academicJournals

Vol. 11(6), pp. 304-323, June 2017
DOI: 10.5897/AJEST2017.2308
Article Number: 99368D264363
ISSN 1996-0786

http://www.academicjournals.org/AJEST

African Journal of Environmental Science and Technology

Full Length Research Paper

Using Citizen Science Approach to monitor water, sanitation and hygiene Related Risks in Karonga Town, Malawi

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Received 25 February, 2017; Accepted 13 April, 2017

Relatively few studies have explored how resilience of water, sanitation and hygiene (WASH) systems to hazards can be enhanced under the current and future development and climatic challenges pressures in urban areas. This study employed the citizen science approach to build the capacity of citizens and integrate communities into scientific research on water quality and WASH related risk monitoring. Data was collected with assistance of 8 self-motivated and trained citizen science research counterparts. Standard sampling procedures were used to collect water samples from a total of 27 unsafe water sources in Karonga Town. The water samples were analysed for biological, physical and chemical parameters using standard methods. Personal observations were done to determine major sanitary risks impacting on a water sources in the town. It was observed that water from the majority of water samples collected from shallow wells, rivers/streams, lake and boreholes were highly contaminated with *Escherichia coli*, which were considerably higher than Malawi Bureau of Standards water quality specifications for drinking water. In general, the water is of low mineralization with rock-water interactions and surface pollution from anthropogenic activities such as agricultural activities and municipal wastes being responsible for input of biological, chemical and physical pollutants especially into the unlined and uncovered water sources. The results of the water quality index (WQI) and water quality (WQ) ratings indicated that water is not suitable for direct human consumption prior to treatment. It is recommended that onsite treatment and point of use water treatment interventions should be instituted and advocated to improve human health, livelihoods and to build resilience to WASH related risks and hazards in Karonga Town.

Key words: Citizen Science, resilience, urban risks, water quality index, water, sanitation, hygiene.

INTRODUCTION

There have been increasing worldwide scientific research interests on urban areas as critical points for climate change adaptation over recent decades. This trend has been ignited by two vital attributes of urban areas: (1) Urban areas are places that concentrate risk related to changes in climatic pressure, owing to the high population densities, infrastructural development and investment (2) Urban areas possess significant potential in response to risks as a result of their high concentration of resources. One of the greatest risks to urban dwellers in developing countries is the unavailability of improved water, sanitation and hygiene (WASH) provision (United Nations Office for Disaster Risk Reduction (UNISDR), 2012).

Access to water and sanitation is a vital element in determination of natural hazards' social vulnerability, not only for attaining instantaneous needs, but also for the broader use of relevant disaster prevention (UNISDR, 2012). Particularly, the state of access to improved WASH provision is a global crisis, and addressing the post 2015 United Nations (UN) Sustainable Development Goals (SDGs) is critical since the 2015 Millennium Development Goal (MDG) for sanitation lagged significantly behind the other goals (Global Analysis and Assessment of Sanitation and Drinking-Water (GLAAS), 2012). According to GLAAS (2012), 83% of countries significantly lagged behind the national targets they set for sanitation.

Literature on the performance of Malawi in the achievement of the MGDs is mixed. Mamba and Gondwe (2010) and National Statistical Office (NSO) (2010) reported that out of 14 million Malawians, only 62% (95% urban and 58% rural) have access to safe drinking water and 64% (90% urban and 60% rural) have adequate improved sanitation. The Government of Malawi (2013) reported that the majority of households relied on unsafe water sources such as shallow wells and rivers domestic purposes for domestic purposes. This is the case because the majority of people in peri-urban, informal settlements and rural areas are not supplied with to piped water by utility providers (Water Boards). Nevertheless, the World Health Organization/United Nations Children's Fund Joint Monitoring Programme (WHO/UNICEF JMP) Report (2015) reported that Malawi was one of the countries in Sub-Saharan Africa that registered better progress in provision of safe and potable water by about 67%.

The majority of cities in low-income countries that experience rapid urbanization, significantly struggle to meet basic WASH needs and keep up with service provision owing to shortfalls in financing, capacity and governance. This in turn results into severe health, social and economic implications (Koppenjan and Enserink, 2008). In other words, even without considering external hazards such as droughts or floods, urban areas may be unsustainable due to internal health hazards resulting from poorly designed, implemented and maintained WASH systems (Koppenjan and Enserink, 2008). In the area of climate change, resilience emphasises the capability of a system to be dynamic and to cope with climate change, recuperate and change itself in the long term (Pasteur and McQuistan, 2016; Szoenyi, 2016).

Empirical evidence on risk and climate change adaptation is limited for African cities, Intergovernmental Panel on Climate Change (IPCC), (2014). In the African context, cities are growing rapidly, both formally and informally. At the same time, levels of inequality are high, yet strong governance and service delivery is lacking in many areas. As a consequence, the risk space is characteristically higher, and the risk burden is usually borne largely by the urban poor in African cities.

Until recently, Karonga Town, Northern Malawi has been directly affected by serious disasters like earthquake, drought and floods. These disasters affect both quantity and quality of water in addition to sanitary facilities thereby affecting WASH governance and service delivery in the Town.

The most effective approach in management of WASH systems in urban areas such as Karonga is to develop programs that incorporate a holistic approach with respect to: Prevention, protection, preparedness (through technology transfer initiatives among others), emergency response and recovery and lessons learned (returning to normal conditions as soon as possible and mitigating both the social and economic impacts on the affected population) (Oates et al., 2014).

In addition to disasters, some factors such as: Climate, topography, chemical composition of recharge water, type of minerals in aquifer matrix (water-rock interactions), evapotranspiration and impact of anthropogenic activities within catchments (Stallard and Edmond, 1983; Deutsch, 1997; Parkhurst and Appelo, 1999; Rajmohan and Elango, 2004; Appelo and Postma, 2005; Subba Rao et al., 2006; Gupta et al., 2007; Jayaprakash et al., 2008; Devadas et al., 2007) are also vital factors impacting on water sources. In the context of climate change, recent work on the resilience of water supply and sanitation was conducted by Howard and Bartram (2010), Howard et al. (2010), Calow et al. (2011), and Batchelor et al. (2010). An understanding of these underlying factors as well as the monitoring and assessment of the water, sanitation and hygiene (WASH) risks is essential in sustaining usable water supplies and building resilience under climatic pressures in Karonga Town.

Despite the apparent urgency of current and future challenges from climate change and development, few studies have explored how the resilience of WASH systems to hazards can be enhanced in Karonga Town.

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Integrating the public into scientific research is a rapidly growing phenomenon known as citizen science, whereby scientific research projects are developed with some level of public engagement (Bonney et al., 2009; Hand, 2010; Shirk et al., 2012).

Citizen Science is a form of crowdsourcing using trained volunteers to help collect data that traditionally, financially, spatially, or temporally not be feasible in large scientific research projects (Gura, 2013). Citizen scientists can provide an inexpensive, substantial, and long-term labor force (Conrad and Hilchey, 2011; Gouveia et al., 2004; Stokes et al., 1990) capable of collecting reliable and large datasets in a relatively short time over large geographical areas (Fore et al., 2001; Foster-Smith and Evans, 2003; Newman et al., 2003; Bonney et al., 2009).

There are also many perceived challenges such as the integration of data collected by citizens into the scientific process, ensuring data quality, difficulties of working with volunteers (including maintaining their engagement) and quantifying success (Bonardi et al., 2011; Kremen et al., 2011).

This study employed the citizen science approach to monitor water quality and enhance understanding of how the resilience of WASH systems to water-related hazards (e.g. floods and water scarcity) can be improved. The main aim of the assessment of risks associated with water pollution in Karonga Town project was to build community capacity in the assessment of risks associated with water pollution based on principles of the citizen science water quality monitoring approach. Through the citizen science water quality monitoring approach, data was gathered and tested by self-motivated and trained non-professionals. This was envisaged as a contribution towards the Urban Africa Risk Knowledge (Urban ARK) Research Project in Karonga Town which aims to build a public participation in monitoring and recording water quality in their town. Objectives of the study were four fold:

1. To determine nature of the sources of domestic water in Karonga Town.
2. To identify WASH related risks impacting on domestic water sources in Karonga Town.
3. To determine levels of microbial (that is, faecal coliform) and physicochemical (that is, pH, electrical conductivity (EC), total dissolved solids (TDS), chlorides, sulphates, phosphates, nitrates, total hardness (TH), total alkalinity (TA), carbonates, bicarbonates, sodium ion, potassium ion, calcium ion and magnesium ion) in water sources in Karonga Town.
4. To build resilience of WASH systems to water-related hazards (e.g. floods and water scarcity) through training counterparts on basics of the citizen science approach to monitor the water quality and assess WASH related risks in their neighborhood.

MATERIALS AND METHODS

Description of the study area

Karonga Town covers a gazetted land size of 4,386 ha and is located about 225 km north of Mzuzu City in the Northern Malawi. Karonga Town is located on a low-lying North Rukuru River flood plain (Figure 1), with altitude range of 447 to 550 m above sea level. Located by the shores of Lake Malawi, Karonga Town experiences a sub-tropical climate with two distinct seasons (that is, dry season and wet season, from June to October and November to May, respectively). Though a small city it is Malawi's fifth largest and, owing to its location on a major regional trade route to the Port of Dar es Salaam (Tanzania), it is one of the mostly rapidly urbanising towns in a country with still a very low level of urbanisation of only 20%. With, a total population of about 41,000 in 2008 and growing at growth rate of 4.3% per year with a total fertility rate of over 6.0, the population of Karonga Town is projected to reach nearly 63,000 in 2018 (NSO, 2010). In 2013 the Karonga local council extended the boundary of the city. Consequently, the population became larger than currently known.

The degradation caused by pollution arising from WASH related risks such as excess water brought about by floods (that is, the urban storm water pollution), is serious, and affects a significant proportion of the population in Karonga Town. Changes in land use that increase impervious cover lead to further flooding, erosion, habitat degradation, WASH infrastructure damage and water quality impairment. Everyday activities such as driving, maintaining vehicles and lawns, disposing of waste, and even walking pets and animals often cover impervious surfaces with a coating of various harmful materials. Construction sites, failed septic systems, illegal discharges, and improper siting and construction of sanitary facilities such as pit latrines and solid waste dump sites also contribute substantial amounts of contaminants to runoff. When these contaminants enter Lake Malawi, streams, rivers as well as groundwater sources, they result in water pollution.

Data collection

The study employed both qualitative and quantitative methods of data collection. Random sampling was used to select sampling sites.

Recruitment and training of citizen science research counterparts and preliminary survey of the study area

To ensure smooth technology transfer and ensure quality of citizen science data collection and processing, this study used 8 self-motivated research counterparts, with minimum qualification of the Malawi School Certificate of Education (MSCE) (equivalent to O-level). The research counterparts were identified with assistance from the four local disaster risk management (DRM) committees in Karonga Town. Each DRM committee was requested to provide a list of potential men and women with good MSCE. It was easier for the DRM committees to identify the potential candidates because Karonga is one of the towns in Malawi that has high literacy rates with a number of unemployed MSCE holders. The identified candidates underwent some interviews and two successful self-motivated research counterparts were selected to represent each of the four DRM committees. Equal opportunity was provided to both men and women during the entire recruitment process. The successful research counterparts were trained to equip them with both theoretical and hands-on experience on principles of of citizen science for water quality monitoring and risk communication among

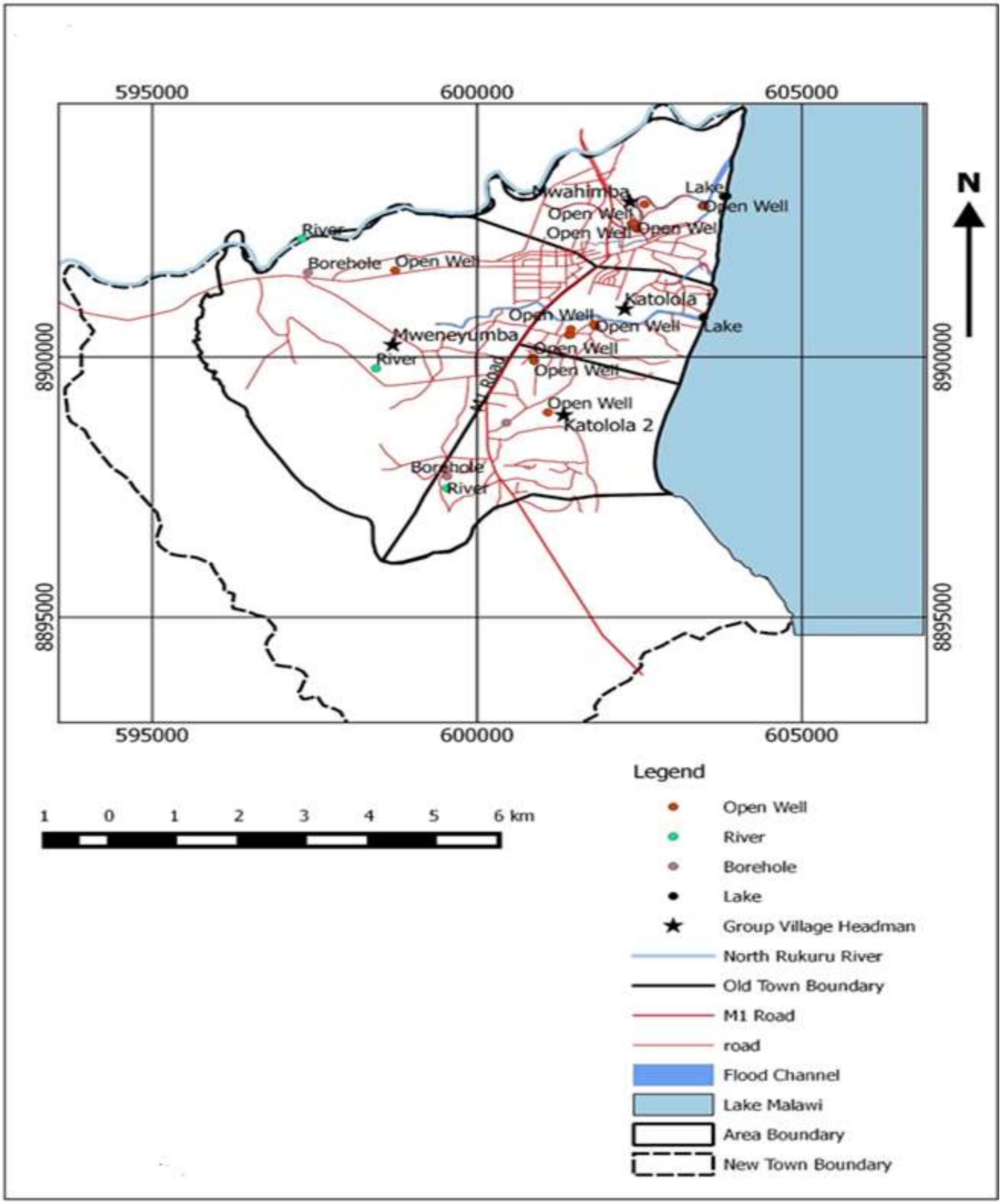

Figure 1. Map of Karonga Town showing sampled water points.

others.

The training sessions were conducted from 18 to 22nd January, 2016 and 21 to 23rd June, 2016 at the Karonga District Education Office (Figure 2). The training sessions covered the following topics: Introduction to the concept of citizen science, research ethics, basic bio-physicochemical properties of water, key water quality

Figure 2. Citizen science research counterparts' theoretical and hands on training sessions with portable multi-meters for onsite water quality analyses in Karonga Town.

monitoring parameters, the analytical protocol for water quality monitoring, water quality standards used in water quality monitoring, application of the Citizen Science Model in Urban ARK water quality monitoring, water sample collection (Figure 2), preservation and treatment, water sample analysis, water quality assessment using the water quality index (WQI), basics of quality control and assurance in Urban ARK water quality monitoring, basic analytical instrumentation techniques for water quality analyses, role of citizen science in building resilience and hands on experience on the application of citizen science for water quality monitoring and statistical treatment of analytical data. A debriefing session was conducted after hands-on experience sessions (Figure 2) to highlight grey areas and clarify what was expected of research counterparts when in the field. The data entry clerks were closely supervised and at the end, data was cleaned to check inconsistencies and insert missing values as well as wrongly entered values before starting data analysis.

Prior to the hands-on experiences in the field, a survey of the study area was done to: (1) Locates and map water sources and select the study sites. A global positioning system (GPS, GARMIN-GPSMAP 60Cx, USA) was used to collect the geo-referencing data (northings, eastings and elevation) of all sampled sites; (2) Brief members of the DRM committees and local leaders on principles of citizen science water quality monitoring and building WASH related risks resilience approach as part of technology transfer; (3) To conduct a household as part of assessing the full spectrum of risks. The household survey covering the whole town whose results partly inform this work used the sample frame provided by the National

Statistical Office, that is, 8007 households in the entire Karonga Town enumeration area (NSO, 2010), from which 380 households were selected for interviews (Appendix 1). A systematic random sampling was used, and every 26th household was interviewed. This household survey involved administration on an open-ended questionnaire to the selected households. The household survey questionnaire was developed in English and then translated and conducted in the common languages of the area, Chi-Nkhonde and Chi-Tumbuka. Translation relied on a team of the citizen science research counterparts from the community, who were given a two-day training session on administering the questionnaire. The questionnaire was pre-tested and revisions were made to improve both face and content validity prior to administration.

Personal observations were made to observe sanitary risks impacting on a particular water source in terms of: protection of the water sources, proximity of sanitary facilities such as toilets, rubbish pits, garbage dumpsites, stagnant water pool, animal kraal, garden, graveyards etc, nature of activities in the water resource's recharge zone and depth and mouth diameter of the water source.

Water sample collection and analysis

Data on water quality is based on water samples which were collected from 27 randomly selected unprotected water sources in Karonga Town. The water samples were collected in triplicate using standard sampling procedures (American Public Health Association (APHA), 2011; Malawi Bureau of Standards (MBS), 2005). The water samples were collected using pre-cleaned polyethylene bottles which were rinsed thrice on site with water from the sources prior to collection of water samples. The water samples were analyzed for the following physico-chemical parameters: pH, total dissolved solids (TDS), electrical conductivity (EC), faecal coliform and total coliform on-site. The levels of pH, TDS and EC were determined using a pH-TDS-EC multimeter (Hanna instruments, Model HI 9812). The multimeter was calibrated using standard buffer solutions of pH 4.00 and 7.00 before measuring pH.

For microbial analyses, the petrifilm and multiple tube method, also known as the dilution method or the most probable number method, and membrane filtration were used to examine faecal and total coliform organisms. Sample bottles were flame sterilized using tissue paper soaked in 70% methanol for 30 to 60 s and rinsed three times with source water to minimize the risk of external contamination (Paqualab Manual, 2005). In membrane filtration method, known volumes of water were filtered through each of two membrane filters consisting of a cellulose compound with a uniform pore diameter of 0.45 µm *in situ* within 60 s after sampling in accordance with internationally recognized standards techniques (American Public Health Association (APHA), 2011). The bacteria were retained on the surface of the membrane filter. Both membranes were incubated *in situ* in a potable incubator for preliminary period at relatively low temperature of 30 ◦C, and then changed to a higher temperature, one at 35 or 37°C and one at 44°C. Acid producing colonies were counted after a total incubation time of 18 h. The results were respectively a presumptive membrane faecal coliform count, and a presumptive membrane *E. coli* count.

For offsite physicochemical analyses, the levels of chlorides, fluorides carbonates, bicarbonates, sulphates, phosphates and nitrates were analysed using ion chromatography (Dionex DX 500). Titrimetric methods were used to determine the concentrations of Total hardness (EDTA) and total alkalinity (acid). The total concentrations of Na^+, K^+, Ca^{2+} and Mg^{2+} were determined using atomic absorption spectroscopy (Buck Scientific Model 200A) at specific wavelengths as follows: Potassium (K) (769.9 nm), calcium (Ca) (422.7 nm), magnesium (Mg) (285.2 nm) and sodium (Na) (589.0 nm). The levels of suspended solids were determined gravimetrically.

Data analysis

The quality of the chemical data was assessed by checking ion balances. The biological, physical and chemical water quality results obtained during this study was compared to maximum values recommended by the Malawi Bureau of Standards Board (MBS) (2005), the MS 733:2005 for water quality. For statistical analyses, R statistical software was used to describe temporal and spatial distribution of the analyses. Descriptive statistics, computed at 95% confidence level, provided the concentration mean, median, standard deviation, outliers, as well as normality distribution in different water sources. All chemical variables determined in samples were analyzed using analysis of variance (ANOVA) at 95% confidence level, Hierarchical Cluster Analysis (HCA) and Principal Components Analysis (PCA). The ANOVA was used to determine any statistically significant spatial variations among levels of the analyses (Appendix 1). The HCA and PCA were used as a quantitative and independent approaches for water classification allowing grouping of the water samples and making of correlations between chemical parameters and water samples, respectively.

The HCA was implemented in R using stats package, and was performed using a combination of Ward's linkage method and adopted the Euclidean distances as a measure of dissimilarity. The WQI was computed to turn multifaceted water quality data obtained from the survey, citizen science water quality monitoring program as well as laboratory analyses into simple information that is comprehensible and useable by the public to assess overall quality of water at a specific water points (Prasad et al., 2013). The computed WQI and water quality ratings were given single ratings which were used to categorise the water into different categories as shown in Table 1, the form as well as the extent of water pollution in the water sources used by households and businesses in the town and the risks this brings.

Ethical consideration

Ethical consideration was observed through following all the regulations set by the National Commission for Science and Technology (NCST) of Malawi as part of the Urban Ark research project in Karonga.

RESULTS AND DISCUSSION

Sources of domestic water in Karonga Town

The preliminary household survey, which utilized 380 households, showed that up to 90.2% of the respondents claimed to have access to potable water as follows: Piped water inside the house (17.4%), piped water on the plot (41.8%), on neighbors' plots (11.3%) and communal water pipe (19.7%) (Figure 3). However, 7.4 and 2.4% of the respondents access drinking water from boreholes and river/lake/well, respectively (Figure 3). It is against this background that the citizen science research team sought to establish type and nature of unsafe water sources. To this effect, it was established that the majority of households who reported accessing water samples from unsafe water sources (41%) were using

Table 1. The WQI rating scale.

WQI (%)	Water quality rating category and interpretation
95-100	Excellent water quality (does not require treatment before human consumption)
91-94	Very good water quality (does not require treatment before human consumption)
71-90	Good water quality (require minor treatment works before human consumption)
51-70	Medium or average water quality (reasonable potable water which require advance and conventional treatment before human consumption)
26-50	Fair water quality (polluted water that has doubtful potable use)
0-25	Poor water quality (highly polluted water that is unacceptable for human consumption)

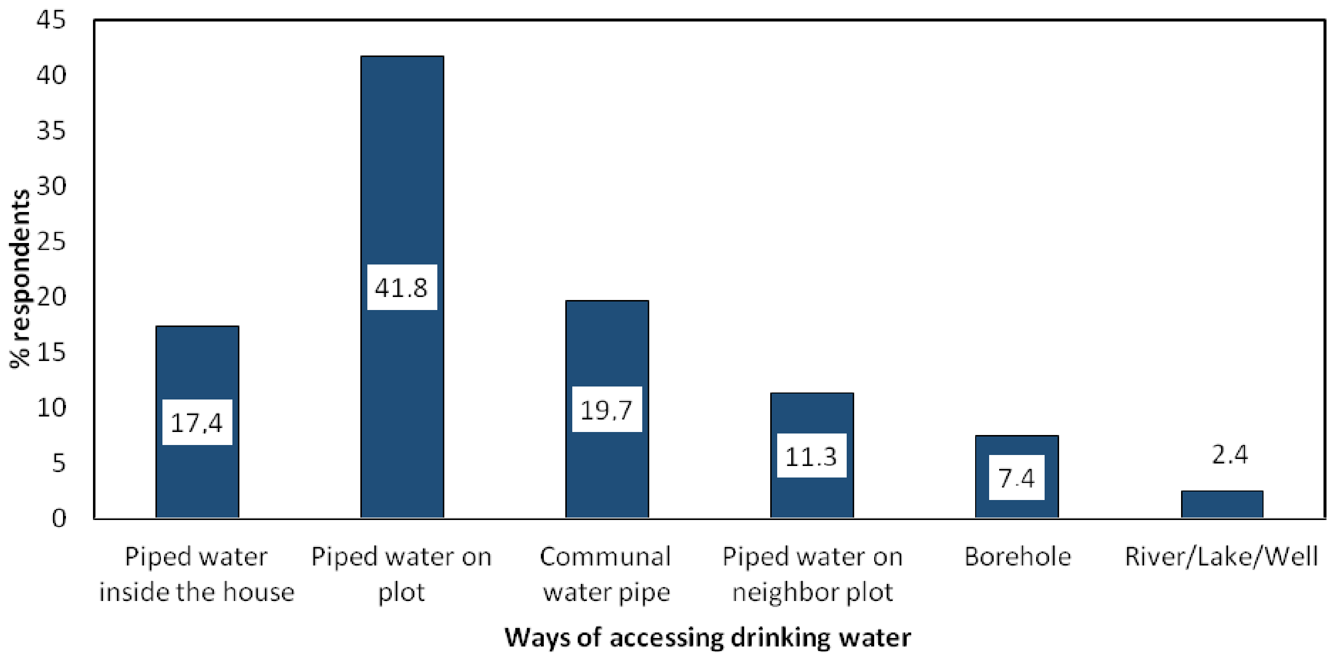

Figure 3. Ways of accessing water for respondents in Karonga Town.

uncovered shallow wells (with average depth= 3.4 ±0.9 m, and average diameter range of 0.48-1.1 m) as their most frequent and reliable source of water (Figure 4). The remaining 22, 15, 11 and 11% were using covered shallow wells, streams/rivers, Lake Malawi and boreholes as their most and reliable source of water, respectively (Figure 4). In case of both covered and uncovered shallow wells, the majority (78%) were reported to have been aged less than 5 years, suggesting that issues of access to water in Karonga Town were serious and demand for water was increasing over the years. On average, each unsafe water source was reported to be serving up to 50 or more households, suggesting that, on average more than 300 individuals were relying on each particular water source. The majority of the respondents pointed out that they opt for unsafe water sources because of the large monthly water bills provided by the Northern Region Water Board (NRWB), intermittent piped water supply and unavailability of steady and continuous flow of piped water provided by the NRWB during daytime. Similar observations were made in Mzuzu City Northern Malawi by Wanda et al. (2012a) who noted that people were resorting into unsafe water sources due to low water pressure and intermittent water supply problems by the utility.

Up to 51.2% of the respondents perceived the water from the boreholes, shallow wells, streams and lake as of good taste and safe for consumption with 70.5 and 64.1% indicating that the shallow well water was odourless and good turbidity, respectively (Table 2). Nevertheless, some waterborne diseases such as cholera (18.68%), diarrhea (6.05%) and dysentery (6.58%) were reported to be

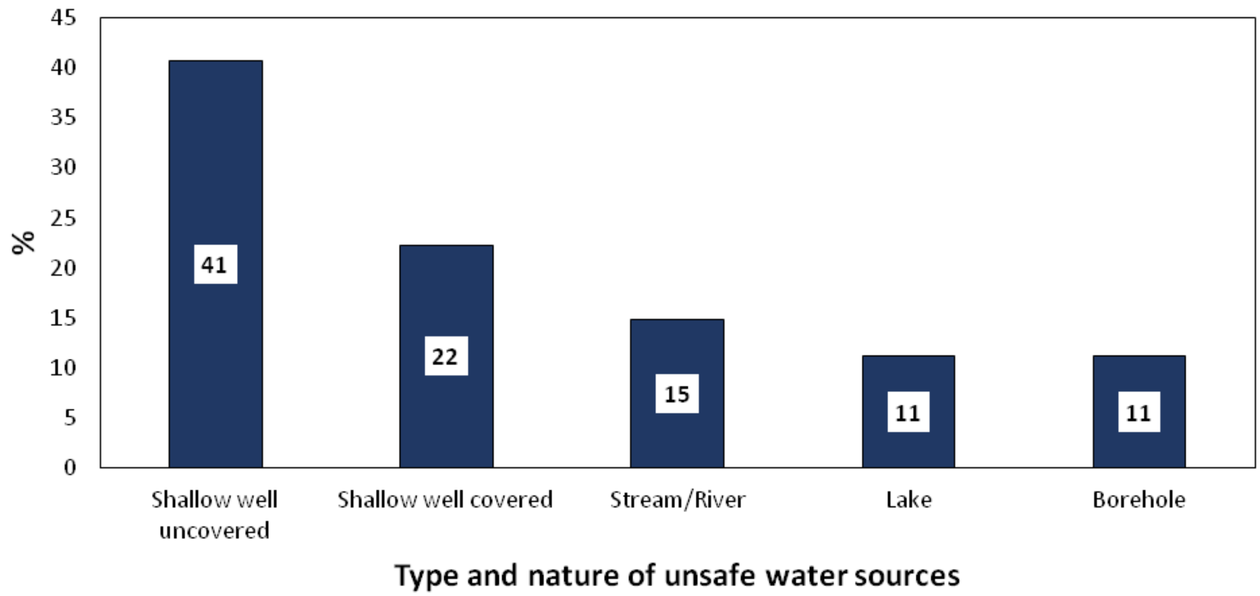

Figure 4. Type and nature of unsafe water sources in Karonga Town.

Table 2. Perception of some of the attributes of unsafe water sources (that is, lake, rivers, shallow wells and boreholes) by households.

Condition	Taste of water (%)	Odour of water (%)	Turbidity of water (%)
Good	51.2	70.5	64.1
Bad	46.1	28.5	35.9
Not sure	2.7	1.0	0.0
Total	**100.0**	**100.0**	**100.0**

commonly experienced by family and community members of households in Karonga Town (Figure 5). Occurrence of such diseases was largely attributed to use and consumption of contaminated water by the affected members of the community in Karonga Town (Manda and Wanda, 2017).

WASH related risks impacting on domestic water sources

An earlier study by Manda and Wanda (2017) reported the occurrence of multiple every day, small and large disaster risks which have the potential to worsen WASH related risks and health indicators thereby leading to premature deaths in Karonga Town. These disasters also affect both quantity and quality of water in addition to damaging sanitary facilities (Karonga District Council, 2010). This study found that up to 51.1% of the households used traditional pit latrines, 27.9% used ventilated improved pit (VIP) latrines, 13.2% used flush toilets connected to septic tanks, 4.2% used neighbours' pit latrines and 3.7% do not have toilets (Figure 6). On-site water source inspections revealed that all the shallow wells were not lined and covered. In addition, various sanitary factors that impact on groundwater, surface water sources as well as the health of households were noted. These included pit latrines constructed <100 m away from shallow wells/boreholes/rivers (27.4%), indiscriminate disposal of wastes (6.6%), graveyards located <100 m away from shallow wells/boreholes/rivers (1.1%), lack of hand washing facilities (8.2%), open defecation due to lack of toilets (2.4%), availability of stagnant waters close to boreholes and shallow wells (2.4%), lack of proper drainage system (5.0%) (Table 3 and Figure 7).

It was also observed that the sanitation around the majority of boreholes was very poor with dirty stagnant waters coming from water collection containers and washing sinks. The water sources were thus at risk of contamination through direct and indirect leakages from anthropogenic activities such as washing of clothes close

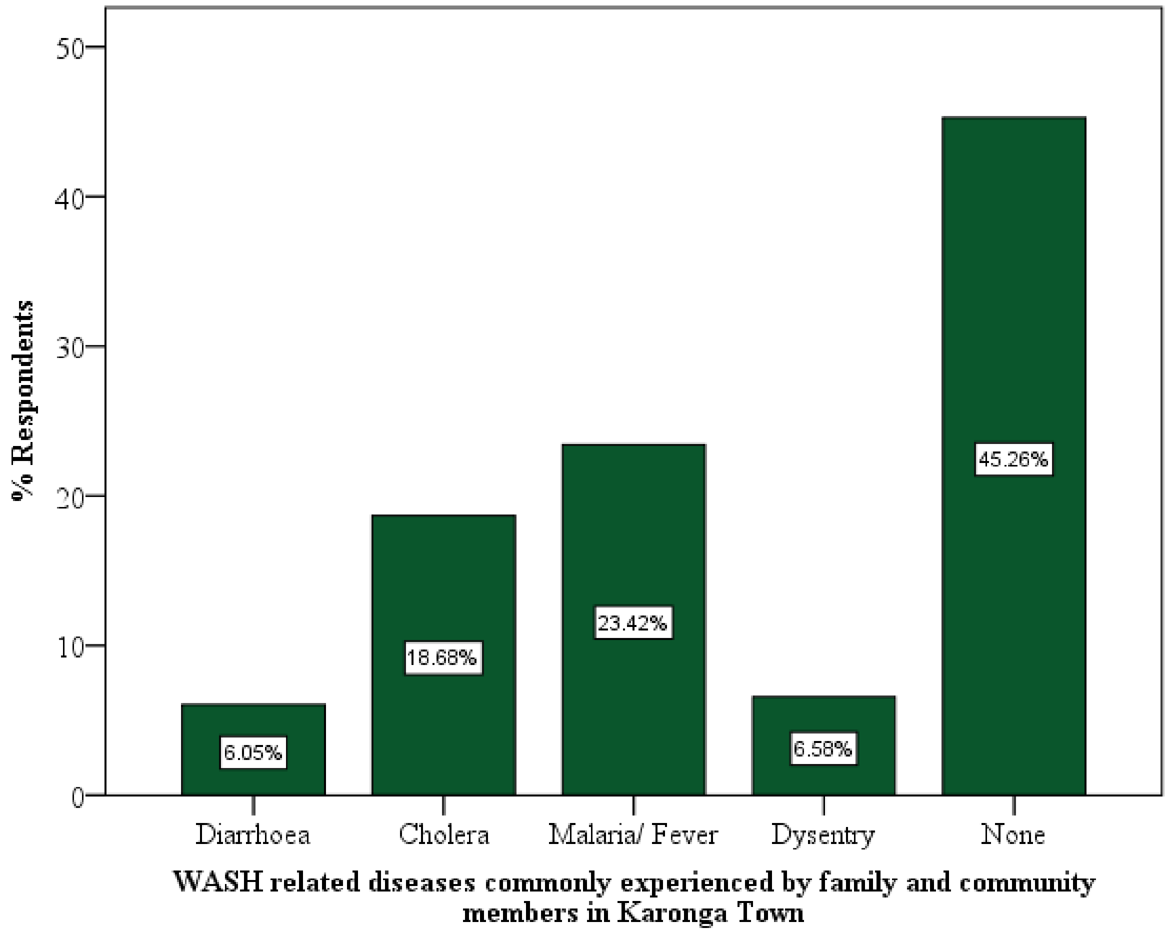

Figure 5. WASH related diseases commonly experienced by family and community members in Karonga Town.

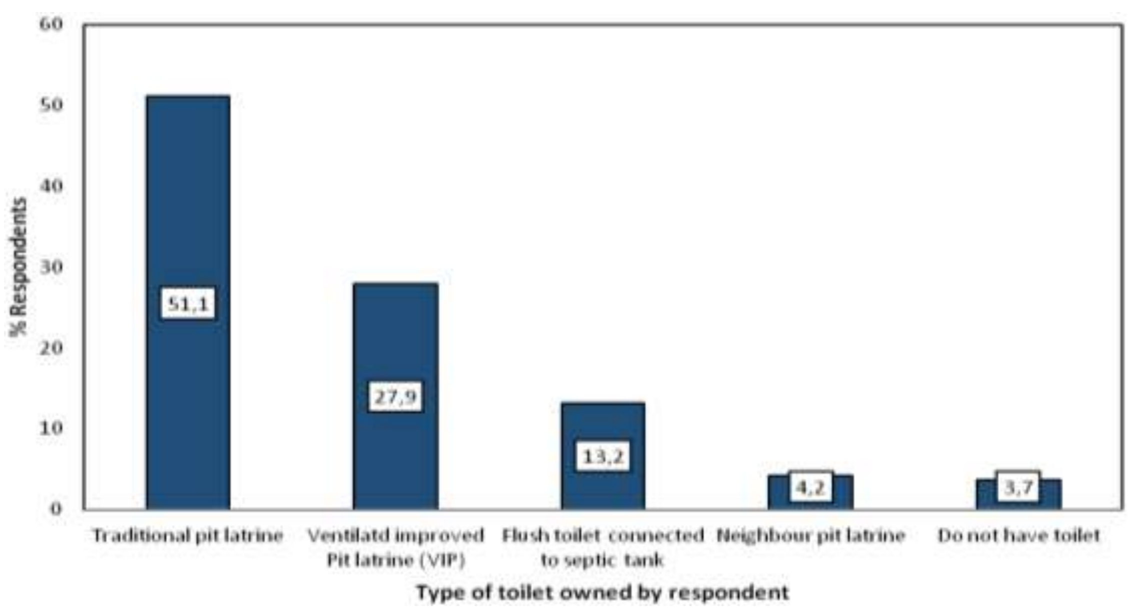

Figure 6. Type of toilets owned by respondents in Karonga Town.

Table 3. Summary of the sanitary risks impacting on a particular water source in Karonga Town.

Sanitary risks impacting a particular water source	%
Pit latrine <10 meters away from wells/boreholes/river	27.3
Indiscriminate disposal of wastes	6.5
Graveyard < 10 meters from wells/boreholes/river	1
Lack of hand washing facilities	8.1
Lack of toilet/pit latrine (open defecation)	2.3
Stagnant waters close to wells/boreholes/river	2.6
House connected to road/drainage	4.9
No risk	47.1
Total	**100**

Figure 7. Major sanitary risks impacting on water sources in Karonga Town such as proximity of water sources to sanitary facilities such as pit latrines, small gardens, stagnant water sources and uncovered nature of the water sources among others.

Table 4. Summary of descriptive statistics showing minimum, maximum, mean, standard deviation (p-value at 95% confidence level) and Malawi Bureau of Standards Board (MBS) water quality specifications (* = specifications not found).

Parameter	MBS limit	Min.	Max.	Mean	Std. Dev.	p-value
pH	6.0-9.5	5.20	8.30	6.92	0.65	0.171
TDS (mg/L)	2000	50.00	580.00	283.70	141.97	0.015
EC (µS/cm) at 20 ◦C	3500	252.00	1380.00	719.56	300.33	0.007
E-Coli (cfu/100mL)	0	0.00	7200.00	751.85	1535.82	0.911
Total Coliform (colonies/100 mL)	*	100.00	>20000	10596.29	8781.12	0.514
CO_3^{2-} (mg/L)	*	0.00	78.00	4.27	15.75	0.004
F^- (mg/L)	6	0.00	1.05	0.28	0.37	0.406
Mg^{2+} (mg/L)	200	0.60	42.45	6.66	9.29	0.943
Ca^{2+} (mg/L)	250	3.20	233.60	59.30	60.411	0.199
Na^+ (mg/L)	500	3.30	138.70	21.89	30.76	0.993
K^+ (mg/L)	1	0.10	3.60	0.87	0.89	0.975
Cl^- (mg/L)	750	1.00	178.00	21.69	37.18	0.129
SO_4^{2-} (mg/L)	800	1.10	126.20	9.66	23.39	1.000
HCO_3^- (mg/L)	400	16.00	746.44	220.60	210.42	0.652
NO_3^- (mg/L)	45	0.02	8.25	2.02	1.91	0.974
Turbidity (NTU)	25	0.00	230.00	20.06	43.16	0.000
Suspended solids (mg/L)	*	2.00	217.00	19.30	40.60	0.000
Total Hardness (mg/L)	800	15.00	616.00	175.41	174.33	0.307
Total Alkalinity (mg/L)	*	13.00	612.00	187.81	182.39	0.566
Electrical balance (%)		1.92	9.04	6.71	2.44	
WQI (%)		40.00	65.56	52.39	7.90	

to water sources, inadequate vegetation filtering buffers, rubbish pits, stagnant water pool, toilets, animal kraal, graveyards and dumpsites located close to the water sources.

As stagnant water pools become breeding sites for mosquitoes malaria was prevalent (23.42 %) in the study area (Figure 5). It is worth noting that the WASH related risks contribute to everyday risks that lead to premature deaths among the majority of residents in the town.

Similar observations were also made by Manda and Wanda (2017), who reported that inadequate provision for WASH services is one of the everyday risks impacting on the population, especially those from low income areas of the town. Manda and Wanda (2017) also observed that the majority of the population in Karonga Town lived in flood-prone areas, specifically along rivers, where flooding was annual. This suggested that the economic advantages of living in such flood prone places significantly outweigh the perceived risks of flooding (United Nations Office for Disaster Risk Reduction, 2011).

Microbial and physicochemical quality of the water

The mean values of the test water quality parameters for water samples from unprotected sources in Karonga Town have been presented in Table 4. The calculated electrical balance errors were ≤±10% (Table 4) suggesting good quality of the chemical data. Among all the physicochemical parameters analysed, pH is one of the most important parameters which determine the suitability of water for various purposes. The levels of pH ranged from 5.20 to 8.30 with an average of 6.9 indicating occurrence of slightly acidic to slightly alkaline waters (Table 4). It was observed that 7.4% of water samples registered pH values not in the range of the MBS specification of 6.0 to 9.5. These water samples had their pH values below 6.0. Such waters are acidic, soft and tend to be corrosive in nature and not suitable for direct human consumption (Wilkes University, 2007).

The levels of EC and TDS ranged from 255 to 1380 µS/cm and 50 to 580 ppm at 20°C, respectively indicating water sources of lower levels of mineralization (Table 4). Both EC and TDS were within MBS specifications of 3500 µS/cm and 2000 ppm, respectively. Similarly, in all water samples, levels of chlorides (range = 1.0 to 178 mg/L), sulphates (range = 1.10 to 126.20 mg/L), nitrates (range = 0.02 to 825 mg/L), total hardness (range = 15.0 to 616.0 mg/L), carbonates (range = 0 to 78.0 mg/L), sodium ion (range = 3.30 to 138.70 mg/L), calcium ion (range = 3.20 to 233.60 mg/L) and magnesium ion (0.60

to 42.45 mg/L) were within the permissible levels of both WHO and MBS (2005) water quality guidelines (Table 4). On the other hand, some of the water samples registered levels of potassium ion (22.2%), bicarbonate ion (22.2 %) and turbidity (11.1%) above the MBS water quality specifications of 1 mg/L, 400 mg/L and 25 NTU, respectively. The relatively higher turbidity values in water indicate the intrusion of run-off which could be attributed by the uncovered and unlined nature of shallow wells or soil disturbance and re-suspension within the well during water withdrawal. Similar observations were made by Pedersen and Price (2005), who also reported that increased levels of turbidity were as a result of inflow of sediments into water sources. Higher levels of HCO_3^- and K^+ ion could be attributed to mineralization processes within the water catchment (Wanda et al., 2011).

The levels of feacal coliforms (*E. coli*) ranged from 0 to 7200 colonies/100 mL (Table 4) which implied that the majority of water samples (56%) were above the WHO drinking water quality specification of 0 colonies/100 mL as well as the MBS standards and at high risk of faecal contamination arising from a number of sanitary risks such as open defecation, uncovered water sources and water sources located close to pit latrines. Such waters are not fit for domestic purposes prior to treatment. In terms total coliform, the levels ranged from 100 to 8700 colonies/100 mL with an average of 3073 colonies/100 mL. Generally, the average faecal coliform density was relatively high in water from the lake, streams, uncovered water sources compared to the covered ones and boreholes. This indicated possible contamination by human and animal faeces and possibly from naturally-occurring bacteria mainly because the water sources were open, not lined and often located very close to sanitary facilities which made the water highly prone to microbial contamination. The results agree with those of Tandlich et al. (2008), Pritchard et al. (2007), Pritchard et al. (2008) and Mkandawire and Banda (2009) who also reported possible microbial contamination of water sources due to their open, not lined nature coupled with their proximity to sanitary facilities. Computation of the analysis of variance showed that only turbidity had statistically significant spatial variation ($p < 0.05$) at 5% significance level (Appendix 2).

Overall water quality indices for each of the sampled sites

Principal component analysis

The principal component analysis isolated three major principal components (PCs) which controlled 70.01% of the observed variations in water quality (Table 5). These included PC 1, which controlled 39.19% of the variance, PC 2, which controlled 17.36% of the variance and PC 3, which controlled 14.46% of the variance. The PC 1 had high loadings in Ca^{2+}, total hardness, F^-, Mg^{2+}, EC, total alkalinity, TDS, HCO_3^- and SO_4^{2-}. Most of the parameters highly loaded in PC1 are products of mineralization processes, suggesting the influence of such process on the observed variations in water quality in the town. PC 2 had high loadings in turbidity, suspended solids, *E. coli*, chlorides, total coliform, Na^+, K^+ and NO_3^-. These factors could be attributed to the influence of anthropogenic activities such as municipal wastes, run-off and agricultural activities impacting on water resources in the area. PC 3 had high loadings on pH only. This suggested that pH is a major factor and that acidification of water bodies due to natural rainwater and other hydrochemical processes within catchments had a greater impact on the observed variations in water quality (Wanda et al., 2011).

Hierarchical cluster analysis

The hierarchical cluster analysis (HCA) revealed two main clusters (1 and 2) (Figure 8). Cluster 1 was composed of comprised of 12 water sources. Cluster 2 was composed of total of 15 water sources. The two clusters mainly differ in their level of mineralisation and microbial quality. Of the two clusters, Cluster 1 was more mineralized and had higher levels of E-coli and total coliform colonies/100 mL. Based on topographic patterns, cluster 1 members are located at lower topographic levels designated as discharge zones in terms of water flow. Furthermore, water sources in cluster 1 lay in areas where there was a higher rate of open defecation (3.7%) in the bushes, the lake as well as sand and some households relying on neighbors' toilets (4.2%) (Figure 6). It was generally observed that the water was of low mineralisation, indicating that the water in the study area was derived from recent recharge (Chimphamba et al., 2009; Wanda et al., 2011).

Overall water quality index

None of the sampled sites during entire study period registered a water quality index (WQI) of 100% (Table 6). The results of the water quality index (WQI) ranged of 40.00 to 65.56%, representing bad-medium water quality (WQ) ratings (Table 6). Specifically, up to 55.6% of the water sources registered a medium WQ rating whereas the remainder, 44.4% registered bad WQ rating. Nevertheless, the results suggested that none of the water sources was suitable for direct human consumption without treatment as all the waters were slightly polluted. The results suggested some grey areas and that there is need to intensify campaigns for substantial onsite water treatment or point of use water treatment works by households using the water for direct consumption

Table 5. Factor loadings for each parameter, a percentage variance for each principal components and the cumulative variance for the principal components principal components behind water quality in Karonga Town.

Parameter	Principal components (PCs)		
	1	2	3
Ca^{2+}	0.977		
Total Hardness	0.961		
F^-	0.931		
Mg^{2+}	0.931		
EC	0.927		
Total Alkalinity	0.899		
HCO_3^-	0.899		
TDS	0.822		
SO_4^{2-}	0.732		
Turbidity		0.946	
Suspended solids		0.941	
E-Coli		0.817	
Cl^-		0.776	
Total Coliform		0.739	
Na^+		0.729	
K^+		0.727	
NO_3^-		0.576	
pH			0.594
% of variance for each PC	39.190	17.363	14.455
Cumulative % for the PCs	39.190	56.553	70.008

(Wanda et al., 2012b).

Role of the citizen science approach in building resilience of WASH systems to water-related hazards in Karonga Town

Resilience has been defined as the capability of a society, community or system to undertake its economic, ecological and social growth and development strategies, while managing its disaster risk over time in a way that contributes to sustainable growth and helps to mitigate disaster risk (Szoenyi, 2016). Historically, DRM was the jurisdiction of stakeholders in the humanitarian sector who mostly focused on response and recovery as opposed to dealing with fundamental factors that lead to vulnerability. Even though the cost-benefits of risk reduction and preparedness measures are known to be higher than that for response and recovery, there still remains a higher tendency for increased financial support towards disaster recovery than to prevention (Pasteur and McQuistan, 2016). The citizen science approach used in this study was aimed at correcting this bias and shift the focus towards WASH risk and water related hazard reduction in Karonga Town. This approach is the first of its kind in the disaster disk reduction initiatives in Malawi which centered on building the capacity of communities in exploring enhance resilience of WASH systems the town. Integrating the public into scientific research through the citizen science approach has the virtue of improving management of water resources holistically with respect to: Prevention, protection, preparedness (through technology transfer initiatives among others), emergency response and recovery and lessons learned (returning to normal conditions as soon as possible and mitigating both the social and economic impacts on the affected population) (Oates et al., 2014). The approach used in this study was based on lessons learnt from some of the principles of the vulnerability to resilience (V2R) framework proposed by Pasteur and McQuistan (2016). Just like the V2R framework, our citizen science approach training sessions emphasized on the interlinkages between the wellbeing of the communities and local drivers of the WASH related risks and hazards at local, level (Pasteur and McQuistan, 2016). Figure 9 illustrates V2R framework, unravelling the complicatedness of a systems approach to resilience in a simple diagram.

Through the citizen science approach, both research counterparts and communities in Karonga were equipped with knowledge and skills of investing in WASH related risk reduction measures prior to occurrence of disaster

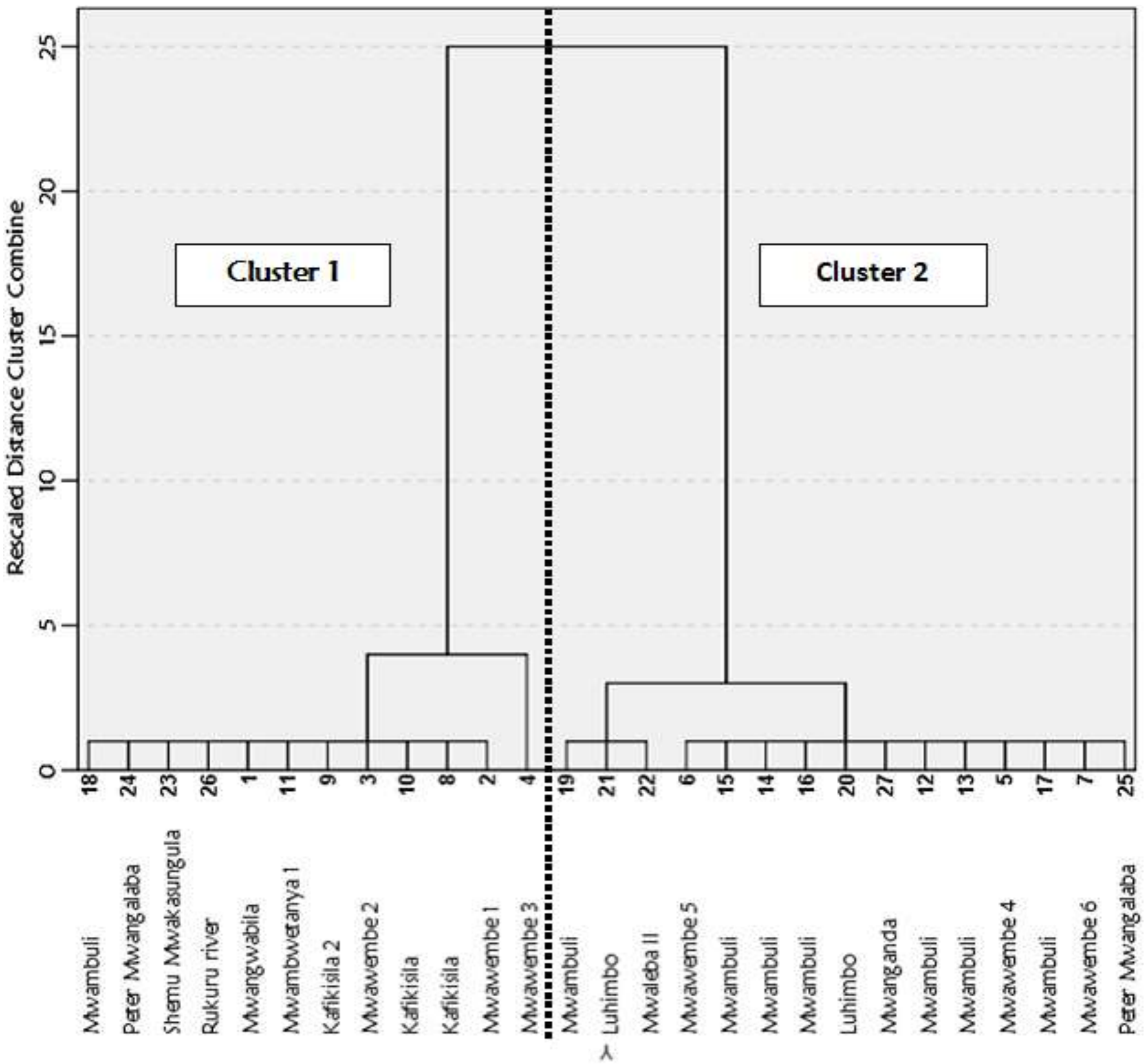

Figure 8. Dendrogram showing resulting of the hierarchical cluster analysis in Karonga Town.

events thereby assisting them to make informed and appropriate no-regret choices, principally in the context of an unpredictable future. Over and above, through the citizen science approach, the citizen science research counterparts and communities in Karonga Town have been empowered on WASH related risk knowledge, monitoring, communication as well as dissemination and the ability to respond. The research counterparts were involved throughout the research project including dissemination of research findings to communities and stakeholders as part of risk communication and technology transfer. Unlike the many perceived challenges outlined by Bonardi et al. (2011) and Kremen et al. (2011), the results of the citizen science water quality monitoring showed high level of accuracy in the obtained data. Electrical balance errors were ≤±10% showing good quality of the chemical data were obtained by the research counterparts throughcitizen science approach. This also suggested that with proper planning and implementation, the citizen science approach could help build resilience with high degree of accuracy and reliability.

CONCLUSIONS AND RECOMMENDATIONS

This study utilized the citizen science approach in assessing water quality, identifying WASH related risks and enhancing the understanding of how the resilience of WASH systems to water-related hazards (e.g. floods and

Table 6. Summary of results of water quality index and water quality rating.

Sample site	Description	Cluster	pH	*E. coli* (colonies/100 ml)	WQI (%)	WQ rating
Mwangwabila	Shallow well uncovered	1	6.6	200	45.78	Bad
Mwawembe 1	Shallow well uncovered	1	6.7	3400	43.68	Bad
Mwawembe 2	Shallow well uncovered	1	6.6	2000	43.16	Bad
Mwawembe 3	Shallow well uncovered	1	6.8	7200	46.47	Bad
Mwawembe 4	Shallow well uncovered	2	6.1	0	57.20	Medium
Mwawembe 5	Lake water	2	7.5	100	48.88	Bad
Mwawembe 6	Lake water	2	7.6	0	56.68	Medium
Kafikisila	Shallow well uncovered	1	6.8	1700	46.04	Bad
Kafikisila 2	Shallow well uncovered	1	6.9	0	57.45	Medium
Kafikisila	Shallow well uncovered	1	7.1	2000	44.18	Bad
Mwambwetanya 1	Lake water	1	7.8	400	50.10	Medium
Mwambuli	Shallow well covered (Toilet < 2m away)	2	6.7	0	58.93	Medium
Mwambuli	Shallow well uncovered but lined	2	7.0	0	60.65	Medium
Mwambuli	Shallow well covered (Toilet < 5m away)	2	6.8	0	64.38	Medium
Mwambuli	Shallow well covered (Toilet <10m away)	2	6.6	500	49.69	Bad
Mwambuli	Shallow well covered (Toilet < 8m away)	2	7.0	0	57.11	Medium
Mwambuli	Shallow well covered	2	6.6	300	45.69	Bad
Mwambuli	Shallow well uncovered	1	6.9	900	52.66	Medium
Mwambuli	Shallow well covered	2	6.4	100	54.08	Medium
Luhimbo	Borehole	2	7.0	0	65.56	Medium
Luhimbo	Shallow well uncovered but lined	2	7.0	0	62.76	Medium
Mwaleba II	Phapa river	2	8.1	0	63.79	Medium
Shemu Mwakasungula	Bwiba, Mwaskakata water stream	1	5.9	500	40.00	Bad
Peter Mwangalaba	Bwiba, water stream	1	5.2	800	40.16	Bad
Peter Mwangalaba	Borehole	2	7.3	0	52.55	Medium
Rukuru river	River	1	8.3	200	44.95	Bad
Mwanganda	Borehole-Rukuru Primary school	2	7.5	0	61.92	Medium

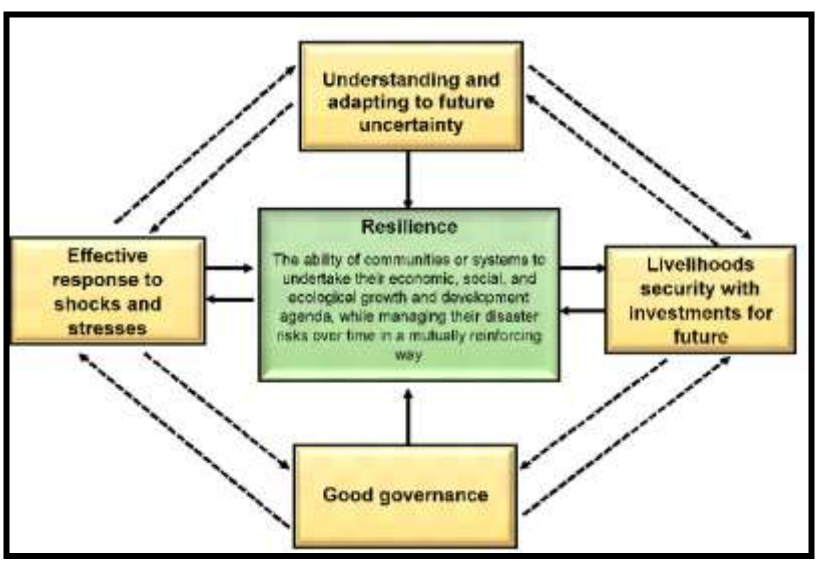

Figure 9. Framework for vulnerability to resilience (adapted from Pasteur and McQuistan, 2016).

water scarcity) can be improved. The community representatives took the lead in the assessment of risks associated with water pollution. Through the citizen science water quality monitoring approach, data was gathered and tested by trained non-professionals, the citizen science research counterparts. This capacity building or technology transfer was one of the major contributions of Urban Africa Risk Knowledge project in Karonga Town as it empowers local communities to understand the monitoring and recording of water quality in their area.

It was observed that water from the majority of shallow wells, rivers/streams, lake and boreholes were highly contaminated with E-coli, which were considerably higher than MBS water quality specifications for drinking water. In general, the water is of low mineralization with rock-water interactions and surface pollution from anthropogenic activities such as municipal wastes being responsible for input biological, chemical and physical pollutants especially into the unlined and uncovered water sources. The results of the water quality indices and ratings indicated that the water quality obtained from water sources in the studied area is not suitable for direct human consumption before onsite or household point of use treatment. It is recommended that onsite treatment and point of use water treatment interventions should be instituted to protect the households from further possible consequences of using the water. The application of citizen science approach can be tested in other urban centers in Malawi both to build capacity as we as to speed up scientific data collection for monitoring WASH related risks.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

This work is part of the Urban ARK Research Project funded by the UK Department for International Development (DFID)/Economic and Social Research Council (ESRC). The authors extend their thanks to the following for their contribution in various forms: (a) Wisdom Bwanali, Masozi Gondwe, of Mzuzu University, and (b) the 8 citizen science research counterparts from Karonga Town.

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APPENDICES

Appendix 1. Households Interviewed per enumeration area.

Enumeration area	Total number of households in enumeration area	Number of households interviewed
EA701	299	14
EA702	176	8
EA703	125	6
EA704	92	4
EA705	256	13
EA706	136	6
EA707	251	12
EA708	672	31
EA709	169	8
EA710	214	10
EA711	492	23
EA712	557	26
EA713	465	21
EA714	165	8
EA715	129	6
EA716	106	5
EA717	292	14
EA718	146	13
EA719	295	17
EA720	149	7
EA721	367	19
EA722	61	3
EA723	152	7
EA724	104	5
EA725	304	14
EA726	289	13
EA727	285	13
EA728	90	4
EA729	203	9
EA730	71	3
EA731	93	4
EA732	85	4
EA733	66	3
EA734	134	6
EA735	31	1
EA736	361	17
EA737	125	6
TOTAL	**8007**	**380**

Appendix 2. The analysis of variance (ANOVA) table for all analyses together with the p-values at 95% confidence level.

Parameter	Group			Sum of squares	df	Mean Square	F	Sig.
pH	Between groups	(Combined)		7.784	16	.486	1.561	.240
		Linear term	Weighted	.155	1	.155	.497	.497
			Deviation	7.629	15	.509	1.632	.219
	Within groups			3.117	10	.312		
	Total			10.901	26			
TDS	Between Groups	(Combined)		392166.296	16	24510.394	1.859	.161
		Linear term	Weighted	83875.799	1	83875.799	6.361	.030
			Deviation	308290.498	15	20552.700	1.559	.242
	Within groups			131863.333	10	13186.333		
	Total			524029.630	26			
EC	Between groups	(Combined)		1483636.800	16	92727.300	1.076	.467
		Linear term	Weighted	240335.873	1	240335.873	2.790	.126
			Deviation	1243300.927	15	82886.728	.962	.542
	Within groups			861565.867	10	86156.587		
	Total			2345202.667	26			
E-Coli	Between groups	(Combined)		14241074.074	16	890067.130	.189	.998
		Linear term	Weighted	1183714.148	1	1183714.148	.251	.627
			Deviation	13057359.926	15	870490.662	.185	.998
	Within groups			47086333.333	10	4708633.333		
	Total			61327407.407	26			
Total coliform	Between groups	(Combined)		1178825962.963	16	73676622.685	.892	.596
		Linear term	Weighted	79982067.846	1	79982067.846	.968	.348
			Deviation	1098843895.117	15	73256259.674	.887	.596
	Within groups			825983666.667	10	82598366.667		
	Total			2004809629.630	26			
CO_3^{2-}	Between groups	(Combined)		2344.320	16	146.520	.357	.968
		Linear term	Weighted	15.974	1	15.974	.039	.848
			Deviation	2328.346	15	155.223	.378	.956
	Within groups			4102.080	10	410.208		
	Total			6446.400	26			
F^-	Between groups	(Combined)		2.563	16	.160	1.742	.188
		Linear term	Weighted	.011	1	.011	.116	.741
			Deviation	2.553	15	.170	1.851	.164
	Within groups			.920	10	.092		
	Total			3.483	26			
Mg^{2+}	Between groups	(Combined)		1065.009	16	66.563	.564	.852
		Linear term	Weighted	39.307	1	39.307	.333	.577
			Deviation	1025.702	15	68.380	.579	.836
	Within groups			1180.055	10	118.006		
	Total			2245.065	26			
Ca^{2+}	Between groups	(Combined)		70606.252	16	4412.891	1.817	.170
		Linear term	Weighted	3149.257	1	3149.257	1.297	.281
			Deviation	67456.995	15	4497.133	1.852	.164
	Within groups			24281.227	10	2428.123		
	Total			94887.479	26			

Appendix 2. Cont.

Na^+	Between groups	(Combined)		16039.487	16	1002.468	1.171	.411
		Linear term	Weighted	299.465	1	299.465	.350	.567
			Deviation	15740.021	15	1049.335	1.226	.381
	Within groups			8561.580	10	856.158		
	Total			24601.067	26			
K^+	Between groups	(Combined)		10.362	16	.648	.631	.801
		Linear term	Weighted	.388	1	.388	.378	.552
			Deviation	9.974	15	.665	.648	.783
	Within groups			10.258	10	1.026		
	Total			20.620	26			
Cl^-	Between groups	(Combined)		29914.779	16	1869.674	3.100	.037
		Linear term	Weighted	271.192	1	271.192	.450	.518
			Deviation	29643.587	15	1976.239	3.276	.032
	Within groups			6031.715	10	603.171		
	Total			35946.494	26			
SO_4^{2-}	Between groups	(Combined)		6951.162	16	434.448	.597	.827
		Linear term	Weighted	120.082	1	120.082	.165	.693
			Deviation	6831.080	15	455.405	.626	.800
	Within groups			7271.906	10	727.191		
	Total			14223.068	26			
HCO_3^-	Between groups	(Combined)		854774.888	16	53423.430	1.802	.174
		Linear term	Weighted	40960.099	1	40960.099	1.382	.267
			Deviation	813814.788	15	54254.319	1.830	.169
	Within Groups			296464.219	10	29646.422		
	Total			1151239.107	26			
NO_3^-	Between groups	(Combined)		68.754	16	4.297	1.628	.219
		Linear term	Weighted	.761	1	.761	.288	.603
			Deviation	67.993	15	4.533	1.718	.195
	Within groups			26.391	10	2.639		
	Total			95.144	26			
Turbidity	Between groups	(Combined)		48283.799	16	3017.737	219.525	.000
		Linear term	Weighted	47950.829	1	47950.829	3488.179	.000
			Deviation	332.970	15	22.198	1.615	.224
	Within groups			137.467	10	13.747		
	Total			48421.265	26			
Total hardness	Between groups	(Combined)		611572.185	16	38223.262	2.140	.112
		Linear term	Weighted	27511.121	1	27511.121	1.541	.243
			Deviation	584061.064	15	38937.404	2.180	.108
	Within groups			178578.333	10	17857.833		
	Total			790150.519	26			
Total alkalinity	Between groups	(Combined)		620014.207	16	38750.888	1.582	.233
		Linear term	Weighted	30009.713	1	30009.713	1.225	.294
			Deviation	590004.495	15	39333.633	1.606	.227
	Within groups			244963.867	10	24496.387		
	Total			864978.074	26			