

Article

Quantification of Groundwater Exploitation and Assessment of Water Quality Risk Perception in the Dar Es Salaam Quaternary Aquifer, Tanzania

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Abstract: This study quantified groundwater exploitation and assessed water quality risk perception in the Dar es Salaam quaternary aquifer through a socio-economic survey. Annual total groundwater exploitation was estimated, using the daily per capita consumption of groundwater derived from the household survey. A logistic regression analysis was performed to ascertain the influence of sex, marital status, education level, employment, income, and cost of water on groundwater quality risk perception. It was revealed that most residents of Dar es Salaam use groundwater as a main source of water supply. The results of this study further showed that 78% consider groundwater as a reliable source. Averting strategies for insufficient quantity of groundwater consist of minimizing less necessary water uses, while for poor quality, buying bottled water and water treatment by boiling and using chemicals. The chance for water quality risk perception is 0.205 times greater for married than unmarried household heads, and it is 623 times higher for employed versus unemployed household heads. To get an overall view of the importance of groundwater for domestic needs in Dar es Salaam it is imperative to combine a time series data of groundwater and surface water exploitation.

Keywords: household survey; groundwater quantity; groundwater importance; groundwater quality awareness; quaternary aquifer

1. Introduction

Clean drinking water plays an important role in protection of health and reduction of poverty in households. Therefore, access to clean water is one of the indicators of poverty levels. Arguably, water is increasingly becoming a scarce commodity; particularly in large cities of developing countries [1], where households usually have the choice between piped and non-piped sources. These sources have different characteristics and levels of services (e.g., price, distance to the source, quality, availability, etc.) [2]. Getting water from non-tap sources outside the house invariably involves collection costs which must be considered in water development projects [3]. Notwithstanding the role of water in both economic and health aspects, water sources are becoming overexhausted and polluted, thus making it scarcer and too expensive for households to afford. According to previous research [4], nearly one sixth of the world population is without access to safe water, and most of them reside in the developing countries. Moreover, as a result of increasing pollution of surface water, demand on groundwater has greatly increased. Thus, helping people obtain safe drinking water is a critical step towards social and economic prosperity and development [5]. Nevertheless, expanding coastal populations and emerging industrial activities in Dar es Salaam, Tanzania are exerting pressures on coastal aquifers, thus

negatively affecting groundwater quality through saltwater intrusion and other chemical pollutants [6]. In that regard, Dar es Salaam has frequently been the epicenter of water-borne and water-related diseases. Thus, as a result of unsafe water, its people are keen at instituting mitigation measures as suggested by [7–10].

Furthermore, previous research [11] estimated that 1.8 million people in developing countries die every year from diarrhea and cholera, and out of these, 90% are children under the age of five years. Arguably, 88% of diarrheal diseases are attributed to unsafe water supply, inadequate sanitation and hygiene [11]. The situation is not very different in Pakistan, where the crisis of drinking water pollution has been reported by other researchers [12,13], where access to safe drinking water is estimated to be available to 23.5% of population in rural areas and 30% in urban areas, with 0.2 million children dying every year due to diarrheal diseases. In that regard, inadequate drinking water not only results in more sickness and deaths, but also augments health costs, leading to lower worker productivity and school enrolment. Other economic effects of unsafe drinking water include changes in household expenditures and well-being in terms of medical costs, earning lost, lost production in the household, lost leisure time, and mitigating expenditures. It is thus important to investigate the extent of groundwater exploitation, water quality problems, and needs, consequences of overexploitation and the mitigation strategies to unsafe water services.

Following immense concerns on water quality, previous studies [14] provided a conceptual model which describes the linkages between changes in groundwater quality and the services received by households. In addition, other researchers described the averting behavior approach to the valuation of drinking water quality [15] while the cost of water pollution using averting expenditure increase of household to cope with contamination was investigated [16]. A general conclusion was that estimates obtained through averting expenditure analysis can reliably be used for groundwater policy improvement and decisions. Moreover, in most averting studies, the main averting strategies were found to be boiling, hauling, and purchasing bottled water. Reportedly, the average monthly household defensive expenditures were found to be between US\$16 and US\$35 [17]. Further to that, some insights into public preferences for water quality improvements were provided using contingent valuation survey [18], while other researchers [2] estimated the mean willingness to pay for drinking water quality improvement to be 0.3% of total household income. In previous works [19], it was reported that the estimates of willingness to pay are significantly higher for households without self-protective actions. In addition, a multinomial model of averting behavior in response to water contamination risks for Georgia residents was used [20]. In that study, the main determinants of perceived risk from tap water quality were found to be race and age. Using nitrates found in household wells, ref. [21] demonstrated that perceptions of health risks across exposure levels are affected by the individual's current exposure level.

Different researchers perceive the consequences of groundwater overexploitation differently. It is argued by [22] that it is predominantly the point of view of over-concerned conservationists and people suffering from real or assumed damage, and not always of well-informed people. Previous works [23] asserted that perception on groundwater overexploitation is an unconscious and sometimes incited overreaction to a particular situation. In that very same line of thinking, it was argued that groundwater overexploitation is a result of deeply entrenched hydromyths [24]. Generally, exploitation of groundwater for domestic uses is mainly determined by unreliability of alternative sources of water and perception on quality of other sources of water. Notwithstanding different views on groundwater uses, groundwater overexploitation is a worldwide phenomenon with serious consequences but few effective solutions [25].

While there are enormous efforts to provide drinking water, which win the trust of consumers in developing countries, Tanzania included, the perception of drinking water quality and risks are inadequately understood [26]. Therefore, the study quantified the extent of exploitation of groundwater in the Dar es Salaam aquifer; analyzing water quality risk perception, assessing averting actions to groundwater quality and quantity problems, and establishing levels of groundwater reliability and importance for meeting household water needs.

2. Materials and Methods

2.1. Study Area Description

Most residents of Dar es Salaam use groundwater as a main source of water supply as reported by [27]. As such, the first borehole was drilled at Temeke Dairy Plant in 1943, which was only 30 m deep, with a yield of 8 m³/h [28]. In 1949 surface water supply started to replace groundwater as a source of water in Dar es Salaam after the Mtoni Water Treatment Plant on Kizinga River was constructed. This was further increased after the construction of the Upper and Lower Ruvu Water Treatment Plants on Ruvu River in 1959 and 1975, respectively. However, due to population growth, water demand in Dar es Salaam has kept on increasing. Therefore, groundwater has helped to reduce pressure on water scarcity in the city.

2.2. Household Survey Design and Sampling Procedure

A non-random, non-probabilistic sampling method (Snowball sampling technique) was mainly used to collect household data on the magnitude of awareness, perception, practices, and exploitation of groundwater in Dar es Salaam. This is because it was not practically feasible to carry out random sampling for groundwater consumers in Dar es Salaam since groundwater consumers are not homogenous and are not located in one location. In addition, in non-probability sampling, since elements are chosen arbitrarily, it is impossible to estimate the probability of any one element being included in the sample. Thus, when using non-probability sampling technique, no assurance is given that each item has a chance of being included, making it impossible either to estimate sampling variability or to identify possible bias.

Therefore, by using that survey design and its inherent methods, we began by a reconnaissance survey to identify households which meet the criteria for inclusion in the survey. The criteria included, but were not limited to owning a borehole, water needs met through an access to a nearby borehole, and medium to lower income households. After the interview, the interviewee was asked to recommend other nearby groundwater consumers or borehole owners. Snowball sampling technique was especially useful because we were trying to reach populations that are inaccessible and hard to find. From the non-probabilistic sampling method, a deterministic sample size of 200 households was chosen, consisting of small to medium groundwater users in the study area. The household survey covered Mbagala, Mtoni, Vingunguti, Tabata, Mwenge, Ubungu, Kawe, and Manzese suburbs (see Figure 1).

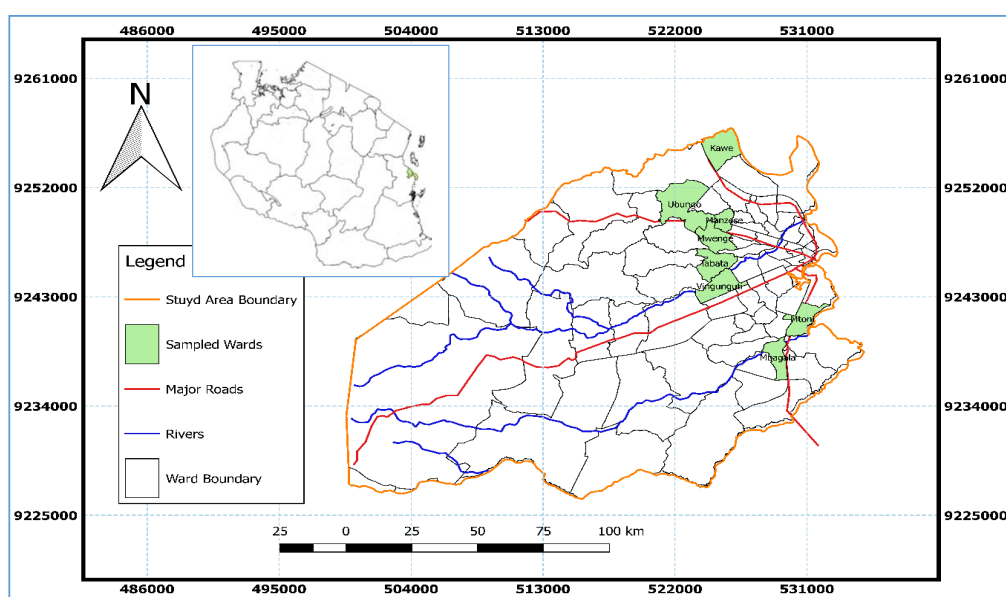


Figure 1. Map of Dar es Salaam showing surveyed areas.

2.3. Quantification of Groundwater Exploitation

Percentile and quartile analyses were first carried out to correct for outliers in the groundwater exploitation data. Upward and downward errors of groundwater exploitation data were also calculated to determine the extent of data dispersion, and thus determine the most appropriate and symmetrical sample size (n) from which groundwater consumption would be realistically estimated using central tendency measures (e.g., mean or median).

Specifically, skewness coefficient was calculated to characterize the location and variability of groundwater exploitation dataset. Downward error, (Q_2 —Minimum value) and upward error (Maximum value— Q_2) were also determined to indicate data dispersion, where Q_2 is the second quartile of the data. As for skewness, any value above 0 indicated that the data are skewed to the right while skewness below 0 is an indication that the data are skewed to the left, and therefore all datasets needed an adjustment. Mathematically, skewness is given as shown in Equation (1).

$$\text{Skewness} = \frac{\sum (x - \bar{x})^3}{(n - 1)s^3} \quad (1)$$

where s is the sample standard deviation, Σ means sum all the values, and $\bar{x}$ represents a sample mean, n is the sample size and x is the sample variable.

The interquartile range (IQR), which is usually the difference between the third quartile (Q_3) and the first quartile (Q_1) was used to find out the outlying data points. The rule of thumb was, the observations which fell below $Q_1 - 1.5(\text{IQR})$ or above $Q_3 + 1.5(\text{IQR})$ were regarded as outliers, and thus were disregarded when estimating per capita exploitation of groundwater in the Dar es Salaam aquifer. After eliminating the outliers, average groundwater consumption was used to compute per capita groundwater consumption using the mean household size. Using the population data of the study area, annual total domestic groundwater exploitation was estimated, using the daily per capita consumption of groundwater derived from the household survey.

2.4. Groundwater Importance and Averting Behavior Analysis

The basic assumption of the averting behavior analysis is that a decision to adopt an averting activity against polluted and inadequate water is a three-step process, beginning with the fact that households in the study area have been exposed to problems of water pollution and scarcity, and they perceive that the problems exist. Secondly, with their level of perception, households must decide whether actions to avert water shortages and quality problems should be taken or not, and this involves a decision on which kind of action should be chosen to mitigate the problems. The choice of an averting action is governed by the fact that people make choices to maximize their level of well-being when faced with exposure to water problems, which makes a groundwater consumer to move towards more reliable alternatives. The third step puts forward the fact that households must decide on the intensity of the averting action. A household's averting cost is usually used as an indicator of the intensity of averting action.

In this survey, households were asked about several averting behavior and actions regarding groundwater quantity and quality issues. These included estimating time spent collecting water (including time spent walking to and from a water source and time waiting for water), purchasing bottled water, purchasing water from vendors, water treatment (including the use of filters, chemicals and boiling), and water storage (including purchasing the storage facilities).

2.5. Groundwater Quality Risk Perception Assessment

Given different levels of income, occupation, education, and other socio-economic variables, it was postulated that different households perceive the risk of groundwater contamination (quality) and scarcity (quantity) differently. Therefore, the probability that households take action to mitigate

groundwater problems is a function of perceived risk, which is possibly determined by some socio-economic factors.

The main factors of risk perception of groundwater quality and quantity were modeled using the binary logit model to describe the relationship between the perception of risk and a set of independent variables, which explain the response to risk factors. An independent variable with a regression coefficient not significantly different from 0 ($p > 0.05$) was termed not to contribute to the regression model, but whenever the variable was found to be statistically significant ($p < 0.05$) it was thought to contribute significantly to the prediction of the outcome variable, which is groundwater quality risk perception.

The goal of applying logistic regression was to find the best fitting model to describe the relationship between water quality risk perception and a set of independent variables which explain the response to groundwater quality risk factors. Logistic regression generates the coefficients, the odds ratios, and significance levels of a model to predict a logit transformation of the probability of risk perception. The binomial logistic model was in the following form (See Equation (2)).

$$\ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1x_1 + \beta_2x_2 + \beta_3x_3 + \beta_4x_4 + \beta_5x_5 + \beta_6x_6 \quad (2)$$

p is the probability of risk perception, β_0 is the model constant, β_n are the factor coefficients. $\{n = 1, 2, 3, 4, 5, 6\}$ which are (1) sex of respondent (male/female), (2) marital status, (married/unmarried) (3) education level, (educated/not-educated) (4) employment, (employed/unemployed) (5) income (high/low) and (6) the cost of water (high/low).

Since risk perception occurs with probability p , then the possibility of perceiving a risk is equal to $\ln\left(\frac{p}{1-p}\right)$.

When the probability of risk perception is less than the probability of not perceiving a risk, then the odds ratio will be less than 1. When the probability of perceiving a risk is greater than the probability of not perceiving a risk, the odds ratio will be greater than 1.

Moreover, Likert scale has been used, containing several statements with a weighting scale after each statement, specifically designed to determine the perception of sampled residents of Dar es Salaam on the importance and reliability of groundwater supplies. For groundwater importance, the Likert scale contained the statements “Not Important (1), Somehow Important (2), Important (3) and Very Important (4)”. As for reliability, the scale was “Poor (1), Fair (2), Good (3), and Very Good (4)”.

However, take note that the use of the “uncertain” or a “neutral” category is controversial because it allows the subject to avoid making a clear choice of positive or negative statements. Therefore, only four options were given, which is known as a forced-choice Likert scale. The average Likert score was calculated as follows:

Average Likert Score = {(Number of responses for Likert category 1 × Weighting for the Likert scale category 1) + (Number of responses for Likert category 2 × Weighting for Likert scale category 2) + (Number of responses for Likert category 3 × Weighting for Likert scale category 3) + (Number of responses for Likert category 4 × Weighting for Likert scale category 4)}/Total Number of respondents.

All the data were cleaned, coded and analyzed using a Statistical Package for Social Sciences (SPSS 16). The analytical techniques in this study included descriptive statistics, cross tabulation, and binomial logistic regression model. Moreover, R and Excel software were used for additional data analysis and graphical representation of the data.

3. Results

3.1. Groundwater Exploitation

Table 1 summarizes statistical results for outlier analysis with sample sizes $n = 200$, $n = 168$, and $n = 156$. The results show that for all three sample sizes, the minimum value is 2, while the first

quartile (Q_1) is 8 for $n = 200$, and 7 for both $n = 168$ and $n = 156$. In addition, the second quartile values (Q_2) for $n = 200$, $n = 168$, and $n = 156$ are 14, 12 and 10 respectively while the third quartile (Q_3) values are 25, 18, and 16 for $n = 200$, $n = 168$, and $n = 156$ respectively. The maximum and minimum values are reflected in the values of upward and downward errors and as shown in Table 1.

Table 1. Quartile data for outlier analysis (20-liter buckets/day).

Statistic	n = 200	n = 168	n = 156
Minimum	2	2	2
Q_1	8	7	7
Q_2	14	12	10
Q_3	25	17.75	16
Maximum	600	50	30
Error down	12	10	8
Error up	586	38	20

After outlier analysis, it was found that groundwater exploitation data have a big upward error for $n = 200$ (Table 1), which was 586. Therefore, the consumption parameters generated using $n = 200$ to compute groundwater exploitation could be misleading. Equally important, skewness for $n = 200$ was found to be 3.4 (Table 2), which corresponds to the observed large upward error. This indicates that the data are extremely skewed to the right (Figure 2), and thus the use of mean or median for computing groundwater exploitation is highly unrealistic. In addition, the percentile analysis as shown in Table 3 shows that for slightly over 70% of the dataset, the maximum quantity was 25 20-liter buckets per day (approximately 500 L/day), indicating that the dataset has a very large upward error as depicted in Table 1. This suggests a need for dataset adjustment using bias correction statistical methods. Figure 3 shows the classes of groundwater exploitation, with the largest consumption being from 0–20 20-liter buckets per day, which is approximately 70% of the sampled households in the study area. This is equally an indication that the data is skewed to the right since the class consuming 101 to 600 20-liter buckets per day makes only 12.5% of the households.

Table 2. Summary statistics of daily consumption of water.

Statistical Variable	Summary Data (n = 200) (20-Liter Buckets)	Summary Data (n = 168) (20-Liter Buckets)	Summary Data (n = 156) (20-Liter Buckets)
Mean	46.30	14.10	11.89
Std. Error of Mean	6.50	0.79	0.51
Median	14.00	12.00	10.00
Mode	10.00	10.00	10.00
Std. Deviation	91.83	10.29	6.34
Skewness	3.40	1.77	0.66
Minimum	2.00	2.00	2.00
Maximum	600.00	50.00	30.00
$Q_1 - 1.5(IQR)$		−17.50	−6.50
$Q_3 + 1.5(IQR)$		50.50	30.00

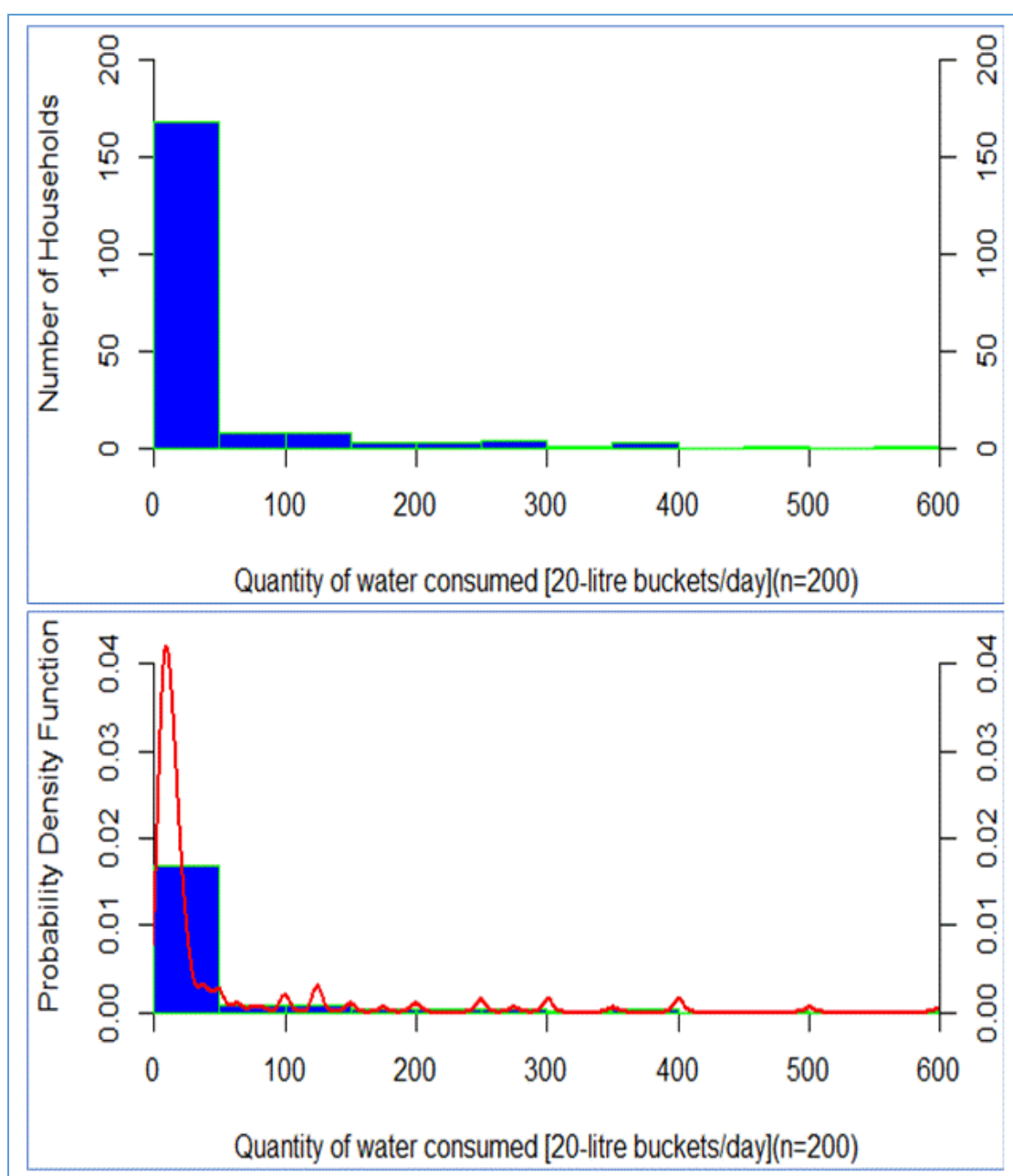


Figure 2. Skewness data for groundwater consumption at $n = 200$.

Table 3. Percentile analysis of groundwater exploitation data.

Percentile Classes	Quantity Exploited ($n = 200$) (20-Liter Buckets)	Quantity Exploited ($n = 156$) (20-Liter Buckets)
10	5.0	5
20	7.0	6
30	9.7	8
40	10.0	10
50	14.0	10
60	16.0	12
70	20.0	15
80	38.4	17
90	125.0	20
100	600.0	30

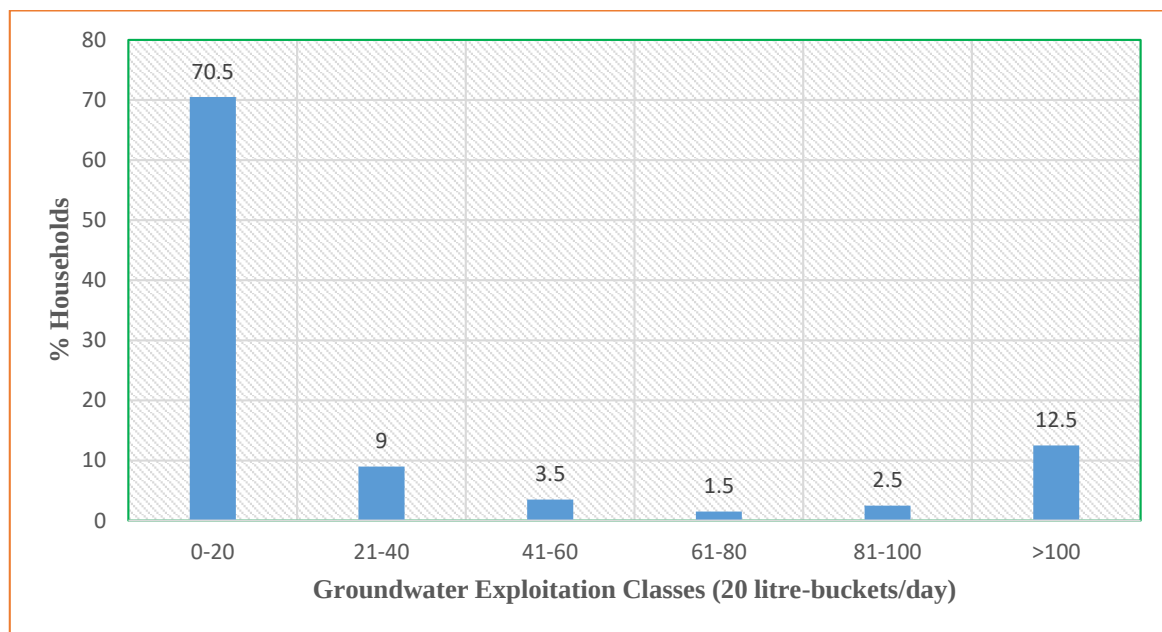


Figure 3. Groundwater exploitation classes.

In that regard, the IQR of the groundwater consumption dataset was calculated to help figure out how precise the groundwater exploitation data are. IQR also helped to eliminate outliers from the groundwater exploitation dataset, and therefore make it realistic to use the central tendency measures (e.g., mean, median) to estimate groundwater exploitation from households.

Given that the first quartile (Q_1) = 8, and the third quartile (Q_3) = 25, the IQR was found to be 17, (i.e., $25 - 8$). Thus, all the data which fell below $Q_1 - 1.5(\text{IQR})$ and all the exploitation data which fell above $Q_3 + 1.5(\text{IQR})$ were regarded as outliers, and they were disregarded from the calculation of groundwater exploitation. It follows, therefore, that $Q_1 - 1.5(\text{IQR}) = -17.5$, and $Q_3 + 1.5(\text{IQR}) = 50.5$. This reduced the sample size to $n = 168$. However, the results for $n = 168$ show that the groundwater consumption data are reasonably realistic but the skewness coefficient (1.77) still indicated that the exploitation data are asymmetrical, being skewed to the right (Figure 4). Skewness was also shown graphically in terms of the probability distribution of the groundwater exploitation data about its mean.

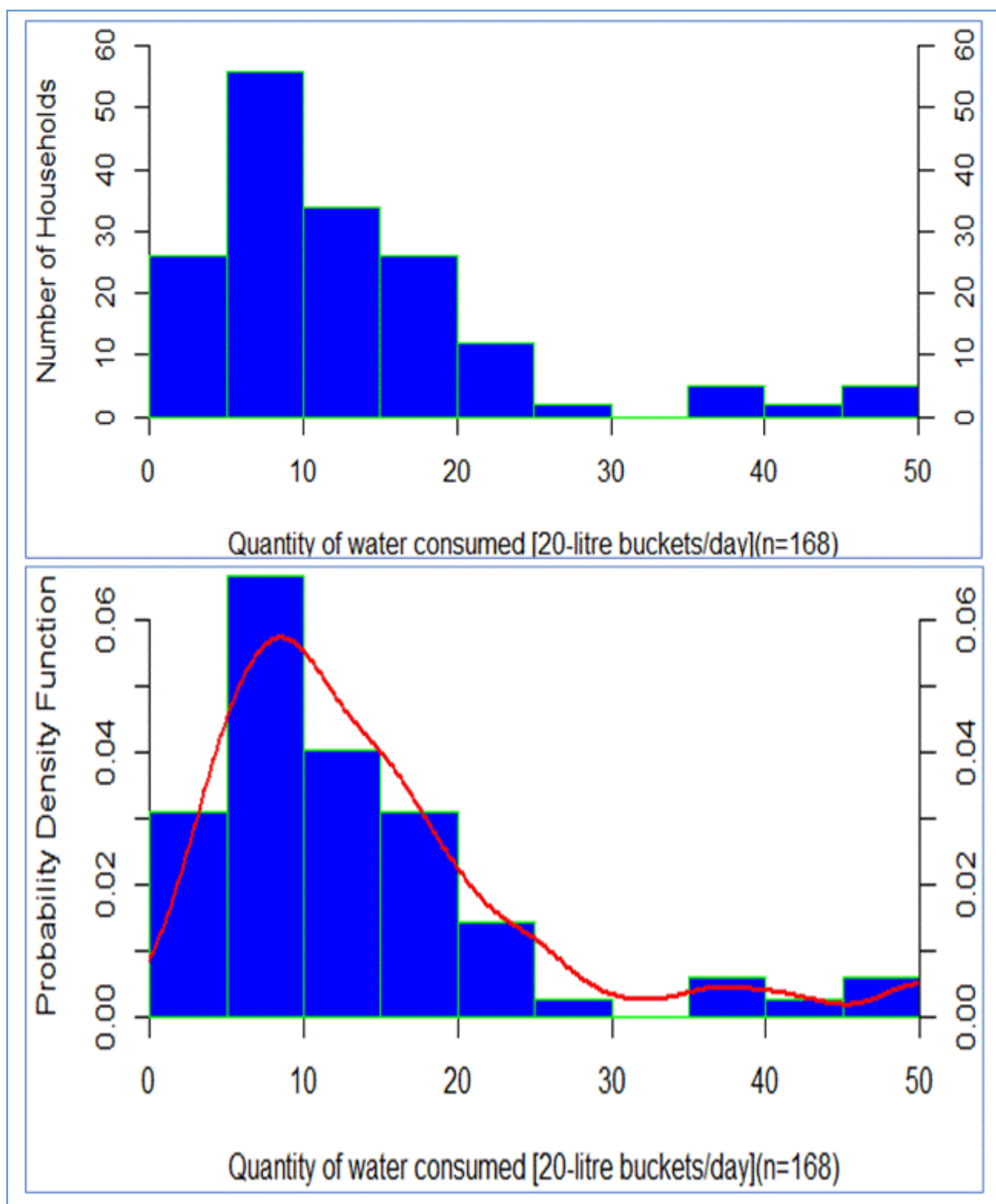


Figure 4. Skewness data for groundwater consumption at $n = 168$.

Figures 3–5 represent groundwater consumption data but using different sample sizes ($n = 200$, $n = 168$, and $n = 156$ respectively). The graphs show an attempt to deal with skewed data, and a procedure on how skewness was dealt with to attain a reasonably normal sample which is less skewed for estimating central tendency measures which are not biased. This graphical visualization of the skewness of the data, indicate that the data in Figures 3 and 4 ($n = 200$ and $n = 168$ respectively) have high positive skewness as the tails are on the right, which cannot meaningfully be used for estimation of groundwater exploitation using central tendency values.

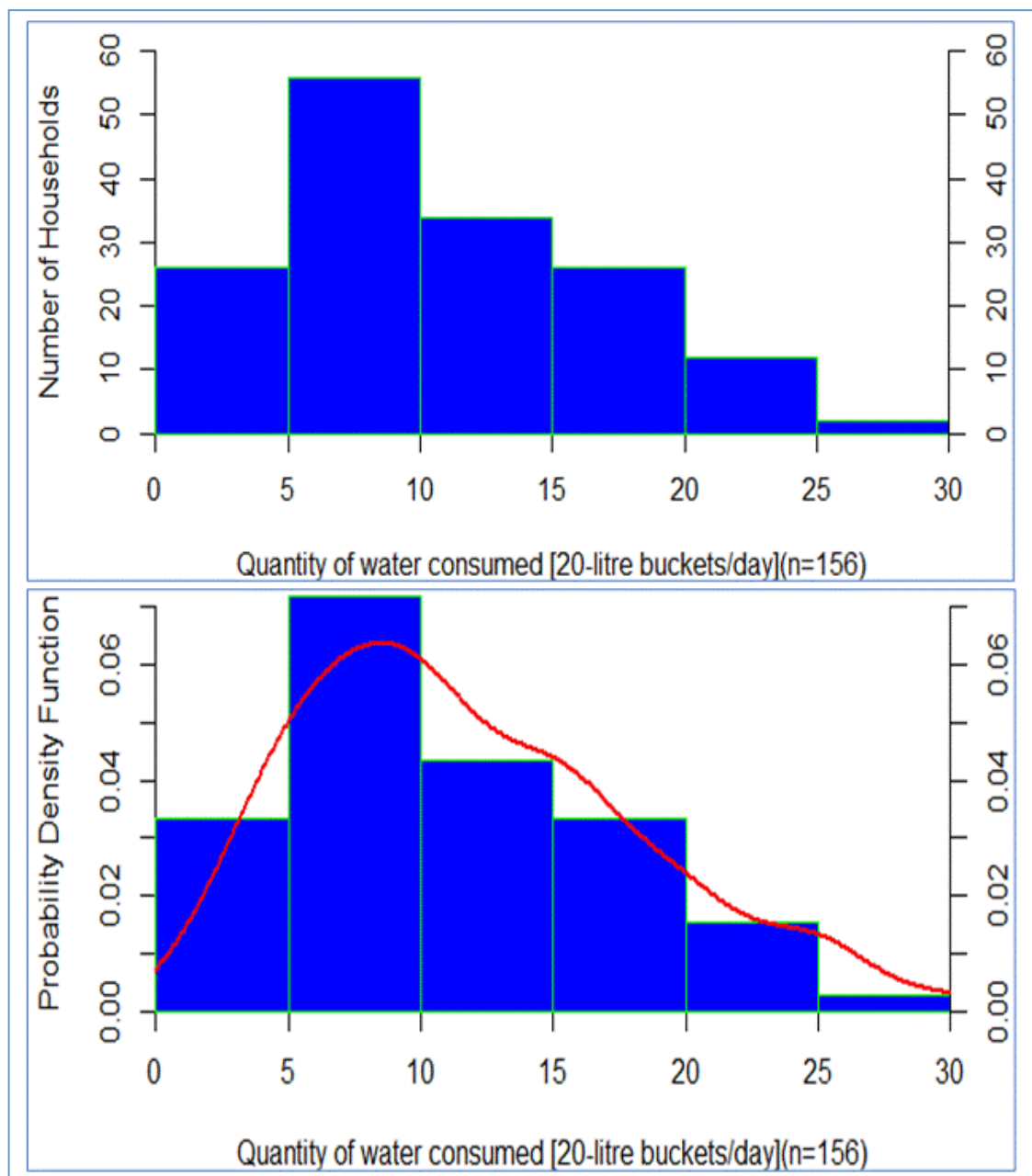


Figure 5. Skewness data for groundwater consumption at $n = 156$.

Since skewness is still far greater than 0, calculating upward and downward error was carried out again using $n = 168$, where $Q_1 - 1.5(IQR)$ was -6.5 , $Q_3 + 1.5(IQR)$ was 30, and the skewness coefficient was 0.66. Therefore, all the groundwater consumption figures above 30 were termed as outliers, and thus trimmed from the groundwater exploitation analysis. The sample size was therefore reduced to $n = 156$, with the maximum data point in the groundwater consumption dataset being 30 20 liter-buckets/day. This analysis was used for estimating household consumption of groundwater in the Dar es Salaam aquifer because the skewness of 0.66 suggested that the groundwater exploitation data at $n = 156$ were close to being symmetrical as shown in Figure 5. Table 4 shows the statistical variables (i.e., mean, median, mode, standard deviation, minimum and maximum) of groundwater consumption data for $n = 156$.

Table 4. Summary Statistics on household sizes.

Statistical Variable	Number of People in the Household
Mean	6.0
Median	5.0
Mode	5.0
Std. Deviation	2.8
Minimum	1.0
Maximum	20.0

Therefore, a new mean was found to be 11.89 20-liter buckets per day per household (approximately 238 L), while the median value was found to be 10 20-liter buckets (approximately 200 L) per day per household (Table 2). This justifies the use of the mean value in calculating groundwater exploitation. With an average household size of 6 people per household, groundwater consumption in the Dar es Salaam aquifer stands at 39.6 L per person per day (i.e., 11.89 20-L buckets per day per household $\times$ 20 L/6 people per household). This is the quantity used for drinking, washing, and bathing by every person per day, which is far more than the average water consumption in Sub-Saharan Africa [29].

To estimate total domestic consumption, the per capita groundwater consumption (39.6 L/person/day) was used in combination with population data. According to the 2012 *national* census, the study area had a total number of 1,784,141 residents [30]. Therefore, taking 5.6% annual growth rate of Dar es Salaam region, it was estimated that the population in the study area had grown to 2,098,888 by the end of 2015 [30]. However, according to previous researchers [27], not all Dar es Salaam residents rely on groundwater for domestic uses, hinting that it is only 50% of residents in the city who use groundwater. Therefore, using the data reported by previous works [27] as a conservative figure, around 1,049,444 people rely on groundwater for domestic uses in the study area. The total domestic consumption of groundwater in 2015 was therefore estimated to be 39.6 L/person/day $\times$ 1,049,444 people $\times$ 365 days, which amounts to 15.17×10^6 m³ per year. Nevertheless, previous works [31] estimated the total domestic groundwater exploitation in 2005 at 1.76×10^6 m³ per year [31] while other researchers estimated that 350 pumping wells were active in Dar es Salaam, and from these producing wells the exploitation of groundwater in the Dar es Salaam aquifer was estimated at 14.9×10^6 m³ per year [6,32]. Therefore, the findings of this study are in line with what was reported 3 years before this study by previous works [32], and thus this gives confidence in the results reported in this study.

In rating the importance of groundwater to household needs, the average score was 3.60 on a 4-point Likert scale. It is clear that groundwater is very important to Dar es Salaam residents. The results show that approximately 94% attach a significant importance to groundwater as a source of household water needs (Table 5). Nevertheless, to get an overall view of the importance of groundwater for domestic needs in Dar es Salaam it is imperative to combine a time series data of groundwater and surface water exploitation.

Table 5. Importance against reliability of groundwater in Dar es Salaam (n = 200).

Groundwater Importance for Domestic Use (%)	Groundwater Reliability for Domestic Use (%)				Total (%)
	Poor	Fair	Good	Very Good	
Not important	0.5	0.0	3.0	0.5	4.0
Somehow important	0.5	1.5	0.5	0.0	2.5
Important	1.0	8.0	7.0	6.5	22.5
Very important	1.0	10.0	27.5	32.5	71.0
Total (%)	3.0	19.5	38.5	39.5	100.0

As for reliability of groundwater (e.g., availability on time and enough quantities), 78% of the surveyed respondents find groundwater reliable to meet their water needs (Table 5). This is probably

so because surface water supplies are very limited in most parts of Dar es Salaam, and therefore groundwater offsets water problems faced by most people in urban areas, including Dar es Salaam. Reportedly, households with access to groundwater perceive it as water of good quality [33].

3.2. Averting Strategies for Inadequate and Unsafe Drinking Water

Approximately 5.5% of the respondents (Table 6) had no idea on whether the water is safe for drinking or not. From a health point of view, it raises concerns as unawareness makes people vulnerable to contaminated water, thus exposing them to water-borne and water-related diseases. On the other hand, 51% of respondents reported that groundwater is of satisfactory quality while 43% are not satisfied with the quality of groundwater they are using (Table 6). Therefore, despite groundwater being reliable and important as a resource, groundwater quality is another aspect that must be looked at to assess its significance to communities in Dar es Salaam. A location-specific analysis of water quality would allow revealing the areas that are highly affected, so that mitigation measures can be instituted immediately.

Table 6. Responses on potability of groundwater in the study area (n = 200).

Response Category	Percent
Potable	51.0
Not potable	43.0
No idea	5.5
No response	0.5
Total	100

The averting behavior for coping with unreliable water in terms of quality and quantity in Dar es Salaam include buying bottled water (1.5%) and abandoning unimportant needs (13.5%, Table 7). Furthermore, 85% of the respondents have their needs met by the available quantity of groundwater, and therefore they do not have to relinquish some of their water uses. Even though most households reported getting sufficient water for daily uses, it is clear that households with high levels of consumption may experience temporary scarcity, possibly more severe than those accustomed to using much less water. Furthermore, the fact that only 1.5% of respondents buy bottled water for drinking does not imply that the quality of groundwater is acceptable for all consumers. This has something to do with budget constraints of a particular household since the amount of disposable income of many Tanzanians is limited and low, and in most cases a trade-off in expenditure must be made.

Table 7. Averting actions to meet household water needs (n = 200).

Averting Action	Percent
Buying bottled water	1.5
Minimizing unimportant water uses	13.5
Not applicable	85.0

In addition, some households (29.5%) also reported spending on buying chemicals to treat water and boiling water (Table 8). All the same, households in Dar es Salaam avoid a lot of the averting costs simply because groundwater services are reliable as reported in Tables 5, 8 and 9. This reflects the results on the reliability of groundwater in terms of quality reported earlier in Table 5.

Table 8. Averting strategies for unsafe drinking water (n = 200).

Water Treatment Method	Percent
Boiling	25.0
Use of industrial chemicals	4.5
N/A	70.5
Total	100.0

Table 9. Perception on treatment of water (n = 200).

Response Category	Percent
Yes	21.5
No	41.0
N/A	37.5
Total	100.0

3.3. Water Collection Time and Roles in the Household

This study also gathered information on time needed to collect water, and the results show that the longest time needed to reach the source, waiting, hauling, and going back is between 15 to 30 min, whereby only 3% of the respondents fall in this category. Nevertheless, approximately 95% of the respondents reported that time was not a constraint in collecting water as they hardly spend 10 min (Table 10). Table 11 summarizes the results of water collection roles in the household. It was revealed that water collection roles are primarily women's responsibility (76%) as compared to men's role in water collection (24%).

Table 10. The average time spent for collecting water (n = 200).

Time Category	Percent
Less than 5 min	65.0
5–10 min	27.5
11–15 min	4.5
15–30 min	3.0
Total	100

Table 11. Water collection roles in the household (n = 200).

Sex	Percent
Male	24.0
Female	76.0
Total	100.0

3.4. Factors Explaining the Level of Groundwater Quality Risk Perception

A logistic regression analysis was performed to ascertain the effects of sex, marital status, education level, employment, income and the cost of water on the likelihood that groundwater consumers have on risk perception on groundwater quality. Logistic regression model was applied to find out how the factors could explain the observed perception on groundwater quality. First, the fitness of the model in predicting the observed responses about how safe groundwater can be for domestic uses was performed, and the results revealed that the overall model was statistically significant at the 5% ($p < 0.05$) ($\chi^2 = 78.219$, $p = 0.01$). Tables 12 and 13 contain the results for the goodness of fit of the logistic model and the results which help us understand how much variation in the dependent variable was explained by the model. The amount of variation in the dependent variable which is explained by the model ranged from 58% (Cox & Snell R Squared) to approximately 79% (Nagelkerke R Squared).

Table 12. Model Summary.

Criteria	Coefficient
−2 Log likelihood (−2 LL)	41.074
Cox & Snell R Square	0.585
Nagelkerke R Square	0.792

Table 13. Estimates of Risk perception factors.

Variable	β	Standard Error	Wald	df	Significance Level	Exp(β)	95% Confidence Interval of Exp(β)	
							Lower	Upper
Sex (x_1)	−1.037	1.857	0.312	1	0.577	0.355	0.009	13.514
Marital Status (x_2)	−1.585	0.620	6.527	1	0.011	0.205	0.061	0.691
Education level (x_3)	45.468	4.432×10^4	0.000	1	0.999	5.577×10^{19}	0.000	0.000
Employment (x_4)	6.435	3.005	4.586	1	0.032	623.074	1.725	2.250×10^5
Income (x_5)	5.657	3.194	3.137	1	0.077	286.341	0.547	1.498×10^5
Cost of water (x_6)	1.822	1.048	3.024	1	0.082	6.186	0.793	48.244
Constant (β_0)	23.804	4.019×10^4	0.000	1	1.000	0.000		

Where Exp(β) is the odds ratio, which represents the chance that people will perceive a risk associated with groundwater quality as compared to the chance of not perceiving the risk.

The results in Table 13 show the odds of perceiving water quality risks based on various socio-economic factors, as well as the statistical significance/levels of confidence. It was revealed that sex of the household head, ($p = 0.577$, Exp(β) = 0.355) did not add significantly to the model. This means that sex could not significantly explain the observed variation in water quality risk perception. It was further found that marital status ($p = 0.011$, Exp(β) = 0.205) was statistically significant at the 5% level, and thus it significantly added to the water quality risk perception prediction model. The chance of perceiving water quality risk as explained by this model is lower for married household heads as compared to unmarried household heads (Exp(β) = 0.205). Literally, this means that the water quality risk perception for unmarried household heads is 5 times higher than it is for married counterparts. Moreover, the water quality risk perception based on the difference in education levels was found to be insignificant ($p = 0.99$) at any reasonable confidence level. Therefore, education level as a factor could not add to the water quality risk perception model at any reasonable level of confidence. On the other hand, employment was found to be a significant explanatory factor to the water quality risk perception model at 5% level of significance ($p = 0.032$, Exp(β) = 623). Thus, the odds of an employed household head perceiving a water quality risk is significantly higher (more than 600 times) than that of an unemployed household head. Additionally, income added significantly to the model at 10% level of significance ($p = 0.077$, Exp(β) = 286.341). At this level, the level of perceiving a water quality risk is 286 times higher for higher income households than it is for lower income households. Equally so, the cost of accessing water added to the model at 10% level of significance ($p = 0.082$, Exp(β) = 6.186). Thus, the chance of perceiving a water quality risk is 6 times higher for households incurring high costs than those incurring low costs of accessing clean water. However, from the results on sex and education, it does not mean that there is no difference in the level of water risk perception between men and women, or the educated and the uneducated. It simply explains the fact that these two factors (sex and education) could not significantly add to the model at 5 and 10% significance levels.

4. Discussion

Less than half of the households in Dar es Salaam receive their water directly from surface water as reported by previous studies [34]. This suggests that groundwater is the most important source of water in some areas of Dar es Salaam as reflected by the findings of this study, which found that groundwater is important as a source of water for domestic, industrial, and other uses. Reportedly, in 2005, the actual water supply in Dar es Salaam was about 126,900 m³/day, out of which 50,000

m³/day was coming from groundwater. There were estimated to be losses of 53% along pipelines due to leakage, irrigation and other upland uses [34]. Albeit, water demand by then was 410,000 m³/day. However, it has been established that almost two thirds of the water delivered by the Upper Ruvu system and 10–20% of that delivered by the Lower Ruvu System are estimated to be lost by leakage along the transmission mains before reaching the reservoirs in Dar es Salaam [34]. Together with other factors, it is most probable that these vast surface water losses make groundwater being the most important and reliable sources as it compensates for the deficit from surface water supplies in Dar es Salaam. However, it is not certain whether groundwater is sufficiently available to cater for future water needs in the city. This reiterates the fact that groundwater accounts for over 97% of the accessible global freshwater resources, and therefore it is important to have a framework for valuing the benefits of preventing groundwater contamination after assessing the importance of the risk and risk perception of the exposed population as suggested by [35]. Moreover, the study revealed that most people in Dar es Salaam use above average amount of water (i.e., 40 L per person per day) as compared to other places in sub-Saharan Africa [29]. According to previous studies [29], people in the sub-Saharan countries use between 15 and 20 L of water per person per day, with some of them living in arid and semi-arid regions using even less water, recommending a basic water requirement of 25 L per person per day to meet the most basic human needs.

The fact that most people in the study area get their water requirements from groundwater sources, it does not guarantee sustainable use of the resource. Sometimes there is overexploitation, which may result in such consequences as continuous drops in groundwater levels over long time periods, large seasonal drops in water levels in wells and the drying up of wells in the dry season. In addition, overexploitation could also exacerbate the danger of saltwater intrusion through the upconing effect, which may result from pressure changes in response to pumping [36], thus increasing salinity of groundwater in the aquifer. Land subsidence is another foreseeable consequence of groundwater overexploitation. Economically, if some or all the aforementioned consequences happen, there will be an increase in cost of groundwater extraction. The aforementioned undesirable consequences appear when abstraction exceeds recharge. Reportedly, aquifer overexploitation is no longer a myth as it is happening everywhere in the world with several discernible environmental consequences [22,37]. The quality of groundwater for drinking in Dar es Salaam is taken up with a pinch of salt, and therefore a household's averting cost is usually an indicator of the intensity of averting behavior [38,39]. This study revealed mixed perceptions on how safe groundwater can be for drinking without treating. The results on averting methods generally indicate that people in the study area are concerned by the quality of groundwater, and are keen at developing mitigation measures for their drinking water as pointed out by other researchers [7]. This is because polluted drinking water poses a significant public health threat as opined by previous researches [8], thus, coping with undesirable characteristics of drinking water is not a choice but a mandatory option. According to other studies [9], coping strategies for unreliable and unsafe water supplies impose coping costs, which can be as much as US\$3 per month (about 1% of disposable income). This represents hidden but real costs of poor and unreliable water services to households in the developing countries, including Tanzania. Nevertheless, it was pointed out that an increase of 0.3% investment in household access to safe drinking water generates 1% increase in Gross Domestic Product (GDP) [10], adding that provision of safe drinking water supply is one of the most commendable and effective health interventions, which reduce the mortality caused by water-borne diseases by an average of 70%. Therefore, despite groundwater being reliable and important as a resource, groundwater quality is another aspect that must be looked at to assess its significance to communities in Dar es Salaam. A location-specific analysis of water quality would allow revealing the areas that are highly affected, so that mitigation measures can be instituted immediately. In addition, although not mentioned as one of the coping strategies to groundwater quality, previous researches [40] hinted that water filtering is one of the coping mechanisms, and the benefits of filtration significantly outweigh the costs of drinking unsafe water.

Time spent for water collection in the study area was found to be negligibly small (Table 10). This is due to the fact that boreholes and hand dug wells have been drilled in almost every household, and thus travel distances have been reduced significantly. Other researchers [41] considered roundtrip walking time to water source and waiting time at the source while distance from source in meters as an explanatory variable in the demand model was used in other works [42]. However, hauling time per unit of water consumed was considered in other works too [43]. According to previous works [41,43], to convert time cost into monetary cost, one needs to measure the opportunity cost of time of the person in charge of water collection.

Nevertheless, there has been increasing concerns over the time spent by women and girls collecting water, and it is being highlighted as a neglected socio-economic challenge. Worldwide, women and girls spend a considerable number of hours daily collecting water. This is particularly prominent in poor developing countries. In Ethiopia for example, women and girls spend about 5 h per day fetching drinking water which is more than 1500 h per year [44]. This is far higher than the 700 h spent per year per person in Ghana as reported by previous works [45]. Therefore, the argument that the opportunity cost of those who collect water in the households is negligible is highly debatable and needs concerted investigations. Fetching water from non-tap sources usually involves hauling time that comprises time to and from the source, time to wait at the source, and time to haul water. Moreover, it was recounted that almost 50% of the population still have to bring water from a source outside of their home in most rural areas [46], adding that women generally are responsible for fetching water. This is very well in line with the findings of this study, although it was conducted in urban area. Nevertheless, in urban areas men also take on this responsibility as reported in this study. Further to that, it has been pointed out that a greater proportion of urban households compared to rural households get water supply within their house, or the nearby selling points. However, some researchers [46] argued that collecting water is often a huge waste of time for women and girls. In most African countries, including Tanzania, water collection is a woman's role, something which has been revealed by this study too. Additionally, most women who do the household chores, including water collection are either unemployed housewives or house maids whose main daily roles in the house include water collection. In this regard, translation of time cost into collection cost may not make much sense because, in most cases, the opportunity cost of time of those in charge of collecting water in the household is negligibly small.

The study revealed further that the chance of perceiving the groundwater quality risk was 623 times greater for the employed than the unemployed household heads. This is probably connected to the fact that most of the employed people are those who have a relatively higher level of education than the unemployed ones, who are less aware of water quality issues. Nonetheless, as suggested by [26], perceptions of water quality and risk come from a complex interaction of diverse factors, including attitudes towards water chemicals, contextual signs provided by the supply system, familiarity with specific water properties, trust in suppliers, past experiences with problems attributed to water quality and information provided by the mass media. It is usually logical that education influences the way people perceive water-related risks, and in fact, the more educated people are, the more they become aware of risks to water quality. It was not evident in this study as the results showed an indifference in water quality risk perception, suggesting that in the study area, people are highly sensitive to water quality, whether they are educated or not. This can partly be explained by the highly rampant water-borne problems striking the study area almost every year. The experiences with past water-related contaminations and diseases have made people aware regardless of their different levels of education, sex, or marital status. Nevertheless, more educated people with higher income and with fewer household members are, on average, willing to pay more because they have a higher perception and understanding of the water quality risk problems [2]. Albeit, people's concerns regarding drinking water quality and perceptions of the health risk of drinking water quality can influence people's willingness to invest in mitigating drinking water quality problems. Therefore, research on averting

behavior is likely to help decision-makers understand the local population's demand for improved drinking water quality as recommended by previous studies [2].

The difference in income contributed significantly to water quality risk perception model at 10% level. From the results of this study, the chance of perceiving water quality risk is 286 times higher for those with high income at $p = 0.08$. This explains the fact that affluent families are more sensitive to water quality issues than the less affluent families. This is in line with how the difference in education contributes to perceiving the water quality risk as reported by previous works [2]. Likewise, the water quality risk perception for married against single heads of households was found to differ significantly at 5% level ($p = 0.011$). It was revealed that unmarried household heads perceive the risk of water quality more than the married household heads. This is possibly so because the roles of accessing water are the primary responsibility of unmarried household heads while it could be a shared responsibility for married household heads. Moreover, employment, as much as it is for education, contributes to the awareness of water quality risk [2]. Regardless of their differences in marital status, differences in income and education, people are bothered by unsafe water and are keen at developing mitigation measures for their drinking water [7].

Although the model failed to reflect on the reality of education in water quality risk perception, this factor is most likely reflected on employment and income factors indirectly. These two factors added significantly to the water quality risk perception prediction model at 5% (employment) and 10% (income). The variation of water quality risk perception through differences in levels of education may be so obvious in other environments, especially those with less cases of water-borne diseases. In the study area, cases of water-borne diseases have been so rampant and frequent. Therefore, government interventions and public health education campaigns to mitigate water-borne and water-related illnesses have possibly camouflaged the influence of the difference in levels of education in water quality risk perception in this model. The results of this study are not surprising. A previous study for example used a multinomial model of averting behavior in response to water contamination risks for Georgia residents [20]. The main determinants of perceived risk from tap water quality were found to be race and age. Education did not feature as the main determinant at any reasonable level of confidence. Therefore, the results of this study agree with the results reported by previous works [20] on education not being the major determinant of perceived water quality risk. Literally, depending on the socio-economic settings and levels of exposure to water quality problems, it may not matter whether one is educated or not to perceive water quality problems and their associated risks to health. This argument has been supported by other works that perceptions of health risks across exposure levels are affected by the individual's current exposure level [21]. Generally, as pointed out earlier, it should not be interpreted that there is no difference in the level of groundwater risk perception between men and women, or the educated and the uneducated. It simply explains the fact that these two factors (sex and education) could not significantly add to the model at 5 and 10% significance levels of significance.

5. Conclusions

Groundwater consumption in the study area was found to be higher compared to other places in sub-Saharan Africa, and higher than the recommended basic water requirement of 25 L per capita per day. It was estimated that the total domestic groundwater consumption in the study area in 2015 was $15.17 \times 10^6 \text{ m}^3$ per year. This is likely to go up on a yearly basis as the population increases. Moreover, approximately 94% of respondents attach a meaningful importance to groundwater as a source of household water needs, and 78% consider groundwater as a reliable source. Averting strategies for insufficient quantity of groundwater consist of minimizing less necessary water uses, while for poor quality, buying bottled water and water treatment by boiling (mainly) and using chemicals are done. Approximately 93% of respondents reported to spend hardly 10 min for collecting water, and therefore collection cost is negligibly small. Respondents reported that 76% of water collectors in the households are women. However, cumulatively, the time spent by women and children for fetching water in

developing countries is becoming a global concern. Therefore, more research into it is required to establish the real but hidden cost of fetching water.

A binary logistic regression analysis was performed to ascertain the effects of sex, marital status, education level, employment, income, and cost of water on the likelihood that groundwater consumers have a risk perception on groundwater quality. The overall model was statistically significant at 5% level. The amount of information in the dependent variable explained by the model was 58–79%. Marital status and employment were significant at 5% level of significance while income and cost of water were significant at 10% level. However, education and sex were not significant at either 5% or 10% level of significance. It was found that the chance for water quality risk perception is 0.205 times greater for married than unmarried household heads, and it is 623 times higher for employed as compared to unemployed household heads.

Generally, the model has performed better, since 4 out of 6 factors could predict well the chances of water quality risk perception. These factors are employment and marital status at 5% level of significance and cost of water and income at 10% level of significance. Therefore, it suffices to conclude that the differences in income, marital status, employment and the cost people incur to access clean and safe water could explain the variation in how people perceive the risk of water quality.

Nevertheless, to get an overall view of the importance of groundwater for domestic needs in Dar es Salaam it is imperative to combine a time series data of groundwater and surface water exploitation. In addition, estimating groundwater recharge in the Dar es Salaam aquifer is important to establish the extent of exploitation, and thus project the likely signs of overexploitation and plan for proper mitigation actions. This should be the focus of continued research in the Dar es Salaam quaternary aquifer.

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