



Wastewater Collection and Transportation through Drainage Network- a Potential Threat to Biodiversity & Local Eco-system in Zanzibar Stone-town & Surroundings

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Authors' contributions

This work was carried out in collaboration between all authors. Author ZMA designed the study, wrote the protocol, Author ARR managed literature and wrote the first draft of the manuscript. Author AMU performed the statistical analysis and author MAB managed the laboratory analysis. Author RAA managed field work and the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Waste water effluents voided in the coastal areas of Zanzibar are highly polluted posing a public health crisis. This cross-sectional study, carried out in September 2017, investigated bacterial load and physicochemical characteristics of the effluents discharged into coastal marine waters of the Zanzibar stone town and peri-urban areas. Ten drains, seven of which were impervious and three pervious, were sampled twice per day in mornings and afternoons. Each drain was sampled at three sites; the out-pour site close to the sea and two sites upstream 100 meters apart. Physicochemical parameters including Dissolved Oxygen (DO), pH and turbidity were determined immediately after arrival in the laboratory. Colony forming units/ ml were also determined.

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Bacterial counts were higher in impervious drains, in out-pour sites and in the afternoons. Conversely counts were lower in the out-pour sites compared to upstream sites in the pervious drains. DO was significantly higher in the pervious compared to impervious drains ($p = 0.004$). Turbidity was high in the mornings, but one drain had significantly high turbidity ($p=0.0009$). In all drains pH was high in the afternoon than mornings. Thirteen bacterial species, mostly gram-negative *Enterobacteriaceae* were isolated. *Vibrio cholerae* was isolated from 5 drains. Ground water close to pervious drains had coliforms beyond WHO guidelines. Waste water drains in Zanzibar urban and peri-urban areas are vastly contaminated with organic matter and pathogenic bacteria leading to high turbidity and oxygen depletion. It is recommended to increase awareness to the public and introduce waste water treatment strategies both physically and chemically.

Keywords: Coliforms; waste waters; pervious and impervious drains; physicochemical characteristics; Zanzibar stone town.

1. INTRODUCTION

The Zanzibar stone town and surrounding peri-urban areas discharge most of its untreated waste waters into nearby coastal marine waters, a phenomenon that predisposes the beaches to environmental pollution and may render them unsafe for bathing and recreation purposes. According to Maalim et al. [1], 1300 tons of sewage from Zanzibar urban and peri-urban areas is discharged daily into the coastal marine waters. This situation may have a negative impact on public health and tourist industry that is core to the Zanzibar economy. Studies have shown that non-indigenous pathogens from sewage, once introduced in the marine environment, can become established with adverse impacts on human health, countries economy and marine ecology [2].

Pollution of coastal waters due to sewage effluents is a worldwide problem leading to increase of total suspended matter, spread of potential pathogenic and antibiotic-resistant bacteria and depletion of dissolved oxygen with ultimate degradation of fragile marine coastal ecosystems [3]. The degree of pollution in coastal based towns is, in most cases, directly correlated to urbanisation and population density [4-6]. According to 2012 Tanzania population census, the population density in Zanzibar stone town is 13,542 people/km² while it is 18,897 people/km² in the peri-urban areas which is quite high. Moreover, drainages that have impervious floors made of concrete such as the ones seen in the stone town of Zanzibar, are more likely to cause pollution in coastal waters due to lack of natural soil filter [7].

Several traditional strategies have been used worldwide to minimise sewage pollution to acceptable limits that include chlorination which

kill most microbial pathogens and use of natural soil filters. However chlorination of sewage effluents has a short time effect and chlorine dilution is high in large water bodies enabling some microbes to survive the process and others to acquire resistance leading to public health hazard [5,8]

Thermo-tolerant (Faecal) coliforms including *Escherichia coli* and other pathogenic bacteria that carry multi-drug-resistant genes which pose public health hazard have been isolated in beaches and other water bodies worldwide [4]. Several sites were implicated as sources of pathogenic bacteria including hospitals, agricultural and rainwater run-offs, industries and domestic sewage [9-11]. Treatment of sewage sourced water by chlorination and natural filters can significantly reduce heavy loads of bacterial counts in water bodies but do not provide guarantee of sterility and freedom from public health risk [11]. Recent studies by Rabia et al. [12] have revealed wide range of pathogenic bacteria isolated from marine sourced fish foods in Zanzibar.

This study was designed to investigate the bacterial load and physicochemical characteristics of waste water effluents discharged into coastal marine waters of the Zanzibar stone town and peri-urban areas and make comparison between pervious and impervious drains. Physicochemical parameters studied in this research were Dissolved Oxygen (DO), pH and turbidity. The study also aimed to identify the isolated bacteria.

2. LITERATURE REVIEW

Wastewater is among the major causes of coastal water and beach pollution and results in to a number of health problems to bathers and marine food consumers. The health effects

including gastrointestinal, ear, eye, skin and respiratory diseases are more pronounced in the highly polluted and populated beaches [13]. Presently only 20% of globally produced wastewater receives proper treatment while up to 90 % of wastewater in developing countries flow untreated into rivers, lakes and highly productive coastal zones, causing serious problems on marine environment and human health and threatens sustainable coastal development [14]. Furthermore, bioaccumulation and bio-transportation of pollutants such as microbes from wastewater discharges aggravate the health problems to sea food consumers. Studies reveal that bathing in polluted seas may cause 250 million cases of gastrointestinal and upper respiratory diseases every year which cost approximately US\$ 12-24 billion per year worldwide with other underlying economic and social effects [15].

Use of faecal coliforms as indicator organisms for monitoring of faecal pollution in coastal water allows evaluating the probability of contamination of human population by pathogenic microorganisms of enteric origin [16]. Referring to Zanzibar on this perspective, most of the coastal water pollution is derived from sewage drainage and, if mitigation measures are not implemented soon may adversely affect human population health, biodiversity and marine ecosystem [1,12].

3. STUDY OBJECTIVES

This study had the following objectives:

- Investigation of bacterial load in waste water drains in Zanzibar stone town and peri-urban areas
- To explore the physicochemical characteristics of waste water effluents discharged into coastal marine waters of the Zanzibar stone town and peri-urban areas
- Compare bacterial load and the physicochemical characteristics of pervious and impervious drains

4. MATERIALS AND METHODS

4.1 Study Area

The study was conducted in Zanzibar islands which are 32km off the coast of Tanzania mainland. Zanzibar is part of the United Republic

of Tanzania consisting of two sister islands; Pemba on the north and Unguja in the south. They are situated between latitudes 4 degrees and 6.5 degrees south of the equator. The weather is permanently humid tropical climate with four seasons- long rains between March and June, cool dry season July to August, short rains September to November and dry hot season between December and February.

Sewage and waste water discharges are drained from Zanzibar stone town and peri-urban areas from 27 outlets into the coastal marine waters. Sites that were sampled are listed in Table 1 and demonstrated in Fig. 1.

Table 1. Classification of drains studied

	Impervious	Pervious
Stone town	Kizingo	-
	Mizingani	-
	Bwawani	-
	African house Palace	-
PERI-Urban	Bakhresa	Kinazini
	Kilimani	Saateni
		Maruhubi

4.2 Research Design

This is a cross sectional design study in which waste water samples were collected and processed during September 2017.

4.2.1 Sample collection

Duration: samples were collected at the end of dry season in mid-September 2017. Samples collection exercise was completed within two weeks.

Ten drains (Table 1; Fig. 1.) were sampled consisting of 7 concrete impervious concrete drains and 3 open soil drains. Each drain was sampled during the morning and afternoon at three different locations- the outpour site and two additional sites upstream around 100 metres apart. First batch of samples were collected in the mornings between 6.30 am and 9.30 am. Second batch of samples were collected during peak flow hours in the afternoon between 2.00 pm and 4.30 pm.

Ground water samples were collected just after rainy season in mid-June from six dug bore-hole wells that were 50-100m away from pervious drains.

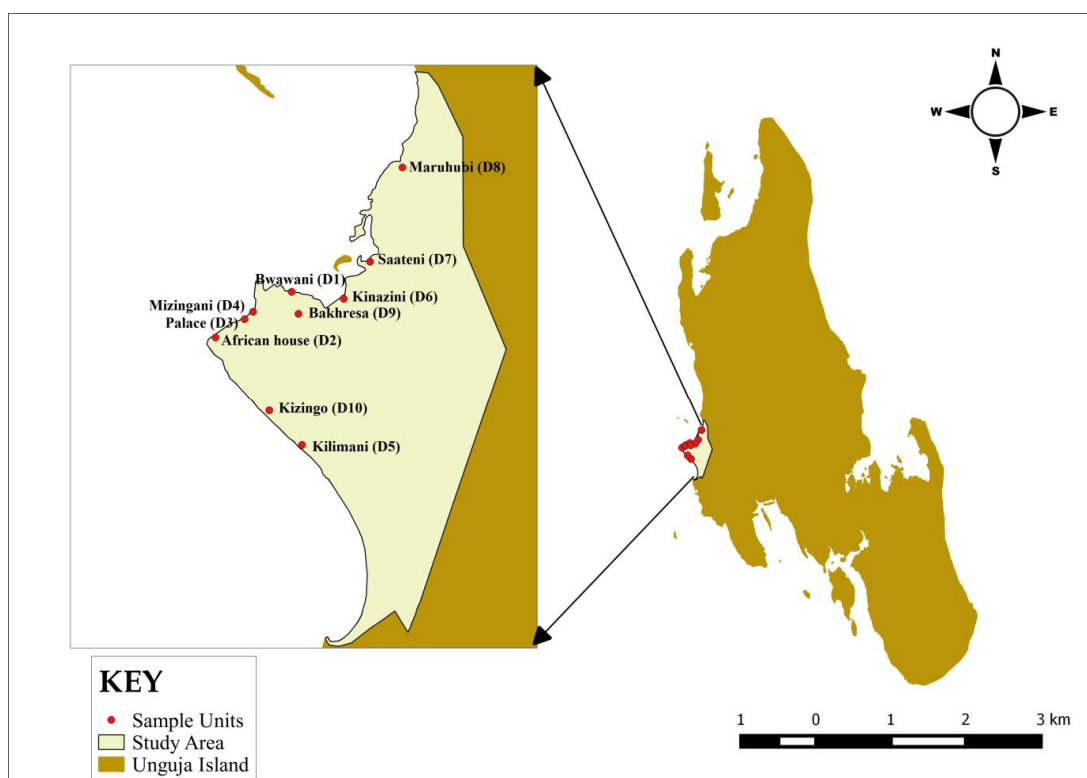


Fig.1. Sampled sites in Zanzibar stone town and peri-urban areas

Fifty mls of each sample was collected in sterile syringes and stored in cooler box at 4°C and sent to ZAWA (Zanzibar Water Authorities) laboratory and State University of Zanzibar for processing within two hrs of sample collection. The bacterial isolates from ZAWA laboratory were identified at the Zanzibar Veterinary laboratory.

4.2.2 Colony forming units

Waste-water samples were serially diluted in sterile phosphate buffer saline (PBS) and 1: 10,000 dilutions were used for thermo-tolerant Coliform count and 1: 100,000 dilutions used for total Coliform count. Potalab®+ (C) kits (Palintest, UK) were used for filtration as per manufacturer's instructions. Membrane Lauryl Sulphate broth (Avonchem Ltd, UK) was used for culture. Colony forming units' counts were made after 18hrs of incubation.

4.2.3 Physicochemical characteristics

Physicochemical parameters that were investigated were Dissolved Oxygen (DO), pH and turbidity. Portable Multi Meter kit (Hach

Company, US) was used for measuring DO, pH and turbidity as per manufacturer's instructions.

4.2.4 Bacterial identification

Traditional biochemical methods as described by Cheesbrough [17] were used in identifying bacteria

4.3 Statistical Analysis

Statistica -7 was used to perform statistical analysis. One way-ANOVA test was used to compare inter-site variability and inter-substrate type variability in DO, FC and TC. The validity of using parametric analyses was tested with Bartlett test. Heterogeneous data were log transformed to meet parametric requirements. Student-Newman Keuls test (SNK-test) was used to determine the differences among the means. Non-parametric Kuskal Wallis test was used to compare mean pH and turbidity among sites when data did not meet the assumptions of parametric test, and Mann-Whitney U tests were used to compare their inter-substrate type variability.

5. RESULTS AND DISCUSSION

5.1 Results

5.1.1 Colony forming units

Total Coliform counts were higher in impervious than pervious drains (Fig. 2). Similar results were obtained with thermo-tolerant Coliforms (Fig. 3).

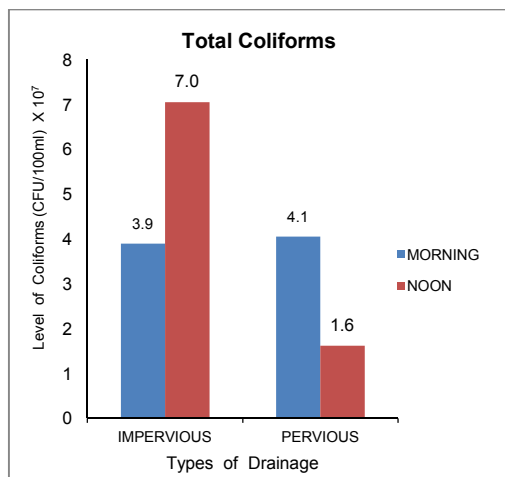


Fig. 2. Total Coliforms in impervious and pervious drains during morning and noon peak flow hours

A marked difference on bacterial counts was observed among sites within the same drains. Higher counts were obtained from impervious drains (Kilimani, African house and Palace) in the out-pour sites close to the coast than the upstream sites.

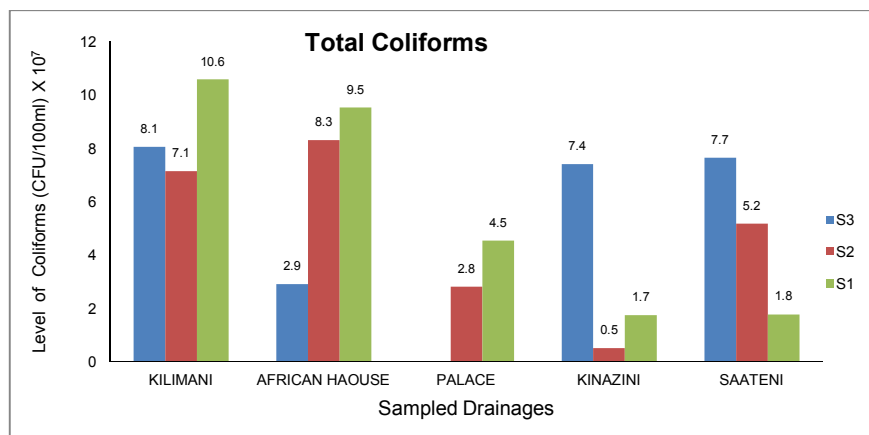


Fig. 4. Total Coliform counts of sites in impervious and pervious drainages
Key: S1-Out-pour site, S2-middle site, S3- upstream site

Conversely counts were lower in the out-pour sites compared to upstream sites in the pervious drains (Kinazini and Saateni) (Fig. 4)

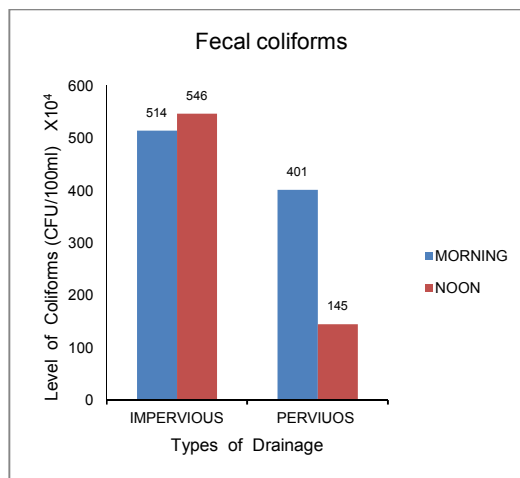


Fig. 3. Thermo-tolerant Coliforms in impervious and pervious drains

This study revealed that both TC and thermo-tolerant counts were higher than the set standards of TBS of 10⁴ cfu/ml.

5.1.2 Dissolved oxygen

Dissolved oxygen was higher in the morning (mean 6.5mg/100mls) than an afternoon (mean 5.2mg/100mls). This observation was uniform throughout the drain categories except Kizingo drain (Fig. 5).

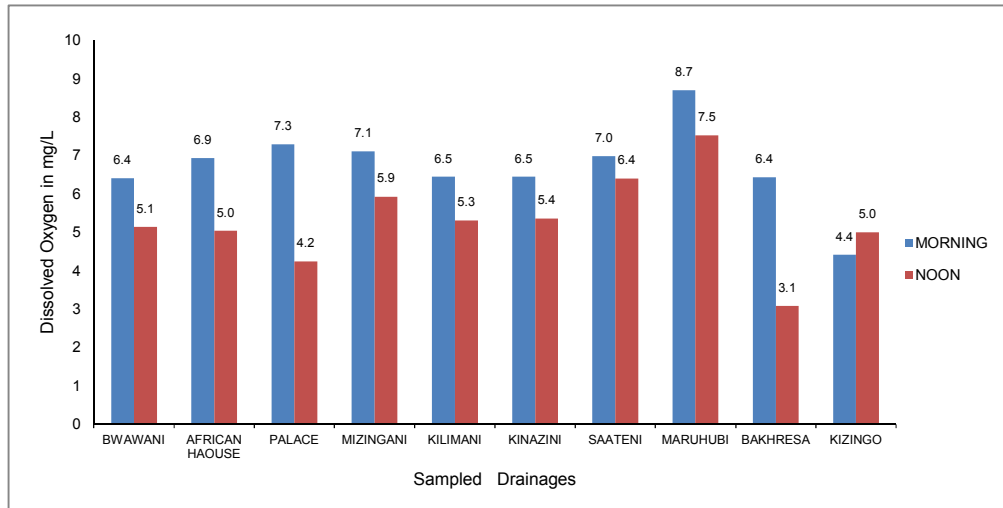


Fig. 5. Dissolved Oxygen during morning and noon in the studied drains

However there was no statistical significant variability in DO between morning and noon within sites. Moreover, when time data were pooled to compare inter-site variability, significantly higher DO was observed at Maruhubi which is pervious drain relative to Bakhresa and Kizingo which are impervious (ANOVA; $F = 3.8, p = 0.002$) (Fig.6). Likewise, when sites were grouped based on whether they are pervious or impervious, significantly higher DO was found in pervious substrate (6.9 ± 0.4) than in impervious (5.6 ± 0.2) substrate (ANOVA; $F = 8.8, p = 0.004$).

5.1.3 Turbidity

Most of the drains in stone town had slightly higher turbidity readings in the mornings especially with Kizingo drain. In contrast Bakhresa drain had higher turbidity range (697 nephelometric turbidity units (NTU) in the afternoon and lower 304 NTU in the morning. Kizingo drain had high range of turbidity (410 NTU) in the morning compared to the rest of the drains (Fig. 8).

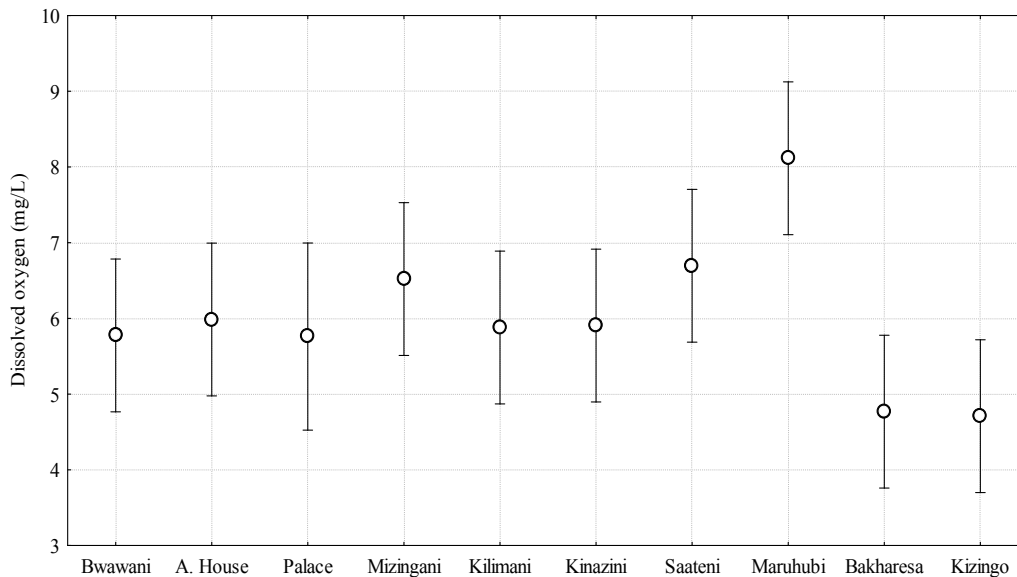


Fig. 6. DO variability within sites

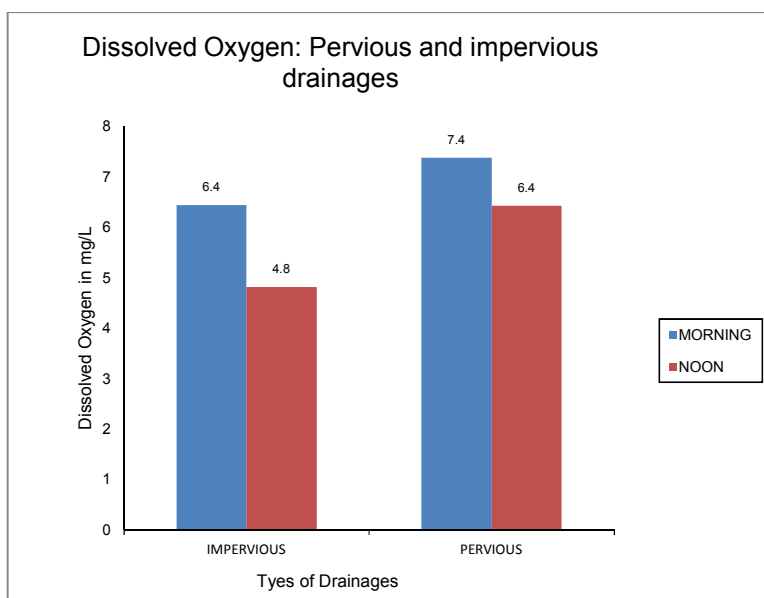


Fig. 7. Dissolved oxygen in impervious

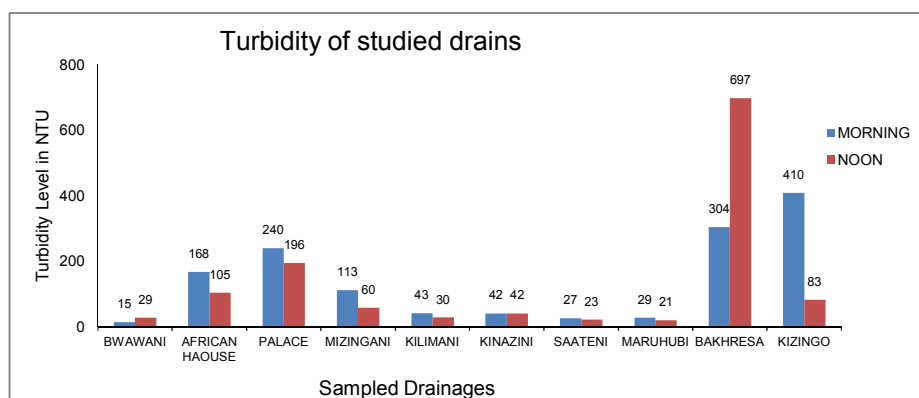


Fig. 8. Time variability in turbidity of studied drains

There was no significant time variability in turbidity within sites. However when data were pooled to compare inter-site variability, significantly higher turbidity was found at Bakharesa than all other sites ($H = 28.2$; $p = 0.0009$) (Fig. 9). Likewise, when sites were grouped on whether they are pervious or impervious, significantly higher turbidity in impervious (176 ± 33.8) than in pervious (30.6 ± 50.5 substrates ($U = 189$; $p = 0.04$).

5.1.4 pH

Higher pH was observed in all drainages in the afternoon compared to morning. Range of pH was recorded from 7.17 to 7.66 in the afternoon and from 6.17 to 7.06 in the morning (Fig. 10).

pH was generally significantly higher during noon than in the morning ($H = 27.72$; $p < 0.0001$), with significant intra-site variability at Bwawani, Africa House, Palace, Kilimani and Kizingo (Fig. 11). When sites were grouped based on whether they are pervious or impervious, significantly higher pH was observed on sites with pervious drains ($p = 0.013$).

5.1.5 Bacteria identified

Table 2 enlist the 13 bacterial species identified from their respective drains. Bacteria were mostly gram negative Enterobacteriaceae. *Vibrio cholerae* was isolated from 5 drains all of which were from peri-urban areas.

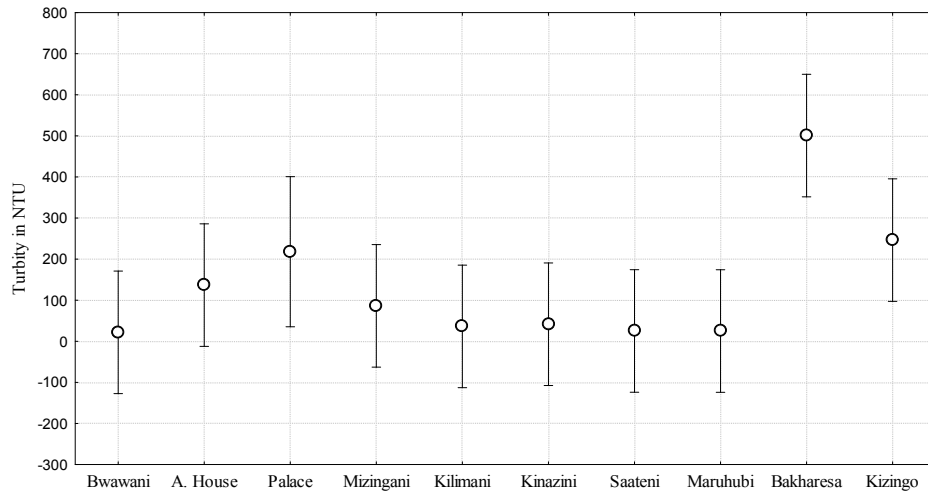


Fig. 9. Drainage site variability in turbidity

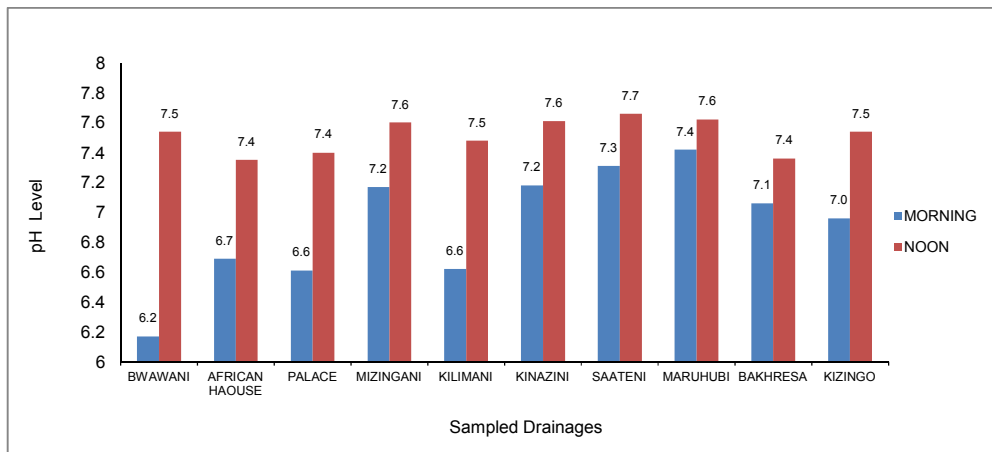


Fig. 10. Time variability of pH within sites

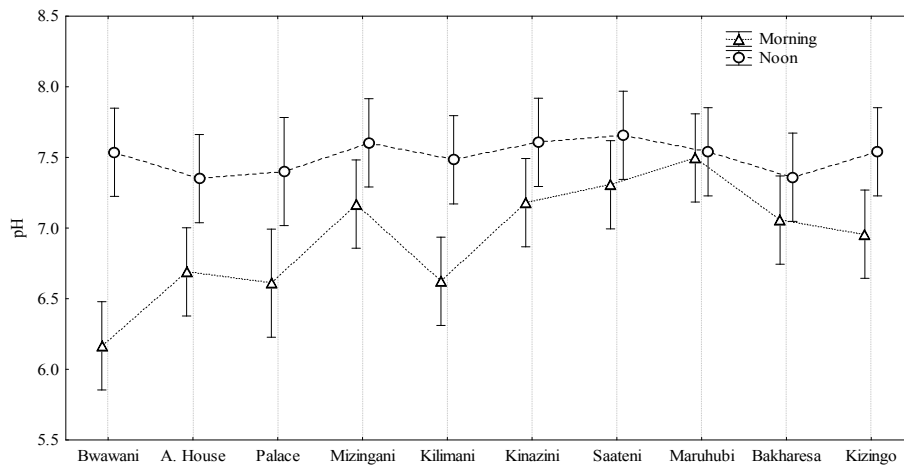


Fig. 11. Temporal variability of pH within sites

Table 2. Bacteria isolates from different drains

Site	Bacteria isolated
Bwawani	<i>Proteus</i> <i>E. coli</i> <i>Enterobacter</i> <i>Staphylococcus aureus</i> <i>Micrococcus</i> <i>Vibrio cholerae</i>
African House	<i>Klebsiella</i> <i>Pseudomonas stutzeri</i> <i>Enterococci cloaca</i> <i>Pseudomonas aureginosa</i> <i>E. coli</i>
Palace	<i>Proteus</i> <i>Staphylococcus aureus</i> <i>Klebsiella</i> <i>Enterococcus</i> <i>Enterobacter</i> <i>E. coli</i> <i>Micrococcus</i>
Mizingani	<i>Proteus</i> <i>Staph. aureus</i> <i>Enterococcus</i> <i>Enterobacter</i> <i>E. coli</i>
Kilimani	<i>Klebsiella</i> <i>Proteus</i> <i>E. coli</i> <i>Enterobacter</i> <i>Enterococcus</i> <i>Staphylococcus aureus</i> <i>Vibrio cholerae</i> <i>Vibrio parahemolyticus</i>
Kinazini	<i>Staph aureus</i> <i>Proteus</i> <i>Klebsiella aerogenes</i> <i>Enterobacter</i> <i>Pseudomonas stutzeri</i> <i>Vibrio cholerae</i>
Saateni	<i>Proteus</i> <i>Pseudomonas aureginosa</i> <i>Enterobacter aerogenes</i> <i>Pseudomonas stutzeri</i> <i>Vibrio cholerae</i> <i>Vibrio parahemolyticus</i>
Maruhubi	<i>Klebsiella</i> <i>Proteus</i> <i>Pseudomonas aureginosa</i> <i>Vibrio cholerae</i> <i>Vibrio parahemolyticus</i> <i>Enterobacter aerogenes</i> <i>Pseudomonas stutzeri</i>
Bakhresa	<i>Proteus</i> <i>Klebsiella</i> <i>Pseudomonas aureginosa</i>

Site	Bacteria isolated
Kizingo	<i>Alcaligenes faecalis</i> <i>Bacillus spp.</i> <i>Vibrio parahaemolyticus</i>
	<i>Proteus</i> <i>Klebsiella</i> <i>E. coli</i> <i>Pseudomonas aureginosa</i> <i>Enterococcus</i> <i>Micrococcus</i>

5.1.6 Ground-water Microbial and Physico-chemical analysis

The bacteria isolated from ground water were identified as *Streptococci*, *Klebsiella species*, *Pseudomonas aureginosa*, *Staphylococcus aureus*, *E coli* and *Enterobacter*.

The physico-chemical characteristics of the six ground water sites are shown in Table 3.

5.2 Discussion

This study was conducted to assess the physicochemical characteristics and extent of bacterial contamination of waste water effluents sourced from impervious and pervious drains of Zanzibar town that are discharged into the nearby coastal marine waters.

Results in this study indicate that total coliforms and thermo-tolerant coliforms counts were higher than National standards set by Tanzania Bureau of Standards [18]. High counts are expected due to lack of any waste water treatment in the Zanzibar municipality; moreover chlorine treatment in Zanzibar is restricted to fresh drinking water only. The afternoon counts were generally higher than the morning counts. This can be attributed to increased human activities in the afternoons and people tend to converge into towns to attend their employment duties, conduct trade activities and look for necessary requirements with accompanying increased use of toilets. The high bacterial contamination in waste waters correlates with urbanisation and high population density as observed by previous researches [5,19],

Marked difference was observed in this study between pervious and impervious sewage drain bacterial counts, an observation that could be explained by natural filtering effect of soil in pervious drains. Generally the Zanzibar stone town drainages are strengthened by concrete tunnels that are impervious to bacteria

penetration. Moreover, the outpour sites in the concrete impervious drains tended to have higher bacterial counts than the upstream sites implying cumulative effects of bacteria and bacterial multiplication. This is in contrast to what was found in the pervious drains which had lower counts in the outpour sites which again is due to filter effect of natural soil. Ultimately, though microbes from drainages can settle in the sediments on sea bed, they may multiply and contaminate surface waters during turbulence.

High bacterial load of sewage effluents found in this study send an alarm of a public health risk that also endanger the ecological health of marine waters of Zanzibar beaches which are commonly visited by tourists and local population for recreational purposes and fishing activities. The current study shows that Zanzibar sewage waste water has high organic load of suspended nutrients and minerals, evidenced by high turbidity, which are a primary food source of algae risking eutrophication of coastal waters. Waste water treatment will certainly significantly reduce bacterial contamination and improve beach microbial water quality as observed by Ouattara et al. [5].

Results of the physicochemical parameters in this study are in agreement to findings of other workers [3,18,19] that relate to consequences of high bacterial contamination in water bodies. The observations especially refer to low amount of dissolved oxygen and high turbidity, more so in impervious drains that correlate to high microbial count. Despite the high dilution in large water bodies like marine waters huge outpour of microbes and nutrients have been reported to be responsible to eutrophication, oxygen depletion, disturbance of coastal ecosystem and mortalities of marine life [20,21]. Moreover the high nutrients content in waste waters can lead to increased algal growth, oxygen depletion, nitrification of ammonia and reduction of photosynthesising microbes resulting to detrimental effect of coastal ecosystems.

Table 3. Mean physico-chemical and microbial parameters in wastewater drains and ground water

Drainage samples					Ground water samples					Statistical analysis
pH	Turbidity	DO	TC x10 ³	FC x10 ³	pH	Turbidity	DO	TC x10 ³	FC x10 ³	
6.9	28.7	6.4	8000	3390	8.7	0.8	8.1	1.168	0.468	Extremely significant difference p<0.000 was observed in TC and FC counts of drainage and ground water samples Difference in Physico-chemical characteristics were highly significant p<0.001
7.1	105.5	6.9	58170	7090	9.1	14.3	8.6	4.680	0.150	
7.0	196.0	7.3	29800	5060	9.3	1.6	8.1	12.040	0.068	
7.4	59.7	7.1	41700	8050	8.9	1.7	8.1	3.432	1.950	
7.1	29.6	6.5	1700	870	8.6	4.3	8.2	7.800	1.424	
7.4	41.6	6.4	64130	5030	8.6	0.9	8.5	2.048	0.008	
7.5	23.2	7.0	50530	6590						
7.5	20.6	8.7	6900	420						
7.3	697.0	6.4	104330	4340						
7.3	83.2	4.4	52000	7180						

The low pH observed in mornings especially in stone town impervious drainages could be attributed to use of acidic chemicals in hotels for cleaning porcelain utensils and sinks. pH increased in afternoons that could be due to use of alkaline soaps and increased urea excreta voided in toilets. For sustainable coastal water health however, it is recommended to keep under control the overuse of chemicals for cleaning purposes.

Thirteen types of bacteria species were identified many of which could be pathogenic. Gram negative *Enterobacteriaceae* were the most frequently isolated. Five drainages yielded *Vibrio cholera*. This is not the first time that *Vibrio cholera* was isolated from environment in Zanzibar; Rabia et al. [22] reported isolations from drainages during 2015/2016 cholera epidemic, but surprisingly isolations in this study was done during inter-epidemic period that imply sporadic occurrence of cholera cases and impending next cholera outbreak.

Two remarkable observations were observed in ground water variables; presence of coliforms specifically thermo-tolerant faecal coliforms and

high pH. Mohamed et al. [23] also isolated coliforms from boreholes in Zanzibar. Counts in this study are above allowable limits by WHO [24] suggestive of the possibility of seepage of waste water to ground water, a point to be noted by water and public health authorities. The increased pH could be explained by increased hydroxyl ions (OH⁻) in ground water during rainy season [25].

Depletion of oxygen due to high organic matter, high turbidity and bacteria counts in drains that void their contents in the shore line cause impairment of coast water health and pose a threat to public health. Most of the bacteria identified are pathogenic to humans and, for the sake of reduction of risks of gastroenteritis and other ailments, waste water treatment both physically and chemically could substantially reduce the degree of contamination of ground water and improve coastal waters and health which is vital for Zanzibar economy.

6. CONCLUSION

This study revealed that waste water drains in Zanzibar urban and peri-urban areas are highly

contaminated with organic matter and pathogenic bacteria leading to high turbidity and oxygen depletion and therefore a potential threat to biodiversity and coastal eco-system. Furthermore, isolation of Coliforms and other bacteria from groundwater can compromise the health of water consumers. Results of this study, therefore, emphasize the need of enforcement of health policies that are to be integrated with infrastructure and environment as well as direct involvement of civil society. Application of these policies should be interpreted into concrete actions for the health of the population.

Immediate steps are needed to be implemented, especially by public managers, to improve the situation that will ensure rules of hygiene including awareness and education are enforced that will ultimately reduce contamination of waste waters, Zanzibar beach waters and ground water.

7. RECOMMENDATION

The results of this study accentuate the need to do further research that will assess the public health risks posed by contaminated drainage system in Zanzibar. Recommended areas of further research include assessment of contamination in coastal waters in recreation areas, comprehensive study on the extent of ground water contamination close to the drains, chemical contamination especially of heavy metals in both coastal waters and aquatic organisms, and pathogen contamination in the marine food chain.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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