Chapter Number:

The Beauty of Groundwater Use. Unlocking the Potential of Groundwater in the Upper Great Ruaha River Basin in Tanzania

Authors

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ABSTRACT: Groundwater use has been proposed as a solution to increasing water scarcity in semi arid areas worldwide. However, little information is available on the role of groundwater in supporting agricultural livelihoods in many countries in Sub Saharan Africa, and opportunities to expand this role in the future. This particular chapter provides an overview of the beauty, the roles and benefits of using groundwater and inform policy makers on important to unlock the potential of GW resources in Tanzania. The Chapter use data from the GroFutures study in Tanzania, involving 90 households, collected in between 2015 and 2017 in selected three villages in Usangu Plains. The paper adopted sequential exploratory research design to collect quantitative and qualitative data. Data were analysed using the Statistical Package for Social Science (SPSS) and Microsoft Excel. Findings revealed the majority of smallholder farmers depend on groundwater sources particularly during dry season. The findings show that investing in groundwater had positive Net Present Values at a discounting rate of 12% 18% and 20% per ha in all examined well depths and the Benefit Cost Ratio has positive value implying financially viable in groundwater investment; and clearly shown irrigation using GW is more profitable than that of using surface water. This calls for efforts from the Government and development partners to unlock the potential of GW for use in irrigation farming.

Keywords: Groundwater, irrigation, smallholder farmers, Net Present Value, Cost Benefit Ration, Usangu Plains, Tanzania.

1 INTRODUCTION

Globally, the use of groundwater has been growing rapidly, especially for developing countries, where a range of factors including urbanization, industrialization, land use changes and population growth are putting pressure on water provisioning systems (Gronwall & Oduro-Kwarteng, 2018). Population of Sub-Saharan Africa (SSA) is projected to be between 1.5 and 2 billion and approximately 50% of the population will be living in urban areas by 2050 (ibid). All these people will require clean and safe water, which is both a fundamental human right and a cornerstone of the Sustainable Development Goals (Osborn et al., 2015).

Changing climatic conditions, particularly rising incidences of drought, high temperatures and change in the frequency and intensity of extreme events are accentuating the challenge for Africa (Mwakalila, 2014; Sapa *et al*., 2015). For instance, in the Upper Great Ruaha River Catchment (UGRRC), river flows have been diminishing because of continuous drought, while at the same time there is a high demand of water for irrigation (Mwakalila, 2011). Securing access to sufficient surface water is a growing challenge in the Catchment, with groundwater increasingly seen as the most viable solution (Malley *et al.*, 2009; Foster *et al*., 2012; Mosha & Tarimo, 2019). Groundwater in principle holds particular benefits including drought resilience and ubiquity, on-demand availability providing a buffer against climate variability (Taylor *et al*., 2013). We found groundwater to be vital because more than 80% of households of villages under this Study within the Usangu Plains depend directly upon aquifers for domestic purpose, especially in dry season. The use of privately owned shallow/dug wells has become the fastest growing water source in the Plains.

Drawing on existing literature, three major factors are driving the heightened interest in groundwater development and management for future in Tanzania. The first, and arguably the most pressing interesting is the Sustainable Development Goal and National Water Policy dream of providing improved access to safe and clean water supplies to all affected communities (Osborn *et al*., 2015; URT, 2002). To reach this goal, the delivery of groundwater through well-placed and appropriately constructed and maintained bore holes has a vital role to play. A vivid example is seen in Dodoma (Capital City of Tanzania), where almost 100% of the population depend on groundwater sources. Secondly, access to groundwater for livestock use and small scale irrigation improves livelihood potential, food security, and a pathway out of poverty. Groundwater represents a vast untapped source of water in the Usangu Plains, but technical, socio-economic, and institutional factors, have constrained its use (Gudaga *et al.*, 2018; Mosha & Tarimo, 2019). Thirdly, climate change affects precipitation and temperature dynamics on a global scale, and hence impacted surface water supply. There is increasing, but often anecdotal, evidence that while the availability of rainwater and freshwater from rivers and lakes will likely become more erratic and thus less reliable as a result of climate change, groundwater is likely to be less affected than surface resources (Mwakalila, 2014), thus making groundwater important for future. Besides, Mwakalila (2011) reports enhancing water storage capacity, both above and below ground, is widely accepted as a coping strategy against hydrological shocks, such as floods and droughts.

Even though pressure on surface water has called for groundwater use in UGRRB, its beauty and potential remain uncovered. Hitherto, there is serious concern whether the local water users really benefit from this crucial resource. Thus, we believe that unlocking the potential of groundwater is paramount for transforming subsistence paddy production to commercialisation and for an inclusive economic development and poverty reduction. In the earlier literature, threats to groundwater resources because of lack of data and information on scale, safe yield of the aquifers was especially prominent in the debate (Ibrahimu *et al.*, 2010; Kashaigili *et al*., 2010; Sappa *et al*., 2015). Most of these earlier studies identified groundwater threats as pollution, overexploitation, and how to manage the resource to a sustainable manner. In the last decade, there has been a rapid increase in the number of effectiveness studies on groundwater governance involving Integrated Water Resource Management and institutional framework (e.g. Foster *et al*., 2012; Mosha *et al.*, 2016; Gudaga *et al*., 2018). Many recent research papers and reports in the UGRRB and elsewhere in catchment in SSA (e.g. Kashaigili 2010; Mwakalila, 2011; 2014; Gudaga *et al*., 2018; Howard, 2017; Gama, 2018) underline that little is known about the actual role of groundwater use in supporting agricultural livelihoods in the region, or opportunities to expand this role in the future. There is also a demand for improving understanding of groundwater availability in SSA, this could include recharge processes: flow and storage mechanisms at local and catchment scale; ground and surface water interactions and groundwater quality and impact on changes in climate, storms and land use (Mwakalila, 2014). To distil generalized inferences from this rapidly growing body of evidence, a systematic review is needed to understand the beauty of groundwater and how to unlock its potential in the UGRRB in Tanzania.

This particular Chapter therefore tries to fill some of the foresaid gaps by attempting to address the following basic questions; (i) what are the uses of GW and what are the beautifulness of using it? (ii) what are the costs and benefits of using groundwater for irrigation by smallholder farmers and how can they inform policy makers on how to unlock the potential of GW resources? (iii) what are the factors likely to influence smallholder farmers into using groundwater for irrigation and what are the expected challenges? The Chapter makes use of data that has been collected under the Groundwater Futures in Sub-Saharan Africa, (GroFutures) Programme[1]. The programme focuses on improving the evidence base around groundwater availability and management in Sub-Saharan Africa (SSA) to enable developing countries and partners in SSA to use groundwater in a sustainable way in order to benefit the poor. UPGro projects are interdisciplinary, linking the social and natural sciences to address this challenge.

Data was collected in the Usangu Plains involving about 90 households in three villages namely Ubaruku, Mwaluma and Nyeregete, surveyed in 2017/18. All three villages belong to Mbarali District in the Plains, in Mbeya region. In addition we conducted several focus group discussions and in-depth interviews to collect qualitative information in three waves (2016, 2017 and 2018). The protocol for the interview has been peer followed and the opinions presented here reflect views about groundwater resource and its use in the UGRRC. We show that groundwater is a vital resource for both low income and medium scale households, and in future is a pathway for rice commercialisation and medium scale livestock keeping.

2 METHODOLOGY

2.1 Description of the Study Area

This study builds on both secondary and primary sources, involves a case study of the Upper Great Ruaha River Catchment (UGRRC), with particular reference to the Usangu Plains. The UGRRC was selected for investigation of groundwater matters as part of a larger study of river basin observatories in Tanzania, Ethiopia, Niger, and Nigeria under the Groundwater for Futures in Sub-saharan Africa, which is part and parcel of Unlocking the Potential of Groundwater for the Poor research programme

(UPGro). The UGRRC is situated in the upper reaches of the Rufiji River Basin (RRB). It lies within a semi-arid belt from North to South through the central portion of Tanzania (Mwakalila, 2014). It encompasses an extensive wetland, comprising seasonally flooded grassland and a much smaller area of a permanent swamp commonly known as *Ihefu* which collects water from all the streams in the Uporoto and Kipengere mountain ranges. This makes the area critical to Tanzania for livelihood options of smallholder farmers and agro-pastoralists as well as due to its wetlands and associated biodiversity and catchments that provide crucial waters to the downstream of the Ruaha National Park, and the Mtera and Kidatu hydropower plants and emptying its water into the Indian Ocean (Walsh, 2012).

The catchment is characterised by two distinct landscapes - central plain (Usangu Plains) and highlands (Uporoto Mountain ranges). Ubaruku, Nyeregete and Mwaluma villages are the Study villages, located in Mbarali District (Usangu Plains) (Figure 1), which lies between Latitudes 7^{o} 41’ and 9^{o} 25’ south, and between Longitudes 33^{o} 40’ and 35^{o} 40’ east at an altitude range of 1 010 to 1 100 meters (m) above the sea level (Mwakalila, 2011). The climate of the area is mostly semi-arid with seasonal temperature and rainfall variations. Temperatures range from 20 to 25^{o} C, whereas the annual rainfall varies between 500–700 mm/year. The area has a unimodal type of rainfall which falls from November to May, and which is normally scattered and varies across the Usangu Plains. Rainfall is generally unreliable, and with common localized droughts (URT, 2010).

According to 2012 national census, the Usangu Plains has a total population of about 790 500 people with the annual growth rate of 2.7 (URT, 2013). The population is multi-ethnic and multi-cultural in which Sangu are the indigenous ethnic group; other ethnic groups include Bena, Hehe, Maasai, Sukuma, and Nyakyusa. There has been a huge change in ethnic composition with increasing competition in land-use systems (SMUWC, 2001). Figure 1 shows the map of the study area.

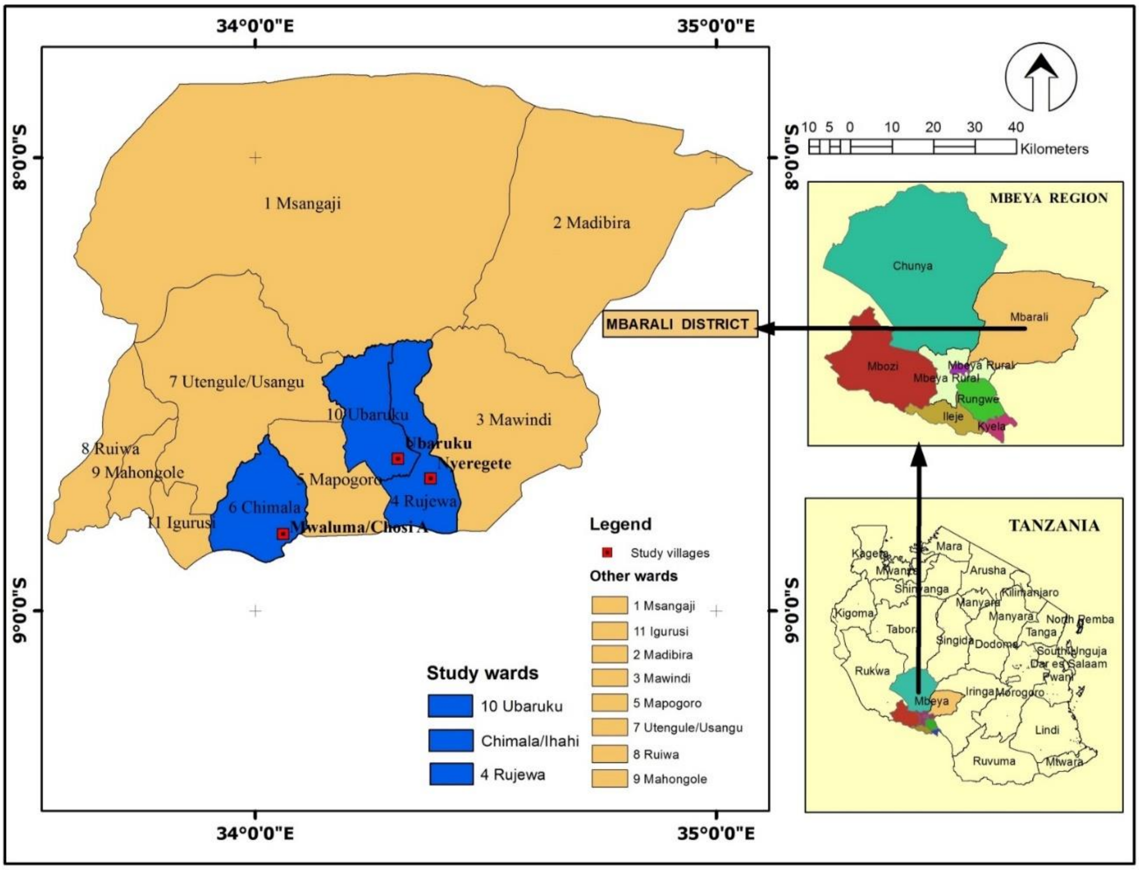

Figure 1: Map of Usangu Plains and location of the study villages

2.2 Research Design, Data Collection and Analysis

The study employed a descriptive cross-sectional research design of which data on the variables of interest from households were collected only once, and the data were examined and the relationship between variables was determined. Primary data were collected during field work using a mixed method approach. In September 2015 stakeholders' workshop and policy dialogue was carried out to gain understanding on existing use of groundwater resources and institutional framework governing water resources in Tanzania. In between 2016 and 2018 in depth interviews and focus group discussions (FGDs) focused on how groundwater resource is managed by different stakeholders (local water users, local government authorities, RRB, and Non-Government Organizations (NGOs)) were conducted. Direct observations and inventory of well structures, water access point and storage infrastructures were successful done. The focus groups were held in each village composed of an average of 8 people comprising men and women, youth and elders as well as poor and wealthy individuals to further validate the collected information. Semi-structured questionnaire was administered to 90 households in Ubaruku, Nyeregete and Mwaluma villages in the Usangu Plains.

Respondents were selected from a list of households in each village, consisting both male and female household heads. Systematic sampling was done at every fifth household. Household surveys were conducted by trained enumerators, who interviewed the household heads in the villages.

2.3 Data Analysis

Data were analysed using the Statistical Package for Social Science (SPSS) and Microsoft Excel.

Financial analysis: Net Present Value (NPV) and Cost Benefit Ratio (CBR) were applied to evaluate the long-term financial viability of using groundwater for small scale irrigation. Information on surface water irrigation was included in this analysis in order to compare the profitability with and without groundwater irrigation while other factors such as climate change notwithstanding. NPV and CBR were obtained using the following formula (Lin *et al.*, 2000):

$$\mathrm{NPV} = \sum_{i=0}^{n} \frac{B_t - C_t}{(1-r)^t} \quad \text{.......... (1)}$$

$$CBR = \frac{\sum_{t=1}^{T} \frac{B_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{C_t}{1+t^t}} \quad \text{.......... (2)}$$

Where for all equation 1 and 2

Σ	=	is the sum of the discounted cost and benefits
B	=	benefits at year at year 2016 (market value of yield at year 2016)
C	=	Cost at year 2016 (market value of inputs, fees and other production costs)
t	=	the time in years i.e. 30 years (t=30)
r	=	discount rate 12%, 18% and 20%
$(1 + r)^t$	=	discount factor

The cost component included the initial capital cost of the borehole, operation and maintenance cost, water fee, market prices of inputs, the cost of ploughing, planting weeding, and harvesting. Discounting reflects the time value of money. Benefits and costs are worth more if they are experienced sooner such that all future benefits and costs should be discounted to its present value for the investments with long life span. The higher the discount rate the lower the present value of future benefits and costs. The discounting rate of 12% was used in this analysis as per the Bank of

Tanzania (BOT), and as indicated in the Monthly Economic Review of Feb 2017. Apart from constant discounting rate from the Central Bank in Tanzania (BOT), the study also considered 18% and 20% of interest rates that are used by different microfinance banks of Tanzania as they are the main credit sources for smallholder farmers. However, there is considerable uncertainty over the correct discount rate and also high uncertainties are expected in agricultural production and which include an increase in the production costs and a decrease in returns that can affect investment financial viability. Different scenarios were assumed to check the investment sensitivity.

Scenario one anticipates the increase of production cost and reduced income while scenario two assumes an increase in production cost and increased income. Therefore, scenario one assumes a 25% increase in the production costs and 10% decrease in income while scenario two assumes 100% increase in the production costs and 25% increase in income. However, Gebrehewaria *et al*. (2016) also revealed that the size of land for production affects the investment economic viability. This is due to the economies of scale whereby the cost per unit of an output generally decreases with an increase in the scale of production.

Estimating the life of a project or program is difficult, subjective and widely debated. Since this GW involves fixed cost which is capital intensive, lifespan is one of the important variables of determining the viability of an investment. This takes into account the entire income stream for the whole lifespan of the investment. The available evidence shows that boreholes are drilled and function for a lifespan of 20 to 50 years (Carter *et al.,* 2014). This study opted for 30 years investment lifespan so as to avoid underestimation or overestimation of the financial viability.

CBA basic assumptions

Cost-benefit analysis (CBA) was applied to estimate the direct costs and benefits accrued from investing in GW by smallholder farmers. In-line with the CBA framework, the analysis was carried out on the basis of the following considerations:

i. All costs and benefits are estimated in incremental terms as opposed to groundwater irrigation did not exist as a do-nothing option.
ii. The analysis starts at (year 0) when the initial investment costs of the GWI facilities occurred while the maintenance and operation cost were assumed to start from the second year after the investment.
iii. All production costs and benefits from using groundwater for irrigation were regarded with the crude assumption that, since it was difficult to forecast the cash flows for the entire lifespan of the investment, constant value was used in measuring project viability throughout the

lifespan of the project. Costs and benefits have been quantified and valued in TZS using Nov – Dec 2016 market prices.

iv. Two production seasons in a year for groundwater irrigation were assumed where paddy could be produced during the wet season and during the dry season the same field would be used to cultivate any other crop. This is due to the argument that through GW, the farmer has an added advantage of irrigating his/her farm during the dry season. Empirical evidence was observed during data collection, whereby some households that owned wells (mostly dug wells) had irrigated back yard gardens during the dry season. Vegetables and tree fruits were grown in these gardens for their own consumption and for sale in the local market. At Mont Fort secondary school paddy seedlings, vegetables, onions and orchard crops were found grown on school gardens using GWI in the dry season.

v. This analysis used onion as the second crop during the dry season. This was due to the argument that paddy was reported as both a cash and food crop grown during wet season, while onions, water melon and vegetables were reported as cash crops grown in the dry season. Thus, paddy and onion were selected in estimating the viability of investing in GW irrigation by smallholder farmers. By considering such scenarios, a relative profitability of using GW for small scale irrigation was compared to surface water irrigation.

vi. Operation and maintenance were estimated to take 10% of the investment cost per year. This was estimated from the communal deep well supplying water to the villages Ubaruku and Mpakani where hydroelectric power is used as a source of energy.

Binary logistic regression technique was used to determine the relationship between independent variables (age, education level, household's size, occupation, and credit access and income level) in influencing GW use for irrigation. The independent variables are categorized into two distinct groups that are binary and continuous). The variables used in the regression are presented in Annex 1. The Hypothesis here was concerned with the influence of household characteristics on the GW usage. Binary Logistic regression analysis was used to test this hypothesis:

$$Logit(Y) = \ln\left(\frac{\pi}{1-\pi}\right) = \alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n + \varepsilon_i \quad (7)$$

Where: π is the probability of the event, α is the Y intercept, β_s are regression coefficients, and X_s are a set of predictors.

$$H_0 : \beta_1 = \beta_2 = \beta_3 = \ldots = \beta_k = 0 \quad (8)$$

(i.e. households' socio-economic and demographic factors have no effects on GW usage)

H_1 : At least one of the $\beta_s \neq 0$ (9)

(i.e. some household's socio-economic and demographic factors do have effects on GW usage)

3 RESULTS AND DISCUSSION

3.1 Socio-economic and Demographic Characteristics of Respondents

Table 1 presents the demographic and socio-economic characteristics of the respondents. Most of the respondents (73.2%) were in the age ranging from 18-35 years, which is productive and active working age group. This age group suggests that the selected respondents are the best representative sample since most of them are engaging in various activities and probably utilizing incentives available for economic development.

According to information presented in Table 1, most of the respondents (77.3%) were male while females constituted 22.7%, and out of which 81.4% were married couple.

Table 1: Respondent Characteristics

Parameter		Nyeregete (n=33)	Ubaruku (n=34)	Mwaluma (n=30)	Total (N=97)
Household heads' age group (years)	18 - 38	8 (24.2)	6 (17.6)	9 (30)	23 (23.7)
	39 - 59	15 (45.5)	19 (55.9)	14 (46.7)	48 (49.5)
	≥ 60	10 (30.3)	9 (26.5)	7 (23.3)	26 (26.8)
Household heads' sex	Male	22 (66.7)	29 (85.3)	24 (80.0)	75 (77.3)
	Female	11 (33.3)	5 (14.7)	6 (20.0)	22 (22.7)
Household heads' marital status	Single	0 (0)	1 (2.9)	0 (0)	1 (1.0)
	Married	27 (81.8)	30 (88.2)	22 (73.3)	79 (81.4)
	Divorced	2 (6.1)	1 (2.9)	1 (3.3)	4 (4.1)
	Widow	4 (12.1)	2 (5.9)	7 (23.3)	13 (13.4)
Household heads' education level	Primary	26 (78.8)	26 (76.5)	18 (60)	70 (72.2)
	Secondary	0 (0)	2 (5.9)	0 (0)	2 (2.1)
	Illiterate	7 (21.2)	6 (17.6)	12(0)	25 (25.8)
Household size (group)	2-5	16 (48.5)	14(41.2)	23 (76.7)	53 (54.6)
	6-9	14 (42.4)	20 (58.8)	7 (23.3)	41 (42.3)
	≥ 10	3 (9.1)	0 (0)	0 (0)	2 (3.1)

Numbers in brackets are percentages

The number of male respondents is high probably due to the fact that males are the bread winners in most cultures of Tanzania. This cultural setting makes males more aggressive in searching for every opportunity that can easily enable them to undertake their roles as household heads.

In terms of education level almost three quarter of respondents (72%) had primary education, very few (2%) had attained secondary education and about 25% had no formal education. Education plays a major role in the socio-economic development of many societies through the adoption of technology and innovation of new initiatives in the effort of fighting against poverty (Gama, 2018). With this kind of educational backgrounds, farmers need to be trained on the proper use of groundwater before they can be advised to invest on it as an alternative source of declining surface water for irrigation.

Table 2 shows that more than half of respondents (61.9 %) were engaged in crop farming, while others earn a living through other means including livestock keeping and petty business such as tailoring, bricks making, crop selling etc. It was observed crop production plays a significant role in income and livelihood support of many smallholder farmers. Numerous crops were grown in the Study area including paddy, maize, vegetables, onions, watermelons, sweet potatoes, and fruits. Participants in FGD reported that horticultural crops were mainly grown in backyard gardens irrigated by groundwater, and play a significant role in improving household income, food security and nutritious status. These results are in agreement with what was reported by Vilholth *et al*. (2013).

Table 2: Percentage distribution of households in economic generating activities

Variable	Nyeregete n= 33	Ubaruku n=34	Mwaluma n=30	Total (n=97)
Crop production	12 (36.4)	20 (58.8)	28 (93.3)	60 (61.9)
Crop production and livestock keeping	14 (42.4)	3 (8.8)	0 (0)	17 (17.5)
Crop production and petty business	2 (6.1)	9 (26.9)	1 (3.3)	12 (12.4)
Employment and crop production	0 (0)	1 (2.9)	1 (3.3)	2 (2.1)
Crop production livestock keeping and business	4 (15.2)	1 (2.9)	0 (0)	6(6.2)

Number in brackets are percentages

3.2 Groundwater sources in the Upper Great Ruaha River Catchment

The groundwater is abstracted from shallow wells, deep wells/ or boreholes. These wells are almost available in all villages and hamlets where surface water supply distribution networks do not exist or are unreliable. As shown in Table 3, more than half of the respondents (67 %) used groundwater from deep wells and few (33%) used shallow (drilled or dug) wells.

Table 3: Groundwater sources

Type of groundwater source	Nyeregete	Ubaruku	Mwaluma	Total
Deep well	0(0.0)	30(100)	30(100)	60(66.7)
Drilled Shallow well	30(100)	0(0.0)	0(0.0)	30(33.3)
Total	**30(100)**	**30(100)**	**30(100)**	**90(100)**

Note: Numbers in brackets are percentages

These results are in disagreement with a study that was conducted in 2012 by Population and Housing Census (PHC), which reported that dug wells are the main source of water in semi-arid rural areas of Tanzania, which are often an unprotected water source (URT, 2014). Probably this is because the sampled population of the three villages is quite small compared to the number of villages in Usangu Plains.

Collins (2010) defines dug wells as those excavated and lined by human labour. Often, most of them are small as 80 cm diameter, and can range in depth from about five metres deep, to wells over 20 metres deep. Moreover, during FGD in Nyeregete village, one of participant narrated that *"---both deep and drilled shallow wells provide adequate amount of water throughout a year"*

Plate 1a and b: Groundwater sources (a shallow well) in Nyeregete village, Usangu Plains (Photo by Mosha, D, 2016)

A deep well refers to a constructed well by either cable tool or rotary-drilling machines (van der Wal, 2010). Most of the deep wells in the Study villages are either 60 m deep or more, and the space around the casing is sealed with grouting material of neat cement to prevent contamination by dirty surface water (Mosha & Tarimo, 2019). Drilled shallow well comprise a pipe drilled into a soft ground, such as gravel or thick sand and a perforated pipe is attached at the end of the pipe to allow water to seep into the well. Besides, their construction is done in such a way that locally available materials are put into use.

2a

2b

Plate 2a and 2b: Deep wells in Mwaluma and Ubaruku villages respectively (Photo by Mosha, D, 2016)

3.3 Groundwater Use at household level

Findings indicate that groundwater has numerous uses mainly for domestic purpose, livestock, brick making and to a small extent backyard gardening. Table 4 shows the overall amount of groundwater used per day at the household level. The results showed that the overall mean of the amount of water used at the household per day was 221 litres. A household has an average of 5 people, which is equivalent to 44 litres per person per day in the Study villages. This is relatively high compared to the minimum amount of 20 litres per person per day as suggested at the national level (URT, 2015). The difference can be associated by the accessibility in terms of distance from the household to the water source and its adequacy. However, this amount of water is low compared to the United Nations (UN) recommendations on the water poverty line suggesting that a sufficient amount of water is at least 50 to 100 litres per person per day obtained from a safe source (Akoteyon, 2016). Reflecting that the amount of water used at the households' level in the Study villages did not meet the requirement of the UN.

Nevertheless, the results also show that the amount of groundwater used per person per day at Nyeregete village met the UN recommendations. Probably, the types of socio economic activities that used groundwater in Nyeregete led to high amount of groundwater used per day per person than other villages.

Table 4: Amount of groundwater used per household per day in litres (n= 90

Village	N	Mean	Std. Deviation	F	P. Value

Nyeregete	30	261.00	105.02		
Ubaruku	30	236.00	96.22	8.966	0.00
Mwaluma	30	166.00	63.65		
Total	**90**	**221.00**	**97.80**		
Amount of water used per person per day					
Nyeregete	30	49.97	37.39	1.249	0.292
Ubaruku	30	40.09	19.99		
Mwaluma	30	39.95	24.02		
Total	**90**	**43.34**	**28.22**		

The results also show that there was significant difference in terms of the amount of water used at a household per day in Nyeregete and Ubaruku villages at 0.1% level of confidence. Furthermore, findings indicate that there was significant difference between Mwaluma and Ubaruku villages at the 1% level of significance. The difference can be attributed to a number of factors including availability of other water sources. For instance, in this study, 100% of the households in Nyeregete village used groundwater because it was the only source available. The amount of water reported at a household in Nyeregete village was higher than the amount reported at a household level in Ubaruku and Mwaluma villages respectively (Table 4). Possibly, this variation is caused by differences in economic activities that were using groundwater resource. Through FGDs in Nyeregete village, it was reported that smallholder farmers were watering gardens using groundwater. However, in Mwaluma and Ubaruku, smallholder farmers were not using groundwater to water their gardens because of the belief that groundwater is hard water, which is unsuitable for plant growth including fruits. This perception has to be technically verified.

The results also show that there was significant difference in terms of the amount of water used per person per day at Nyeregete and Mwaluma villages at 0.1% level of confidence. Similarly, there was significant difference on the amount of water used per person per day at Ubaruku and Mwaluma villages at 0.1% (Table 4). Since these significant differences are in line with the significant differences on the amount of water used at the household per day between villages, it implies that the factors that influence the amount of water used at the household per day are likely to influence the amount of water used per person per day too. The key determinants of quantity of water use per day are household size, number of under-five years and wealth status of the household. Findings from FGD indicate the unprivileged groups are consistently using less amount of water than the better-off and middle-class groups. The difference between the groups is highly pronounced in Ubaruku, and Nyeregete than in Mwaluma village. Situational analysis in the two later villages shows that people had very few economic development project or petty business as compared to the former village. Moreover, the extent of dependence on groundwater increases up to 100% in all three villages during dry season, from May to November each year.

The second use of groundwater is livestock farming. Livestock plays an important role in people's livelihood in all three villages, particularly in Nyeregete village where some of the villagers are agro-pastoralists (Mang'ati) rely on the livestock for most of their income and food. Farmers said, all the better-off, middle and poor groups in all villages are generally able to increase the amount of water provided to livestock in the dry season from groundwater sources. The main reason for this is because livestock is a key source of income, food and nutrition for them.

3. 4 Irrigation Practices using Groundwater Source in the Study Area

In terms of irrigated agriculture, groundwater was observed and reported to irrigate paddy nurseries particularly in November and December and various horticultural crops (green vegetables, tomatoes, fruits tree, banana and onions) in backyard gardens. In Mont Fort Secondary School, field observation showed a range of horticultural crops (vegetables, bananas and yams, as well as citrus, mangoes, guava, avocado and pawpaw trees) are grown and irrigated by groundwater since 1998, and students use groundwater for all their basic needs.

Construction of dug wells was reported to be financed by households themselves. The mean average cost for constructing a dug well was estimated to be TZS 250 000 (USD 114) and these includes lining of the earth walls with bricks and a top cover (made with timber or aluminum corrugated sheets) of depth 9 – 23 m. Apart from construction costs, it also requires to have pumps or buckets tied with ropes for fetching water from the wells. Manual driven pump in the Study area cost about TZS 500 000 (USD 227), while a bucket with a rope will cost about TZs 20 000 (USD 9).Boreholes were owned by the community and according to the findings of the study they were either financed by the Government or Non-Governmental Organisation or Donors. The depth of these wells ranged from 60 to 100 m.

The cost of drilling these wells ranged from TZS 150 000 (USD 68) to 180 000 (USD 82) per meter depth. The preliminary survey for the wells to be drilled cost ranged from TZS 1 000 000 (USD 455) – 1 500 000 (USD 682) depending on the distance between the drilling company and the site. Community boreholes were reported to be used mostly for domestic water consumption with an exception of Mont Fort Secondary School where a borehole was found to be used not only for domestic water supply but also for a livestock unit, fish pond and also for small scale irrigation activities such as orchards, vegetables and paddy seedlings.

Plate 3 and 4: GW irrigation technologies in Mont Font Secondary School (Photo by Gama, D, 2016)

Plate 5 & 6: Groundwater use to irrigating paddy crop at Mont Fort Secondary School

(Photos by Gama, D 2016)

Plate 6: Groundwater use in fish farming at Mont Fort Secondary School (Photo by Mosha, D, 2016)

However, despite the fact that groundwater is increasingly proponent as a potential source for augmentation of irrigation in semi-arid and arid area in Tanzania including the UGRRC, so far its use in intensive irrigation activities is yet to be implemented. Farmers strongly argued that they had less knowledge on quality, abstraction and irrigation technologies on groundwater. This imply there is a potential of groundwater use as supplement to surface water for irrigation in the Usangu Plains and elsewhere in dry areas of Tanzania. This finding corroborates by the facts put forward by Villholth *et al.* (2013) arguing that many countries in SSA lags behind in terms of groundwater development and use for irrigation and Tanzania being one of them.

3.5 The beauty of groundwater

Groundwater is the water which is found under the Earth's surface in the soil pore spaces and in the fractures of rock formations. Groundwater is well suited to rural water supply in the UGRRC. This is supported by argument put forward by Foster *et al.* (2012) and Ngigi (2009) studies that groundwater is an attractive water resource for smallholders' farmers that allow incremental development, autonomy and flexibility of water use in the hands of individual farmers or small farmers groups. The characteristics of groundwater differ in a number of ways from surface water. Groundwater has proven to be a reliable and accessible water source for irrigation, which, offers opportunities that surface water sources cannot provide (ACPC, 2011; Walraevens *et al.,* 2015). Since groundwater responds slowly to changes in rainfall, the impacts of droughts are often buffered (Pavelic, 2012). In areas with a long dry season, groundwater is still available when sources such as rivers and streams have run dry. As Villholth *et al*. (2013) argues, groundwater can be used for irrigation as a mechanism of reducing risks associated with environmental degradation, rainfall variability and food insecurity. However, it is recognized that groundwater is currently an under-utilized resource in irrigation in the UPGRRC and elsewhere in Tanzania. Its use in irrigation could minimise the effects of crop failure which are associated with surface water depletion and unpredictable rainfall events (Pavelic *et al.*, 2012).

Furthermore, the beauty of groundwater also lies on: microbiologically uncontaminated and to a certain extent naturally protected from pollution. The resource is relatively cheap to develop, since large surface reservoirs are not required and water sources can usually be developed close to the demand (ACPC, 2011). These characteristics make groundwater well suited to the more demand responsive and participatory approaches that are being introduced into most rural water and sanitation programmes. Where groundwater is readily available, wells and boreholes can be sited using mainly social criteria qualified by simple hydrogeological considerations. However, problems arise in areas where communities are underlain by difficult geological conditions, where groundwater resources are limited and hard to find (Walraevens *et al.*, 2015).

The availability of groundwater depends primarily on the geology. Groundwater is stored within pore spaces and fractures in rocks. Where the pores or fractures are interconnected, groundwater can flow easily and the rocks are said to be permeable. Fractured or porous rocks (such as sandstones and limestones) therefore have a high potential for groundwater development. The availability of groundwater also depends to a certain extent on the volume and intensity of rainfall. However, research suggests that recharge to groundwater can occur even in arid parts of Africa. Since the volume of groundwater abstracted for rural domestic water supply is generally low, recharge to the aquifers is less important than the geology in determining initial yields, but very important in determining sustainability (Shaki & Adeloye, 2006).

Groundwater has excellent natural microbiological quality and generally adequate chemical quality for most uses. Nine major chemical constituents (Na, Ca, Mg, K HCO3, Cl, SO4, NO3 and Si) make up 99% of the solute content of natural groundwater. The proportion of these constituents reflects the geology and history of the groundwater (Shaki & Adeloye, 2006).

Minor and trace constituents make up the remaining 1% of the total, and their presence (or absence) can occasionally give rise to health problems or make them unacceptable for human or animal use (ACPC, 2011). Health problems are associated with elevated concentrations of arsenic and fluoride, or the deficiency of iodine. In some places the total salt content of the water is high and makes the water unsuitable for drinking (Walraevens *et al*., 2015).

3.6 Reasons for accessing and using groundwater

Table 5 shows the reasons that influenced access to groundwater resource apart from other sources. The results show that 40% of the respondents used groundwater because they perceived it to be clean. Other reasons include being the only source of water available and near walking distance. For instance, FGDs reported that majority of the people in Ubaruku village used groundwater than water from irrigation canals because it was considered to be clean while people from Nyeregete village reported that it was the only source available. With regard to the situation of water availability in Nyeregete, one of the key informants reported that *"----I thank God for groundwater availability at Nyeregete village. I sometimes ask myself, what would happen in our village if we should have no groundwater resource? Perhaps many people could migrate to other villages to sustain their livelihoods"*.

Table 5: Factors influencing access to and use of groundwater source (n=90)

Reasons	**Male**	**Female**	**Total**
Near walking distance to groundwater source	8(17.8)	6(13.3)	14(15.5)
Adequate groundwater source	2(4.4)	4(8.9)	6(6.7)
Affordability to groundwater charges	2(4.4)	6(13.3)	8(8.9)
Is the only source available	14(31.1)	12(26.7)	26(28.9)
Groundwater is clean and safe	19(42.2)	17(37.8)	36(40.0)
Total	**45(100)**	**45(100)**	**90(100)**

Note: Numbers in brackets are percentages

3.7 Cost and Benefit Analysis

3.7.1 Short Term Cost Benefit Analysis

Table 6 shows the results on the use of both surface and groundwater for irrigation on annual basis. Both surface water and groundwater small-scale irrigation had a positive gross margin of TZS 630 415 (USD 287) and 4 820 415 (USD 2191) respectively

Table 6: Profitability of using groundwater for irrigation

Operation	**Parameter**	**Surface water (TZS/ ha)**	**Groundwater (TZS/ ha)**

Production Cost [a]	(Wet season) **Paddy**		
	Nursery management	40 000	40 000
	Ploughing	162 500	162 500
	Furrowing	162 500	162 500
	Inputs (fertiliser, seeds, and pesticides per acre	296 250	296 500
	Planting	210 000	210 000
	Weeding	165 000	165 000
	Bird scaring	50 000	50 000
	Harvesting	500 000	500 000
	Total cost of production (paddy)	**1 586 250**	**1 586 250**
	Dry season (Onion)		
	Nursery management	NA	60 000
	Ploughing and basin preparation	NA	212 500
	Inputs (fertiliser seeds and pesticides)	NA	1 775 000
	Planting	NA	150 000
	Harvesting	NA	212 500
	Total cost of production (onion)		2 410 000
	Water use fee per year	50 000	150 000
Other cost	O and M [b]	0	2 300 000
	Others total cost	50 000	2 450 000
	Total Production cost	1 636 250	6 446 250
Benefits			
Crop yield (ton/ha/year)	Paddy	4.25	4.25
	Onion	NA	20
Output price (TZS/ton)		533 333	533 333
		NA	450 000
Total revenue (TZS/ton/year)	Paddy 4.25 Onion 20	2 266 665	11 266 665
Gross Margin [c]		630 415	4 820 415

Note: 1 USD = 2200 TZS

Data represent farm statistics from the harvest of the cropping season 2016

Production cost [a:] Production cost per hectare per season

O and M cost [b]: Operation and Maintenance Cost per year

Gross margin [c:] Total revenue from sale of crop — total cost of crop production

However, this is highly influenced by crop values, the price of inputs and outputs and the prevailing market situation. The revealed gross margin implies that the use of both surface water and groundwater for irrigation was able to cover all its associated cost of production.

It is worth noting that, highest gross revenue was obtained from the use of groundwater for irrigation despite its production being doubles that of surface water production cost. The possible reason for this may have been the use of groundwater gives an opportunity of having more than one cropping season per year. Whereas the Rufiji River Basin does not issue water permits for abstraction of surface water for irrigation purposes during dry seasons. Judging from the findings, the use of groundwater by smallholder farmers is economically viable. A study by Shah *et al.* (2013) ascertains that groundwater is economically worthwhile since it supports dry-season irrigation of smallholder farmers.

3.7.2 Financial viability of Groundwater

The depth of the wells used in CBA was adopted from the dug wells and also from motorised wells found in the Study area; as per report from the Mbarali District council and from the Rufiji Basin Water Board and also well labels. About 25 dug wells and 5 functioning machinery drilled wells were observed during the survey. Their depth ranged from 9 to 23 for dug wells with an average of 15 meters and 14 to100 meters for machine drilled wells. This study focused on three different types of well depths namely, 40, 50, and 100 meters. This is due to the reason that, the GW demands for initial capital increases as the well depths increases. Also shallow wells (both dug and machinery drilled wells) were reported to have low recharge capacity and sometimes they dry up completely during the dry season. As a result a 40 m well depth was chosen as a yardstick in the analysis of well depth to support small scale groundwater irrigation due to the empirical evidence observed during case study survey at Mont Fort Secondary School whereby their 40 m well depth supports water to the compound for domestics, livestock, fish pond and also small-scale irrigation.

Table 7 shows a summary of (Net Present Value) and Cost Benefit Ration (BCR) calculations for 1 hectare of paddy and one hectare of onion. As shown in Table 18, the highest NPV was observed while investing in 40 meters depth with the value of TZS 38 636 794 (USD 17 562), 23 032 915 (USD 10 470), and 19 807 103 (USD 9003) at the discounting rate of 12% 18% and 20% respectively. Likewise, investing in 50 and 100 meter depth had positive NPVs at the same discounting rate although less than that observed when investing in 40 meters deep well. The possible reason for this was due to the increasing cost of drilling as the well depth increases.

Table 7: Summary of the results of Cost Benefit Analysis

Parameter	40 meters deep (TZS/ha)	50 meters deep (TZS/ha	100 metres deep (TZS/ha)	Surface water irrigation (TZS/ha)

Investment	7 800 000	9 437 500	23 000 000	_
Production cost				
Maintenance cost and Operation	780 000	943 750	2 300 000	_
Inputs cost	3 996 250	3 996 250	3 996 250	1 586 250
Water use fee	150 000	150 000	150 000	50 000
Total Production cost	4 926 250	5 090 000	6 446 250	1 636 250
Crop Value	11 266 665	11 266 665	11 266 665	2 266 665
Net Benefit	6 340 415	6 176 665	4 820 415	630 415
NPV at 12%	38 636 794	35 997 029	14 133 330	4 534 025
NPV at 18%	23 032 915	20 879 629	3 045 165	2 947 353
NPV at 20%	19 807 103	17 763 101	833 783	2 615 663
CBR at 12%	6.55	5.27	1.69	-
CBR at 18%	4.48	3.61	1.16	-
CBR at 20%	4.05	3.26	1.04	-

Investing in groundwater had positive NPVs at a discounting rate of 12% 18% and 20% per hectare in all adopted well depth; this implies that the present value of benefits stream was greater than the present value of the cost stream. Therefore according to the NPV criterion, investing in groundwater by smallholder farmer is financially viable. The BCR was also greater than one and according to decision criteria, projects with BCR which is positive and greater than one are financially viable because the discounted benefits are higher than the discounted costs. These results supports to the observation made by Abric *et al.* (2011, Dittoh *et al.* (2013) and Namara *et al.* (2011). In different parts of Sub-Saharan Africa, groundwater has been developed by many smallholders' farmers because of its low investment that might be affordable by smallholder farmers also the investment was expected to have high return.

3.8 Socio-economic Factors Influencing the use of Groundwater by Smallholder farmers

Logit model wa use to analysis socio-economic factors that influence the use of GWI by smallholder farmers. The inferential test for goodness-of-fit, the Hosmer & Leme show (H-L) statistic, indicates that the model fits the data well at $p > 0.05$. The descriptive measures of goodness-of-fit also supports that the model fits the data well (Cox & Snell R2=0.189; & Nagelkerke R2=0.388). Households size ($P < 0.05$) was the ony descriptor which was statistically significant as the determinant of GW use (Pallanti, 2007). The results show further that the model performance is statistically significant (χ^2 (44.045) = 8, $p < 0.001$).

Referring to Table 8 household size was statistically significant ($P < 0.05$) and positively related to the use of GW by smallholder farmers. This implies that, when, the household size increases by one unit, there is an increase in the probability that the households will use GW for irrigation by 38.3%. The plausable explanation for this situation is availability of adequate labour to be deployed in groundwater small scale irrigation. Furthermore, this finding indicates that an increase in the number of the households leads to an increase in the ability and desire to diversify the available resource for food security and livelihoods support.

The findings indicate positive association between sex of the household head and the use of GW for irrigation. Male headed household are more likely to use GW for irrigation compared to female headed household probably because male headed households have more benefits on the use GW for irrigation than female headed households. This is because women have less access to resources like land, education and production assets (Ndiritu *et al*., 2011). The positive relationship between the use of GW for irrigation and age implies that, older farmers are more likely to invest in GW as compared to younger farmers. This can be associated with their experience for foresee event and also capital accumulation. In terms of household income level is positively related to the use of GW for irrigation, suggesting that household with high level of income are more likely to invest in GW irrigation as compared to poor households. This is consistent with findings of study carried out in Ethiopia (Gebregziabher *et al.,* 2013) which found that farmers with limited incomes are reluctant to adopt unfamiliar technologies. The result also suggest, there is positive association between the uses of GW for irrigation with the farmers linked with farmer's social networks and assets accumulation. This implies the importance of strengthening farmer's formal and informal associations.

Table 8: Logistic regression analysis result

Variable	B	S.E	Sig
Gender	1.181	0.979	0.228
Households size	0.383	0.190	0.043*
Age	0.020	0.30	0.501

Education level	16.224		0.777
Access to financial institution	19.235	10073.519	0.998
Social network membership	1.275	1.163	0.273
Households income level	0.000	0.000	0.777
Constant	-42.232	30063.844	0.999

The positive relationship between the use of GW for irrigation and age implies that, older farmers are more likely to invest in GW as compared to younger farmers. This can be associated with their experience for foresee event and also capital accumulation. In terms of household income level; it is positively related to the use of GW for irrigation. This suggests that households with high level of income are more likely to invest in GW irrigation as compared to the poor. This is consistent with findings of a study carried out in Ethiopia (Gebregziabher *et al.*, 2013) which found that farmers with limited incomes are reluctant to adopt unfamiliar technologies. The results also suggest, there is positive association between the uses of GW for irrigation with the farmers linked with farmer's social networks and assets accumulation. This implies the importance of strengthening farmer's formal and informal associations.

3.9 THREATS AND CHALLENGES ON THE GW USE

Major threats to groundwater resources in Usangu Plains include: pollution, overexploitation, management of abandoned water wells and inadequate data and information on safe yield of the aquifers (Sappa et al., 2015; Ibrahimu et al., 2010). In addition, farmers reported some challenges facing them on how to utilize groundwater effectively as follows: (i) lack of awareness, (ii) lack of capital, (iii) long distance to community boreholes which was said to provide quality water; (iv) suitability of groundwater for irrigation – in terms of salinity, alkalinity and acidity; (v) potential of groundwater in aquifer –the amount of water stored in aquifer is unknown and therefore decision on how much to use it is difficult; and (vi) pastoralists competition.

4 CONCLUSION

The majority of smallholder farmers in the Study area depend on groundwater sources particularly during dry season because they do not have an alternative. Therefore, in Usangu Plains groundwater storage and use offers a number of unique benefits, including potentially wider, more reliable and equitable access. Based on the Study findings there is a great potential of GW use for irrigation purposes in the UGRRC. This is evident from point of view where farmers use GW for backyard gardens, paddy nurseries, orchard, and bananas as well as for livestock. It is therefore, the views of the Authors that a country like Tanzania needs to unlock the potential of GW for use in irrigation activities that will fill the irrigation vacuum in the irrigation industry that has been created due to diminishing surface water. Furthermore, financial analysis has clearly shown that irrigation using GW is more profitable than that of using surface water.

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Annex 1: **Description of variables used in the Logistic Regression Model**

Variable	*Description*
Y	GW use for irrigation (1 = yes, 0=no)
X_1	Sex of households head (1 = female , 0 = male,)
X_2	Households size
X_3	Age of the respondent (years)
X_4	Access to financial institutions (1= yes; 0 = no)
X_5	Education level of households head (1= educated; 0 = illiterate)
X_6	Households income (TZS)
X_7	Social network membership (1 = yes, 0 = no)