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Social knowledge, attitudes, and perceptions on wastewater treatment, technologies, and reuse in Tanzania

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ABSTRACT

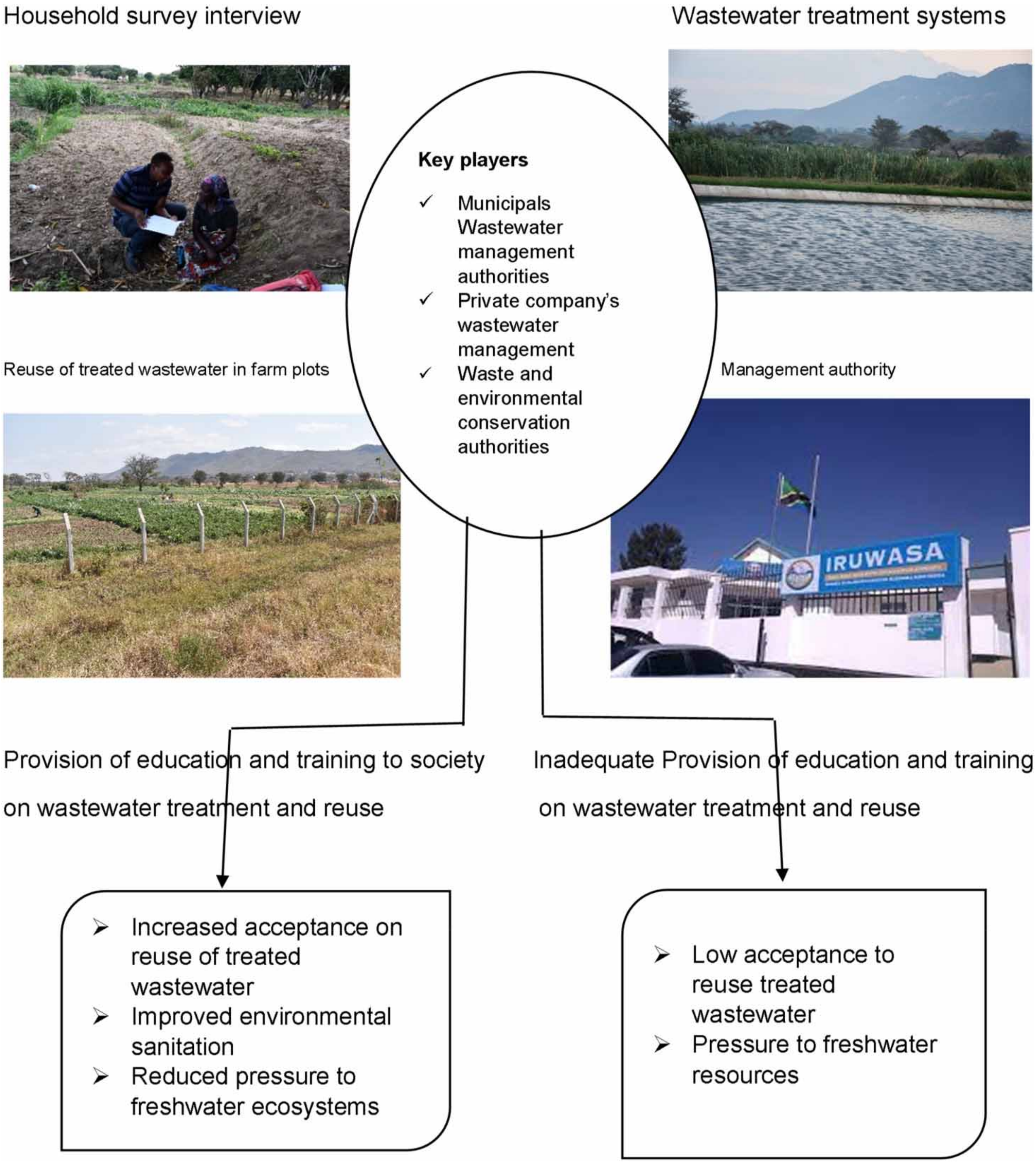
This study assessed the social knowledge, attitude, and perceptions (KAPs) on wastewater treatment, the technologies involved, and its reuse across different wastewater treatment areas in four regions of Tanzania. We used both quantitative and qualitative data collection methods in a household-level questionnaire (n=327) with structured and semi-structured questions, which involved face-to-face interviews and observation. Our results show that social KAPs surrounding wastewater treatment and reuse were sufficient based on KAP scores achieved from asked questions. However, the general knowledge on treatment technologies, processes, and reuse risks was still low. Of the respondents, over 50% approved using treated wastewater in various applications, while the majority (93%) were reluctant if the application involved direct contact with the water. Furthermore, over 90% of interviewees did not know the technologies used to treat wastewater and the potential health risks associated with its use (59%). Multivariate analysis of variance revealed significant differences ($P<0.05$) in the KAPs on treated wastewater across different studied demographic variables, i.e., age, sex, and education level. Therefore, we recommend that more effort be spent on providing public education about the potential of wastewater treatment and existing technologies in order to facilitate their adoption for the community's and environment's benefit.

Key words: constructed wetlands, health risks, irrigation, multivariate analysis, potable use

HIGHLIGHTS

- We conducted 327 survey interviews with local communities on wastewater treatment, technologies, reuse, and benefits.
- There was low acceptance for the reuse of treated wastewater for potable uses.
- General knowledge, attitude, and perceptions (KAPs) over wastewater treatment processes, technologies, and the potential health risks of reuse were low.
- We recommend better education and policies for increased adoption of wastewater reuse and sustainability.

GRAPHICAL ABSTRACT



INTRODUCTION

In recent years, the growing human population, industrialization, and expansion of various economic activities have led to significant demand for water. This demand has increased the coverage of water supplies, and in turn, greater quantities of municipal wastewater are produced (Kilobe *et al.* 2013; Fukase & Martin 2017). The release of untreated wastewater, which may contain heavy metals, harmful microorganisms, radionuclides, nutrients, pharmaceuticals, and personal care products into the environment contaminates land and water, causing significant damage to plants, domestic and wild animals, humans, and the entire ecosystem (Edokpayi *et al.* 2017). Igbinosa & Okoh (2009) reported that the release of untreated wastewater into the environment causes fish death due to low levels of dissolved oxygen in the receiving water and the death of plants and animals in the nearby environment. Increased water demands associated with the growing human population and increasing dry spells and uneven precipitation patterns around the world highlight the importance of finding alternative sources of water (Menegaki *et al.* 2007; Bakopoulou *et al.* 2010). Moreover, water has become a limited resource in the many growing towns and cities of developing countries. It is also true that water resources are not equally distributed in space and time (Ling *et al.* 2013) and that they are currently under pressure due to human activities and economic development.

Both the impact of releasing untreated wastewater into the environment and the increased demand for this scarce resource stress the need for developing wastewater treatment technologies that can lessen these impacts and improve the economy through the reuse of treated wastewater. For many decades, onsite technologies of pit-latrines and septic tanks–soak-away pit (ST–SP) have been used for treating wastewater in many parts of Tanzania. On the other hand, waste stabilization ponds (WSPs) are the most common systems for centralized wastewater treatment and have been used worldwide for many years. These systems have been popular because they are cost-effective, as wastewater is treated by naturally occurring processes through the influence of solar light, wind, microorganisms, and algae (Quiroga 2013). Recently, there has been significant innovation and development of wastewater treatment technologies and projects across the globe. This development has produced many wastewater treatment designs, including integrating WSPs and constructed wetlands (CWs). CWs are engineered wastewater treatment systems that encompass a plurality of treatment modules, including biological, chemical, and physical processes, similar to those occurring in natural wetlands (Vymazal 2005). CWs that are positioned at the final stage of a treatment system operate (polishing) more efficiently and deliver other beneficial outcomes such as enhanced biodiversity (Kihila *et al.* 2014). The incorporation of CWs into WSPs has improved the ecology of these systems as they attract different types of animals such as reptiles, amphibians, and birds (Kohler 2015). They also host a vast diversity of insects and microorganisms.

Despite the great innovation in the development of wastewater treatment technologies, the uptake of such eco-friendly projects in many developing countries is not widespread. In Tanzania, there have been several initiatives and projects – most of which integrate WSPs with CWs – aimed at treating wastewater in municipal cities such as Moshi, Arusha, Dar es Salaam, Morogoro, Musoma, Iringa, Mbeya, and Mwanza. Also, several businesses in the country have implemented wastewater treatment projects, such as Banana Investment Limited, Meat King Corporation Limited, and also public institutions such as the Nelson Mandela African Institution of Science and Technology (NM-AIST), Ruaha Secondary School, and Kleruu Teachers College (Njau & Machunda 2013; Kipasika *et al.* 2014). Despite these initiatives, the adoption of modern wastewater treatment systems, such as CWs, by the community and government has been relatively low and mostly unprogressive. Studies reveal that uptake by community and government on any project solely depends on the general knowledge, attitudes, and perceptions (KAPs) on what it is, its benefits, and the consequences of implementation (Saad *et al.* 2017). Perceptions and public acceptance of water reuse are recognized as principal factors for the successful introduction of wastewater reuse projects, regardless of the strength of scientific evidence in their favour (Michetti *et al.* 2019). Moreover, understanding community perceptions on wastewater treatment initiatives and reuse of treated wastewater is crucial for planning an effective use of the resource. Acknowledging these perceptions helps to understand people's opinions, actions, knowledge gaps, and the existing limitations in patterns of water reuse (Michetti *et al.* 2019). Furthermore, it is crucial in developing strategies to promote wider public acceptance on the use of the wastewater treatment technologies and resources extracted from them including treated wastewater. The use of treated wastewater for agricultural activities in some regions might be challenging due to inadequate understanding of the community's safety, thus resulting in failures of wastewater treatment facilities worldwide (Scott *et al.* 2009).

Some research studies have focused on designing innovative wastewater treatment technologies, such as integrating various treatment systems with CWs to enhance treatment efficiency and establishing the removal efficiency of these systems (Njau *et al.* 2011; Mtavangu *et al.* 2017). However, fewer studies provide a snapshot of the public's KAPs on wastewater and treatment technologies (Kilobe *et al.* 2013; Kihila *et al.* 2014; Mayilla *et al.* 2017) and usage patterns.

In this study, we aimed to (1) document social KAPs on wastewater treatment, associated technologies, and various options for using the treated wastewater and (2) assess the public's knowledge on the potential health risks and benefits associated with the production and use of treated wastewater in Tanzania. We hypothesized that respondents with a higher level of education would be more knowledgeable and have a positive attitude towards wastewater treatment, technologies, and reuse. Moreover, we expected respondents living close to wastewater treatment systems to be more informed about such processes and technologies. Furthermore, we hypothesized that respondents' gender and age would influence their social KAPs on wastewater treatment, technologies, and reuse. Finally, we also predicted that respondents would have a positive attitude towards using treated wastewater for a range of applications.

Our study will help support the adoption of these eco-friendly technologies that provide benefits to humans and the environment by providing up-to-date information on social KAPs in the community. Moreover, the findings should be helpful in establishing guidelines for implementing wastewater projects, including incorporating wastewater treatment systems, as part of a biodiversity conservation portfolio.

METHODOLOGY

Study areas

The study was conducted in four regions of mainland Tanzania: Kilimanjaro, Arusha, Iringa, and Dar es Salaam (Figure 1). These locations were representative regions for wastewater treatment systems and hosted well-established wastewater treatment systems, including CWs, that had been running for more than 3 years.

Dar es Salaam is the largest city with the fastest-growing population and is thereby characterized by a vast sewerage system that collects wastewater from domestic and industrial sources (Venkatachalam 2009; Worrall *et al.* 2017). The other regions have growing sewerage systems to match an increase in their human populations and the industrial development of recent years (Thomas *et al.* 2013).

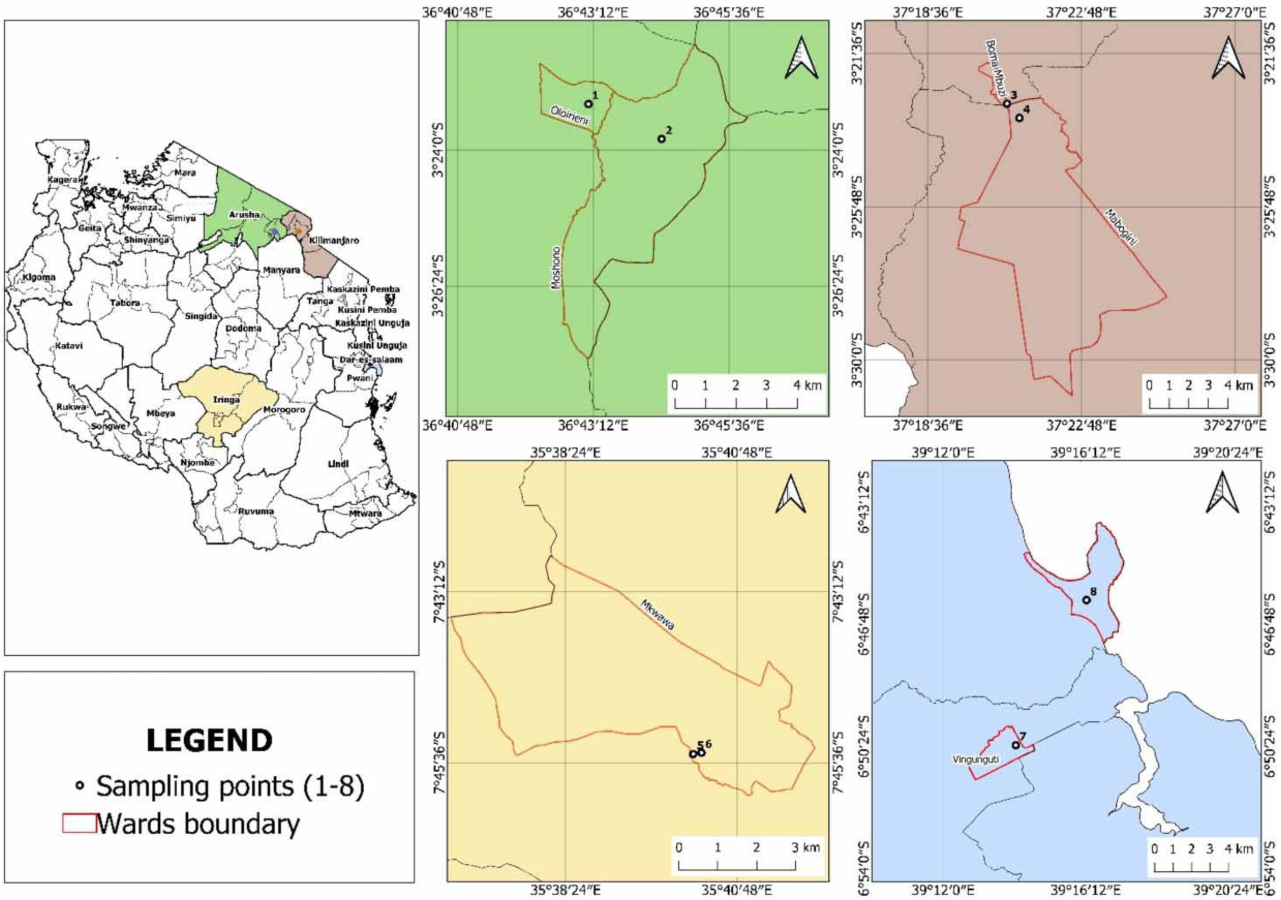


Figure 1 | Map of the study areas selected for sampling during data collection in the year 2020 in Tanzania. For more detailed descriptions of the wastewater treatment locations, see also Table 1.

Table 1 | Selected study areas, their names, location, water supply, wastewater treated, and population surrounding the wastewater treatment location in Tanzania, assessed in the year 2020–2021

Region	Ward* name (address)	Location of surveyed wastewater treatment areas and streets	Individual population of study wards	Volume of water supplied in the region (m^3/day)	Volume of wastewater treated in the visited treatment system (m^3/day)	Number of individual connected to centralized wastewater treatment system	Reasons for selection (characteristics)
Iringa	Mkwawa	Bwawani A Bwawani B	9,673	16,000	112.23	2,386	Have well-developed wastewater treatment systems managed by the Iringa urban water supply agency outflow water used for irrigation by the community around.
Kilimanjaro	Bomambuzi and Mabogini	Bogini Juu Relini	44,758	24,500	4,300	3,098	Have well-developed wastewater treatment systems managed by the Moshi urban water supply agency. Previously was directly used for irrigating rice plots and vegetable gardens.
Dar es Salaam	Mjimpya	CCBRT and Mnyamani wastewater treatment systems	106,946	406,877	6.4 and 429	Mostly industrial connections	Have well-developed wastewater treatment systems managed by Dar es Salaam water supply agency and the Majani ya Chai school.
Arusha	Moshono	Banana Investment Company (BIL) and Meat King Company	20,698	109 (BIL)	62.8 and 9	For industrial treatment only	Have well-developed CW, managed by companies, outflow water used for irrigation of gardens in the companies' premises.

*A ward is an administrative structure made of several streets making a portion of a bigger town (Urban Wards). For rural areas, it is composed of several villages and usually a division of the area within the jurisdiction of a local authority (Mzee 2008).

Water supply and wastewater treatment systems

Water supply to the households in urban wards of Tanzania has significantly improved in recent years. Most of the families living in urban wards have good access to fresh water and mostly own a tap at their home or nearby environment (U.R.T 2020). On the other hand, in Tanzania, currently, because of the vastly growing population and rise of sewerage production, there is an increased need for developing wastewater treatment networks to support the treatment of produced wastewater for the safety of the environment and reuse purposes (Wawa 2020). In this study, we studied a combined WSP–CW treatment system owned by municipals of the four regions and two CWs owned by private companies. The data for this objective were collected in households living close to these systems, which are attached to these systems in one way. The government operates the municipal systems, and the effluent is discharged to the community for other uses, which are mainly centred on small-scale vegetable and paddy plots farming. The effluent from private companies was used to irrigate gardens and vegetables around the company premises, and the other water was released to a nearby stream.

The treatment of wastewater in the visited sites is to the standards set by the Tanzania Bureau of Standards (TBS), with the limits of the major parameters being commonly measured in all the sites being; BOD5 at 20 °C 30 mg/L; COD 60 mg/L; pH ranges 6.5–8.5; total suspended solids (TSS) 100 mg/L and 300 TCU (EWURA 2014).

Data collection

Purposive sampling was used to select the study sites (Figure 1) based on their proximity to wastewater treatment plants and the use of treated wastewater for socio-economic activities. The purposive sampling was also done in these areas to increase the chance of having respondents connected to centralized wastewater treatment plants, which were thought to be an essential group to learn of social KAPs. Simple random sampling was used to select households from which representative respondents were chosen. A sampling fraction of 5% of households was applied to each study ward, and because the number of households varied between sites, the numbers selected from each site differed. A total of 327 households from the selected sites were involved in the study. Both quantitative and qualitative data collection methods were used to obtain primary data. A questionnaire, with structured and semi-structured questions, was the main instrument, which involved face-to-face interviews with one respondent from each of the selected households. Interviews were conducted between August 2020 and March 2021 with the assistance of a trained research assistant who was a local resident of the site being surveyed. The heads of the households were chosen as respondents (father or mother) or, in their absence, another permanent resident (an adult $\geq$18 years old) of that household. The questionnaire was designed in English and translated into Kiswahili, the national language of Tanzania, which is understood by the majority of the respondents in the study areas. A preliminary study survey involving 15 respondents was used to test the reliability of the survey instrument. The questionnaire was divided into four parts to tackle the following themes as shown in Table 2.

Prior to administering the questionnaire to the respondent, a short definition and elaboration on wastewater, wastewater recycling, reuse, and treatment technologies were given:

- Wastewater refers to any water that has been used in the home, in a business, or as part of an industrial process.
- Wastewater treatment is a process used to remove pollutants/contaminants from wastewater and convert it into an effluent that can be suitable for other uses and/or discharged to the environment and returned to the water cycle.
- Wastewater reuse/recycling in this questionnaire survey refers to all the application of treated wastewater in any socio-economic activities (i.e., brick making and vegetable, fish farming, etc.) and for any purpose of gaining income and/or improving the quality of the environment.
- Wastewater treatment technologies include all conventional and modern techniques geared to reduce pollutants/contaminants from wastewater.

This aimed to create a general understanding for those respondents with no basic knowledge of wastewater treatment and reuse to develop an idea. However, the definitions were too general to allow us to assume that they did not affect the overall approach of the respondents towards the study subject.

Table 2 | A summary of the questionnaire and construct themes

Parts	Sections	Question constructs	Response/answer
I	A	Demographic information of respondents such as sex, education level, age, and marital status	Multiple picks
II	B	Water availability and change	Multiple picks
III	C	General KAPs on wastewater recycling/treatment, reuse, treatment technologies, and their importance	Multiple picks
	D	Knowledge on wastewater recycling/treatment, treatment technologies and their importance	Strongly disagree/disagree/agree/strongly agree
	E	Attitude on various wastewater reuse options	Disagree/not sure/agree
	F	Perception on wastewater recycling/treatment, treatment technologies, and their importance	True/false/I do not know
IV	G	Part E: awareness of potential risks of using treated wastewater/effluents for various socio-economic activities	Multiple picks

Data analysis

The collected data were catalogued into SPSS (version 20) and Microsoft Excel for analysis. Descriptive statistics were used to compute frequencies and percentages of respondents' demographic characteristics and KAP items. Partial correlation coefficient was used in this study to measure the strength and direction of a linear relationship between a respondent's knowledge on wastewater and reuse option by age and educational level. The correlation coefficient is represented by r. Multivariate analysis of variance (MANOVA) was used to determine whether the various groups comprising the general studied population differ from each other with respect to KAP on wastewater recycling, technologies used in wastewater recycling, and reuse patterns. The analysis also aimed to determine whether any of the groups have significant/meaningful differences in opinions from those expressed by the whole studied population. All statistical tests were considered significant at a confidence level of 95% ($P<0.05$).

Reliability assessment

Cronbach's α is the most common measure of internal consistency ('reliability') of a set of scale or test items (Gliem & Gliem 2003). Therefore, it is most appropriate if one has used multiple Likert questions in a survey/questionnaire that form a scale and one wishes to determine if that scale is reliable (Gliem & Gliem 2003). Reliability is the extent to which an experiment, test, or any measuring procedure yields the same result in repeated trials (Mugenda & Mugenda 1999, 2003). In this study, the instrument reliability was measured using seven questions to test the respondent's attitude and five questions testing the respondent's knowledge on wastewater recycling, technologies, and reuse patterns; these two sets yielded Cronbach α values of 0.864 and 0.83, respectively. Since these values were >0.7, we concluded that the instrument used to collect data yielded reliable responses with high internal consistency (Appendix 2).

RESULTS

Demographic characteristics of respondents

We interviewed 58% female and 42% male household heads. About 35.5 and 32.7% of the respondents were found to be in the age groups 36–53 and 18–35 years, respectively. The results also show that 73.4% of the surveyed heads of household were married, 19.6% were single, and 4.0% were widows, whereas only 1.80 and 1.30% were separated and widowers, respectively. The findings further revealed that 55.05% of the heads of household had received primary education, whereas 24.2% had had secondary education, 18% of the heads of the household had tertiary education, and very few of the heads of the household had received no formal education. Furthermore, 41.0% of the respondents were unemployed and 31% were employed. The results also indicate that most of the households had 3–6 members (>78%) (Table 3).

Water availability, quality, and costs in study areas

The majority of the respondents (79%) fetch water from a location less than 100 m from their homes and very few go beyond 300 m (Table 4). Across all study sites, 55% of the respondents indicated that water is plentiful. Approximately 50% of respondents stated that there had been an increase in water availability in the past 5–10 years. This expansion is associated with a rise in sewage production. Moreover, regarding the quality of supplied water, more than 70% of respondents pointed out that the water quality was good. Regarding the cost, the majority of the respondents revealed that the cost for provided water is moderate; however, an observational study found out that respondents connected to direct wastewater systems claimed that the cost for water has risen, for instance. In Iringa, some respondents revealed that the average cost of water before connected to the centralized wastewater system was 2,000 Tshs/m^3 and now there is an increase of 40% of the original costs. This has also been confirmed by the water management authority of municipality; furthermore, it was said that for companies and institutions, the costs have even risen to 80% of the original cost. On the other hand, in Kilimanjaro, the cost was around 800 Tshs/m^3 and now there is an increase of about 50% of the original costs to the respondents connected to centralized wastewater treatment systems.

Knowledge on wastewater recycling, reuse, and benefits

The results on the knowledge of wastewater recycling, reuse, and benefits are shown in Table 5. More than half of the respondents asserted that there had been an increase in the volume of wastewater produced in cities and towns that can be recycled for other uses. Eighty-two percent of respondents strongly agreed that it is crucial to have wastewater treatment plants as they help to reduce pollution in the environment. Eighty-seven percent of respondents approved the use of recycled wastewater for economic activities, for example, agricultural irrigation. These findings indicate that most interviewed respondents had good

Table 3 | Demographic characteristics of respondents across study wards in four regions of Tanzania in the year 2020–2021 ($n = 327$)

Demographic variables	Sample wards: Bomambuzi ($n = 111$)	Bogini Juu ($n = 37$)	Mkwawa (Bwawani B) ($n = 43$)	Mkwawa (Bwawani A) ($n = 48$)	Mjimpya ($n = 88$)	Total ($n = 327$)	% ($n = 327$)
Sex							
Male	52	15	21	15	34	137	41.9
Female	59	22	27	28	54	190	58.1
Age							
18–35	34	16	17	16	24	107	32.7
36–53	38	17	20	21	38	116	35.5
54–71	34	3	11	6	24	78	23.9
> 72	5	1	0	0	2	8	2.4
Marital status							
Single	19	9	11	6	19	64	19.6
Married	82	26	34	36	62	240	73.4
Widow	6	2	1	0	4	13	4
Separated	3	0	1	1	1	6	1.8
Divorced	0	0	0	0	0	0	0
Widower	1	0	1	0	2	4	1.2
Education							
Primary	63	20	28	28	41	180	55.1
Secondary	26	11	11	8.0	23	79	24.2
Tertiary	18	5	9	6	21	59	18
None	4	1	0	1	3.0	9	2.75
Occupation							
Unemployed	45	16	21	15	37	134	41
Employed	9.0	2	2	3	5	21	6.4
Self-employed	40	16	16	21	29	122	37.3
Student	9.0	2	7	3	10	31	9.5
Retired	8.0	1	2	1		19	5.8
Family size							
1–2	7	3	3	2	5	20	6.1
3–4	45	19	24	16	40	144	44
5–6	42	10	14	16	32	114	34.9
7–8	17	2	7.0	9	10	45	13.8
> 8	0	3	0	0	1	4	1.2

knowledge about wastewater, recycling, and patterns of reuse. However, it was observed that respondents who lived away from these systems had less knowledge about the subject.

Attitude on wastewater reuse in various situations

Figure 2 shows the respondents' attitudes towards the reuse of treated wastewater in various situations. The majority of respondents (93%) were reluctant to use treated wastewater for domestic applications such as washing and cleaning the home. By contrast, more than 70% of respondents agreed to the use of treated wastewater for irrigation of forests, sport fields, urban gardens, and for farming of vegetables and animal crops. However, general observation found that respondents residing far from a wastewater treatment system and who do not use treated wastewater for any activity disapproved of applying treated wastewater in situations involving direct contact.

Table 4 | Proportion (%) of respondents that perceived differently on water availability, quality, and costs across study wards in four regions of Tanzania in the year 2020–2021(n=327)

Environmental variable	Bomambuzi (n=111) (%)	Bogini Juu (n=37) (%)	Mkwawa (Bwawani A) (n=48) (%)	Mkwawa (Bwawani B) (n=43) (%)	Mjimpya (n=88) (%)
Respondent average distance to water source					
<100 m	82.9	81.1	75	69.8	78.4
101–200 m	16.2	16.2	22.9	30.2	19.3
201–300 m	0	2.7	0	0	1.1
>300 m	1	0	2.1	0	1.1
Respondent comment on water availability for daily uses					
Plenty available	57.7	45.9	54.2	55.8	55.7
Moderate available	35.1	43.2	41.7	34.9	36.4
Less available	7.2	10.8	4.20	9.3	8
The trend of water availability and change in past 5–10 years					
Decreased	29.7	24.3	25	18.6	31.8
Increased	49.5	54.1	50	55.8	45.5
No changes	15.3	16.2	22.9	25.6	19.3
Uncertain	5.4	5.4	2.1	0	3.4
How do you rate the quality of water supplied					
Very good	43.2	29.7	45.8	23.3	43.2
Good	44.1	43.2	45.8	55.8	38.6
Fair	12.6	24.3	8.3	20.9	18.2
Poor	0	2.7	0	0	0
Price of water supplied					
Too costly	34.2	27	37.5	30.2	38.6
Moderate cost	49.5	56.8	45.8	53.5	42
Fair	16.2	16.2	16.7	16.3	19.3

Table 5 | Proportion (%) of respondents knowledge on wastewater recycling, reuse, and benefits across study sites in four regions of Tanzania in the year 2020–2021(n=327)

Variables	Strongly disagree (%)	Disagree (%)	Agree (%)	Strongly agree (%)
There is a large volume of wastewater produced from economic activities that may be recycled and reused in economic activities	0.6	12.2	53.8	33.3
It is important to have wastewater treatment systems in place to help reduce environmental pollution	0	0	17.7	82.3
Wastewater may be recycled and reused into economic activities, e.g., agriculture irrigation	0	0	46.2	53.8
Wastewater treatment systems enhance biodiversity	2	27	52.9	38.2
Wastewater treatment systems create green infrastructure	0.6	10.7	59.9	28.7

Perception on wastewater recycling/treatment, reuse, treatment technologies, and their importance

Table 6 presents findings on community perceptions towards wastewater recycling, reuse, treatment technologies, and their importance. These perceptions were tested with six questions on a three-point Likert scale. The majority of respondents had positive perceptions towards wastewater reuse and its importance. Specifically, 84.4% of the respondents believed that the

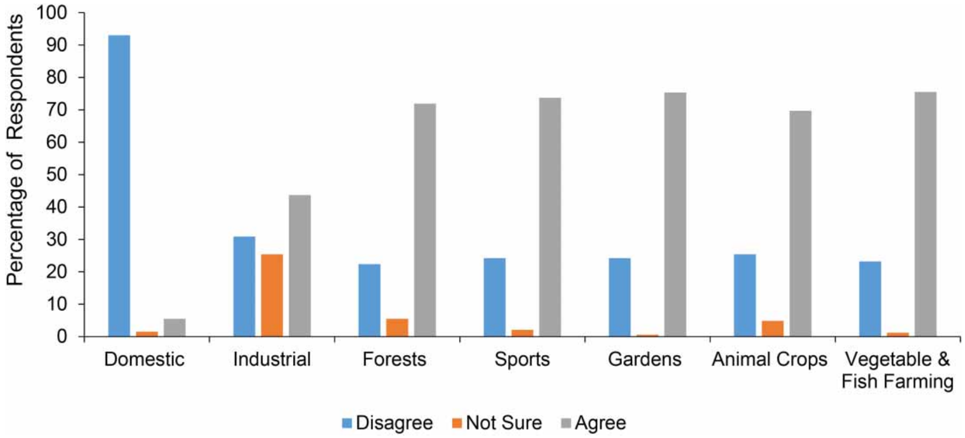


Figure 2 | Attitude on wastewater reuse on various applications across study sites in four regions of Tanzania in the year 2020–2021 (total *n*=327).

Table 6 | The proportion (%) of respondents that perceived differently on wastewater recycling/treatment, reuse, and treatment technologies across study sites in four regions of Tanzania in the year 2020–2021(*n*=327)

Respondents response, % (*n*=327)			
Wastewater variables	**True**	**False**	**I do not know**
There is an increase in wastewater production in an urban environment in Tanzania	85.3	8.9	5.8
The release of untreated wastewater to the environment may cause significant environmental consequences	84.4	10.7	4.9
Wastewater may be recycled and used in economic activities	68.8	23.2	8
Wastewater recycling technologies in the country have significantly developed	61.8	24.2	14.1
Wastewater recycling and treatment is important for the environment and economy	63.3	27.5	9.2
Recycled wastewater is safe for use in various human economic activities	59.9	30.9	9.1

release of untreated wastewater might cause harm to the environment, 68.8% of the respondents said wastewater could be recycled and reused in economic activities, and 59.9% thought it was safe to do so. Furthermore, 61.8% perceived that treatment technologies have significantly developed.

Knowledge on various wastewater treatment technologies

Figure 3 presents the respondents' knowledge on various wastewater treatment technologies. In the survey, 58.7% of the respondents were familiar with the use of WSPs. On the other hand, a majority of respondents were not well informed on other wastewater treatment technologies: 91.1, 98.8, 89.6, and 98.6% of respondents admitted to lacking knowledge about CWs, wastewater bio-digesters, ST–SP, and anaerobic baffled reactors (ABF), respectively. This indicates that most community members are ill-informed on existing technologies for wastewater treatment, even those that could help them cut costs of pumping out/cleaning wastewater from septic tanks.

Awareness of the potential health risks of using treated wastewater

The results in Figure 4 show the respondents' awareness of the potential health risks of using treated wastewater for various economic activities. The majority of respondents (59%) were either completely or somewhat unaware of the health risks of using treated wastewater. The rest felt sufficiently informed, but only 9.5% felt fully informed.

Figure 5 gives the factors mentioned by respondents that would deter them from using treated wastewater. A majority of respondents indicated that they fear using reclaimed water owing to the following factors: the presence of toxic chemicals (70.3%), the presence of harmful microorganisms (64.9%), bad odour (64.2%), and ethical considerations (65.1%).

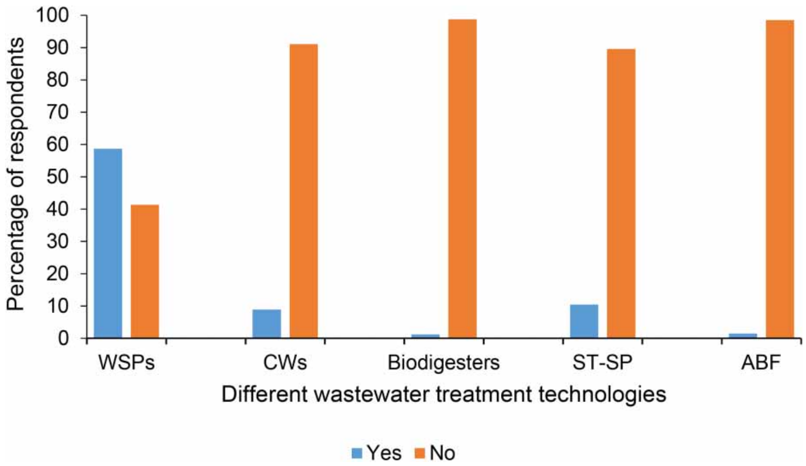


Figure 3 | Respondent's knowledge on different wastewater treatment technologies, i.e., WSPs, waste stabilization ponds; CWs, constructed wetlands; ST–SP, septic tank–soak-away pit; ABF, anaerobic baffled reactor.

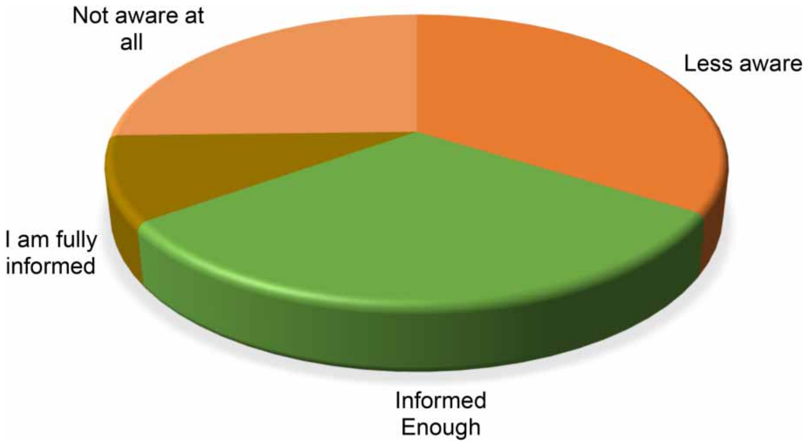


Figure 4 | Awareness of the potential health risks of using treated wastewater (n=327) across study sites in four regions of Tanzania in the year 2020–2021.

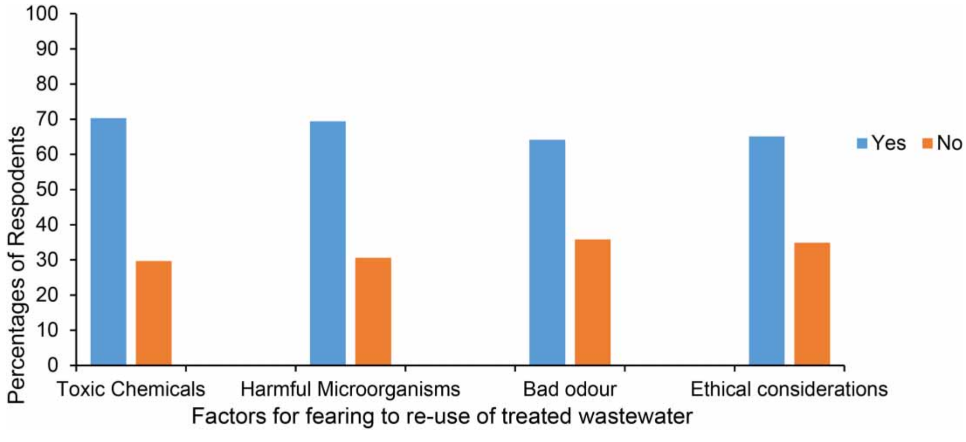


Figure 5 | Factors against the use of treated wastewater across selected study sites in four regions of Tanzania in the year 2020–2021 (n=327).

Correlation analysis on respondent's knowledge and perception on wastewater reuse options

The relationship between respondent's knowledge and perception of wastewater treatment and reuse was explored using partial correlation (Tables 7 and 8) while controlling for age and education. It was found out that there was a low to somewhat moderate positive correlation between respondents' age and their attitude over the reuse of treated wastewater towards different applications. On the other hand, it was also found a moderate correlation between different knowledge and perception items, which indicates the existence of a correlation between the study subjects.

Multivariate analysis of KAPs among the different groups of the studied population

Attitude towards treated wastewater reuse in various situations by gender, education, and age

The MANOVA was performed among different studied demographic groups. The Wilk's lambda values show a significant difference in attitudes towards various treated wastewater usage patterns between males and females ($P<0.05$), with females taking a more pessimistic view on the use of treated water in domestic activities such as washing and cooking. However, individual analyses (Table 9) of the responses revealed no significant differences between the attitudes of males and females over six of the questions asked.

The results did indicate a significant difference in respondents' KAPs on wastewater recycling, technologies, and reuse between the different educational categories. Of the seven questions used to test respondents' attitudes towards wastewater reuse, six revealed significant differences between different educational levels of the study population (Table 9). Furthermore, respondents were found to hold similar attitudes towards the use of reclaimed water for domestic applications such as washing and cleaning, as there was no significant difference in their responses ($P>0.05$).

Furthermore, multivariate testing revealed significant differences in attitude between the age groups ($P<0.05$; Wilks lambda), indicating that respondents from different groups tended to hold different attitudes concerning wastewater reuse. Further analysis showed that the age group 36–54 years had a significantly different view on many reuse options. Age is considered an important parameter that can influence attitudes towards the environment, such as approval of using recycling

Table 7 | Correlation analyses for respondents' knowledge and perception on wastewater and the different reuse options by age

Control variables	Domestic applications	Industrial processes	Forest irrigations	Sports field irrigations	Urban garden irrigation	Animal crop irrigation	Vegetable and fish farming
Age of the respondent							
Domestic applications							
	1						
Industrial processes	**0.166**						
	0.003	1					
Forest irrigations	**0.109**	**0.433**					
	0.05	$P<0.001$	1				
Sports field irrigations	**0.088**	**0.459**	**0.819**				
	0.112	$P<0.001$	$P<0.001$	1			
Urban garden irrigation	**0.057**	**0.422**	**0.791**	**0.803**			
	0.307	$P<0.001$	$P<0.001$	$P<0.001$	1		
Animal crop irrigation	**−0.108**	**0.395**	**0.664**	**0.702**	**0.685**		
	0.052	$P<0.001$	$P<0.001$	$P<0.001$	$P<0.001$	1	
Vegetable and fish farming	**0.054**	**0.403**	**0.634**	**0.629**	**0.621**	**0.586**	
	0.328	$P<0.001$	$P<0.001$	$P<0.001$	$P<0.001$	$P<0.001$	1

Bold values are coefficient of variation (*r*).

Table 8 | Correlation analyses for respondents' knowledge and perception on wastewater and the different reuse options by education

Control variables	There is increase in wastewater production in an urban environment in Tanzania	Release of untreated wastewater to the environment may cause significant environmental consequences	Wastewater may be recycled and used in economic activities	Wastewater recycling technologies in the country have significantly developed	Wastewater recycling and treatment is important for the environment and economy	Recycled wastewater is safe for use in various human economic activities
Education level of the respondent						
There is an increase in wastewater production in an urban environment in Tanzania	1					
Release of untreated wastewater to the environment may cause significant environmental consequences	**0.819**					
	P<0.001	1				
Wastewater may be recycled and used in economic activities	**0.586**	**0.663**				
	P<0.001	*P*<0.001	1			
Wastewater recycling technologies in the country have significantly developed	**0.397**	**0.444**	**0.687**			
	P<0.001	*P*<0.001	*P*<0.001	1		
Wastewater recycling and treatment is important for the environment and economy	**0.46**	**0.476**	**0.778**	**0.802**		
	P<0.001	*P*<0.001	*P*<0.001	*P*<0.001	1	
Recycled wastewater are safe for use in various human economic activities	**0.466**	**0.546**	**0.753**	**0.777**		
	P<0.001	*P*<0.001	*P*<0.001	*P*<0.001		
Recycled wastewater are safe for use in various human economic activities	**0.466**	**0.546**	**0.753**	**0.777**	**0.864**	
	P<0.001	*P*<0.001	*P*<0.001	*P*<0.001	*P*<0.001	1

Bold values are coefficient of variation (*r*).

wastewater for other purposes and protecting the environment. In addition, of the seven reuse options, four were found to have no significant differences, meaning respondents of different age groups hold similar attitudes towards these options (Table 9). Correlation analysis shows a moderate to somewhat positive correlation between age and education to the respondent's knowledge on various wastewater recycling and reuse options.

Table 9 | Attitudes towards reclaimed water use in various situations by gender, education, and age across selected study sites in four regions of Tanzania in the year 2020–2021

Test factor	Dependent variable (questions)	*F*	*P*
Gender	Domestic applications	4.54	0.034*
	Industrial processes such as machine cooling and cleaning	2.2	0.14
	Forest irrigation	0.27	0.6
	Sports field irrigation	1.25	0.26
	Urban garden irrigation	2.53	0.11
	Animal crop irrigation	3.07	0.081
	Vegetable and fish farming	1.08	0.29
Education	Domestic applications	0.25	0.86
	Industrial processes such as machine cooling and cleaning	3.07	0.03*
	Forest irrigation	8.17	<0.01
	Sports field irrigation	8.68	<0.01
	Urban garden irrigation	16.36	<0.01
	Animal crop irrigation	12	<0.01
	Vegetable and fish farming	18.2	<0.01
Age	Domestic applications	0.18	0.909
	Industrial processes such as machine cooling and cleaning	0.96	0.41
	Forest irrigation	0.67	0.573
	Sports field irrigation	0.90	0.439
	Urban garden irrigation	7.19	<0.01
	Animal crop irrigation	18.64	<0.01
	Vegetable and fish farming	10.21	<0.01

*Values are significant at $P<0.05$.

Perceived knowledge on wastewater treatment, reuse, and technologies by age, sex, and education level

The multivariate analysis revealed significant differences in environmental knowledge between various age groups ($P<0.05$; Wilks lambda) (Table 10). The age group of 36–53 years was found to provide more accurate answers to the asked questions than any other age groups. The analysis of the individual questions indicated only a significant difference between two

Table 10 | Perceived knowledge on wastewater treatment, reuse, and technologies by age, sex, and education level across selected study sites in four regions of Tanzania in the year 2020–2021

Test factor	Dependent variable (questions)	*F*	*P*
Age	Q1: There is an increase in wastewater production in urban environments in Tanzania	6.95	<0.01
	Q2: Release of untreated wastewater to the environment may cause significant environmental consequences	9.52	<0.01
	Q3: Wastewater may be recycled and used in economic activities	1.66	0.17
	Q4: Wastewater recycling technologies in the country have significantly developed	1.92	0.13
	Q5: Wastewater recycling and treatment is important for the environment and economy	1.55	0.19
	Q6: Recycled wastewater is safe for use in various human economic activities	1.07	0.36
Sex	Q1: There is an increase in wastewater production in urban environments in Tanzania	26.9	<0.01
	Q2: Release of untreated wastewater to the environment may cause significant environmental consequences	16.5	<0.01
	Q3: Wastewater may be recycled and used in economic activities	2.99	0.08
	Q4: Wastewater recycling technologies in the country have significantly developed	0.38	0.53
	Q5: Wastewater recycling and treatment is important for the environment and economy	0.79	0.37
	Q6: Recycled wastewater is safe for use in various human economic activities	0.04	0.83
Education	Q1: There is an increase in wastewater production in urban environments in Tanzania	3.61	0.01*
	Q2: Release of untreated wastewater to the environment may cause significant environmental consequences	0.70	0.55
	Q3: Wastewater may be recycled and used in economic activities	2.60	0.05
	Q4: Wastewater recycling technologies in the country have significantly developed	0.59	0.62
	Q5: Wastewater recycling and treatment is important for the environment and economy	0.29	0.82
	Q6: Recycled wastewater is safe for use in various human economic activities	0.08	0.97

*Values are significant at $P<0.05$.

questions (Q1 and Q2), and the other four questions had no significant differences, indicating that respondents held similar knowledge on the other four questions. The *post-hoc* analysis shows that the age group >72 years had less knowledge on most of the questions asked, indicating that these respondents were less informed on issues relating to wastewater recycling. Further multivariate analysis on the respondents' gender showed no significant difference in four of the six questions, indicating that males and females hold similar knowledge on wastewater recycling, technologies, and reuse (Table 10). From this analysis, only the responses to two questions were significantly different between males and females. In the analysis, it was discovered that despite this difference, males tended to score higher on all the questions.

Moreover, a multivariate analysis of the respondents' level of education indicates a significant difference in knowledge on wastewater recycling and reuse among the different educational categories in two of the six questions (Table 10). Respondents that had received a tertiary education were found to score well on more questions than those who had had primary education. Respondents with a low education level were found to give more incorrect answers than any other group. Overall, the correlation analysis showed that knowledge is significantly associated with the level of education of the respondent.

DISCUSSION

Our results revealed that more than 93% of the respondents had negative attitudes towards the use of treated wastewater in potable uses such as drinking, cooking, washing, toilet flushing, and cleaning of home premises. Only 7% of the respondents agreed on the use of treated water for potable application, mostly for cleaning, washing, and toilet flushing. This negative view is not unique: Baghapour *et al.* (2017) reported that their studied population had the least acceptance (8%) for using reclaimed wastewater for cooking, drinking, laundry, and bathing. The findings are also consistent with those of several other studies, such as Alhumoud & Madzikanda (2010) and Kantanoleon *et al.* (2007), who found low acceptance of reusing treated wastewater for various potable uses such as cooking, drinking, washing, and cleanliness. Ormerod *et al.* (2019) conducted a study in the Reno-Sparks area of northern Nevada, USA, and found low acceptance of the reuse of treated wastewater for potable use, even when respondents were asked, 'Would you be willing to drink tap water mixed with treated wastewater if it was treated to a water quality level that matched or exceeded your current tap water quality?' Additionally, studies by Chfadi *et al.* (2021), Dolnicar & Hurlimann (2010), Dolnicar *et al.* (2011), Wilson & Pfaff (2008), and Miller (2006) found low acceptance to reuse treated wastewater for potable uses. The findings of this study suggest that increasing community acceptance of potable reuse of treated wastewater is more difficult than simply providing more information or education about the safety of treated wastewater. The community's opinions on accepting to reuse treated wastewater may change or not with new information, as there are divergent preferences and views among the community that must be established.

On the other hand, respondents to our survey had a somewhat positive attitude towards using the treated wastewater for irrigation of sports fields, urban gardens, forests, and farms. The findings are similar to those reported by Kantanoleon *et al.* (2007), Khanpae *et al.* (2020), and Robinson *et al.* (2005) whose respondents were positive towards similar irrigation applications, but negative towards any application that involves direct contact with the treated water, such as vegetable farming. Consistent with other reports (Kantanoleon *et al.* 2007), we found that the reluctance to use treated wastewater might be due to the community's fear of the safety of the water owing to the presence of chemicals (70.3%), pathogenic microorganisms (60.9%), ethical considerations (65.1%), and bad odour (64.2). Similarly, the data are inconsistent with those from the study by Chfadi *et al.* (2021) who found that the hesitation to reuse the treated wastewater was due to beliefs that the treated wastewater may contain some human waste (50.1%), pathogenic microorganism (47.7%), chemical substances (45.1%), and bad odour (44.4%), while only 26.8% claim to be hesitant for religious or ethical reasons. This negative attitude and perception might arise from a lack of well extension services that may educate about its potential to be harnessed from the treated wastewater and how to use it safely.

Furthermore, the respondents in this study had a generally positive outlook towards wastewater recycling and reuse. Indeed, the majority (63.3%) of interviewed respondents pointed out that wastewater treatment and reuse is a vital endeavour towards conserving the environment that can bring economic gains from its use including application in urban garden farming. This finding concurs with the study by Akpan *et al.* (2020) who also reported that 77% of the interviewed respondents said recycling and reusing wastewater would protect the environment from damage by pollutants. Also in their study, 63% of the respondents agreed that wastewater recycling and reuse could boost agricultural productivity. However, in our study, despite the general perception of the respondents being positive, there were still some negative perceptions, perhaps from respondents with significant knowledge of the possible health risks that might arise from using treated wastewater. Moreover, in this study, some respondents perceived a health risk from the consumption of food material farmed using treated wastewater. Alhumoud & Madzikanda (2010) also discovered that a respondent's perception of wastewater treatment and reuse is principally attached to public health concerns and a fear of the health risks introduced by the initiative. Generally, regardless of the strength of scientific evidence, public perceptions and acceptance of treated wastewater reuse are recognized as overriding factors for the successful implementation of such reuse projects.

We also found out that most of our respondents (59%) had inadequate knowledge of the potential health risks that may be associated with the use of treated wastewater in economic activities such as urban farming. Respondents purported to have no prior knowledge of whether the use of treated wastewater could have any detrimental effects on their health and environment. Few respondents revealed that they were aware of likely risks that include lymphatic filariasis (elephantiasis) from mosquitoes and gastrointestinal diseases. It was also found that a limited understanding of the health risks influences the acceptance of using treated wastewater. These findings are similar to those of studies by Khanpae *et al.* (2020) and Kantanoleon *et al.* (2007) who reported that the majority of interviewed respondents had little knowledge of the health risks of using treated wastewater in urban farming. In contrast, in this study, those respondents with a significant understanding strongly rejected the use of treated wastewater. The study by Shakir *et al.* (2017) reported that the application of treated wastewater for human activities such as agricultural irrigation and potable uses poses a number of potential health risks to human health through consumption or exposure to pathogenic microorganisms, heavy metals, or organic chemicals. According to the findings of this study, respondents' willingness to reuse treated wastewater is strongly linked to their knowledge of the treated wastewater and associated health hazards. The results complement those of Saad *et al.* (2017) and Gu *et al.* (2015) who also found in their study that the degree of acceptance of treated wastewater use relies on the understanding of the risks of a specific reuse project, which a community may accept or reject.

As hypothesized, our results revealed that the gender of a respondent significantly ($P<0.05$) influenced their attitude towards treated wastewater reuse in various applications. Females were found to have a more positive KAP on wastewater recycling and reuse. This might be because, in the visited sites, females were found to be using treated wastewater for urban farming. By contrast, women were more reluctant to use treated water in domestic applications such as washing and cleaning the home. This could be due to a belief that the treated wastewater is dirty and may contain faecal contamination. Many studies show that there might be a correlation between demographic factors and social attitudes and perceptions towards wastewater recycling and reuse and also the level of knowledge on associated benefits and potential health risks (Alhumoud & Madzikanda 2010; Wester *et al.* 2015). The findings from this study are not dissimilar to those of Robinson *et al.* (2005) and Kantanoleon *et al.* (2007) who showed that females had positive attitudes towards various uses but disfavoured the reuse of treated water in applications involving direct contact. Further, age was also found to be a significant factor for KAPs on wastewater recycling and reuse. Those of active age (36–53 years) and older age (>54) were found to be more positive and knowledgeable about wastewater recycling and reuse. Robinson *et al.* (2005), Gu *et al.* (2015), and Fielding *et al.* (2018) found that, with the exception of younger respondents, the majority of age groups were more knowledgeable and had positive attitudes toward water reuse than those older than 65 years. Moreover, the respondent's level of education was found to be a significant factor in influencing the respondent's knowledge over wastewater treatment technologies and reuse. This might be because education helps people to understand and explore many issues around the environment. Similar findings have been reported in studies by Akpan *et al.* (2020), Mu'azu *et al.* (2020), Gu *et al.* (2015), Hartley (2006), and Tsagarakis & Georgantzs (2003) that respondent education level influences knowledge of wastewater treatment and reuse.

In general, this study found that the social KAPs among the respondents on wastewater recycling and reuse were sufficient and low with respect to some aspects based on KAP score from the administered questions. Therefore, we recommend providing more public education to the communities involved, explaining the potential benefits and likely health risks of wastewater recycling and reuse.

CONCLUSIONS AND RECOMMENDATIONS

The prosperous execution of wastewater projects significantly relies on public KAPs regarding their value and health risks. This study highlights the level of social KAPs on wastewater recycling technologies and reuse in Tanzania. More than half of the 327 participants in this study had a basic knowledge of wastewater treatment, technologies, reuse, and associated benefits, and fewer had a good knowledge of such technologies. The study also observed that most respondents living close to wastewater treatment plants perceived the importance of recycling wastewater and acknowledged it as a viable solution for protecting the environment and providing water for urban agriculture. MANOVA tests illustrate that demographic factors have a significant influence ($P<0.05$) on a respondent's KAP towards wastewater recycling, technologies, and reuse options. A majority of respondents admitted to being unfamiliar with new wastewater treatment technologies. This knowledge gap could be filled by providing communities with information on small-scale household-level treatment technologies such as CWs.

Our study creates awareness for key players on the potentiality of assessing community KAPs to develop wastewater management projects. For integrated water resources management, it informs decision-making processes to increase the acceptance of reusing treated water for different socio-economic activities to reduce pressure on freshwater ecosystems. Moreover, the information from this study works as a tool for developing an inclusion criterion of the community needs in wastewater management initiatives and as a tool for designing good policies and approaches to enhance a top–down approach in the management of wastewater across the different parts of the world. KAPs information on wastewater treatment and reuse will also help the communities and key players in growing urban cities and towns to align on the right path towards achieving the SDG 6 and 11 at the local level and later bring significant impact at large as it creates an excellent portfolio to the key players to implement sustainable sanitation programmes for sustainable cities and communities.

This study recommends that the wastewater management authorities focus on disseminating information for appropriate wastewater treatment technologies to the communities to enhance adoption. There should also be extensive outreach efforts before implementing wastewater projects to collect information that may help to steer acceptability and avoid failure. Furthermore, extensive programmes must focus on educating communities on the proper use of treated wastewater and how to deal with health risks associated with it.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICTS OF INTEREST STATEMENT

The authors declare there is no conflict.

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