Chapter 15

Valuing groundwater use

Resolving the potential of groundwater in the Upper Great Ruaha River Catchment of Tanzania

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15.1 INTRODUCTION

Globally, the use of groundwater has been growing rapidly, especially in low-income countries, where a range of factors including urbanization, industrialization, land-use changes, and population growth are putting pressure on water provision from surface waters, especially in drylands (Gronwall and Oduro-Kwarteng, 2018). Groundwater is typically viewed as a more resilient water supply option to surface water options for household supply (MacAllister et al., 2020). The population of sub-Saharan Africa (SSA) is projected to increase to between 1.5 and 2 billion with approximately 50% of the population living in urban areas by 2050 (Gronwall and Oduro-Kwarteng, 2018). This rising population will require safe drinking water, and water for irrigation to enhance food security (Osborn et al., 2015).

Changing climates including rising incidences of drought, higher temperatures, and changes in the frequency and intensity of extreme events accentuate water supply challenges in Africa (Mwakalila, 2014; Sappa et al., 2015). In the Upper Great Ruaha River Catchment (UGRRC) of Tanzania, for instance, it is suspected that river flow has been diminishing while the demand for irrigation water has increased (Mwakalila, 2011). Securing access to sufficient surface water is a growing challenge in this semi-arid catchment. Groundwater is increasingly considered as the most viable solution to sustain irrigation (Taylor et al., 2019). Groundwater, in principle, holds particular benefits including drought resilience and ubiquity as its widespread availability provides a buffer against climate variability (MacDonald et al., 2012; Taylor et al., 2013a). Here, we examine the role of groundwater as a freshwater source to sustain livelihoods in the UGRRC (Figure 15.1). Privately owned shallow wells and hand-dug wells have become the fastest-growing source of freshwater in the Usangu Plains.

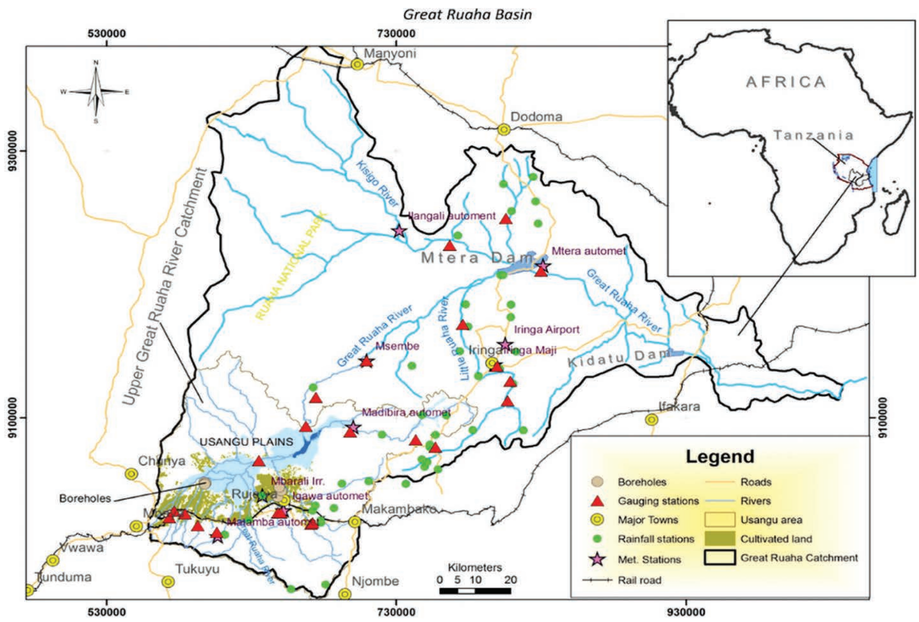

Figure 15.1 Map of the Upper Great Ruaha River Catchment showing major towns, drainage network, and hydrological monitoring stations.

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 issue is poverty, reflected in the need to realize the UN Sustainable Development Goals 2 and 6, and the aim of the National Water Policy to provide improved access to safe water supplies to all communities (Osborn et al., 2015; URT, 2002). To reach this goal, the delivery of groundwater through well-placed and appropriately constructed and maintained boreholes is vital. A vivid example is that of the city of Dodoma where the piped water supply derives entirely from a single wellfield (Taylor et al., 2013b). Second, increased water use for livestock and small-scale irrigation improves livelihoods and food security, and a pathway out of poverty (Tucker et al., 2014). Groundwater represents an untapped source of water in the UGRRC but technical, socio-economic, and institutional factors have so far constrained its use (Gudaga et al., 2018). Third, climate change intensifies precipitation and amplifies temperatures that strongly impact the availability of surface water. There is increasing evidence that while the availability of rainwater and surface water are projected to become more erratic and less reliable as a result of climate change, groundwater are less affected (Komakech, 2018; MacDonald et al., 2012) and may often be enhanced (Cuthbert et al., 2019). Enhancing water storage capacity, both above and below ground, is widely accepted as a coping strategy against hydrological extremes such as floods and droughts (Taylor, 2009; Damkjaer and Taylor, 2017).

A key question is whether groundwater can transform the productivity and climate resilience of smallholder farming to alleviate poverty and enable inclusive economic development. Many research papers and reports in the UGRRC (e.g. Kashaigili, 2010; Mwakalila, 2011, 2014; Gudaga et al., 2018; Gama, 2018) and across SSA (Howard, 2017) highlight that little is known about the role of groundwater use in supporting agricultural livelihoods or opportunities to expand this role in the future. Drawing evidence from focus-group discussions (FGDs) and ninety household interviews in the Usangu Plains (Figure 15.1), this chapter explores the following questions: (a) what are the uses of groundwater and what are the benefits of using it? (b) what are the costs and benefits of using groundwater for irrigation by smallholder farmers and how can they inform policymakers on how to unlock the potential of groundwater resources? (c) what are the factors that influence the adoption of groundwater-fed irrigation by smallholder farmers and what are the expected challenges? In this chapter, we adopted Abric et al. (2021) definition on smallholder referring smallholders are subsistence farmers, generally with landholdings that are smaller than 2 ha, privately owned, and under the complete control of the household head (Abric et al., 2011).

Field research was conducted under the *GroFutures* (Groundwater Futures in SSA) project under the UPGro (Unlocking the Potential of Groundwater for the Poor) program (2015–2020). Data were collected from three villages: Ubaruku, Mwaluma, and Nyeregete in Mbarali District (Figure 15.2), surveyed from 2017 to 2018. The FGDs and in-depth interviews occurred in 2016, 2017, and 2018. The protocol for interviews was approved by Sokoine University of Agricultural; opinions presented here reflect views on groundwater resources and users from these villages in the Usangu Plains. We show that groundwater is a vital resource for both low- and medium-income households, and in future is a pathway for rice commercialization and medium-scale livestock keeping.

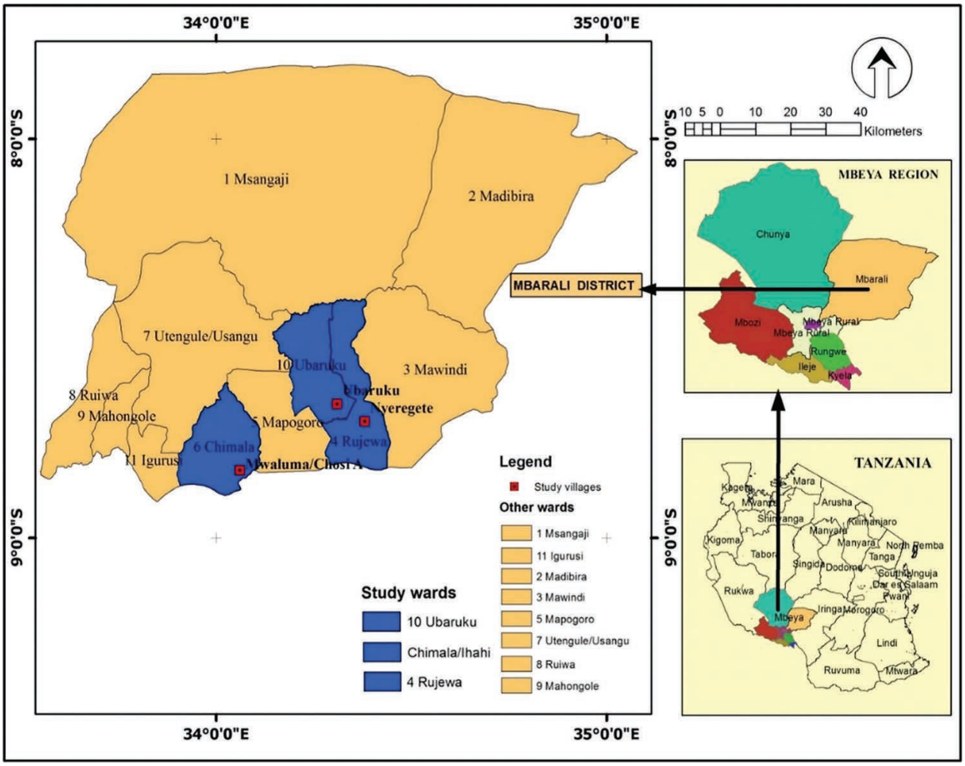

Figure 15.2 Map of Mbarali District showing the locations of the study villages: Ubaruku, Nyeregete, and Mwaluma.

15.2 METHODOLOGY

15.2.1 Study area

The study was conducted in the UGRRC and considered both technical and socio-economic aspects of groundwater resource assessment and management. The UGRRC was selected as a suitable site for investigation of groundwater matters as part of a larger study of allied basin observatories in Tanzania, Ethiopia, Niger, and Nigeria under *Gro-Futures*. 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 locally known as *Ihefu*, which is supplied by streams draining humid upland catchments in the Uporoto and Kipengere mountains. This area is critical to Tanzania as it provides livelihood for smallholder farmers and agro-pastoralists, contributes to food security, and sustains wetlands and their associated biodiversity that, in turn, flows downstream to the Ruaha National Park as well as the Mtera and Kidatu hydropower plants (Walsh, 2012).

The UGRRC is characterized by two distinct landscapes – central plain (Usangu Plains in Mbarali District) and highlands (Uporoto Mountain ranges). The villages of Ubaruku, Nyeregete, and Mwaluma are located in Mbarali District (Figure 15.2). The district lies between Latitudes 7°41′ and 9°25′ south, and between Longitudes 33°40′ and 35°40′ east at an altitude range of 1,010–1,100 m above sea level (Mwakalila, 2011). The climate of the area is mostly semi-arid with seasonal temperature and rainfall variations. Temperatures range from 20°C to 25°C, whereas the annual rainfall varies between 500 and 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 Mbarali District. Rainfall is generally unreliable and localized droughts are common (URT, 2010). According to 2012 national census, the Usangu Plains has a total population of ~790,500 and an annual growth rate of 2.7% (National Bureau of Statistics (NBS), 2012). The population is multi-ethnic and multi-cultural in which Sangu is the dominant indigenous ethnic group; other ethnic groups include Bena, Hehe, Maasai, Sukuma, and Nyakyusa. There has been a significant change in ethnic composition with increasing competition in land-use systems (SMUWC, 2001). Figure 15.2 shows the administrative boundaries of the study area.

15.2.2 Research design and data collection methods

The study uses mixed data collection methods that include: (a) review of existing documents on groundwater use and management in Tanzania; (b) FGDs; (c) key informant interviews; (d) household surveys; and (e) direct observation. In September 2015, a stakeholders' policy dialogue workshop involved twenty-eight participants was conducted to gain an understanding on the existing use of groundwater and the institutional framework governing water resources in the UGRRB and Tanzania. Between 2016 and 2018, the FGDs and key informant interviews were conducted to collect qualitative data on the role played by various stakeholders in groundwater development and management.

FGDs involved an average of ten participants per FGD (32 in total) comprising a diversity of gender social groups (men and women; youth and elders; and wealth category – poor, medium, and rich households). The proportion of women and men participants per group were broadly similar. Different categories of social groupings were consulted to get highlights on various aspects of the research including access points and responsible water management institutions as well as challenges and opportunities. Participants' direct observations were also undertaken to gain information on well locations and conditions, water access points, water abstraction technologies, and storage facilities. A total of twenty-six participants were involved in key informant interviews guided by a checklist of questions.

A quantitative survey was also deployed and involved ninty respondents comprising both male and female heads of households selected randomly from three sampled villages in Mbarali District. A semi-structured questionnaire was used to collect quantitative data. The questionnaire captured a number of variables included: household demographic data, groundwater source, uses and management aspects, technology for water abstraction, distribution, and storage as well as water and production costs, factors constant or enhance development and management of groundwater resources.

15.2.3 Data analysis

15.2.3.1 Descriptive analysis

Qualitative data collected were subjected to content analysis, reducing, and clustering information into small meaningful units based on themes, trends, frequency, and strongly held opinions. Interpretations were made by researchers and subsequently used in the discussions. Descriptive and econometric analyses were undertaken using the Statistical Package for Social Science (SPSS) (Pallanti, 2007). Descriptive statistical analysis was computed to determine frequency and percentages of socio-economic characteristics of the respondents. An econometric analysis, outlined in the following section, was conducted to examine the relations between dependent and independent variables.

15.2.3.2 Financial analysis

Net present value (NPV) and cost-benefit ratio (CBR) were calculated 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 computed from equations 15.1 and 15.2 following Lin and Nagalingam (2000):

$$\mathrm{NPV} = \sum_{i=0}^{n} \frac{B_t - C_t}{(1+r)^t} \tag{15.1}$$

$$\mathrm{CBR} = \frac{\sum_{t=1}^{T} \frac{B_t}{(1+r)^t}}{\sum_{t=1}^{T} \frac{C_t}{(1+r)^t}} \tag{15.2}$$

where

B = benefits 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 (C) component included the initial capital cost of the borehole, operation, and maintenance cost, water fee, market prices of inputs, the cost of plowing, 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 their present value for the investments with long lifespan. As the discount rate increases, the present value of future benefits and costs reduces. A discounting rate of 12% was used in this analysis as per the Bank of Tanzania (BOT) and outlined in their Monthly Economic Review (February 2017). Apart from the fixed discounting rate used by the Central Bank in Tanzania (BOT), the study also considered interest rates of 18% and 20% used by different microfinance banks in Tanzania as they are the main credit sources for smallholder farmers. There is, however, considerable uncertainty over the correct discount rate, and also high uncertainties are expected in agricultural production that can affect investment financial viability. In order to check how investment in motor pump-based smallholder irrigation is sensitive to cost and income changes, different scenarios were assumed. Scenario 1 posits an increase in production costs and reduced income, whereas scenario 2 posits an increase in production costs and increased income (Gebregziabher et al., 2016). More specifically, scenario 1 proposes a 25% increase in production costs and 10% decrease in income. According to Gebregziabher et al. (2016), the assumptions are that production cost and income may continue in an increased and decreased trend, respectively. On this basis, scenario 1 proposes a 25% increase in production costs and 10% decrease in income, whereas scenario 2 proposes a 100% increase in the production costs and 25% increase in income. Gebregziabher et al. (2013) noted that the size of land for production affects the investment economic viability due to the economies of scale whereby cost per unit of output generally decreases with an increase in the scale of production. Estimating the lifespan of an intervention is uncertain, subjective, and widely debated. Since the use of groundwater involves fixed costs which are capital intensive, lifespan is a critical variable to determine the viability of an investment as this affects the income stream over the proposed lifespan of the investment. It has been argued that boreholes are drilled and function for a lifespan of 20–50 years (Carter et al., 2014). Here, we employed an investment lifespan of 30 years that falls within this range.

15.2.3.3 Cost-benefit analysis basic assumptions

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

1. All costs and benefits are estimated in incremental terms and compared against the do-nothing option of no groundwater irrigation.
2. The analysis starts at year 0 when the initial investment costs of the groundwater infrastructure occurred, whereas maintenance and operational costs were assumed to start from the second year after the investment.
3. All production costs and benefits from using groundwater for irrigation were regarded with the assumption that, since it was difficult to forecast the cash flows for the entire lifespan of the investment, the 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 November–December 2016 market prices.
4. The depth of hand-dug and motorized wells in the study areas was extracted from reports from the Mbarali District Council, Rufiji Basin Water Board, and well labels. Depths range from 9 to 23 m (mean: 15 m) for dug wells and 14–100 m for machine-drilled wells. This analysis considers three different well depths of 40, 50, and 100 m as initial capital increases as well depths increase. Because shallow

(<15 m) wells, whether hand-dug and machine-drilled, are vulnerable to seasonal groundwater-level decline, a minimum borehole depth of 40 m was chosen to support small-scale groundwater irrigation.

5. Two production seasons in a year for groundwater irrigation were assumed where rice could be produced during the wet season and during the dry season the same field would be used to cultivate any other crop. This assumption follows the argument that through groundwater, a 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 backyard 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, rice seedlings, vegetables, onions, and orchard crops were grown in school gardens using groundwater in the dry season.
6. This analysis used onion as the second crop during the dry season. This was due to the argument that rice was reported as both a cash and food crop grown during the wet season, whereas onions, watermelons, and vegetables were reported as cash crops grown in the dry season. Thus, rice and onion were selected in estimating the viability of investing in groundwater irrigation by smallholder farmers. By considering such scenarios, the relative profitability of using groundwater for small-scale irrigation was compared to surface water irrigation.
7. 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.

15.2.3.4 Binary logistic regression

Binary logistic regression was used to determine the relationship between independent variables (age, education level, household's size, gender, occupation, and credit access, and income level) in influencing groundwater 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 Table 15.1. The hypothesis was concerned with the influence of household characteristics on groundwater usage. SPSS was employed to compute the Binary logistic regression.

Table 15.1 Description of variables used in the logistic regression model

Variable	*Description*
Y	Groundwater use for irrigation (1 = yes, 0 = no)
X_1	Gender of household 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)

15.3 RESULTS AND DISCUSSION

15.3.1 Demographic and socio-economic characteristics of respondents

Table 15.2 presents the demographic and socio-economic characteristics of the respondents. Most of the respondents (73.2%) were in the age ranging from 18 to 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 using incentives available for economic development.

According to information presented in Table 15.2, most of the respondents (77%) were male with female constituting 23%; 81% of the respondents were married. The number of male respondents is high probably because, in many rural settings, most households are headed by men, who are normally the key speakers for their households; very few women are designated as household heads in an individual family.

In terms of education level, almost three-quarters 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 order to alleviate poverty (Gama, 2018). Given prevailing educational backgrounds, there may be a requirement for farmers to receive information and training on groundwater and its use before they can consider investing in this source of water, despite declining surface water and more restrictive rules and by-laws restricting its use for irrigation during the dry season.

Table 15.3 shows that more than half of respondents (62%) are engaged in crop farming, while others earn a living through other means including livestock keeping and petty business such as tailoring, brick making, crop selling, etc. It was observed crop production plays a significant role in income and livelihood support of many smallholder farmers. Crops grown in the study area include rice, maize, vegetables, onions,

Table 15.2 Survey respondent characteristics

Household details		*Nyeregete (n = 33)*	*Ubaruku (n = 34)*	*Mwaluma (n = 30)*	*Total (N = 97)*
Household head age group (years)	18–38	8 (24)[a]	6 (18)	9 (30)	23 (24)
	39–59	15 (46)	19 (56)	14 (47)	48 (50)
	≥60	10 (30)	9 (27)	7 (23)	26 (27)
Household head gender	Male	22 (67)	29 (85)	24 (80)	75 (77)
	Female	11 (33)	5 (15)	6 (20)	22 (23)
Household heads' marital status	Single	0 (0)	1 (3)	0 (0)	1 (1.0)
	Married	27 (82)	30 (88)	22 (73)	79 (81)
	Divorced	2 (6)	1 (3)	1 (3)	4 (4)
	Widow	4 (12)	2 (6)	7 (23)	13 (13)
Household head education level	Primary	26 (79)	26 (77)	18 (60)	70 (72)
	Secondary	0 (0)	2 (6)	0 (0)	2 (2)
	Illiterate	7 (21)	6 (18)	12(0)	25 (26)
Household size (group)	2–5	16 (49)	14(41)	23 (77)	53 (55)
	6–9	14 (42)	20 (59)	7 (23)	41 (42)
	≥10	3 (9)	0 (0)	0 (0)	(3)

[a] Values given in parantheses are percentages; note that rounding errors may lead totals of 99% or 101%.

Table 15.3 Number and proportion of households in income-generating activities

Type of economic activities	*Nyeregete*	*Ubaruku*	*Mwaluma*	*Total*
Crop production	12 (40)[a]	20 (67)	28 (93)	60 (67)
Crop production & livestock keeping	14 (47)	2 (7)	0 (0.0)	17 (19)
Crop production & petty business	0	7 (23)	1 (3)	9 (10.0)
Employment & crop production	0	1(3)	1 (3)	2 (2)
Crop production, livestock keeping, business	4 (13)	0 (0.0)	0 (0.0)	2 (2)

N = 30 for each village.
[a] Values given in parantheses are percentages; note that rounding errors may lead totals of 99% or 101%.

watermelons, sweet potatoes, and fruits. Participants in FGDs 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 consistent with outcomes reported previously by Vilholth (2013).

15.3.2 Groundwater source and usage

Table 15.4 shows the distribution of respondents by groundwater source in the UGRRC. Approximately 66% rely on boreholes (shallow and deep boreholes) and the remainder (34%) rely on hand-dug wells. Twenty-five dug wells and five functioning types of machinery drilled wells were observed during the survey. These statistics corroborate numerous previous studies indicating that hand-dug wells and boreholes are available in rural settings in SSA where surface water supply distribution networks do not exist or are unreliable (Collins, 2000). Hand-dug wells are constructed, excavated, and lined by human labor (Figure 15.2). Most wells are small (80 cm diameter) and range in depth from 5 to 40 m. In the UGRRC and more broadly in Tanzania, hand-dug wells use a rope and a bucket to access groundwater.

Participants of the FGDs reported that hand-dug wells are under the management and ownership of individual households in which neighboring households have access to this water source. In Nyeregete, the majority (>50%) of users reported collecting adequate groundwater from hand-dug wells in contrast to users in the other two study villages (Ubaruku and Mwaluma). Water supplies from the hand-dug wells are used for domestic hygiene, livestock, house construction, and irrigation.

The other form of groundwater supply is boreholes (Figure 15.3). Borehole depths range from 40 to 120 m. These water sources are under the ownership and management of either village government or an organization, for example, in Ubaruku village there is Community Water Supply Organization popularly known as UBAMPA (a collaboration

Table 15.4 Distribution of respondents on accessing groundwater sources

Source	*Nyeregete*	*Ubaruku*	*Mwaluma*	*Total*
Boreholes	12 (40)	26 (87)	21 (80)	59 (66)
Hand-dug wells	18 (60)	4 (13)	0 (20)	31 (34)
Total	30 (100)	30 (100)	30 (100)	90(100)

Note: Values given in parantheses are percentages.

Figure 15.3 A hand-dug well (a) and a borehole equipped with hand pump (b) in Nyeregete village. (Photos: © Mosha 2016.)

between Ubaruku and Mpakakani villages), and Rujewa Small Urban Water Sanitation Authority. Field observations revealed that boreholes were equipped with either hand-pump or motorized using either solar power, diesel, or electricity. Figure 15.3 depicts a shallow borehole with a hand-pump and a borehole with a hand-pump.

In all study villages, the majority of the groundwater users reported collecting an adequate amount of water throughout the year, and are of the view that water from the borehole is safe and suitable for drinking and cooking. Groundwater users reported being able to collect adequate quantities of water from the boreholes throughout the year, representing a resilience to seasonal climate variability not permitted by surface waters.

15.3.3 Groundwater usage at household level

Findings from household surveys and FGDs reveal that groundwater has uses beyond domestic purposes and includes livestock, brick making, and irrigated gardening. Table 15.5 shows the overall volume of groundwater used per day at the household level. The results showed that the mean daily volume of water used in each household was 221 L. As each household has an average of five people,

Table 15.5 Quantity of groundwater used per household per day in liters (n = 90); standard deviation (σ)

Village	N	*Household water usage*		*Per capita water usage*	
		Mean	σ	Mean	σ
Nyeregete	30	261	105	50	37
Ubaruku	30	236	96	40	20
Mwaluma	30	166	64	40	24
Total	**90**	**221**	**98**	43	28

this per capita usage is equivalent to 43 L/day in the households surveyed in three villages. This total exceeds the minimum criterion of 20 L per person per day recommended nationally (URT, 2015) and observed in a similar study in Ethiopia (Tucker et al., 2014).

Generally, the amount of groundwater collected from water points was higher in Nyeregete village than in the other two villages (Table 15.5). The difference can be attributed to a number of factors including the availability of other water sources and distance from the household to the water point or source. For instance, in this study, 100% of the households in Nyeregete village relied on groundwater. In Mwaluma and Ubaruku, groundwater users were not using groundwater to water their gardens because they perceived that groundwater is hard water. In Nyeregete some water user irrigated their home garden using watering cans. Further, users reported variations in per capita water usage as a function of the proximity and availability (operationally) of water points. The relationship between the amount of water used and the distance from the compound has similarly been shown by Tucker et al. (2014).

The other main usage of groundwater is livestock husbandry. 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) who rely on the livestock for most of their income and food. Further, farmers in all three villages in this study reported that they, independent of their economic standing, are generally able to increase the amount of water provided to livestock in the dry season from groundwater sources.

15.3.4 Determinants of quantity of water use per day

Table 15.6 shows groundwater user perceptions of the determinants of quantity of water use per household. In all villages, users reported the key determinants of using a large amount of water are household size, number of under-5 years, and wealth status of the household. Among these variables, wealth status of the household ranks highest 94% (Table 15.6). Findings from FGDs indicate that poor households consistently use less water than the better-off and middle-class groups, due to partly engaging in fewer household activities, lower incomes, and labor shortages. Poorer households collected less water for domestic use (hygiene and cooking) because of less labor and cash. Labor shortages influence users to opt for the nearer hand-dug wells although the water is less safe compared to boreholes that are more distant located.

Table 15.6 Factors perceived to influence water quantity used per households

Factor	*Frequency*	*Percentage*	*Rank*
Household size	29	91	2
Number of under-5 years	27	84	3
Wealth status of the household	30	94	1
Other factors (distance to source; season)	18	56	4

Source: Qualitative data, 2016; reported percentages are not all based out of a total of thirty-two due to variations in responses.
N = 32 FGD participants.

These findings are also consistent with those of Tucker et al. (2014), who reported poorer households to use less water because they have less labor for water collection and fewer storage and transport assets.

Reported differences as a function of economic status/wealth category are more highly pronounced in Ubaruku, and Nyeregete than in Mwaluma. Situational analyses in the two later villages show that people had very few economic development projects 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 the dry season, from May to November each year.

15.3.5 Irrigation practices using groundwater source in the study area

In terms of irrigated agriculture, groundwater was observed and reported to irrigate rice nurseries particularly in November and December, and various horticultural crops (such as green vegetables, tomatoes, fruits tree, banana, and onions) in household gardens. In Mont Fort Secondary School, field observation showed a range of horticultural crops (e.g. vegetables, bananas, and yams, as well as citrus, mangoes, guava, avocado, and pawpaw trees) that have been grown and irrigated by groundwater since 1998. Students use groundwater for all their basic needs. Hand-dug wells are located around the household compound homestead, their construction 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 this includes the lining of the earth walls with bricks and a top cover (made with timber or aluminum corrugated sheets) ranging in depth from 9 to 23 m. Apart from construction costs, it also requires pumps or buckets tied with ropes for fetching water from the wells. Manual-driven pump in the study area costs about TZS 500,000 (USD 227), whereas a bucket with a rope will cost about TZs 20,000 (USD 9). The cost of drilling these wells ranged from TZS 150,000 (USD 68) to 180,000 (USD 82) per meter depth. This cost is relatively cheap when compared to the cost of drilling a borehole.

For boreholes, the costs of the preliminary survey alone range from TZS 1,000,000 (USD 455) to 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 livestock, fish ponds, and small-scale irrigation activities such as orchards, vegetables, and rice seedlings. Figure 15.4 displays rice seedlings and rice in a farm both irrigated by groundwater. The construction of boreholes was financed by the government of Tanzania through the Ministry of Water and development partners including UNICEF, DANIDA, and WWF.

Groundwater used to provide supplementary irrigation in the UGRRC is increasing but, so far, its use in intensive irrigation activities has yet to be realized. Farmers noted that they had very limited knowledge of groundwater quality, abstraction, and irrigation technologies. These responses suggest more intensive use of groundwater for irrigation may be considered if there was confidence that this magnitude of use could be sustained. This inference is consistent with that drawn by Villholth (2013) who noted that many smallholder farmers in Tanzania lag in their use of groundwater for irrigation because of lack of information and knowledge on groundwater resources and their usage.

Figure 15.4 Groundwater irrigation technology and rice farming in Mont Font Secondary School. (Photos: © Gama 2016.)

15.3.6 Reasons for accessing and using groundwater

Table 15.7 summarizes explanations provided in FGDs of factors that influence access to, and use of, groundwater resources. The results show that 40% of the respondents used groundwater because they perceived it to be safe. Other reasons include that it is the only source of water available and near walking distance. For instance, FGDs reported that the majority of the people in Ubaruku village used groundwater rather than water from irrigation canals because it was considered to be safe, whereas people

Table 15.7 Factors influencing access to and use of groundwater source (*n* = 90)

Reasons	*Male*	*Female*	*Total*
Near walking distance to groundwater source	8 (18)[a]	6 (13)	14 (16)
Adequate groundwater source	2 (4)	4 (9)	6 (7)
Affordability to groundwater charges	2 (4)	6 (13)	8 (9)
Is the only source available	14 (31)	12 (27)	26 (29)
Groundwater is clean and safe	19 (42)	17 (38)	36 (40)
Total	45 (100)	45 (100)	90 (100)

[a] Values in parentheses are percentages.

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".

15.3.7 Cost-benefit analysis

15.3.7.1 Short-term cost-benefit analysis

Table 15.8 summarizes the results of the economic analysis of the use of both surface water and groundwater for irrigation on annual basis. Smallholder irrigation by both surface water and groundwater small-scale irrigation has a positive gross margin of TZS 630,415 (USD 287) and 4,820,415 (USD 2191), respectively. Computed values are strongly influenced by crop prices, the prices of inputs and outputs, and the prevailing market situation. Positive gross margins imply that the use of both surface water and groundwater for irrigation is able to cover the costs of production. It is worth noting that highest gross revenue was obtained from the use of groundwater for irrigation despite its production costs being double that of surface water. These calculations suggest the use of groundwater by smallholder farmers is economically viable. A study by Shah et al. (2013) concludes that groundwater-fed irrigation is economically viable for smallholder farmers because it supports dry-season irrigation.

15.3.7.2 Financial viability of groundwater

Table 15.9 shows a summary of NPV and CBR calculations for 1 ha of rice and 1 ha of onion. As shown in Table 15.9, the highest NPV was observed for investing in a machine-drilled well of 40 m depth with the value of TZS 38,636,794 (USD 17,562), 23,032,915 (USD 10,470), and 19,807,103 (USD 9,003) at the discounting rate of 12% 18%, and 20%, respectively. Likewise, investing in a well with a depth of 50 and 100 m also had positive NPVs at the same discounting rate albeit less than that observed when investing in 40 m deep well due to the increased costs of drilling.

Investing in groundwater has positive NPVs at a discounting rate of 12%, 18%, and 20% per hectare for all considered well depths. In other words, the present value of the benefits stream is greater than the present value of the cost stream, suggesting

Table 15.8 Profitability of using groundwater (GW) and surface water (SW) for irrigation

Operation	*Parameter*	*SW (TZS/ha)*	*GW (TZS/ha)*
Production cost[a]	**Wet season (Rice)**		
	Nursery management	40,000	40,000
	Plowing	162,500	162,500
	Furrowing	162,500	162,500
	Inputs (fertilizer, 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 (rice)	**1,586,250**	**1,586,250**
	Dry season (Onion)		
	Nursery management	NA	60,000
	Plowing and basin preparation	NA	212,500
	Inputs (fertilizer seeds and pesticides)	NA	1,775,000
	Planting	NA	150,000
	Harvesting	NA	212,500
	Total cost of production (onion)		2,410,000
Other cost	Water use fee per year	50,000	150,000
	O and M[b]	0	2,300,000
	Others total cost	**50,000**	**2,450,000**
Benefits	Crop yield Rice (tonne/hectare/year)	4.25	4.25
	Crop yield Onion (tonne/hectare/year)	NA	20
	Output Price Rice (TZS/tonne)	533,333	533,333
	Output Price Onion (TZS/tonne)	NA	450,000
Total revenue	**TZS/tonne/year**	**2,266,665**	**11,266,665**
Gross margin[c]		**630,415**	**4,820,415**

Source: Data represent farm statistics from the harvest of the cropping season 2016.
Note: 1 USD = 2,200 TZS.
[a] Production cost per hectare per season.
[b] Operation and Maintenance Cost per year.
[c] Total revenue from sale of crop — total cost of crop production.

that investment in groundwater by smallholder farmers is financially viable. The CBR was also greater than 1 and according to decision criteria, projects with CBR which is positive and greater than 1 are financially viable because the discounted benefits are higher than the discounted costs. These results are consistent with similar economic analyses of smallholder farmers employing groundwater-fed irrigation by Abric et al. (2011), Namara et al. (2011), and Dittoh et al. (2013). The CBR is, however, strongly linked to the depth of the borehole, with a borehole of 100 m only marginally positive when 1 ha is irrigated.

Table 15.9 Summary of the results of the cost-benefit analysis for irrigation by groundwater (GW) using different well depths and surface water (SW)

Parameter	*GW 40 m (TZS/ha)*	*GW 50 m (TZS/ha)*	*GW 100 m (TZS/ha)*	*SW (TZS/ha)*
Investment	7,800,000	9,437,500	23,000,000	
Production cost				
Maintenance cost & 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/season	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	-

15.3.8 Socio-economic factors influencing the use of groundwater by smallholder farmers

Logistic regression was used to analyze socio-economic factors that influence the use of groundwater by smallholder farmers. The inferential test for goodness-of-fit (Hosmer & Leme statistic) indicates that the model fits the data well at $p < 0.05$. The descriptive measures of goodness-of-fit also support that the model fits the data weakly (Cox & Snell $R^2 = 0.19$) and moderately (Nagelkerke $R^2 = 0.39$). Of the considered variables (Table 15.1) including gender of household head, household size, respondent age, education level of household head, access to financial institutions, household income, and social network membership, households size ($p < 0.05$) was the only variable (beta value of 0.38) that was statistically significant as the determinant of groundwater use.

The outcome of the logistic regression implies that, when, the household size increases by one unit, there is an increase in the probability that the households will use groundwater for irrigation by approximately 38% (based on the computed beta value). One plausible explanation for this outcome is the availability of adequate labor to be deployed in groundwater smallholder irrigation. Furthermore, this finding indicates that an increase in the number of households (to an average of 6) leads to an increase in the ability and desire to diversify the available groundwater resource for irrigation that enhance food security and livelihoods support. Similar findings have been found in Ethiopia where higher household sizes were related to greater groundwater use (Tucker et al., 2014).

15.3.9 Threats and challenges on the groundwater use

Major threats to groundwater resources in Usangu Plains include pollution, overexploitation, and management of abandoned water wells. There is also inadequate data and information on the safe yield of wells not only in the UGRRC but also more widely in Tanzania (Sappa et al., 2015; Mjemah et al., 2010). In addition, farmers reported some challenges facing them on how to utilize groundwater effectively that include (a) lack of awareness, (b) lack of capital, (c) long distance to community boreholes which was said to provide quality water; (d) suitability of groundwater for irrigation – in terms of salinity, alkalinity, and acidity; (e) well and aquifer yields; and (f) competition for use with pastoralists.

15.4 CONCLUSIONS

The analysis of groundwater use in three villages of the UGRRC in southern Tanzania shows that groundwater offers important benefits to these communities. The most significant economic benefit is improved agricultural production, and in particular, the ability to produce a second crop during the dry season. CBR reduces with depth of boreholes as deeper boreholes have higher capital costs but are likely to provide more benefits. Irrigation using groundwater is more reliable and more profitable than using surface water due to the ability to produce a dry-season crop. It is concluded that wider adoption of groundwater-fed irrigation by smallholder farmers will provide opportunities to increase crop production and ensure food security and has the potential to increase income through the sale of surplus. The broad lessons of our analysis are expected to be relevant to other parts of semi-arid Tanzania, where groundwater-fed irrigation can address surface water shortages associated with climate variability and change.

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