)
Advantage				
Always available	78	51.3	102	83.6
Sufficient water	0.0	0.0	17	13.9
Close proximity	56	36.8	0.0	0.0
No extra costs involved	11	7.2	0.0	0.0
Good for irrigation	2.0	1.3	0.0	0.0
Missing	5.0	3.3	3.0	2.5
Total	152	100.0	122	100.0
Disadvantage				
Insufficient water	60	39.5	1	0.8
Not always clean	31	20.4	2	1.6
Expensive	21	13.8	33	27.0
Influenced by drought	12	7.9	0.0	0.0
Share with other SHAE	11	7.2	0.0	0.0
Alkalinity / Saline water	6.0	3.9	12	9.8
Water source is far away	1.0	0.7	0.0	0.0
Dependent on electricity	0.0	0.0	23	18.9
Requires maintenance	0.0	0.0	6.0	4.9
Missing	10	6.6	45	36.9
Total	152	100.0	122	100.0

The finding that surface water was always available as the main source was rather consistent with the earlier ranking (Table 2) of supply from the source as moderate by the majority of respondents for both summer (58.6%) and winter (69.7%) irrigation. Regarding groundwater (as water source 1), over four in five (83.6%) SHAEs perceived it to have the advantage of being always available. With the supply from groundwater having been ranked very high for both summer (55.7%) and winter (34.4%) irrigation, it would be expected for more SHAEs to have received sufficient water from this source (Table 2).

The SHAEs who pump water from a borehole or river can expect to experience relatively higher pumping costs than SHAEs receiving irrigation water from a canal delivery system (Stevens 2007). Almost two in three (64.9%) respondents experienced higher pumping costs with 53.7% having reported electricity while 11.2% incurred fuel costs for their pumps. The SHAEs using groundwater sources would be among those incurring higher pumping costs as pumping depths in boreholes were reportedly greater ($42.03\text{m} \pm 18.10\text{m}$). The cost of pumping would also likely be higher for groundwater compared to that for surface water. Sound discussion of the merits and demerits of surface and groundwater sources, therefore, requires an understanding of the linkages between these sources. The perceptions of SHAE in the area under study regarding the advantages and disadvantages of these sources of water probably considered these linkages.

3.4. Irrigation scheduling and competition for water

3.4.1. Irrigation scheduling

One in three (33.9%) SHAEs indicated that they irrigated between two and four times a day. Fewer SHAEs (13.6%) irrigated daily with the same number ($0.7 + 1.7 + 11.2 = 13.6$) having irrigated once every second to the fourth day. One in five (18.7%) SHAEs irrigated once every eight to 14 days (Table 4). The mean amount of water used to irrigate was reportedly $5\,300.88\text{l} \pm 20\,762.91\text{l}$, with a minimum of 35l and a maximum of $250\,000\text{l}$.

Table 4. Irrigation scheduling by Smallholder Agricultural Enterprises in Vhembe District, Limpopo Province (Source: Own Survey)

Irrigation schedule	Frequency	Per cent
Two to four times a day	100	33.9
Daily	40	13.6
Every second day	2	.7
Every third day	5	1.7
Every fourth day	33	11.2
Between 8 and 14 days	55	18.7
After 2 weeks	15	5.1
When required	4	1.4
I do not record	1	.3
Not specified	39	13.3
Total	294	100.0

Efficient use of irrigation water requires proper scheduling informed by variables that include rainfall, temperature, and accompanying evapotranspiration (ET). Estimation of reference evapotranspiration (ET_o) is one of the most influential factors in proper irrigation

scheduling (Rahimikhoob, Sohrabi, and Delshad 2020). Proper irrigation scheduling prolongs irrigation capability (Levidow et al. 2014) and is an important initiative for improving crop production (Crouch et al. 2020).

Effective scheduling of irrigation is associated with increased crop water productivity (CWP), a measure of crop yield per unit of water consumed (Anupoju and Kambhammettu 2020). With the area under study described as water-scarce, the essence of increased CWP cannot be over-emphasized (Abdelkhalik, Pascual, and Nájera 2020).

With the SHAEs being generally resourced poor, it would be expected for their irrigation scheduling to be based on intuition. The SHAEs would not afford equipment for soil/crop moisture measurement necessary to determine when to irrigate and how much water to apply in each cycle (Bennett, Harms, and Entz 2014). Accordingly, some crops were probably over-irrigated (especially with the case of multiple irrigations per day) while others were under-irrigated (especially where irrigation was applied once in weeks). Over-irrigation would have resulted in reduced CWP (Greaves and Wang 2017), mainly because of lack of increase in crop yield with increased irrigation beyond a certain level of water supply, but also because of prospects of waterlogging and disease infections associated with wet conditions. Under-irrigation would have resulted in plant water stress associated with the closing of stomata, reduced exchange of CO₂ and O₂, reduced photosynthesis and declined crop yield.

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3.4.2. Competition for water use

Table 5 shows the competition for irrigation water experienced by SHAEs in Vhembe District. One in three (33.7%) SHAEs in the study area reported that they were the only users of water from their source. Approximately two in three (62.6%) SHAEs experienced some competition for water, and those were comprised of one in six (16.7%) who competed with other SHAEs and 45.9% who competed with other sectors. Despite the experience of competition for water by the majority (62.6%) of SHAEs, about 43.8% of respondents reported that the situation did not result in conflicts in their case.

Table 5. Competition for irrigation water experienced by SHAEs in Vhembe District, Limpopo Province (Source: Own Survey)

Competition for water use	Frequency	Per cent
I am the only user from the source	99	33.7
I, together with other SHAEs use water from this source	49	16.7
SHAEs and other sectors use water from this source	135	45.9
Missing	11	3.7
Total	294	100.0

Competition for water use, where it occurs, may at times be so severe that it may even result in conflicts among irrigation SHAE, especially in areas experiencing a decline in the supply of water. The relationship between climate change, water scarcity, and conflict is still debated. Much of the existing work relating resource scarcity to conflict has involved regional-

scale analysis linking instances of violent outbreaks to environmental conditions.

A study conducted in Zambia on farmer perceptions of conflicts related to competition for resources such as water revealed that three in four (75%) respondents perceived conflict as misunderstandings or disagreements between people, up to 91% of them had experienced past conflicts, 70% expected to experience future conflicts, while 58% expected to experience future physical violent conflicts (Marcantonio et al. 2018). As was observed in the study, a significant relationship occurred between perceptions of future rainfall decreasing and future physical violent conflict.

Competition for water and its associated conflicts was probably more severe during periods of drought when the water supply was scarcer. Type of water source used highly influenced SHAE' perceptions of drought and the type of strategies implemented to mitigate it. For both surface and groundwater-based irrigation areas, local responses often required close cooperation among users, as the responses might involve redistributing the available resources, sharing extra costs, or combining water from different sources to achieve the desired water quality (Urquijo and De Stefano 2016). Some farmer perceptions on drought were observed in a study conducted by Udmale et al. (2014) in the Maharashtra State of India. Environmental impacts such as increases in average atmospheric temperature, pasture-forest degradation, reduced supplies surface and depletion of groundwater were perceived to be devastating impacts of drought. As revealed by the study, decreases in yield of cereals and horticultural crops, declines in livestock production and subsequent loss of employment were regarded among the major impacts of drought. Social impacts such as conflicts emanating from competition for water were also emphasised. With competition for irrigation water exacerbated by droughts probably being an issue in the study area (Table 5), effective strategies are necessary for managing irrigation water.

Table 6. Level of education and monthly income of the head of household by the main source of irrigation water used by smallholder SHAE in Mutale Local Municipality of Vhembe District. Limpopo Province

The demographic factor of association with the main source of irrigation water	Chi-square value	df	Asymp. Sig. (2-sided)
Level of education of household head	2.867 ^a	3	.413
Monthly income of household	7.099 ^a	1	.008

3.5. Associations between demographic factors and main source of water for irrigation

Among the demographic factors regarded as important was the level of education of household head (Dagada et al. 2013; Tompson 2008), and monthly income of the household (Maele et al. 2020) were regarded important and were hence selected for analysis. The role of education in farming decision making inclusive of irrigation water management cannot be overemphasised.

According to Dagada et al. (2013), human development is influenced by the level of education. Improvement of human resource capacity is essential to meet the challenges of agricultural production and food security. More years of schooling are associated with higher rates of adoption of new technologies (Tompson 2008). With heads of households being major decision-makers in their families, it was therefore deemed important to assess the association

between their level of education and the main sources of irrigation water used by the smallholder irrigation SHAE in the study area. (Table 6). The results of the chi-square test revealed that there was no statistically significant association between the main source of irrigation water and the education level of household heads ($\chi^2(3) = 2.867$, $p = 0.413$).

In line with the result not being statistically significant, the effect size showed a weak association (Cohen 1988), as measured by the Phi measure of effect size ($\phi = 0.10$, $p = 0.413$). It was determined that 51.3% of the participants with less than R5000 a month indicated surface water as their main source for irrigation compared to 69.6% of participants with a monthly income of more than R5000. However, for monthly income, the results of the chi-square test, showed that there was a statistically significant association between the main water source for irrigation and monthly income ($\chi^2(1) = 7.10$, $p < 0.013$) after a Bonferroni adjustment. Although there is a statistically significant association the effect size showed a weak association (Cohen 1988) as measured by the Phi measure of effect size ($\phi = 0.156$, $p = 0.008$).

4. Conclusion

Based on the results of the study, the following conclusions could be drawn: (a) although surface water was generally perceived as the most used (55.4%), groundwater (used by 44.2% of SHAEs) was also an important source of irrigation water; (b) groundwater was regarded to have better supply quantity compared to surface water while also being always available; (c) irrigation scheduling was generally based on intuition and practices of rotation without being backed by science-based information; (d) competition for irrigation water seemed to be an issue although not yet at the level of causing major conflicts among the SHAEs; and (f) statistically significant association was only for the main source of irrigation water and household monthly income where households with more incomes tended to use more surface water sources compared to groundwater sources.

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