

Original article

Elapsed Time Between Wastewater Irrigation, Harvesting, Marketing, Preparation, and Consumption of Vegetables and Fruits and Associated Public Health Risks in Selected Cities, Tanzania

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Email: erastuskinemelo@gmail.com**Abstract**

The reuse of wastewater treatment plant effluents for irrigation of vegetables and fruits is increasingly practiced in urban and peri-urban agriculture in Tanzania due to water scarcity and growing food demand. Concerns remain regarding microbial contamination and public health risks associated with the short time interval between irrigation, harvesting, marketing, preparation, and consumption of fresh produce. The study assessed the elapsed time between wastewater irrigation, harvesting, marketing, preparation, and consumption of vegetables and fruits and the associated public health implications among farmers and consumers in Mwanza, Dodoma, and Dar es Salaam cities. A community cross-sectional study was conducted among 400 participants comprising farmers and consumers between September 2025 and March 2026. Data were collected using structured questionnaires. Frequencies, percentages, means, medians, modes, standard deviations, relative risk, and p-values were computed. Statistical significance was set at $p < 0.05$. Among 400 participants, 147 (36.75%) were farmers using wastewater effluents for irrigation. Wastewater irrigation was significantly associated with exposure risk ($RR = 2.14$, $p = 0.003$). Irrigation occurred mainly two to three times per week, with an average frequency of 1.73 times per day ($SD = 0.46$). Most irrigation activities occurred between 6:00 am and 9:00 am, while harvesting occurred between 8:00 am and 11:30 am. Irrigation to harvesting was reported by 26.25%, compared with 12.25% after harvesting. The mean time required to sell produce was 2.55 hours ($SD = 0.80$). Farmers required an average of 15 minutes ($SD = 4.35$) to transport produce from farms to homes, while consumers required 9.17 minutes ($SD = 7.97$) from markets to homes. Most vegetables were consumed cooked (93.0%), whereas fruits were consumed raw (100%). Vegetable preparation averaged 18.77 minutes ($SD = 3.88$), fruit preparation 13.70 minutes ($SD = 3.86$), and vegetable cooking 12.92 minutes ($SD = 4.15$). Slightly cooked vegetables were preferred by 73.75% of participants. The short interval between wastewater irrigation, harvesting, marketing, and consumption creates conditions favourable to pathogen transmission, which may increase the risk of foodborne disease.

Keywords. Wastewater Irrigation, Vegetables, Fruits, Food Safety, Public Health, Tanzania, Wastewater Reuse

Introduction

Urban and peri-urban agriculture contribute significantly to food security and household livelihoods in developing countries. Increasing urbanisation and climate variability, along with water scarcity, have led many farmers to adopt wastewater reuse for the irrigation of vegetables and fruits [1]. Wastewater contains valuable nutrients that enhance crop growth but may also harbor pathogenic microorganisms, helminths, and other contaminants capable of causing adverse health effects [1, 2]. In Tanzania, particularly in rapidly growing cities such as Mwanza, Dodoma and Dar es Salaam, treated and partially treated wastewater is increasingly used for irrigation due to limited freshwater availability. While wastewater reuse supports agricultural productivity, concerns remain regarding food safety because vegetables and fruits may be harvested, marketed, and consumed shortly after irrigation. The World Health Organisation recommends multiple-barrier approaches including wastewater treatment, safe irrigation methods, withholding periods before harvest, hygienic handling, and proper food preparation to reduce health risks [1]. Several studies have demonstrated that short intervals between irrigation and harvesting increase the persistence of microbial contaminants on fresh produce [3, 4]. Crops consumed raw are particularly vulnerable because pathogens are not eliminated through cooking. Understanding the temporal sequence between irrigation, harvesting, marketing, preparation, and consumption is essential for identifying exposure pathways and informing public health interventions. This study assessed the elapsed time between the irrigation, harvesting, marketing, preparation, and consumption of vegetables and fruits and examined the associated public health implications in the cities of Mwanza, Dodoma, and Dar es Salaam in Tanzania.

Materials and Methods**Study Design and Approach**

A community-based, cross-sectional, quantitative study was conducted. The study was conducted between September 2025 and March 2026.

Study Area

The study was conducted in Mwanza, Dodoma, and Dar es Salaam cities, Tanzania, where wastewater treatment plant effluents are used for urban and peri-urban agricultural production.

Study Population

The study population comprised farmers using wastewater treatment plant effluents for irrigation and consumers purchasing or consuming wastewater-irrigated vegetables and fruits.

Sample Size and Sampling Technique

A total sample of 400 participants was included in the study. Out of an estimated 826,170 households across the named cities, based on the National Bureau of Statistics census data [5], the final sample size of 400 was determined using formula [6]. Within each stratum, the index household was selected via convenience sampling, and a random walk from one house to the next was used, provided the participants were present. In each household visited, either a farmer, a consumer, or both were involved.

$$n = \frac{N}{1 + N(e^2)}$$

$n = N/1 + N(e^2)_i$ whereby: n = required sample size, N = Total population, e = Margin of error (commonly 0.05 for 95% confidence level)

From the formula above: $N = 826,170$ pp/HHs, $e = 0.05$; pp = Participants, and HHs = Households

$$n = \frac{826,170}{1 + 826,170(0.05)^2}$$

$$n = 399.8 = 400 \text{ participants (or HHs)}$$

Hence, the final sample size was 400 households (participants)

To obtain the number of HHs from each stratum, proportional allocation was applied using the adopted formula [7]:

$n_1 = n \times \frac{N_i}{N}$

$$n_1 = n \times \frac{N_i}{N}$$

n_i = Sample size of each stratum, n = Total sample size, N_i = Number of households (HHs) in each city, N = number of HHs in three cities.

Data Collection Methods and Tools

Data were collected using structured questionnaires from farmers and consumers in households. Information was obtained on irrigation frequency, harvesting schedules, marketing patterns, food preparation practices, and consumption behaviour.

Data Analysis and Presentation

Data were analysed using statistical software (SPSS Version 26). Descriptive statistics including frequencies, percentages, means, medians, modes and standard deviations were computed. Relative risk (RR) and p-values were used to assess associations. Results were presented using tables, figures, and summaries. Statistical significance was determined at $p < 0.05$.

Results

Use of Wastewater for Irrigation

Of 400 participants, 147 (36.75%) were farmers who used wastewater effluents for irrigation, while 253 (63.25%) were non-users. Wastewater irrigation was significantly associated with increased exposure risk ($RR = 2.14$, $p = .003$), as Table 1 signifies.

Table 1. Use of Wastewater Effluents for Irrigation

Variable	Frequency	Percentage (%)	RR	p-value
Users	147	36.75	2.14	0.003
Non-users	253	63.25	1.00	Reference

Irrigation Frequency and Scheduling

Irrigation occurred mostly two to three times per week. The average irrigation frequency was 1.73 times per day (SD = 0.46), with a median and mode of 2.0. The short interval between irrigation events implies limited opportunities for pathogen die-off before harvesting.

Timing of Irrigation and Harvesting

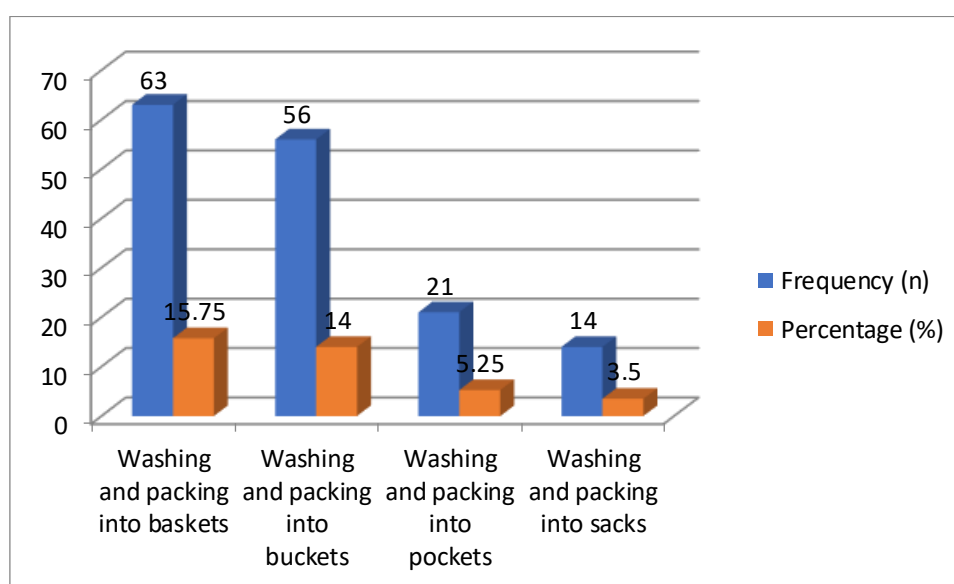
Most irrigation occurred between 6:00 am and 9:00 am, while harvesting was concentrated between 8:00 am and 11:30 am. Irrigation before harvesting was significantly more common (26.25%) than irrigation after harvesting (12.25%), as Table 2 indicates.

Table 2. Time of Irrigation, Harvesting, and Irrigation Prior or Post Harvesting

Event	Time (hours)	Frequency (n=400)	Percentage (%)
Irrigation	6 am to 8 am	21	5.25
	6 am to 8.30	21	5.25
	4 pm to 6 pm	21	5.25
	7 am to 9 am	14	3.50
	6.30 am to 8 am	14	3.50
	7 am to 8 am	7	1.75
	7 am to 8.30 am	7	1.75
	6 am to 7.30 am	7	1.75
	6 am to 8.30 am, and 4 pm to 6 pm	7	1.75
	6 am to 8 am, and 5 pm to 7 pm	7	1.75
	6 am to 9 am, and 3 pm to 5.30 pm	7	1.75
	6 am to 8 am, and 5 pm to 6.20 pm	7	1.75
	7 am to 8.30 am, and 4 pm to 5.30 pm	7	1.75
	6 am to 8 am, and 5 pm to 6.20 pm	7	1.75
Harvesting	9 am to 11 am	28	7.00
	9 am to 11.30 am	28	7.00
	8.30 am to 10.30 am	21	5.25
	9 am to 10.30 am	14	3.50
	8.30 am to 11.30 am	14	3.50
	9 am to 11 am	7	1.75
	9.30 am to 11.30 am	7	1.75
	9 am to 10.40 am	7	1.75
	10.30 am to 12.30 pm	7	1.75
	8 am to 10 am	7	1.75
	12.05 pm to 3 pm	7	1.75
	7 am to 8 am	7	1.75
Irrigation before harvesting	—	105	26.25
Irrigation after harvesting	—	49	12.25

Post-Harvest Handling

More farmers washed produce before packaging. Washing and packaging in baskets (15.75%) and buckets (14.0%) were the most common practices (Figure1).

**Figure1. Preparation of Vegetables and Fruits after Harvesting****Marketing and Consumption**

The mean time required to sell produce was 2.55 hours (SD = 0.80). Consumers predominantly purchased vegetables and fruits in the morning (52.75%), primarily from local markets (31.50%), as (Figure2) shows.

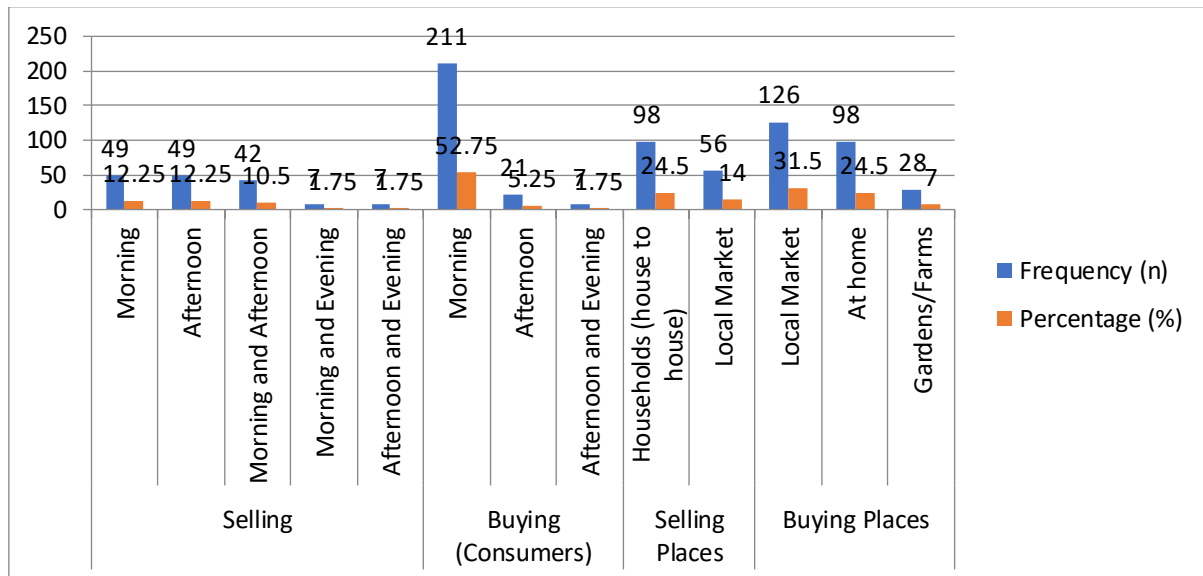


Figure 2. Timing and Places of Selling and Buying Vegetables and Fruits

Transportation Time

Farmers required an average of 15 minutes (SD = 4.35) to transport produce from farms to homes. Consumers required 9.17 minutes (SD = 7.97) to transport produce from markets to homes (Figure 3).

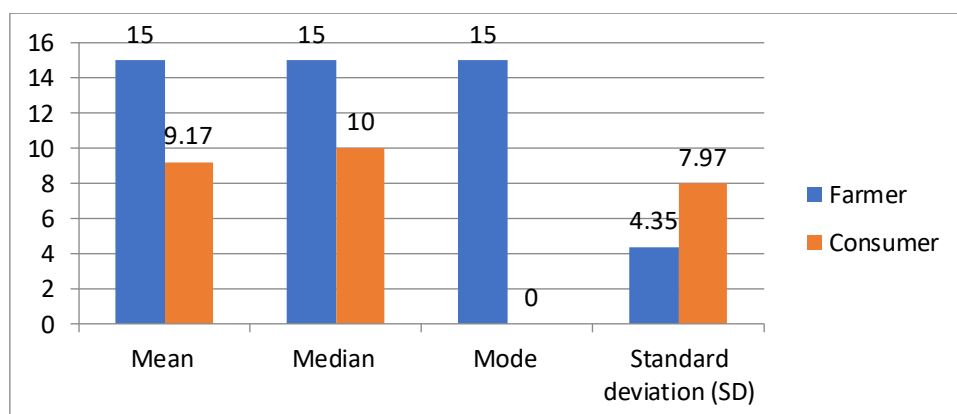


Figure 3. Time (Minutes) for taking vegetables and fruits at home from the garden/farm/local market

Food Preparation and Consumption

Vegetables were predominantly consumed cooked (93.00%), that is, 36.75% for farmers and 56.25% for consumers, whereas fruits were universally consumed raw (100.00%), that is, 39.00% for farmers and 61.00% for consumers. Vegetable preparation required an average of 18.77 minutes (SD = 3.88), fruit preparation 13.70 minutes (SD = 3.86), and vegetable cooking 12.92 minutes (SD = 4.15), as Figure 4 indicates.

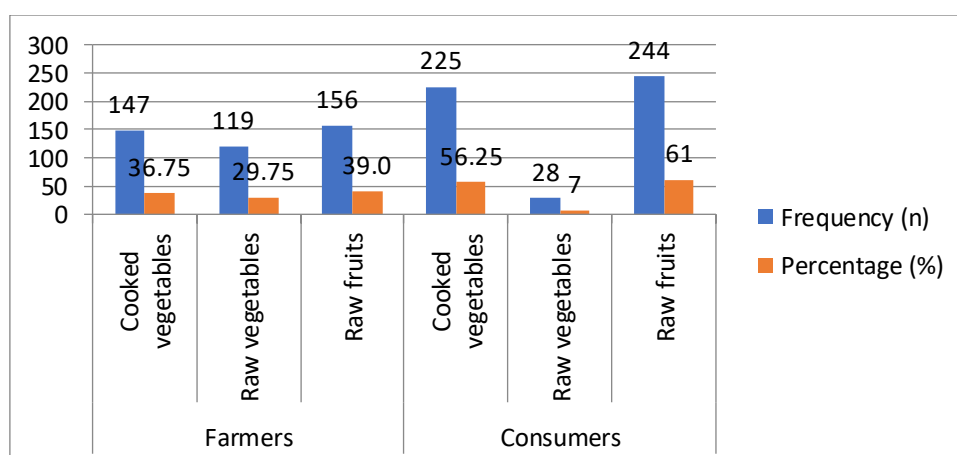


Figure 4. Status of Vegetables and Fruits Consumed from Wastewater-Irrigated Production Systems

Degree of Cooking

Most participants (N = 400) reported that they preferred slightly cooked vegetables (73.75%), that is 47.25% consumers and 26.50% farmers, compared with overcooked vegetables (28.00%), that is 15.75% consumers and 12.25% farmers (Figure 5).

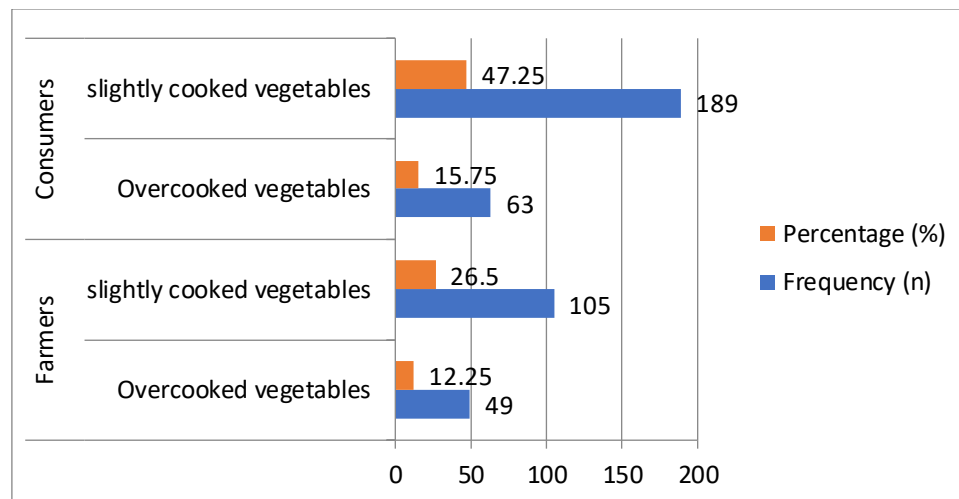


Figure 5. Degree of Cooking Vegetables Consumed

Discussion

The study demonstrates that wastewater-irrigated vegetables and fruits increase rapidly through production, marketing, and consumption pathways in Mwanza, Dodoma, and Dar es Salaam. Frequent irrigation schedules combined with harvesting shortly after irrigation create conditions that favour pathogen persistence on produce surfaces. The irrigation patterns observed in this study were that farmers irrigated two to three times per week with intervals of only 1–3 days between applications. The study is consistent with findings that recurrent wastewater irrigation reduces opportunities for natural pathogen die-off through sunlight exposure, desiccation, and microbial competition [3,4]. The finding that irrigation regularly occurs within hours or one to two days of harvesting is particularly concerning since withholding periods recommended for pathogen reduction are largely absent.

A minimum interval between the last irrigation event and harvesting is necessary to reduce microbial contamination, especially for vegetables and fruits consumed raw [1]. The close temporal relationship between irrigation and harvesting observed in this study increases the likelihood that microbial contaminants remain viable when produce enters markets. Comparable observations have been reported in wastewater reuse systems where pathogens survive on crop surfaces for several hours to days depending on environmental conditions, including sunlight intensity, temperature, and humidity [8, 9]. Rapid marketing and short transportation times further reduce opportunities for natural decontamination. The average time required to complete produce sales was only 2.55 hours, while transportation from farms or markets to households averaged 15 minutes among farmers and 9.17 minutes among consumers. These findings show that produce moves quickly through the food supply chain, often reaching consumers within the same day of harvesting. Such rapid movement is a characteristic of urban and peri-urban agricultural systems in sub-Saharan Africa, where fresh produce is marketed and consumed with minimal storage periods [10, 11]. Although shorter storage durations may limit microbial proliferation under certain conditions, they do not adequately address contamination already present on produce surfaces from wastewater irrigation [1].

The predominance of household-based selling and informal local market distribution raises more public health concerns. Household-based marketing minimizes transportation costs and facilitates direct producer-to-consumer transactions; however, it repeatedly occurs outside formal food safety inspection systems [12]. Previous studies have shown that informal marketing channels may increase the likelihood of contamination during handling, transportation and display, especially when wastewater-irrigated produce is involved [1, 13].

Although vegetables were mostly consumed cooked (93.0%), cooking durations were comparatively short, averaging approximately 13 minutes. Furthermore, most people (73.75%) preferred slightly cooked vegetables rather than thoroughly cooked vegetables. While cooking is recognized as an effective barrier against many foodborne pathogens, insufficient cooking temperatures and durations may fail to completely inactivate heat-resistant microorganisms and helminth eggs associated with wastewater irrigation [1, 11]. The preference for slightly cooked vegetables observed among both farmers and consumers may then maintain residual risks regardless of the protective effects of cooking. The risk appears even greater for fruits since all participants reported consuming fruits raw. Raw fruit consumption represents an important exposure pathway for pathogens associated with wastewater reuse systems. Similar studies have demonstrated that fruits and vegetables consumed without cooking present elevated risks of transmitting faecal coliforms, *Salmonella* spp., *Escherichia coli* and parasitic organisms when irrigated with treated or partially treated wastewater [14]. The high occurrence of raw fruit consumption among both farmers and consumers in the present study therefore represents a critical public health concern. Washing, peeling, and cutting were common preparation practices among participants, with most participants reporting some form of washing before consumption. However, the

effectiveness of these practices depends heavily on the quality of water used and adherence to hygienic food-handling procedures. Studies have shown that washing produce with contaminated water may reintroduce pathogens and sometimes increase microbial loads rather than reducing them [15].

Furthermore, pathogens may adhere strongly to vegetable surfaces or become internalized within plant tissues, limiting the effectiveness of washing and peeling alone as decontamination strategies [1, 11]. The relatively short preparation times observed for vegetables (18.77 minutes) and fruits (13.70 minutes) mean that food preparation serves as an important but incomplete barrier within the multiple-risk reduction framework recommended for wastewater reuse systems. The WHO multiple-barrier approach emphasizes that food safety depends on the combined effectiveness of wastewater treatment, safe irrigation practices, withholding periods, hygienic harvesting, proper handling, and adequate food preparation rather than reliance on a single intervention [1]. The findings of this study point out that while some barriers exist, several critical control points remain inadequately addressed. Therefore, the study highlights the significance of considering the entire farm-to-fork continuum when assessing health risks associated with wastewater irrigation. The combination of frequent irrigation, short intervals between irrigation and harvesting, rapid market distribution, widespread raw fruit consumption, and limited post-harvest risk-reduction measures creates multiple opportunities for pathogen exposure. These findings support previous evidence that health protection in wastewater-irrigated agricultural systems requires integrated interventions targeting irrigation management, post-harvest handling, market hygiene, consumer education, and food preparation practices [1, 2, 11].

Conclusion

The study demonstrates that wastewater-irrigated vegetables and fruits in Mwanza, Dodoma, and Dar es Salaam cities are harvested, marketed, prepared, and consumed within short time intervals that may facilitate pathogen transmission. Frequent irrigation, harvesting shortly after irrigation, widespread raw fruit consumption, and limited withholding periods increase potential exposure to foodborne pathogens. These findings underscore the need for strengthened implementation of wastewater reuse safety guidelines.

Ethical Approval

Ethical approval was provided by the Open University of Tanzania with a reference number OUT/PG2022000859. The Faculty of Science, Technology and Environmental Studies' Research Committee of the Open University of Tanzania approved the study.

Informed Consent

Written informed consent was obtained from all participants before data collection at households.

Conflict of Interest. No conflict of interest occurred.

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