Norwegian University of Life Sciences
Faculty of Social Sciences
Department of International Environment and Development Studies

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Down the Drain: A Social-Ecological Study of the Impacts of Sewage and Wastewater Discharges in Msasani Bay, Tanzania

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MSc Thesis
By Catherine Wilson, May 2015

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Title Photo: Nyirenda River mouth, Msasani Bay (photo: Catherine Wilson 2014)

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Declaration

I, Catherine Wilson, declare that this thesis is a result of my research investigations and findings. Sources of information other than my own have been acknowledged and a reference list has been appended. This work has not been previously submitted to any other university for award of any type of academic degree.

Signature……..

Only when the last tree has died
the last river has been poisoned
the last fish has been caught
will we realise we can't eat money.
-Cree Indian Proverb

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Tanzania is a place I will always hold dear to my heart.

ABSTRACT

Msasani Bay, Dar es Salaam, is situated among important marine habitats such as the highly complex, biologically diverse and productive systems of coral reefs, mangrove forests and seagrass beds. Marine biota in such tropical ecosystems are typically more sensitive to pollution than those of temperate biotopes. This thesis examines the impacts of sewage and wastewater pollution on human communities and the marine ecosystem of Msasani Bay. Data was collected through semi-structured interviews with five main actor groups, namely households, fishers, industries, health clinics and institutions, in addition to measurements of faecal coliform, salinity and phosphorus in the water of the bay and river mouths. A conceptual framework of vulnerability and social-ecological resilience was adopted to frame the findings. The study reveals increased vulnerability and lowered resilience of the SES of Msasani Bay. The current mode of sewage and wastewater disposal failed to protect the rights of communities to a clean, safe and healthy environment and the surrounding ecosystem from deleterious water pollution. Domestic and industrial sewage and wastewater are discharged untreated into streams and rivers, thus creating potential for annual floods to severely impact disadvantaged actor groups, but also to impact the entire community. Institutional analysis and research findings revealed that Government and institutional ineffectiveness, through poor town planning and corruption, have produced the conditions through which these discharges have the greatest impact. The situation has given rise to three key system variables that indicate the seriousness of the SES: lives and livelihood destruction, the spread of diseases, and a major loss of biodiversity. The ecosystem in Msasani Bay has significantly changed over the past few decades and has the potential to flip into a further polluted and dysfunctional alternate state. Faecal coliform and nutrient analysis revealed high contamination in all sample locations throughout the bay. These samples were categorised as unsafe for recreational waters by a wide margin, representing exceedingly high risk to human health. Moreover, a high number of interview respondents, such as those closely located to polluted rivers, and fishers in Msasani Bay noted illnesses known to be associated with sewage. This study concludes by affirming the need for community activism and governmental response for improved sewage and wastewater treatment, and more innovative infrastructure for the growing urban population of Dar es Salaam, as the present SES is simply unsustainable.

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List of Abbreviations

CFU	Colony Forming Unit
COSTECH	Tanzania Commission for Science and Technology
DAWASA	Dar es Salaam Water and Sewerage Authority
DAWASCO	Dar es Salaam Water and Sewerage Corporation
DWSSP	Dar es Salaam Water Supply and Sanitation Project
E. coli	Escherichia coli
EMA	Environmental Management Act 2004
FAO	Food and Agriculture Organization of the United Nations
FIB	Faecal Indicator Bacteria
GDP	Gross Domestic Product
IMF	International Monetary Fund
NEMC	National Environment Management Council
NGO	Non-Governmental Organisation
P	Phosphorus
PAR	Pressure and Release vulnerability model
PPM	Parts Per Million
SAP	Structural Adjustment Program
SCP	Sustainable Cities Programme
SDP	Sustainable Dar es Salaam Project
SES	Social-Ecological System
SUDP	Strategic Urban Development Plan
TC	Total Coliform
TPDC	Tanzania Petroleum Development Corporation
UN	United Nations
UN-HABITAT	United Nations Human Settlements Programme
USD	US Dollars (Currency)
WIO	Western Indian Ocean

1. INTRODUCTION

1.1 Background to Research Problem

1.1.1 Water Pollution

Water pollution is a global problem with far reaching effects on both human health and marine and terrestrial ecosystems. Water pollution occurs in various forms, such as industrial effluents, agricultural chemicals, medical wastes, refuge and domestic sewage. It constitutes an increasing problem for developing countries with expanding urban populations and industrial activities in coastal areas: approximately 90% of sewage in developing countries is discharged untreated directly into rivers (UN Water 2008). Wastewater effluents often contain organic and inorganic substances that are potentially toxic to marine ecosystems. These substances if not decomposed or rapidly diluted "may harm the marine ecosystem causing an adverse impact on marine resources and environmental values" (Bryceson & Mwaiseje 1979: 1). Furthermore, marine biota in tropical climates typically experience pollution more severely in comparison to temperate climates, due to the naturally smaller fluctuations of their environmental conditions (Johannes & Betzer 1975; Bryceson 1981). Tropical marine waters contain lower dissolved-nutrient levels, lower concentrations of suspended particulate material and dissolved humic acids, thus there are "less environmental rigors that must be endured in order to survive" (Johannes & Betzer 1975: 10).

In developing countries, water pollution, and more specifically, sewage and wastewater pollution, affects all income groups, although clearly it is the low-income groups that are increasingly exposed to hazards. Everyday activities such as cooking, washing, fishing, and recreation take place in and around polluted environments such as rivers and coastal waters. The presence or absence of water pollution in an area can be a determining factor in its development: "effective waste handing is at the centre of the development and wellbeing of a community and the sustainability of projects (Chaggu et al. 2002: 609).

Wastewater treatment and sanitation facilities are an important social and economic investment: the estimated return for every dollar investment in water and sanitation services is USD$5 to USD$28 (UN-Water WWAP 2015). The benefits include the enhancement of livelihoods, employment opportunities, and reduced costs to the nation in health and productivity lost (UN Water 2008).

The adequate management of waste can improve a community's quality of life and increase

the liveability of an area: economically, via employment and investment opportunities, the productive activities conducted in and around the sea, tourism via the recreational potential of an area, and new industries created from wastewater disposal; socially, via the health and education improvements; and environmentally, via potential nutrient reuse, reduced water pollution and subsequent positive impacts on coastal biota and ecosystems (UN-Water GLAAS 2014). It is by no coincidence that in 2010 the United Nations adopted Resolution 64/292 recognising the human right to water and sanitation (UN General Assembly 2010). Modern wastewater treatment and infrastructure however remain elusive to a large portion of the world's population, for instance 760,000 children under the age of five die annually from diarrhoea (WHO 2013).

1.1.2 Background Information

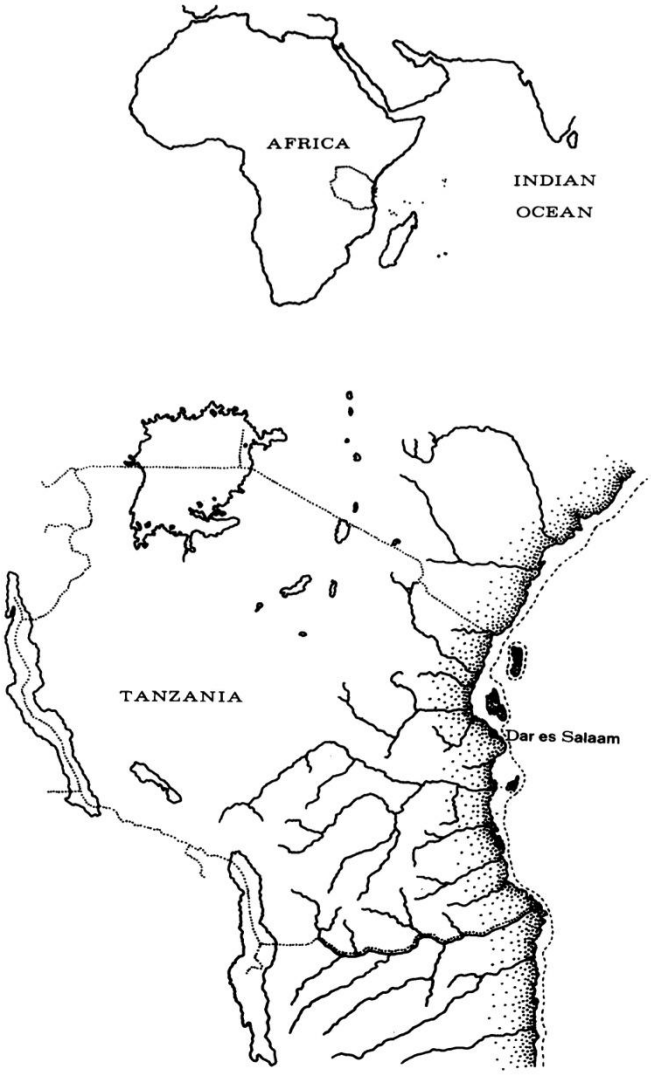


Figure 1. Map of Africa and Tanzania (Bryceson 1977)

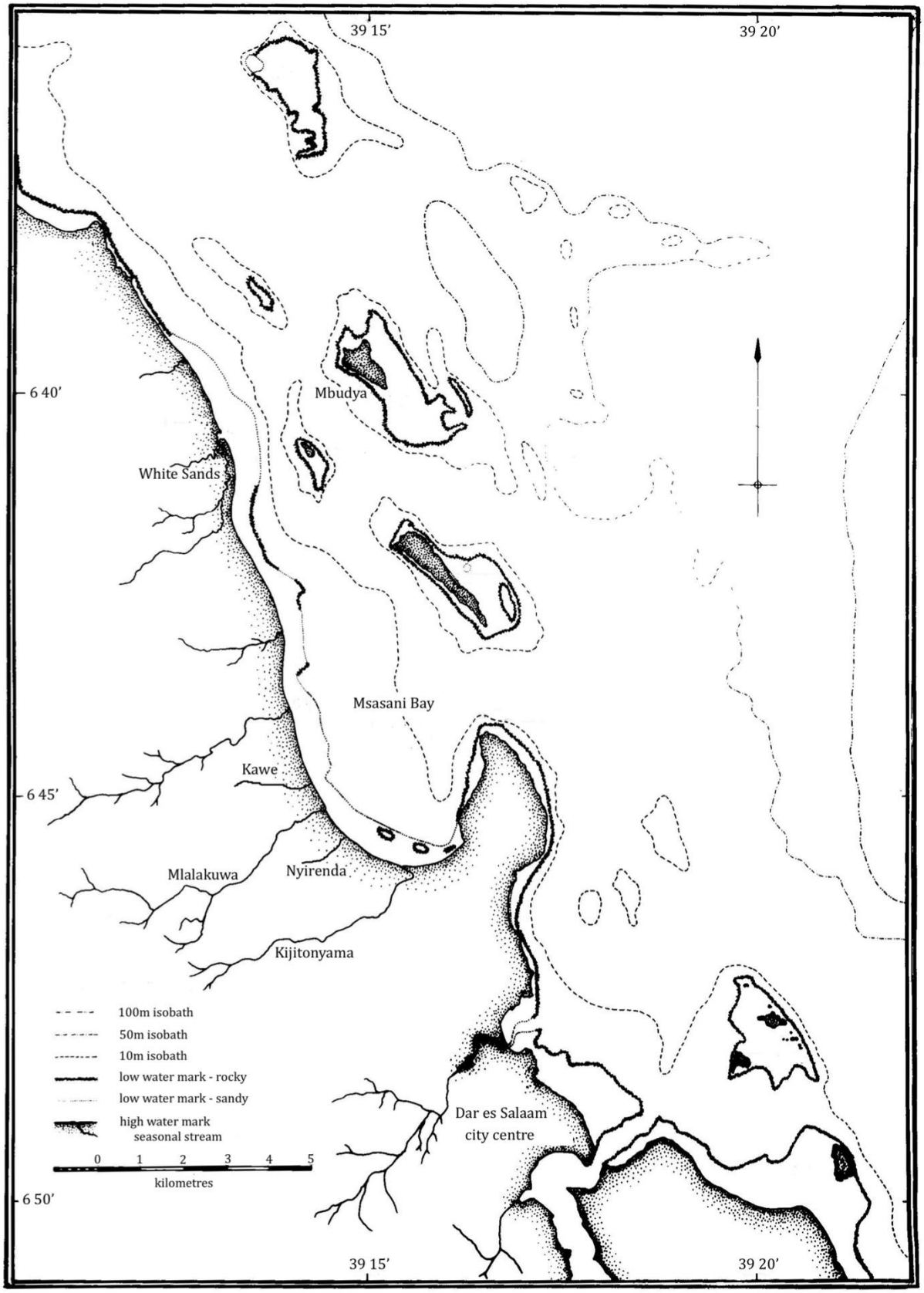


Figure 2. Map of Msasani Bay, Dar es Salaam (Adapted from Bryceson 1977)

Tanzania & Dar es Salaam

Tanganyika won independence from British colonialism in 1961 and Zanzibar in 1963, with the United Republic of Tanzania forged as a union in 1964. The country has an area of 947,300 km^2 (FAO 2012) and a population of 49.25 million people (World Bank 2013). Tanzania is renowned for its rich biodiversity and vast marine ecosystems. Its 800 km coastline features biotopes including mangroves, coral reefs, seagrass beds, wetlands and beaches, amongst others. Obura (2012) conducted a study that found coral reefs in the Western Indian Ocean (WIO) region, from the northern Mozambique Channel to Mafia and Pemba Islands in Tanzania, constitute a central ecoregion of diversity, with these two Tanzanian islands containing exceptionally high species richness (corresponding with Sanders 1968, in Johannes & Betzer 1975). On mainland Tanzania, species richness was however amongst the lowest sampled (Obura 2012). This could indicate the presence of marine pollution and sediment transportation close to shore.

Dar es Salaam region has Tanzania's highest rate of economic activity; in 2000 the region accounted for approximately 33% of national GDP (likely a higher figure in 2015) (Constantinides 2000; Francis & Bryceson 2001). The coastal regions in general are also attractive tourist destinations that contribute to the country's GDP. Economic development in recent decades has however led to environmental deterioration of the country's complex and fragile coastal ecosystems. A contributing factor to this deterioration is water pollution. Dar es Salaam, the 'Harbour of Peace', is one of 30 regions in Tanzania and home to more than 4.36 million people (NBS 2012). The city lies on a lowland plain, typified by a high water table and a tropical climate of two distinct wet seasons: the short rains (*vuli*) from November to December and the long rains from March to May (*masika*). The city also features approximately 95% loamy soils, 4% sandy, and 1% mainly clay (Chaggu et al. 2002).

The region is divided into three administrative districts (municipalities): Ilala, Temeke and Kinondoni, and has a population density of 3,133 persons/km^2 (NBS, 2012). The city experienced exponential population growth during the period 1990 to 2001 (Chaggu et al. 2002). Although this has decreased in recent years, its urban population has continued to rise, increasing by 5.6% over the last 10 years according to the 2012 census (NBS 2012). Expansion of the city has however largely shifted from the outward growth along major transport routes that characterised the 1980s, to an urban infill (Briggs & Mwamfupe 2000). At present, approximately 28-30% of Tanzania's population live in urban areas (Kidata 2013).

As described above, Dar es Salaam's rapid economic development and urbanisation has brought environmental deterioration that has placed intense pressures on the city. These can be seen in increased traffic congestion (through private vehicles and public transport), the growth of unplanned settlements, and overloading of urban services such as the water and sewerage systems (Briggs & Mwamfupe 2000; Chaggu et al. 2002). The sewerage system constructed in the late 1950s was in a state of poor repair, despite an unsuccessful attempt at rehabilitation in the period 1980 to 1988 and few minor improvements carried out since (Constantinides 2000). The small percentage of the city serviced by the central system (estimated between 5 and 10%) had its sewage passed through waste stabilisation ponds and then released to the ocean, largely untreated. The period of urbanisation also saw increases in industrial establishments: in 2009, more than 50% of Tanzania's large industrial establishments operated in Dar es Salaam (NBS et al. 2009). Additionally this period provided an opportunity for Municipal councils to raise funds through the issuance of unscrupulous construction permits (findings from interviews 2014).

The institutional structure of sewerage and wastewater administration in Dar es Salaam is presented in Figure 3, comprising the Ministry of Water, National Environment Management Council (NEMC), Dar es Salaam Water and Sewerage Authority (DAWASA) and Dar es Salaam Water and Sewerage Corporation (DAWASCO). The role of the Ministry of Water in relation to this study is the provision of technical and financial support of the Urban Water Supply and Sanitation Authorities (Ministry of Water 2014). DAWASA's role is to provide water and sewerage services to the city and is accountable to the Ministry of Water. Although given responsibility to provide these services, the organisation is authorised to select a private operator to instead service the area, through provision of their assets (DAWASA.b, s.a.). "DAWASCO is a public parastatal company owned and financed by the Tanzanian state with a board appointed by the Ministry" (Pigeon 2012: 46). It is responsible for the delivery of water supply and sewage removal and directly accountable to DAWASA. NEMC's role is to

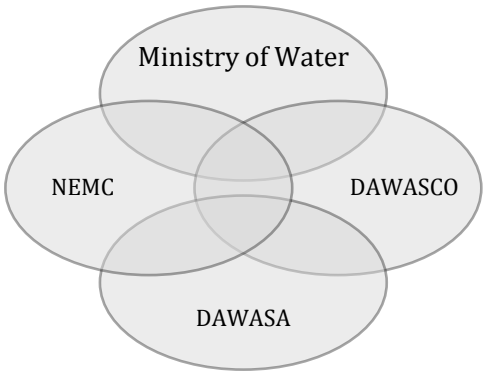


Figure 3. Institutional structure of sewerage and wastewater administration

undertake enforcement and compliance of the national environmental quality standards, review and monitoring of environmental impact assessments, facilitate public participation in environmental decision-making, enhance environmental education and public awareness about rigorous environmental management (Tanzania. EMA 2004).

Historical Institutional Context

The 1980s were marked by political and economic reforms, and a shift from socialism and the one party state, to a multi-party system (Triche 2011; UN-HABITAT 2004). By the late 1980s, the Tanzanian Government (with pressure from the World Bank and International Monetary Fund) had embarked upon a privatisation process that saw virtually all state-owned enterprises transformed. To bring the country into line with economic developments, in 1990 the Government requested assistance from the UNDP for advice in the review of the 1979 Dar es Salaam Master Plan.

The Sustainable Dar es Salaam Project (SDP) was created in 1992 as part of the UN-HABITAT Sustainable Cities Programme (SCP) with the intention to provide, amongst other objectives, a Strategic Urban Development Plan (SUDP) that could form a much needed, revised city Master Plan. A central focus of the SDP included urban environmental issues, which aimed to reduce exposure to environmental hazards and strengthen local capacity (UN-HABITAT 2004). The SDP however had numerous deliverance issues as the "budget was both supplemented and extended several times" (UN-HABITAT 2004: 8). Originally, the SDP was budgeted US$696,000 for a two-year period, although after four years of activities the project had spent nearly four times the original budget. The SDP became the largest of any SCP projects, because of financial inputs: US$5,615,000 over the entirety of the project (until 2003).

The SDP prepared an Environmental Profile early in the project that highlighted five environmental issues, three of which are directly related to this study: inadequate solid waste management; overcrowded, unplanned and poorly serviced settlements; and surface and ground water pollution (UN-HABITAT 2004). SDP then saw actor consultation whereby an agreement was reached and working groups were created, some with legislation (by-laws) and tangible outcomes (such as the Vingunguti dump site). There were initial improvements but lack of effective enforcement, and other causes, allowed poor practices to return.

In 1996, devolution of the city's central administration occurred and a City Commission was implemented to address problems such as the abuse of authority and poor governance. The Commission was in place until 2000 when the new decentralised municipality governance structure was adopted and the Dar es Salaam City Council was re-established with an alternate focus on cross-cutting issues such as fire and rescue, transport and health (Mtani 2004; Dar es Salaam Council 2004; UN-HABITAT 2004). Due to the governmental disarray of this transition period, the Planning and Co-ordination Department recommended to integrate the SDP into the city's restructuring. However this was not fully implemented: although it was established at "city and municipal levels it neither functions according to the proposal nor is it composed of the proposed departments" (UN-HABITAT 2004). Furthermore, the SUDP was completed in 1999 although when the Project report was written in 2004, the SUDP had not superseded the 1979 Master Plan. There has since been an updated Dar es Salaam Master Plan produced (in 2013) that was effective from '2012-2032'.

With the City Council's dissolution and associated reforms, DAWASA was established in 1997, (from the existing National Urban Water Authority) to operate and maintain all water supply and sewerage services in Dar es Salaam (DAWASA.a s.a.). It became clear almost immediately however, that DAWASA did not have the capacity to balance finances with dilapidated infrastructure (DAWASA.a, s.a.). To combat this, a solution was sought via the design of a public-private partnership. The mechanism implemented to finance the new infrastructure and plans necessary for the partnership was the Dar es Salaam Water Supply and Sanitation Project (DWSSP), largely financed by the World Bank (some US$164.6 million) and carried out by DAWASA and other private companies[1]. When the DWSSP was implemented in 2003, the new water and sewerage operator, City Water Services, was engaged under a lease contract. This contract was terminated after less than two years as a result of performance and financial difficulties on the company side and a lack of due diligence on State and DWSSP's side (Triche 2012). After the failed privatisation, public operator DAWASCO took over operations in 2005 with a 10-year lease (which has since been reviewed and renewed). The DWSSP's wastewater rehabilitation works were completed in 2009, with a National Urban Sewerage Strategy and Strategic Plans for Future Improvement of Sanitation Services created; however implementation and awareness of these are yet to be

[1] The World Bank recently debarred Dutch company *Elmcrest Group Ltd* (formerly *Landmarc Ltd*) and joint venture partners, the Norwegian *Norconsult*, and Tanzanian *MMK Project Services* for six years of fraudulent and corrupt practices relating to the Dar es Salaam Water Supply and Sanitation Project (World Bank 2014).

seen. Outcome ratings of the project were published in 2011 with condemning evaluations: the large majority of performance indicators (in terms of project implementation, efficiency, objectives, lender and borrowers performance etc.) were classified as unsatisfactory (Triche 2011).

Msasani Bay

Marine environments in the tropics such as coral reefs, seagrass beds and mangroves are amongst the most highly complex, stable, and productive systems in existence (Odum 1971). These systems have high primary rates of production and energy inputs and flows, for example a high respiratory metabolism to recycle minerals (Odum 1971). Msasani Bay is situated amongst various tropical ecosystems, such as the Dar es Salaam Marine Reserves (Bongoyo and Mbudya Islands), and the Selander Bridge and Kunduchi mangroves. The configuration of these surrounding islands is one that protects the Bay from waves. For much of the 20th century the shallow bay featured clear, unpolluted water, coral reefs and seagrass beds (personal communication with Bryceson and interview respondents). These coral reefs and seagrass beds were important habitats for fish and other organisms, as they acted as a nursery ground. Some techniques practiced by few fishers have been attributed to the coral reductions and fish declines (Ray 1968; Bryceson 1978, 1981; in Guard & Masaiganah 1997), in combination with a rise in nutrient content, unconducive to coral growth (Odum 1989).

The bay features an interesting melting pot of actors and geographic characteristics. Mikocheni (and the section of Msasani ward adjacent to the western shoreline of the bay), is primarily a residential area with households of high income levels, and contrastingly, interspersed with unplanned settlements of low income levels. Situated among the residences is the Mikocheni B light industrial area, constituting a core land use that reflects the city's urban composition. Industrial effluents from numerous businesses are discharged into surrounding environments, as are solid and liquid wastes from households. These rivers, stormwater drains, and sewage outfalls flow directly to the ocean and typify the main sources of water pollution in urban Tanzania (Mbuligwe & Kaseva 2005). The Mikocheni waste stabilisation ponds, Kijitonyama, Nyirenda, Mlalakuwa and Kawe Rivers receive the described wastewaters, which then flow into the waters of Msasani Bay. The livelihoods of Msasani's fishing community depend on the gateway provided by the bay for access to nearby marine reserves. Although some techniques practiced by few fishers have been attributed to coral reductions and fish decline (in combination with a rise in nutrient content

for which corals have a low tolerance (Odum 1989). A number of health clinics operate in the area also. Those who live and work contiguous to Msasani Bay, face a daily struggle with polluted environments.

1.2 Literature Review

Research on pollution and water quality in Tanzania only dates back to the 1970s (Mohammed 2002). There have been a limited number of studies conducted in Dar es Salaam on the impacts of urban water pollution from sewage and wastewater, and few that concentrated on Msasani Bay. The majority of these works focused on the ecological impacts, and although some studies considered social aspects, no studies have focused substantially on both social and ecological impacts. I will review a selection of the pertinent literature in this section.

The complex nature of the coastal Tanzanian marine environment displays adverse reactions to shifts in fundamental stability. One of the first comprehensive studies on the topic of sewage impacts in Dar es Salaam, (Bryceson & Mwaiseje 1979) examined existing and potential effluent outfalls in Dar es Salaam, such as Msasani Peninsula, Kendwa Island and Msimbazi Creek, with particular focus on the Ocean Road (Barack Obama Drive) sewage discharge point. Its authors characterised the latter as ecologically deleterious, as it bio-stimulated growth of plants and animals in the greater area, introduced additional nutrients, increased turbidity and the settlement of suspended solids, and decreased oxygen concentrations. They described unfavourable effects of those factors on biota, aesthetic quality and communities in terms of health and livelihoods that rely on ecosystem functioning of the area. The authors also analysed coastal usage for human activities in Dar es Salaam.

Urban and marine pollution in Dar es Salaam is instigated by a range of human activities and inappropriate waste disposal mechanisms. A study of the marine environment in the Eastern African region (Bryceson et al. 1990), found serious biological and public health effects in Dar es Salaam arising from noxious industrial effluents, poorly located and untreated sewage outfalls, and domestic sanitation system overflows from seasonal flooding. Investigation of contaminants found no existing data on rates of transportation between land and sea or concentration levels, but documented conveyance of wastes to the sea via poor disposal into water bodies such as drains, rivers and groundwater. Risks posed to humans included the

conveyance of pathogenic viruses and bacteria from sewage and chemical contaminants, and their bioaccumulation in seafood. The principal human activities found to affect the sea were the disposal of urban and industrial wastewaters attributed to low rates of central sewage treatment and subsequent transmission to the sea via inadequate and poorly maintained outfalls, deforestation and agriculture-related soil erosion, and siltation from dredging. Also, other human activities that negatively impacted the marine environment include dams, solid waste, oil spills, siliceous sand and other mineral extraction quarries and dynamite fishing.

Hazardous medical, industrial and agricultural wastes in urban Dar es Salaam pose a significant threat to human and environmental health. Mato & Kaseva (1999) found a stark lack of emphasis on appropriate handling and disposal methods, highlighting out-dated laws, low penalties, and environmental mismanagement by Dar es Salaam authorities as responsible for a lack of 'cradle to grave' waste monitoring. Their historical analysis showed that during the pre-colonial period few industries existed, tools were simple and inputs were low, with no record of significant environmental abuse. The colonial era brought modern industrial development and medium to large-scale industries, although processing included a limited range of cash crops and few manufacturing industries. Post-independence, many new industries were established, such as fertiliser, cement, and crude oil refineries, due to changes in government policy. This process took place with almost no environmental consideration as no treatment plants were created or laws enacted. The authors found limited data on the rates of production of hazardous waste, or their impacts. Wastes were disposed of either onsite by burning or burying, or offloading to the Vingunguti dumpsite (there was no categorisation, separation or exclusion for hazardous materials and substances), potentially polluting the bordering Msimbazi River.

Peri-urban mangroves acting as second stage biofilters are emblematic of the lack of urban sewage processing and pose potential human and environmental consequences (Crona et al. 2000). This societal and ecological impacts study examined four locations across Kenya, Tanzania and Mozambique and contributed important baseline data for societal risk perception and vulnerabilities of communities using sewage-impacted mangroves. It discussed the need for low cost, natural sewage treatment technologies in Dar es Salaam, (although not at the cost of societies in the vicinity) and identified and collected perceptions via surveys from the actors dependent on, and vulnerable to such environments. Survey results indicated that the majority of respondents noticed pollution, however the definition

and degree varied significantly by across location and gender. The study found social roles – such as women's focus on the family and home – may have influenced influence perceptions: women perceived risk of sewage primarily in terms of bacteria and disease, whereas men perceived it in terms of garbage and saw little personal risk from exposure. Interestingly, the authors considered links between awareness, risk perception and consequent behaviour: "if an individual is not aware of the consequences of sewage exposure, he or she will be relatively more vulnerable than a similar respondent who is aware of potential effects" (Crona et al. 2000: 236).

The coastal resources of Tanzania may be assessed through the lens of sustainable use for the people who use the natural resources. Francis & Bryceson (2001) described the ecological sustainability of resources such as coral reefs, mangroves, fish stocks, seagrass beds, beaches and endangered species and discussed questions pertaining to their sustainable use through ecosystem dynamics, socio-economic processes, institutional structures, policy implications and integrated coastal management. The authors also examined the interplay between the concepts of conserving an environment, versus people's needs and livelihoods that rely on natural resources and found that revisions in management strategies were necessary.

A socio-cultural and socio-economic study of sanitation conditions in Dar es Salaam (Chaggu et al. 2002) showed that low income significantly inhibited adequate investment into sanitation facilities. Respondents also lacked hygiene education, as more than half usually bathed in the same location as the pit-latrine, and additionally half of the respondents were unaware of the recycling potential of sludge. Interestingly the authors noted, after the City Council decentralisation into three separate Municipalities, "the clear line of operations and working interrelationships between the municipalities and the council are yet to be smoothed out" (2002: 617) in relation to wastewater management. They concluded that sanitation in Dar es Salaam should be managed in an integrated manner so as improve whole areas as opposed to just sections.

A comprehensive review of water quality and pollution studies in Tanzania discussed the expanding coastal population and industrial activities then exerting pressure on water quality and marine environments (Mohammed 2002). Its author evaluated numerous studies that span primarily Dar es Salaam, Zanzibar and Tanga's sewerage systems, and concluded that geographic coverage of studies was lacking in these regions, and that few studies investigated

the impacts of pollutants on the natural or social environments as most placed attention on pollution loads. It proposed development of at least primary wastewater treatment facilities for urban areas to ensure sustainability of the coastal zone and identified promotion of public awareness as the "key to effective management of pollution" (2002: 619).

Dar es Salaam experienced urban planning governance changes in the 1990s with the initiation of the SDP (Mtani 2004). The SDP examined degraded environmental conditions with consultation and the participation of 350 diverse stakeholders, and was intended to strengthen the city council's capacity to plan and manage growth and development, and prepare a long-term dynamic, strategic urban development plan and investment strategy. With support from UN-HABITAT and UNDP funding, numerous action plans were implemented and changes occurred in political attitudes towards citizen participation and contribution: "citizens became protectors of the environment and resources" (2004: 306). This period of environmental awareness instigated the preparation of the Environmental Management Act 2004.

Three years later, NEMC commissioned a consultancy report on the pollution situation of Mikocheni B's stormwater drains (Kayombo 2007); particularly relevant as the study zone resembled one of my own research sites. This detailed study addressed the pollution of a small stream (Nyirenda River) being utilised as an informal drain, by stormwater, grey and black wastewater, industrial effluent, sewage and solid waste from Mikocheni B light industries, residential houses and DAWASCO-owned wastewater trucks. The study noted malpractices such as property owners fencing and destabilising stream banks, thereby impeding the drain's flow and carrying capacity. Such practices exacerbated the chronic impacts of rainy season flooding and produced severe public health risks including strong smells year-round, mosquito breeding, dangers to children playing around the drain and to catchment area crops and animals. The report noted DAWASA water supply pipes suspended in industrial effluents, threatening water supply contamination with industrial chemicals, and the general inadequacy of the constructed drain. Uniquely, the consultancy put forward recommendations for participatory resolution to redesign the drain through actor involvement and contribution, necessitating communication, joint management responsibility and trust by all groups.

Studies assessing microbiological quality of coastal Dar es Salaam waters indicated human health risks in marine waters, as reflected in pollution load.

In two contrasting urban mangrove locations, faecal bacteria indicators and nutrient concentrations showed contamination levels were higher in the mangrove located closer to human settlements and consequently exposed to more anthropogenic influences (Lyimo & Abbu 2007). This article additionally discussed the bioaccumulation of sewage in marine organisms and their ensuing potential to infect humans and, in addition, the risk faecal bacteria posed to water and mangrove users. Heavy metal pollution of mangroves has also been found to be a serious problem in Dar es Salaam (UNEP et al. 2009).

Specific examination of Dar es Salaam coastal bathing waters showed significant positive correlations between microbial indicators and nutrient concentrations, with particularly high levels recorded during rainy seasons (Lyimo 2009). The four sites assessed in this 12-month longitudinal study were chosen for their known recreational use, especially bathing: Ocean Road, Oyster Bay, Kunduchi and Mbweni. Four indicators were utilised: total coliform, faecal coliform, enterococci and Clostridium per-fringens.

A 2009 collaborative status of pollution report supported the expectation that microbial contamination in Dar es Salaam would intensify in future years, creating great socio-economic risk "unless the different sectors that contribute to the problem take measures to address it" (UNEP et al. 2009: 14). The report found that suspended solids such as municipal and industrial wastewater discharges posed high risks to the marine environment, and socio-economic consequences would affect all areas of society. It listed critical impacts to marine ecosystems: "smothering of benthic biota, clogging of gills and feeding apparatus of marine organisms; chronic and acute effects on marine biota; modification of marine biota species composition; discolouration of coastal waters" (UNEP et al. 2009: 15). Its authors observed a lack of political will for improvement of pollution in Tanzania.

A second collaborative report was published in 2009. The challenges for effective municipal wastewater management in the WIO region have been attributed to the drastic urbanisation that has occurred without commensurate improvement in waste management infrastructures: "municipal wastewater development is lagging behind water supply development" (UNEP & WIOMSA 2009: 33). Moreover, sewage systems either discharged "wastewater to poorly working treatment plants or directly to the ocean" (2009: 22). Only 3% of Dar es Salaam's coastal population was served by the central system, while 81% used pit latrines emptied by

tankers or replacement pits dug. Findings showed a high quantity of wastewater discharged through septic tanks and a lack of infrastructure so that industrial effluent was discharged untreated or partially treated into rivers and ultimately the ocean. Furthermore, the lack of road access in densely populated unplanned areas resulted in sewage tankers being unable to extract wastewater. Specific problems were listed in relation to Dar es Salaam's nine waste stabilisation ponds.

1.3 Aim of Study

This study hopes to contribute towards a better understanding of the impacts of the current sewage and wastewater situation in Msasani Bay, Dar es Salaam, by offering a social-ecological perspective to the body of research that emphasises ecological and microbiological factors. It is the purpose of this thesis to investigate these impacts for the actors that live and work in coastal Dar es Salaam, and to examine their social-ecological linkages in terms of vulnerability and resilience.

1.3.1 Research Questions & Objectives

Central Research Question: *What are the impacts of sewage and wastewater discharges on coastal ecosystems and communities in Dar es Salaam?*

To address this central question, my research objectives were to investigate six key questions:

1. *What is known about the ecological and social impacts of sewage discharge into Msasani Bay?*
2. *Who are affected by the discharges, and who are the "winners" and "losers"?*
3. *What are the reasons sewage is discharged in its current locations and untreated state?*
4. *Are there leakages before the effluent reaches outlets at the ocean and if so, what are the impacts of these premature leakages?*
5. *What are the future wastewater management plans for Dar es Salaam?*
6. *What role do institutions play?*

1.4 Conceptual Framework

"Conceptual frameworks are neither models nor theories. Models describe how things work, whereas theories explain phenomena. Conceptual frameworks do neither; rather they help to think about phenomena, to order material, revealing patterns – and pattern recognition typically leads to models and theories" (Rapoport 1985, in Berkes & Folke 1998: 15).

This study will structure its analytical approach within the conceptual frameworks of Resilience and Vulnerability.

1.4.1 Resilience

Urban environments are undergoing unprecedented changes driven for the most part by human activities. These changes feedback from ecosystems to humans (social systems) and challenge the functional integrity on which modern life has been based upon (Chapin et al. 2009). Globalisation has brought vast cultural, economic and ecological modifications to the planet's life-support system (Odum 1989). In order to manage the natural resources we depend upon, a dynamic, flexible approach that enables analysis of disturbances and management of the interactions between community and ecosystem must be adopted (Chapin et al. 2009). In this thesis I have adopted the concept of social-ecological resilience (Berkes & Folke 1998; Berkes et al. 2003; Folke 2006; Folke et al., 2010) to help identify and elucidate the linkages of social and ecological impacts of sewage and wastewater discharges in Msasani Bay, Dar es Salaam.

The concept of resilience has evolved considerably since it emerged from ecology in Holling's (1973) influential paper (Walker et al. 2004) and is now synonymous with discussing Social-Ecological Systems (SESs); the artificial and arbitrary delineation (Berkes & Folke 1998) has been removed. "A social-ecological system consists of physical components, including soil, water, and rocks; organisms (plants, microbes, and animals – including people); and the products of human activities, such as food, money, credit, computers, buildings, and pollution" (Chapin et al. 2009). The definition of resilience used throughout this study is, the ability of a system to absorb disturbances and reorganise while undergoing change and still maintain its core functions, structure and feedback systems (Holling 1973 & 1986; Anderies et al. 2012; Walker et al. 2004).

I will assess the social-ecological dynamics of sewage and wastewater impacts via the

espoused principles and themes of resilience thinking: diversity and disturbances, stability and change, complexity, thresholds, uncertainties, ecosystem dynamics and social dimensions, learning and participation, institutional aspects and the possibilities for promoting polycentric governance (Simonsen et al. 2014).

Due to the path dependence, non-linearity and complexity of systems, a reduction in resilience increases the system's vulnerability to previously manageable minor disturbances, and can incrementally alter conditions so that a critical threshold is surpassed, triggering a rapid system release (Resilience Alliance 2002). This thesis will evaluate the role of water pollution in eroding the SESs resilience.

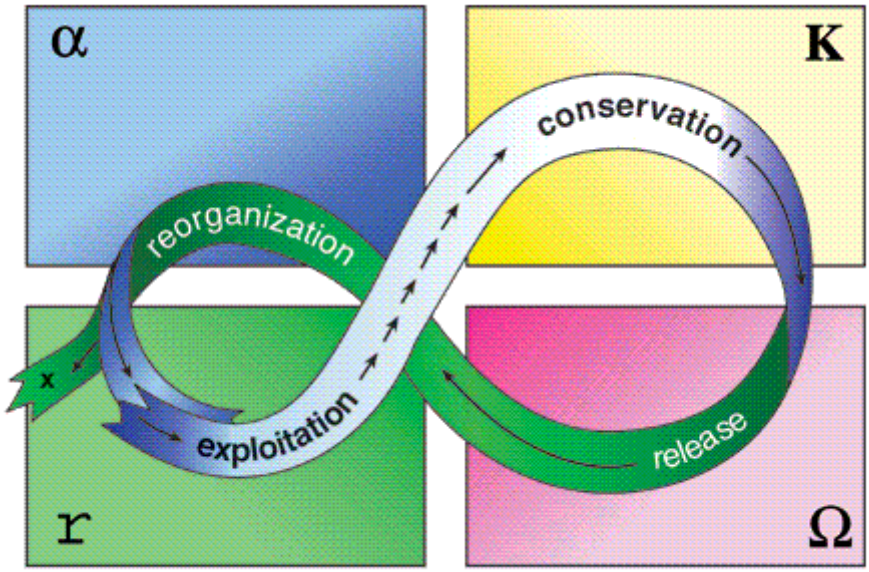


Figure 4. The Adaptive Cycle (Source: Resilience Alliance 2010)
The cycle illustrates the flow of events between four ecosystem functions (r, K, Ω, α). Arrows indicate the cycles' flow speed; short arrows represent slow change while long arrows represent rapid change. The vertical axis represents the degree of capital accumulation, from little to lots, and the horizontal axis represents the degree of organisation and connectedness, from low to high and weak to strong. The exit, or x, represents the potential that can leak out and flip into a new, less productive system (Holling 1986; Gunderson & Holling 2002).

The Adaptive Cycle is a heuristic model that visually presents the four phases of a system's functions: exploitation, conservation, release and reorganisation (Berkes et al. 2003). "The way that the components of the system interact causes the system to go through cycles in which the connections between its components tighten, loosen, and even break apart" (Walker & Salt 2012: 11). The first two phases (r and K) are named the foreloop and the last two (Ω and α) are the named the backloop (Berkes et al. 2003, Walker & Salt 2006). The start of the foreloop, the exploitation or growth phase sees rapid expansion by pioneers tolerant to high

variability. Whereas the shift from exploitation to conservation occurs slowly, building connectedness, organisation and accumulating capital. However, this increased rigidity lowers stability (Allen & Star 1982, in Holling 1986). Accordingly, the system quickly flips to the backloop, the release and reorganisation phase, characterised by destruction, the loss of tight organisation, opportunity, innovation, restructuring and renewal (Folke 2006, Berkes et al. 2003).

1.4.2 Vulnerability

The concept of vulnerability complements resilience thinking in the assessment of SESs and the impacts of sewage and wastewater pollution. "Vulnerability is influenced by the build up or erosion of the elements of social-ecological resilience" (Adger 2006: 269).

This study defined vulnerability as,

> "the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (an extreme natural event or process). It involves a combination of factors that determine the degree to which someone's life, livelihood, property and other assets are put at risk by a discrete and identifiable event (or series or 'cascade' of such events) in nature and in society" (Wisner et al. 2003: 11).

Moreover, "vulnerability can be measured in terms of the damage to future livelihoods, and not just as what happens to life and property at the time of the hazard event" (Wisner et al. 2003: 12).

Hazards affect populations differently: people of low economic status, the aged, and children are typically more prone to hazard-related damage, loss and suffering than other societal groups (Wisner et al. 2003). Turner et al. explain that social groups "have different coping capacities, which enable them to respond to the registered harm as well as to avert the potential harm of a hazard" (2003: 2). Furthermore, the responses of ecological and social systems to a perturbation feed back and influence one another, thus affecting the other's ability to cope (Turner et al. 2003).

A useful tool for analysis of vulnerability is the Pressure and Release (PAR) model (Wisner et al. 2003). The model shows the three compounding processes of vulnerability on the left side (root causes, dynamic pressures and unsafe conditions) and the hazard event on the right; the effect of thus pressure is released via disaster (Wisner et al. 2003). Figure 5 displays the model that will in part be used to guide my study.

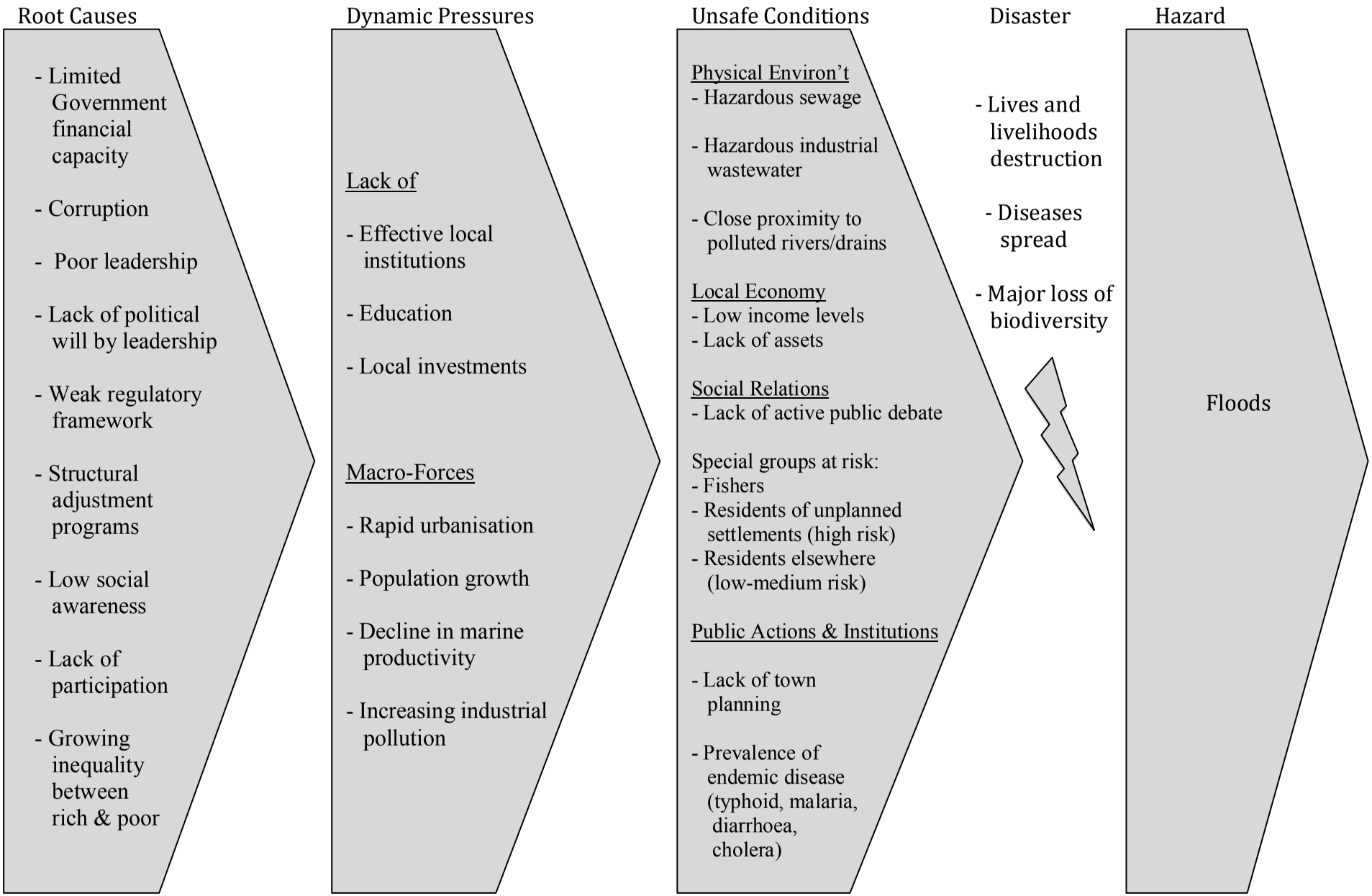


Figure 5. Pressure-and-Release (PAR) Model: the Progression of Vulnerability. (Adapted from Wisner et al. 2003)

2. RESEARCH METHODS

2.1 Study Area

The fieldwork sites were located in Mikocheni and Msasani wards adjacent to the western coastline of Msasani Bay, within the district of Kinondoni. Msasani Bay is located approximately 7 km north of Dar es Salaam city centre. Mikocheni ward is divided into the three sub-wards of Mikocheni A, Mikocheni B and Regent Estate. The ward extends between Old Bagamoyo Road (Mwai Kibaki Road) and Bagamoyo Road, from Mlalakuwa River in the north to Mwanamyamala ward in the south. The population of Mikocheni was 32,947 people and 8,231 households in 2012 (NBS 2012). The area includes planned and unplanned residential housing, the Mikocheni B light industrial area, a large private hospital, schools, Government offices, and few restaurants and bars. Msasani ward extends between Old Bagamoyo Road and the Msasani Bay coastline, from Mlalakuwa River in the north to Ilala ward in the south. The population of Msasani ward is 48,920 people and 12,542 households (NBS 2012). The area bordering Mikocheni and the bay comprises planned residential housing, shops, a private health clinic, small hotels and Government institutions. As the bay curves around to the northeast, the ward changes to an area named Masaki or the Peninsula, with luxury residential areas, hotels, numerous restaurants and bars, and shopping complexes.

Research sites were selected in consultation with my supervisor, NEMC, local Government officials, and by inspection of the area prior to commencement of research. After much consideration, the following sites were chosen for the representativeness of actors located therein and their particular location in relation to the haphazard sewage and wastewater discharges. Locations encompassed lower and higher income groups on both sides of the Kijitonyama River between Senga and Old Bagamoyo Roads in Mikocheni A; a 3.41 kilometre beach site stretching from Kawe in the north to Kijitonyama River mouth in the south of Msasani Bay; the Mikocheni B light industrial area; Sanitas Medics and Diagnostics, and Mwanamyamala Municipal Hospital (the Kinondoni district public hospital) (see Figure 7 below for specific locations).

Although Mikocheni A was considered to be a middle class urban area, low socio-economic, unplanned areas bordered the Kijitonyama River. The River's south-eastern (city centre side)

was informal in land tenure, substandard and densely populated. The settlements were characterised by narrow streets, children playing, women washing and cooking, economic activities, and beside them were the solid and liquid wastes that enveloped the Kijitonyama River. These un-serviced dwellings that backed on to the River (or in close proximity) are referred to as "low income houses" (see Figure 6). In contrast to this, the north-western side of the river encompassed large residences with formal title deeds, sizeable plots, tall fences or walls surrounding properties and typically security guards positioned on the front gate: these are referred to as "high income houses".

Figure 6. The waste stabilisation ponds and the contrasting "high income" and "low income" housing areas, narrowly separated by the Kijitonyama River

The expanse of beach in Msasani Bay from Kijitonyama River mouth to 3.41 km north was littered with solid waste including plastics, shoes, clothes, syringes, etc., amongst seaweed and seagrasses (Figure 7). In this expanse were four discharge points carrying polluted waters to the Bay: Kijitonyama, Nyirenda, Mlalakuwa and Kawe Rivers. A few recreational establishments such as bars and clubs were located along this segment of beach, with patrons typically bathing in the shallow water. Economic activities were practised along the beach, and fishers frequented between land and water with their vessels. Small-scale fishers in and around the bay used traditional equipment such as wooden boats (typically small vessels named *ngalawa* or *mtumbwi*) or old paddleboards, and seine nets (*juya*), basket traps (*dema*) and hand lines (*mshipi*).

Fishing activities have been practiced in Msasani Bay for centuries (Bryceson 1985, in Veland 2005; Hersoug 1986). The fishing village of Msasani was one of the original villages around which Dar es Salaam developed, historically said to have been an ancient Shirazi settlement (Hersoug 1986). The Bay comprised the fishing villages of Msasani, Kawe and Kunduchi, although communities had experienced strong pressure from encroaching hotels and housing developments. These lodgings brought challenges to access rights which, in the case of Msasani village, reduced fishers to a few with limited access to the waterfront or respect for their rights. Fisheries in Tanzania are open-access and therefore anyone can participate, which has seen migrant fishers travel to different areas in search of increased catch. "This movement locally known as *dago* is an important characteristic of many fisheries in Tanzania" (Jiddawi & Ohman 2002: 519).

The Mikocheni B light industrial area commenced accommodating businesses in the 1980s. At the time of research for this study in 2014, it was occupied by numerous industries, producing goods such as soap, plastic, tissue, steel, foam, paint, water and soda, flour and more. The area experienced high traffic of trucks and appeared to employ thousands of workers seen on-foot during opening, lunch and closing times. Streets were in poor condition, with broken pipes and in places, water flowing freely mid-road. Dirt footpaths were characterised by pipes, open connections and drains filled with stormwater and industrial wastewater, in addition to visible outflows from various industry plots. The area comprised industrial buildings that were largely old and worn, some with clouds of smoke emitting from chimneys.

Figure 7. Map of Water Sampling Points, Msasani Bay (Source: Google Earth 2015)

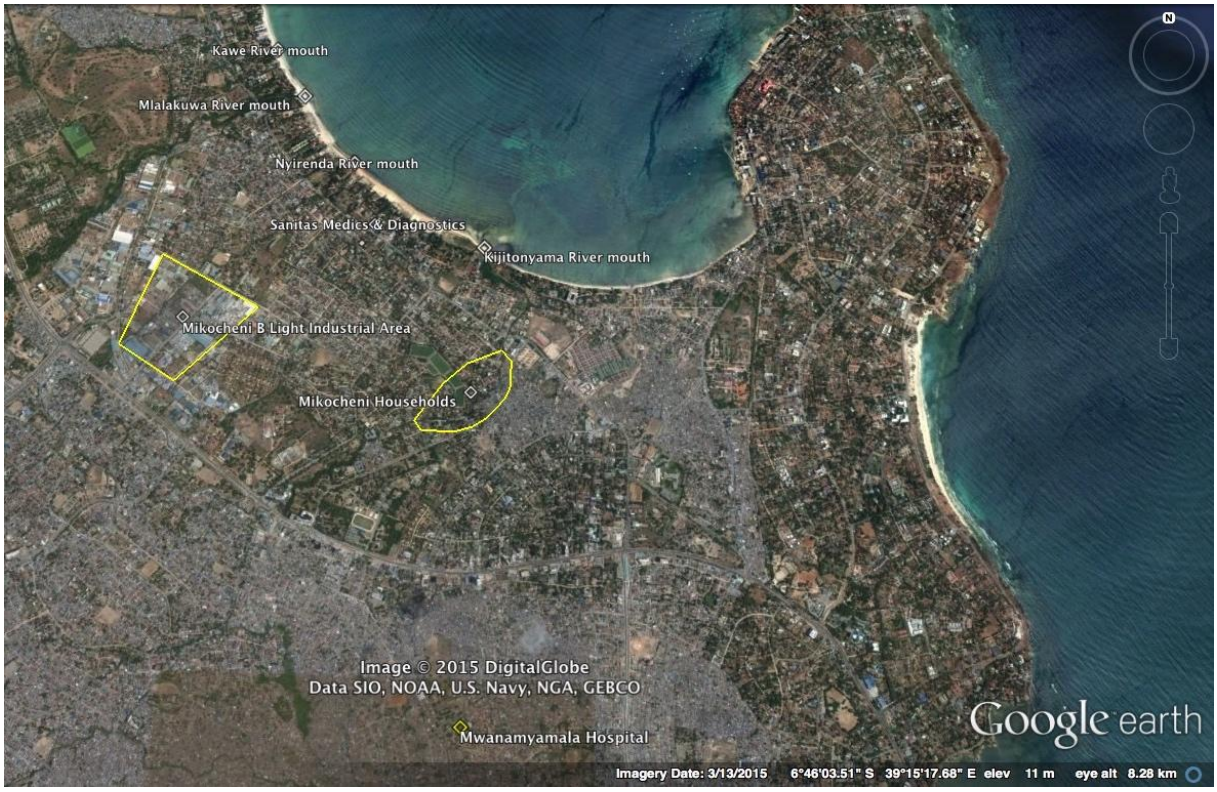


Figure 8. Map of Research Sites (Source: Google Earth 2015)

Figure 9. Magnified Map of Research Sites (Source: Google Earth 2015)

2.2 Research Design

This research study was based on a mixed method data collection approach. Mixed methods can be thought of as a study that incorporates both qualitative and quantitative methods alongside one another or mixed together (Bryman 2008). Three main reasons for this selection of methods include triangulation, offset and completeness. Triangulation essentially strengthens the validity of data collected by allowing it to be cross-checked against other techniques, thus enabling mutually illuminating results. This could also reduce potential interpretivism, which says that facts don't exist independently of subjective experience and are always interpreted. Offsetting allows the researcher to mitigate both methods' weaknesses and instead, through combination, draw on their strengths (Bryman 2008: 612). As the name suggests, completeness provides a more holistic and comprehensive account of the topic under analysis (Bryman 2008). I selected mixed methods on the basis of its potential to provide a better understanding of my research issue and aid in achieving my research objectives.

2.2.1 Data Collection

Fieldwork was conducted from 29 September until 7 November 2014, prefaced by an initial site visit in July 2014. The first week was spent in the planning phase, obtaining research permits, contacting and consulting with University of Dar es Salaam academics, identifying potential translators, and writing interview question guides for the various actor groups. The subsequent five weeks were spent interviewing actors, with a brief intermission of four days to collect water samples for conducting *Escherichia coli* (*E. coli*), Total Coliform (TC) and Phosphorus (P) tests.

In order to conduct the fieldwork, research permits from two wards were required. I gained permits from the Regional Commissioner's Office (Dar es Salaam level), the District Commissioner's Offices (Kinondoni level) in Msasani and Mikocheni wards, in addition to a fourth permit from the Municipal Medical Officer of Health at Kinondoni Municipal Council.

2.2.2 Qualitative Sampling

Non-probability sampling was undertaken for the principal reason that a full list of actor populations for this study would have been impractical and unfeasible, as will be highlighted

in the section following. A combination of three sampling methods was used for this study; purposive, snowball and convenience. Purposive sampling aims to ensure that subjects with certain attributes are targeted and included in the study at hand, whereas snowball sampling entails identifying and interviewing individuals with relevant characteristics and then asking for referrals of other persons with pertinent characteristics (Berg & Lune 2012). These two sampling techniques were expected to be the principal methods of investigation, however there were daily circumstances that arose with respect to the various actor groups that required the option of a more easily accessible respondent. Additionally, there was a point at which it would not have been possible to obtain the desired number of respondents within some of the actor groups given the time frame of the study. Convenience sampling was therefore similarly deemed an appropriate method by virtue of accessibility and time available.

2.2.3 Interviews

Interviews were selected as the most appropriate technique for the qualitative data collection so as to receive data-rich accounts from actors about the situation and their personal opinions on topics pertinent to my research objectives. I identified five relevant actor groups as: households of both upper and lower income groups, fishers (of typically economic status), public and private health clinics, industries located in the Mikocheni B light industrial area, and Government organisations, specifically the NEMC, Dar es Salaam Water and Sewerage Authority (DAWASA) and the Ministry of Water. The actors were located in different parts of the study area but all in close proximity to the Bay and purposely selected for the role they play or stake they hold. I considered they could all hold interesting perspectives and insights into my topic, and thought there would be observable winners and losers amongst them in relation to the social and ecological impacts of the discharges into Msasani Bay.

To prepare for the interviews six separate interview guides were created and tailored to each actor group: households, fishers, health clinics, industry, NEMC and DAWASA. Semi-structured interviews can create an informal environment designed to facilitate a candid response and allow the interviewer freedom to digress, without the interview becoming too lengthy or restricting, as can other structures (Berg & Lune 2012). The interview with the Ministry of Water was more informal as opposed to the other actors as I was unsure of their role in my study and hoped for a more conversation-style interview to obtain general information. I originally drafted the interview guides in July, however after having spent

more time in the country and a deeper insight into Tanzanian people, I revisited and edited the majority of guides prior to fieldwork commencing.

Two pre-test household interviews were conducted on day one to assess the usefulness and relevancy of questions. As there were similarities between all guides, I deemed it necessary to use these two pilot interviews as a tool to refine the other actor interview guides. The finalised guides appear as Appendix 3 of this thesis. Interview questions for the majority of households and fishers were asked in English and then translated into Swahili and then relayed back via my translator from Swahili to English. I made the decision to audio record all interviews to the extent possible where permission was obtained. If a respondent was speaking particularly quickly, my translator and I could then together talk through the interview either directly afterwards to adjust my notes or add a specific detail, or at a later time transcribe the whole interview. Audio recording reduced my reliance on note taking and allowed me to focus on observing the respondent. It also provided the opportunity for my translator and I to re-examine the audio recording of key interviews for missed information. My translator was with me for all household and fisher interviews, in addition to all-but-one industry interviews. His role was particularly important for the interviews with higher income households and industries because it would be impossible to communicate with potential respondents or a receptionist without his ability to speak Swahili and converse with the security guards posted on the front gate. Interviews with health clinics and Government organisations were conducted in English without my translator present as English was prevalent. I interviewed households, fishers and industries simultaneously over a two-week period so as to relate them to one another.

2.2.4 Water Sampling

Representing the quantitative methods in this study, water samples were collected to observe the nutrient P and faecal coliform counts of *E. coli* and TC. These three measurements were sampled to assess the discharges into and within Msasani Bay. It was considered necessary to do this to advance my core research question relating to the social and ecological impacts of these discharges.

On 25 October 2014, my supervisor, Ian Bryceson assisted me in taking pre-tests for faecal indicator bacteria of *E. coli* and TC at the following six locations: directly in front of a *dago* site (seasonal fishers), Kijitonyama River mouth and 200, 400, 600 and 800 meters along the

beach from the stream mouth. Subsequently on 27 October, 40 water samples were collected, consecutively (2 samples x 20 points) distributed at 200 metre points along the Msasani Bay beach for 3.41 kilometres commencing at Kawe and calculated to finish specifically at Kijitonyama River mouth. We also sampled water located at the stream mouth at Kawe River and the visibly polluted Nyirenda (industrial wastewater stream). It is important to include locations that "yield samples representative of the conditions at the most unfavourable sources or places…particularly points of possible contamination" (WHO 1997: 52). I aimed to achieve both favourable and unfavourable source locations by including these two streams in addition to Kijitonyama River, which was considered the most visibly contaminated sample point.

There were also four supplementary locations with two samples taken at each point in the space of one week, providing 24 sampling points: Mbudya Island, White Sands Resort, Mlalakuwa River mouth, and one kilometre offshore (directly straight from the 400 m point from Kijitonyama River) in Msasani Bay. The Bay is well known for its recreational and labour use, including bathing and fishing amongst other activities. The supplementary sampling sites were therefore selected to ensure a representative cross-section of the range of activities and such various discharges for comparative purposes. This sampling method can be described as purposive.

Water samples for *E. coli* and Total Coliform were taken in 1 ml plastic syringes and samples for P were taken in 7 ml uniform glass bottles. Taking into account the 4.2 m tidal amplitude of Msasani Bay, I collected the samples at low tide. For each sample, I methodically walked slowly into the water to approximately knee-height, extended my reach and submerged the sterile glass bottle 20 to 30 cm. While holding it underwater, I flushed the bottle twice, let it fill again and then capped it. Repeating the same procedure, I next held the syringe at the same depth, filled and emptied it twice, before taking the final sample.

Salinity was analysed by placing a few drops of the water sample onto the glass surface of the portable refractometer, holding it to the light and then noting the intensity level. This process was repeated for the 20 samples. A high range handheld colorimeter was used to measure the concentrations of P in the 20 samples of seawater. The size of glass bottles used to collect samples was insufficient to fill the 10 ml test tube (7 ml). The way I compensated for the missing 3 ml was to dilute samples with the addition of distilled water and then multiply the

result to obtain the representative ppm (mg/L). 3M Petrifilm *E. coli*/Coliform Count Plates were used for *E. coli* and TC counts (Figure 10), whereby the syringe sample is aseptically inoculated directly onto the Petrifilm with no additional materials necessary. This method provided independence from access to a laboratory, relatively reduced the cost, and provided simplicity of use and storage. Syringe samples were processed within three to four hours of the first being collected, while the bottles for P analysis were refrigerated. The Petrifilm was then stored at room temperature (between 30 and 32C) to maximise bacteria growth, for approximately 48 hours before I recorded the colony counts of *E. coli* and TC and individually photographed them. When analysing samples with a high number of colonies, TC was counted by summing the number in each Petrifilm square and then multiplying this number by 20 to calculate the colony forming unit (CFU) per 1 ml, as recommended by the product's manufacturer. Additionally, each Petrifilm was calculated at least twice for greater accuracy.

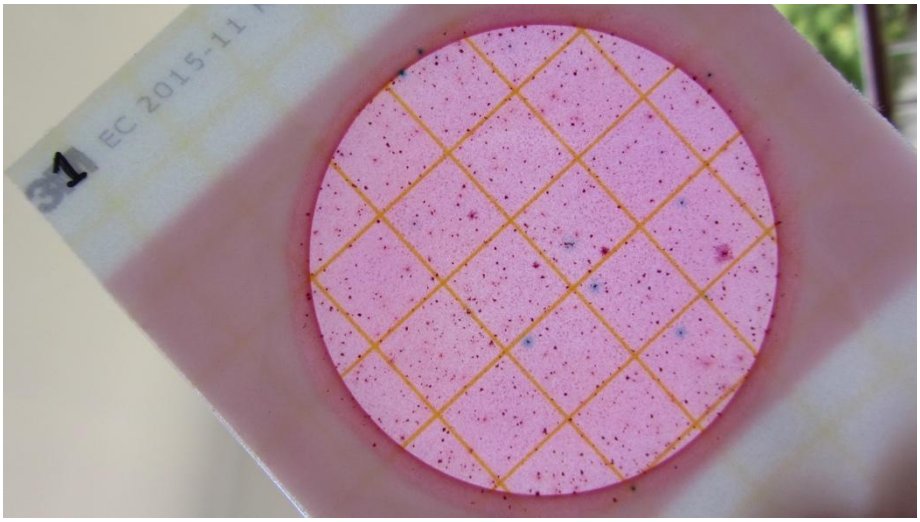


Figure 10. Petrifilm with E. coli and Total Coliform Indicators (Source: Wilson 2014)

2.3 Ethical Considerations and Limitations

2.3.1 Interviews

Before conducting interviews, I believed my topic to be of low sensitivity and thus expected respondents to have little-to-no hesitation in agreeing to interviews and audio recordings and in fact wanting to express their opinion on the subject. However, what I experienced throughout interviews was that some informants were guarded about their responses, as they feared the data they had provided would be given to the authorities. My translator aided in re-

conveying the purpose of my study and in assuring respondents that all data was confidential and that their anonymity would be preserved. Despite this, numerous respondents did request not to be audio recorded. Many respondents also requested an electronic copy of my final thesis upon completion.

Non-probability data can be categorised as data with low external validity, that is the study's ability to be generalised to the greater population. I believed the external validity of this study and, the usefulness of its findings, would be enhanced by encompassing mixed methods of analysis, using five distinct sources of information, and offering a more comprehensive picture by considering different perspectives heard. Additionally I strived to maximise trustworthiness of respondents' answers by engaging these different actor groups, thus cross-checking responses to similar questions, and by explaining to participants to the best of my ability the nature of my research interests.

Language constituted a challenge during my study as it somewhat constrained communication with both interview respondents and other people one interacts with when trying to obtain information or access (eg. Government officers and residential security guards). I was entirely reliant on my translator to bridge the gap between non-English speakers and myself as a non-Swahili speaker. This was a novel experience for me and at first I found it frustrating not being able to understand everything that was being said. Fortunately after the first few days I felt that my translator was effectively conveying my questions to respondents and translating their responses in the context of the purpose of my study. It was evident that he listened to me and did not try to re-interpret the participants' responses in terms of what he thought was interesting or more relevant for my study. After the two-week period with my translator, I attended Government offices, hospitals and most industry interviews alone. These visits did feature language difficulties but with persistence it was possible to generally accomplish what I had hoped for in this short six-week study.

In the case I had had extra time, it could have yielded additional interviews with other Government organisations and perhaps even relevant Non-Governmental Organisations (NGOs). In particular, I found Government organisations difficult to contact, and moreover, to obtain the information I sought. I also could have persisted with further health clinics. In the first week with my translator we requested an interview with TMJ Hospital, a private hospital in Mikocheni. However, much to our dismay we were advised by a manager that my

topic had nothing to do with health and that I should speak to Government, as it would be a waste of the hospital's time to talk to me. As an alternative I contacted a colleague at the Muhimbili National Hospital but she advised me that they deal primarily with high-level cases; all of the everyday cases go to the municipal hospital. As I was principally researching everyday cases such as water-borne diseases, this left me with two remaining clinics in the area: Sanitas Medics and Diagnostics, and Mwanamyamala Municipal Hospital.

2.3.2 Water Sampling

This study adhered to ethical guidelines by observing sampling procedures listed in the World Health Organisation's 'Monitoring Bathing Waters – A Practical Guide to the Design and Implementation of Assessments and Monitoring Programmes' (2000). In terms of limitations of the water sampling methods, the microbial indicator *E. coli* may be considered unsuitable for the study site given that tropical marine water typically has a high level of solar radiation and seawater salinity can accelerate die-off of *E. coli* (WHO 2000). However, studies have shown (WHO 2000) that over the course of a day, accumulation of faecal material can occur despite solar die-off, and can even increase in the water body of a bay.

3. RESULTS

3.1 Interviews

A total of 51 interviews were conducted including two trial interviews with households. My initial aim was to target five main actor groups (households, fishers, industries, health clinics and institutions), but after preliminary investigations of my research area I came across schools, a motel and offices, and so decided to include these in the study also.

Low Income Households	Higher Income Households	Fishers	Industries	Health Clinics	Schools	Motel	Offices	Institutions
17	10	8	4	2	3	1	2	2

Table 1. Actor Groups and Number of Interviews

The data collected encompassed a broad range of issues and a wide range of data was collected. In order to logically present the data, it was categorised into seven topics and sub-divided further where necessary. These were:

- Actor Characteristics
- Current Systems, Preferences & Affordability
- Flooding & Town Planning
- Water-Borne Diseases & Other Illnesses
- Education
- Perceptions of Msasani's Change Over Time
- Perceptions of Policy, Sewage & Wastewater Systems

3.1.1 Actor Characteristics: Households, Fishers and Industries

Characteristics were gathered from 27 households as displayed in Appendix 1. Five measures were taken to establish basic demographic information about respondents: age, gender, length of time in current home, number of people living in the home permanently, and whether the home's residents were tenants or owners. The average age of low income households interviewed was 30 years and a spread of gender represented by 53% female and 47% male. In contrast, high income respondents typically represented an older demographic group with a mean of 51 years. 70% of high income households owned their own home compared to just 35% of low income respondents. Family sizes were larger in low income respondents, however the mean of seven was not an illustrative measure in this case, due to extreme data.

The median of five was a more representative gauge, as was the median of four for high income households. Both low and high income households contributed data at each end of the scale for how long the family had lived in their current home; these extreme values produced averages of around 10 years respectively.

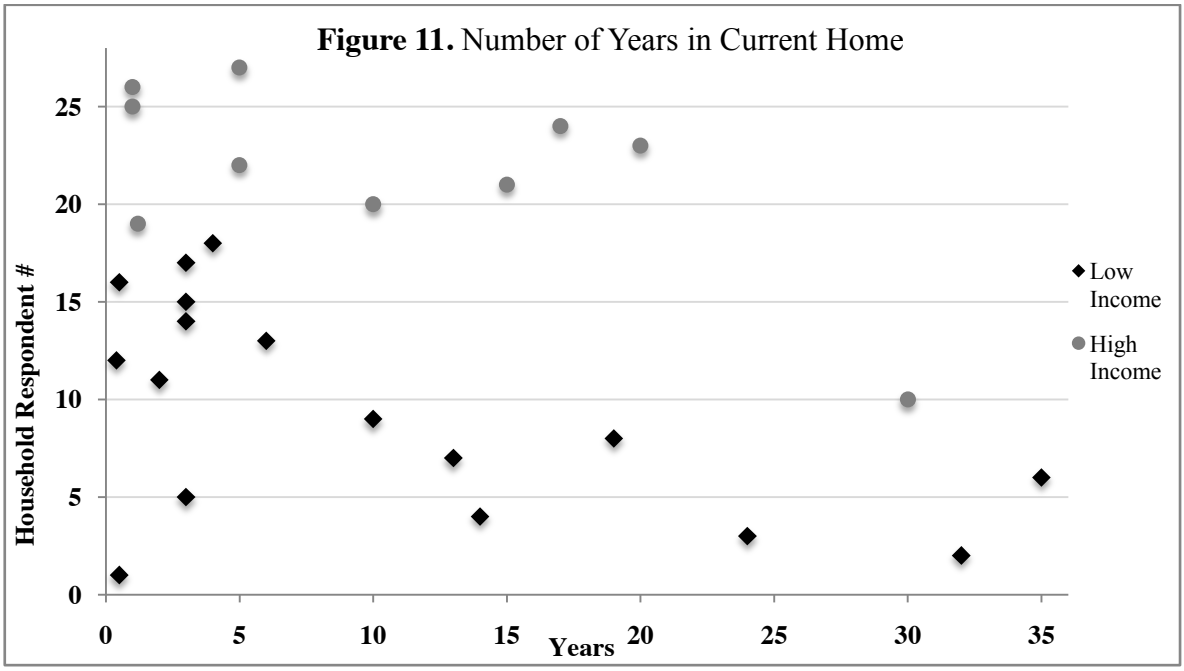


Figure 11. Number of Years in Current Home

Just three demographic measures were utilised when interviewing fishers: age, gender and the number of years fishers had spent fishing in the Msasani area. All fishers interviewed were male, with an average age of 45 years and they had been fishing in the area for 15 years although the scale ranged from 3 to 46 years.

The periods of operation for the four industries interviewed were 32, 19, 14 and 12 years in the Mikocheni B light industrial area.

3.1.2 Current Systems, Preferences & Affordability

Three actor groups (households, industries and health clinics) were surveyed regarding their current sewage and wastewater system, their preferences or attitudes towards a centrally controlled system, and their perceived economic ability to connect to such a system. Individual actors generally expressed dissatisfaction with their wastewater situations and were sceptical as to whether funds were available at the Municipal level to change this. Details of their responses are separated into three sub-issues.

Current Sewage and Wastewater Systems

Households were divided into low and high income so as to facilitate comparison, contrast and parallels to be drawn between the two. Low-income households expressed three types of sewage systems: untreated disposal into stream, pit latrine, and septic tank. As Figure 12 shows, over half of these low income respondents utilised the stream for disposal, followed closely by a pit latrine, while just one household used a septic tank. High-income participants listed the addition of a fourth type of disposal system: the DAWASCO-operated stabilisation ponds. 50% used a septic tank to dispose of their blackwater, 40% used a pit latrine and just one household legally used the ponds for removal via the centrally operated system, with two respondents claiming illegal discharges to the ponds from a neighbouring school. The greywater system in all households was categorised into five types: black and greywater disposed of together, greywater disposed of outside (into the garden for example), into a soakaway pit, disposed of into the stream or directed to a separate tank. Equal numbers of high and low income households disposed of their greywater together with the blackwater, 41% of low-income households disposed of it outside, 18% of low-income and 11% of high-income households used a soakaway pit, 6% of low-income respondents used the stream and 22% of high-income respondents used a tank.

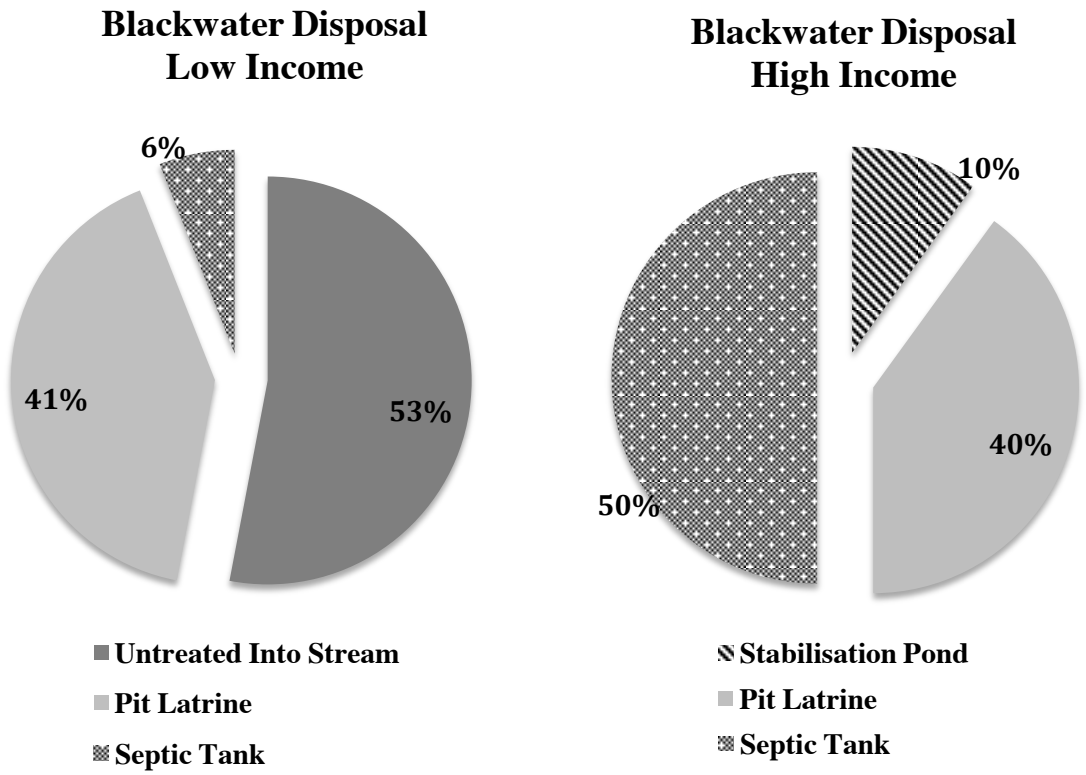


Figure 12. Blackwater Disposal Method Percentages

The sewer system received greywater, blackwater and industrial effluent discharges from industry, as there was no system for differentiation. Three out of four industries interviewed noted that their disposal of grey and blackwater occurred via the central system, operated by DAWASCO (directed to the waste stabilisation ponds). The fourth industry used separate grey and blackwater tanks and would call a '*maji taka*' lorry to empty these as need be. In reference to industrial wastewater systems, there were a variety of answers given. The first respondent stated that their company generated only grey and blackwater from general operations no wastewater from production. The second industry did not provide details of their industrial wastewater system, only stating that NEMC ensured they were fulfilling their requirements. The third respondent stated that onsite sanitation ponds were used to allow the oily wastewater rest and settle so that it could then be extracted, and also that they were upgrading their system to be "more environmentally friendly". The last industry provided a detailed account of their system: five settling ponds were used in combination with a dissolved air floatation unit for primary treatment. They disclosed that their efficiency (sludge reduction) was 10 - 12% but that they were upgrading to a flocculation unit that was due to arrive that month. The respondent said the new technology would not solve their compliance problems but that it would increase efficiency to 35 - 40% and reduce the quantity of sludge so that it would be more solid and easy to transport, reducing their management costs.

One industry went on to say that some companies, (for instance their neighbouring property) released what appeared to be untreated industrial effluents into the stormwater drains. The respondent suggested "NEMC should do more to help companies manage their industrial wastewater so that it's not the colour it is, as it has lumps, smells bad, is corrosive and kills plants that the water touches. Then it goes to the ocean". Another industry made a similar remark: "surrounding residents were concerned with the old stormwater drains flooding their properties, so the Government built large stormwater drains for the area. The drains are not for industrial effluent, but some of them [the industries] are using them for that".

A spokesperson from Mwanamyamala Hospital stated that there was no public sewage system in their area and that because of this they had pit latrines. These latrines were emptied every 3 - 5 days by hired private sector *maji taka* lorries. The respondent detailed that if for budgetary reasons cash was delayed and lorries could not be paid and thus hired, it could

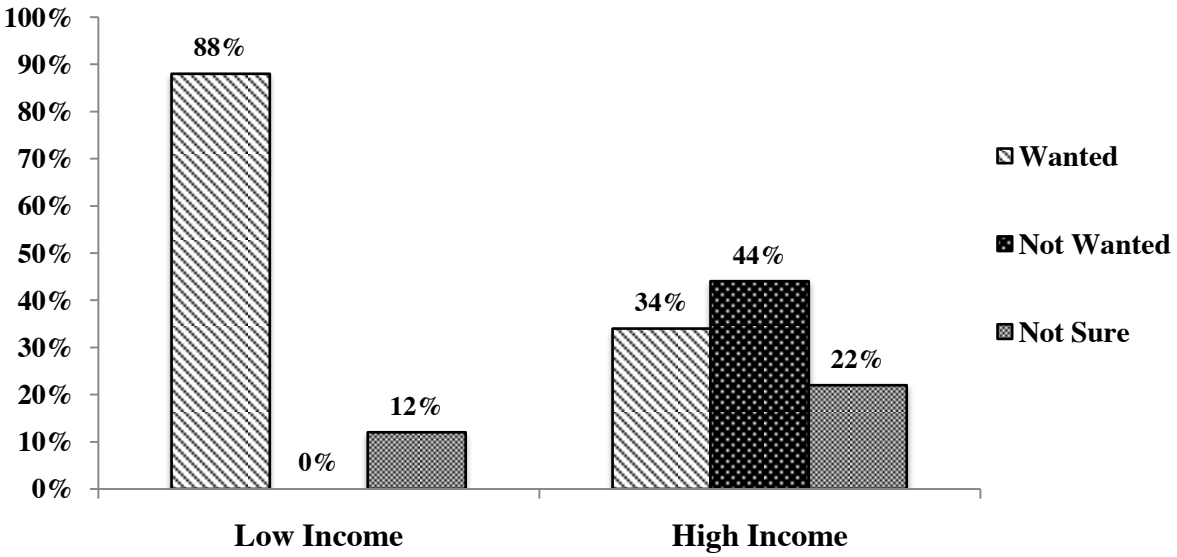
result in latrine overflows. The respondent also said that as there was no budget for treating dirty water, the premises had a soakaway pit for greywater.

DAWASA interview respondents stated that the treatment ponds in Mikocheni were being maintained properly by DAWASCO, but that the system wasn't receiving as much wastewater as it was designed for. Tankers (lorries) were supposed to pump their wastewater into the ponds, however this practice was shut down quickly after operations began in 2007 due to 'political problems'; people complaining about the smell. DAWASA also noted that in addition to wastes from properties connected to the central system, the ponds received industrial wastewater from companies. These industries were expected to comply with the effluent requirements, but inadequate pre-treatment by companies limited the ponds ability to perform their biological activities correctly. DAWASCO and NEMC managed the effluents and connections of such industries.

Attitudes Towards the Central Sewerage System

Households were asked if they would prefer to be connected to a centrally operated sewerage system instead of their current method (see Figure 13). The overwhelming answer (88%) amongst low-income respondents was that they would prefer a central system, in contrast to only 34% of high-income households. 44% of high-income households said they would not prefer it and 22% said they weren't sure. The reasons given for high-income household's non-preference were that they were satisfied with their current system (50% used a septic tank that maintained itself efficiently) or they doubted DAWASCO's ability to provide an effective central sewerage service.

Figure 13. Responses Regarding Central Sewerage System



Attitudes encountered from industry were generally negative towards the existing central sewer system. One respondent stated that Government should make further efforts to unclog the sewer system as it was frequently blocked. Another stated that they received no assistance from NEMC to meet their wastewater requirements and that compliance was difficult. A different industry stated that there were problems with sewage leaks on the road. The company's standard approach was to call DAWASCO instead of waiting for them to arrive, because they were typically "very slow". Another respondent gave a detailed account on the topic of industrial wastewater. "The 6 inch line that was built in the 1980s, everyone has connected to it since then. The volume is not enough. This line goes to the ponds. But the ponds aren't operational. People blame industry." This industry also outlined that Chinese funding was provided to build a new sewerage line, and that it was installed but it was not in use as Government did not have the facilities (and funds) to treat the wastewater that it would produce. Furthermore "a municipality officer and NEMC came to discuss connections for the area but nothing eventuated". The general opinion amongst industry respondents was that the current system was not maintained to the standards required, for example a respondent stated they were told to wait 60 to 70 days to have the sewer pipes unblocked.

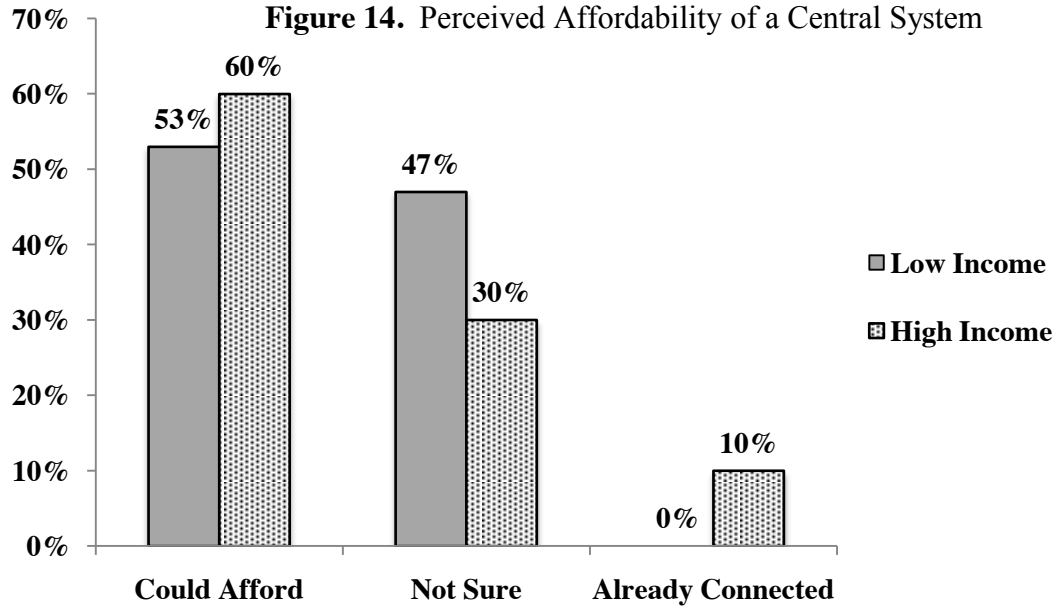
One health clinic respondent thought it would improve their establishment if connection to the public sewer were possible, while the other clinic did not directly express an opinion on the

topic, they did state that sewage water came up from the drains in their area and regularly "smelled awful".

Perceptions of Affordability

Perceptions of affordability between households differed between household types (Figure 14). 53% of low-income respondents said they could afford connection to a central system, whereas 47% were unsure of this due to their tenant status (as the landlord would bear the costs). 60% of high-income households answered they could afford it, with 30% stating they weren't sure of the costs involved and 10% were already connected. No participants answered they could not afford the connection altogether.

Figure 14. Perceived Affordability of a Central System



Industry respondents' perceptions of affordability were similar: meeting compliance standards of wastewater was costly. One industry forthrightly stated they had ordered a new unit worth USD$170,000 and had spent USD$200,000 over the last three years on achieving compliance, of which was around 92-93%. They went on to say:

> "The Government is not so harsh but that's because no industry will continue if they enforce their policies. If everyone contributes [financially and in actions] it is possible. But at the moment NEMC and consultants come and it's all just talk, nothing is done, we're yet to see any action on their behalf. People complain but Government knows the reality that industry is not prepared for compliance."

Another company stated it was costly to comply, but considered it an investment. "Yes it's becoming more tough, which is good. Initially it hurts to comply but then it's ok". When asked whether they would be able to comply without increasing prices if Government enforced current requirements, two industries said they could remain competitive, that it wouldn't affect their net earnings and that prices would remain the same.

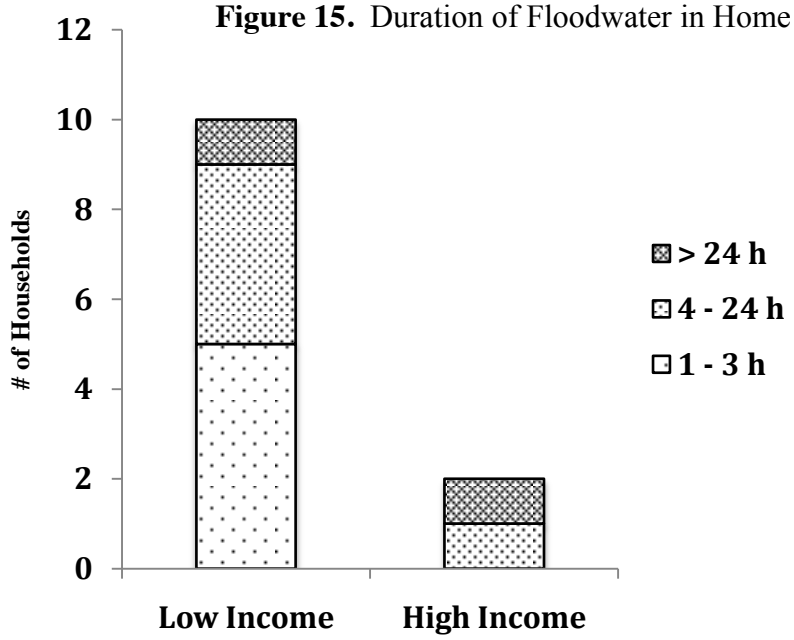
The Mwanamyamala spokesperson perceived the central system as being more expensive than their current system of private *maji taka* lorries and that converting to the public system was outside their limited budget. They believed that an onsite sewage and wastewater treatment system would be a better option for the hospital.

3.1.3 Flooding

In their responses, all actor groups across all interviews mentioned the issue of flooding to some degree.

Households were deemed to be the most significantly affected group and thus the group from which I collected the most data. Respondents were asked whether they ever had flooding in their present house and then follow-up questions accordingly if they answered 'yes', including the duration of the flooding and the frequency. If respondents answered 'no' to the first question, they were still asked about their perceptions as to whether they had had contact with any floodwaters and whether floodwaters impacted their family's health. 59% of low income households (10 households) experienced flooding in their house as opposed to just 20% (2 households) of high-income respondents. Out of the 59%, five experienced flooding for between one and three hours, four houses had floodwater for four hours to one day, and 10% for a whole week. Of the 20% of the high-income households who had floodwaters in their home, half had floodwaters for between four hours and one day and the other half for two days. Figure 15 numerically displays the duration of floodwaters in homes.

Figure 15. Duration of Floodwater in Home



90% of low-income respondents stated that flooding in their area occurred annually and 10% expressed it as a unique incident, whereas 20% of high-income respondents stated flooding was either an annual occurrence or as having happened just twice. Respondents that had experienced floodwaters in their homes stated they spent significant amounts of time removing the polluted water and the mud it brought. These respondents and others additionally stated there were indirect effects to families as flooding in their area caused sickness, significant losses in time spent avoiding waters, or that it prevented children attending school or adults reaching their workplaces. 82% of low-income households came into contact with floodwaters and almost all perceived flooding as affecting their family's health. Half of high-income households stated that they came into contact with floodwaters and 40% said they perceived it as having affected their family's health. 25% of fishers interviewed thought properties built over waterways created flooding and subsequent destruction in surrounding areas, as these waterways had not been redirected effectively.

The four industries interviewed responded that flooding had been an issue for them. Two out of four had experienced flooding onsite through what they described as the overflow of blocked stormwater drains. Two out of four stated previous trouble with access to their property during the rainy season, although apparently the problem had been partially solved by the Government constructing larger stormwater drains some years ago. Another stated their neighbour was the cause of blockages as they clogged the drains with their product's wastewater and viscous chemicals. When asked if this was still the case, the respondent said

the wastewater drain was now diverted so they are unaware as to whether it had improved. This industry also stated they subsequently used to experience flooding on their property for approximately two weeks. One respondent stated that as the current sewage pipeline was built decades ago the flow was not enough. Moreover, the sewage pipe overflowed from heavy rain and pipes became blocked with stones or oil. A different industry stated they managed their onsite stormwater by constructing drains three years ago.

Both health clinics interviewed stated that they had not experienced floods onsite, but that because of the poor infrastructure in the area, when it rained there were problems with sewage overflows in the street. Mwanamyamala Hospital stated they had these problems onsite too. Both clinics added that there were more diseases when there were floods, largely during the rainy season.

Town Planning

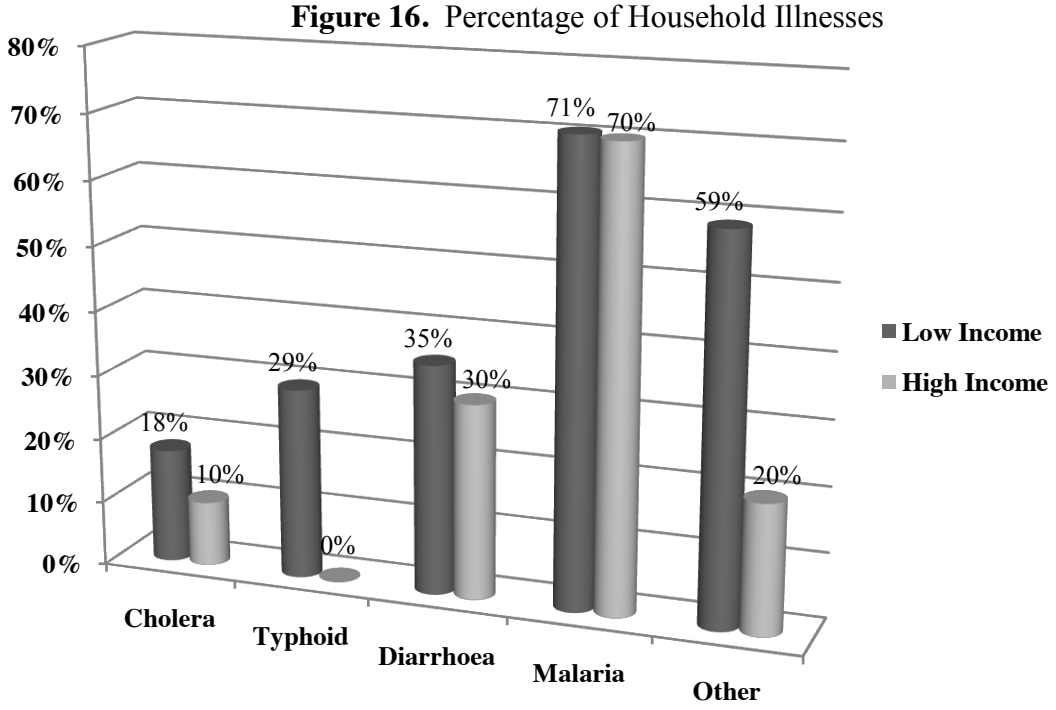
All actor groups discussed the issue of town planning. Fishers and DAWASA noted land use problems as the cause of flooding in Mikocheni. They explained that buildings were constructed with or without permits from the Municipal council that blocked stormwater drains and worsened flooding. Households noted a lack of planning for informal settlements that lived without services or road access, in close proximity to the highly contaminated Kijitonyama River. Most industries interviewed considered lack of planning as the cause of their problems. They mentioned poorly planned residential housing with no basic infrastructure, no central sewer and previously no drainage system nowadays surrounded the industrial area. Residents complained about smells, noises and stormwater from industries. Industry respondents stated that for safety reasons this area should never have included residential housing around the periphery. Several actor groups discussed the low-lying agricultural land in Mikocheni A/Regent Estate that was converted to a suburban area in the 1990s as a clear example of town planning issues. Respondents said the Municipality issued permits to build on the swamplands, interrupting the natural flow of water and effectively redesigning the area. This zone was considered by respondents to be one of the most flood-prone in the city in 2014.

3.1.4 Water-Borne Diseases & Other Illnesses

All households interviewed mentioned various forms of illnesses that occurred regularly. As displayed in Figure 16, water-borne diseases such as cholera and typhoid were identified

respectively as problematic in 18 and 29% of low-income households and 10 and 0% in high-income housing. Malaria was stated as common amongst both low and high-income households, in 70% of all responses. Diarrhoea was common amongst both household types, with approximately 32% of all respondents citing the illness. Skin fungus and other illnesses such as worms, stomach-ache, coughing, vomiting, influenza or fever were listed in almost one quarter of responses. Of 27 participants, around one third said they noticed an increase in sickness during the rainy season while over half said these sicknesses occurred all year round.

Figure 16. Percentage of Household Illnesses



More than half of fishers said they had experienced a health-related issue from what they explained as contact with the polluted streams or areas of dirty ocean water. Illnesses listed include skin fungus, skin diseases, mouth ulcers, rashes, and one fisher stated his skin peeled off when crossing through a particular stream (Kijitonyama).

A health clinic stated that during the rainy season there were more patients with infections and diseases and more sickness in general as opposed to the dry season. When it flooded there was an increase in patients with illness such as cholera, typhoid, malaria and diarrhoea. They also said that insects and mosquitos were worse during the rainy season. Moreover, "contact with contaminated water affects society in a lot of ways: economic, social and education. People can't go to work and they spend a lot to buy medicine, and time taken also. Sanitation is very, very important".

3.1.5 Education

100% of household respondents who were asked whether education would make a difference to the sewage and wastewater situation in Mikocheni believed it would make a difference. A significant number also described that there was no environmental education provided to them and that changing people's way of thinking could influence community involvement and improve their surrounding environments. One fisher also stated that education would be beneficial for protection and conservation in the area.

An industry representative commented similarly that environmental education was needed. The company described:

> "For example the benefits of protective gear. I tell them to wear a facemask and after 10 minutes they're hot and stuffy and they take it off. And then an auditor comes along and says these people aren't wearing a facemask or gumboots or whatever. The people don't really know it's for their safety, and they don't listen to us. If I were to start today I would say start with education of the people".

Health clinics also stated that education was important to prevent and control infectious diseases. Mwanamyamala spokesperson stated, sometimes patients had illnesses due to contact with floodwaters but sometimes people didn't know about the risks of contaminated water and illnesses could be prevented.

3.1.6 Perceptions of Msasani Bay

65% of respondents from household interviews stated they believed the waters of Msasani Bay to be unclean and unsafe for human contact. Although respondents said this was the case, one third admitted they used the beach for recreational activities such as swimming. Another 20% noted that they were wary of the contaminated water and therefore just used the beach for relaxing or a change of scenery without swimming in the water. Around half of households said that the indicators they used to identify the safety of the water were its colour, visible rubbish or the smell. 25% said they noticed changes in its waters during the rainy season, with a small percentage stating they were fearful of eating fish nowadays (I assumed this was because the fish could be contaminated from living in polluted waters).

Out of the eight fisher interviews conducted, there was a clear consensus of perceptions towards Msasani Bay, its streams and the ecology of the area. All fishers were of the opinion

that the water in the bay was polluted, dirty and unsafe. Causal factors given by respondents included the dumping of sewage and wastewater, rubbish and industrial chemicals from streams that entered the bay. They also stated that population increases in the area added to the pollution. All respondents stated that the bay's water changed at different times of the year and that the rainy season (typically March to June) was the most contaminated period. They attributed this to households and industries taking the opportunity to discard stored up rubbish, wastewaters or chemicals. The smell was described as unbearable during this time, sand changed colour (more than usual), and walking in the bay was difficult due to the pollution. Aside from general refuse, items listed by fishers included clothes, syringes and dead animals. The following account represented one of several fishers' statements on this topic;

> "We have this wastewater pipe from Muhimbili Public Hospital, Ocean Road Hospital [Aga Khan Hospital] and other small hospitals found in nearby areas that emit lots of different rubbish, including syringes, maybe fake medicine, so fish can also eat these medicines. These are used syringes spread in the ocean. If you go to nearby pipes you can find lots of things that come from hospitals. Also there is a stream [Kijitonyama] from a place known as Science [COSTECH] and even TPDC [Tanzania Petroleum Development Corporation] has a stream that pours wastewater into the ocean. That stream at the end of the ocean here is surrounded by sandbags with black water, we see that water is not safe. Even the Indians when they die they are burnt and we think the water is coming from them. So whenever we are passing there, our skin peels off".

In assessing the water safety of Msasani Bay at various times of year, indicators identified by respondents were colour, visible rubbish and smell. 'Nearby water' in the bay was considered very dirty whereas deep water, outside of the bay was 'good'. Most fishers stated that the bay had changed significantly over time, including changes in water colour and quality, air pollution from streams, a reduction in fish and algae, and corals had disappeared completely.

> "I remember what it used to be like 25 years ago. Now it's as dead as a dodo. It's dirty and totally different to what it used to be like. I once saw a Scorpion fish in this Bay. We used to see fish and manta rays jumping all the time, from the beach here. Dolphins came quite regularly too".

When asked if there had been fish and other marine changes in the past 10 years, most respondents stated certain algae were not growing in Msasani Bay anymore. They explained that it was difficult to find because the specific fertile areas where it used to grow had been "destroyed" and sand now covered the space and that the algae was necessary for bait in the '*madema*' (mesh basket made from trees). Fishers attributed the way the bay was now to

pollution and 'human activities in the ocean'. Many respondents stated that fish were once plentiful but that nowadays they had to go further to fish as numbers had reduced and the number of fishers had increased. One fisher said "there was a time when we knew exactly how much and the type of fish we would get this month, but now no". Some fish species were described as having disappeared over the period these men had been fishing. Numerous respondents explained that fish and coral were interlinked and listed other reasons for the decreases in fish as, fishing techniques using large 'ring nets', poison and dynamite. From the answers I received, fishers relied heavily on their catch for income: 75% sold their fish on the market but also 62% took it home for their family's sustenance. Many stated they did not have an alternative income and that when no fish were caught they must use their savings to survive.

3.1.7 Perceptions of Government Policy, Sewage & Wastewater Systems

Perceptions & Policy

Popular response across all actor groups was that the Government should take responsibility for, and do more to improve the sewage and wastewater situation, whether this was in the form of action by the Municipality, NEMC or DAWASCO, or at the State level of policy. Respondents also stated social responsibility and leadership was needed at an individual level in order to care for environments. Some actors suggested that people form advocacy groups and demand that wastewater management practices be changed.

The Tanzania Environmental Management Act (EMA) 2004 was discussed in interviews with NEMC and DAWASA. Its function was described as fine or good, but that it required reviewing. Respondents said that as the Act was passed in 2004, it was now somewhat out-dated and did not include important concepts like Climate Change. "People are not aware of what the EMA wants them to do and the roles of the Government", stated the NEMC spokesperson. They described that there was a review currently taking place that would be complete in 2015. The EMA's efficiency was however of more contention. Implementation and enforcement were scrutinised due to what was said to be conflicts of interests by NEMC. DAWASA described that in reality politics played a large role in, for instance the enforcement of industrial effluent standards.

> "Members of parliament represent certain constituents. It depends on their interests. There have been complaints about industry from people but at the end of the day it depends on influence of industry to members of parliament, who they know, how much power they have. It determines how the Member of Parliament will react, and

subsequently Government Ministries and NEMC. In favour of industry's interest depends on how much the industry contributes to the Government in tax money".

NEMC also alluded to this idea: "If we tried to implement fully we would need to review the act. But because it's not fully implemented at the moment it's ok". The EMA was however criticised by industry who said it imitated European standards and was extremely difficult for industries to comply with. "We've had many discussions with NEMC about the standards. We can't just use European or American standards here in Tanzania, it's not realistic for Africa. The standards are not gradual here, you cannot implement 300pd when you've come from no requirement. They want to run before they can walk". When asked about this concern over the EMA, NEMC said, "sometimes we borrow words, etcetera, from European documents, but it has been customised for Tanzania".

Bureaucracy of the Tanzanian Government also featured in various actor groups' responses. Some stated that the problem remained with the decentralisation of institutions, citing they were so independent from one another that nothing gets done; others stated political influence or simply corruption. Also listed by institutions and industry were financial limitations: a prominent reason for the lack of enforcement or lack of infrastructure.

Future Sewerage & Wastewater Plans

Future sewage and wastewater plans for Dar es Salaam included the construction of three conventional treatment plants at Mbezi Beach, Kurasini and Jangwani. These plants were described by DAWASA as still in the planning stage because the existing system needed to redesigned and integrated with new technology at the three locations. When asked about the timeframe for the projects, respondents stated that the delay was purely financial. If money was available, works could potentially commence in one year; the respondents however described that there were no funds available at the time. There were no other sewage and wastewater plans for the city except "a few extensions to existing systems".

3.2 Water Sampling

"Water safety or quality is best described by combination of sanitary inspection and microbial water quality assessment" (WHO 2003: 51). By way of observation, sanitary inspection was conducted throughout the study and is presented in section 3.3.2 (Table 3) of this thesis.

Observations were accompanied by microbial water quality assessment, which is presented in this section.

The mean values of faecal indicator bacteria and nutrient concentrations of 23 sample sites are displayed in Figures 17, 18 and 19. Results are presented from samples collected primarily on 27 October, although some additional points have been added in Figures 18 and 19 for comparative purposes. A full list of the samples taken and their concentrations are presented in Appendix 2. In section 4.1.2 Physical Environments of this thesis I compare the quantities found to standards of safe water for recreation and optimum ecosystem functioning.

3.2.1 Salinity

The percentage of salinity remained almost constant over the 20 sample points, with the exceptions of the two most contaminated sites: Nyirenda River and Kijitonyama River (displayed in Figure 17).

3.2.2 Phosphorus

P results are graphically represented in Figure 17. The absence of P was noted at 11 sample points, the first five of which were 3.41 km to 2.61 km. In comparison, sample locations 2.41 km to 1.81 km contained elevated levels of 0.1, 0,3, 0.4, 0.1 and 0.3 respectively; locations that fell either side of Kawe River. Sample points 1.61 to 1.21 kms also were found to include insignificant levels of P. Nyirenda River (industrial wastewater) contained the highest value of all samples analysed, with a significant concentration of 4.2 ppm. Nutrient concentrations were further absent at sample points 1.01, 0.81 and 0.61 km, however 0.21 km was found to be elevated to 0.5 ppm as were the two samples collected from Kijitonyama River; found to contain high P concentrations of 3.9 ppm in each.

3.2.3 *E. coli* & Total Coliform

A total of 39 samples were analysed for *E. coli* and Total Coliform (TC). Both *E. coli* and TC data collected presented some samples with Too Numerous To Count (TNTC). TNTC or "Confluent Growth was defined as a continuous bacterial growth covering the entire membrane filter without evidence of total coliform-type colonies" (EPA 2005: 21). These maximum concentrations were observed at the outfall sample sites of Kijitonyama, Nyirenda, Mlalakuwa and Kawe Rivers (see Figures 18 and 19). These four sites recorded the contaminations of TNTC over various samples and dates collected. There were no visual or

olfactory evidence of source contaminations at three sample points, of which *E. coli* was also undetectable: 1 km offshore, White Sands Hotel, Mbudya Island. Aside from samples with confluent growth, the highest count of *E. coli* recorded was at sample point 1.41 km with 129 blue colonies. If excluding the three samples recording no *E. coli*, the lowest count was 25 CFU/1 ml at sample point 1.01 km. TC counts were proportionately higher than *E. coli* and ranged from 320 to 1520 (excluding six samples with confluent growth and three with zero *E. coli* (located outside of the central Msasani Bay 3.41 km sample site)).

3.3 Field Observations

3.3.1 Interviews

Some general observations from interviews:

Low Income Households	Women were sceptical to foreigners and took more consideration on whether to accept to be interviewed but were open when they did accept
	Women undertook almost all domestic duties
	Despite the difference in gender roles and distribution of domestic duties, men respected women's opinions and both genders answered questions mostly together
	Appeared truthful in their responses
	Children often played in and around the rivers listed in this study
High Income Households	Around half were reluctant to give truthful responses
Fishers	Expected payment (monetary/consumer goods – did not receive)
	Sceptical to foreigners
	Gave detailed responses when did accept to be interviewed
	Informal group interviews resulted out of multiple fishers becoming interested in the interview topic (interviewing nearby others)
	Appeared truthful in their responses
Industries	Extremely hesitant to be interviewed
	Polluted environments
Health Clinics	Underserviced sewage facilities
Institutions	Reluctant to acknowledge/ignorant of actual sewage and wastewater situation

Table 2. General Interview Observations

Households were amongst the easiest respondents to achieve interviews with, largely due to their accessibility. Low-income households were quite approachable and forthcoming in their responses, in contrast to high-income households that were difficult to gain access to (due to fences and security guards) and in general, taxing to attain honest responses. There are of course exceptions to these generalisations.

Fishers were frequently occupied with activities, which made it difficult to find interview respondents. Due to these activities and the beach environment, it was common to interview with numerous fishers around, overhearing and contributing to responses given. Several individual interviews subsequently became group interviews, which inadvertently resulted in a richer account.

Hazardous industrial wastewater was visible in the street and drains throughout the Mikocheni B Light Industrial Area. Effluents could be seen flowing from company's plots, in shallow open drains, crossing under the road and then continuing to join the Nyirenda River (out of sight on fenced land). Industries were among the most difficult actor group to obtain information from. I approached seven businesses, left my interview guide for management's perusal, and was told to return at a later time or date. However, after follow-up there were only four who agreed to be interviewed. Those who refused included Bidco Oils and Soaps Ltd, IPP Kilimanjaro depot (joint venture with Coca-Cola), and Quality Plastics Ltd. Responses from receptionists or managers of these three indicated their wish to avoid questions and risk prying eyes witnessing onsite activities. Some questioned the legitimacy of my research and queried who had sent me to interrogate them. Of the four industries that accepted to be interviewed, three provided brief and questionable responses. Contrastingly, one industry in particular was very open and candid with me and provided insights into the following issues: their on-site wastewater system, the history of Mikocheni B industrial area and its wastewater woes, costs, institutional assistance, social and environmental concerns and a general outlook on the education level and job market in Tanzania.

Institutional organisations, DAWASA and DAWASCO, were also challenging to gain access to for interviews. DAWASCO did not return phone calls or emails and passed responsibility off to DAWASA, thereby effectively refusing to be interviewed. DAWASA appeared very formal in the way they operate with external persons, as after several attempts to secure an interview, the organisation requested a letter explaining the research and a list of questions I would ask. After I had received permission however, arrangements were made with helpful individuals who allowed me an interview.
The way they talked and described operations, DAWASA and NEMC spokespersons seemed reluctant to acknowledge the reality of sewerage and wastewater in Mikocheni.

3.3.2 Water Sampling

Some general observations during water sampling:

Birds	Egrets, Herons, Sacred Ibis, Kingfishers, Indian House Crows, Terns, Common Gulls
Economic Activity	Women fishers collecting bait fish and bivalves
	Men working with small and large *juya* nets
Genders	Women kept close to shore using hand techniques,
	Men used boats or old paddleboards
Sensory Factors	Pungent smell of sulphur throughout the Bay, especially at all four beach river sites
	Turbid water throughout the Bay's shallow waters, and especially turbid at all four beach river sites
	Visible colour changes in sand
	Large quantities of algae and seagrasses on beach

Table 3. General Water Sampling Observations

Figure 17. Salinity & Phosphorus Levels

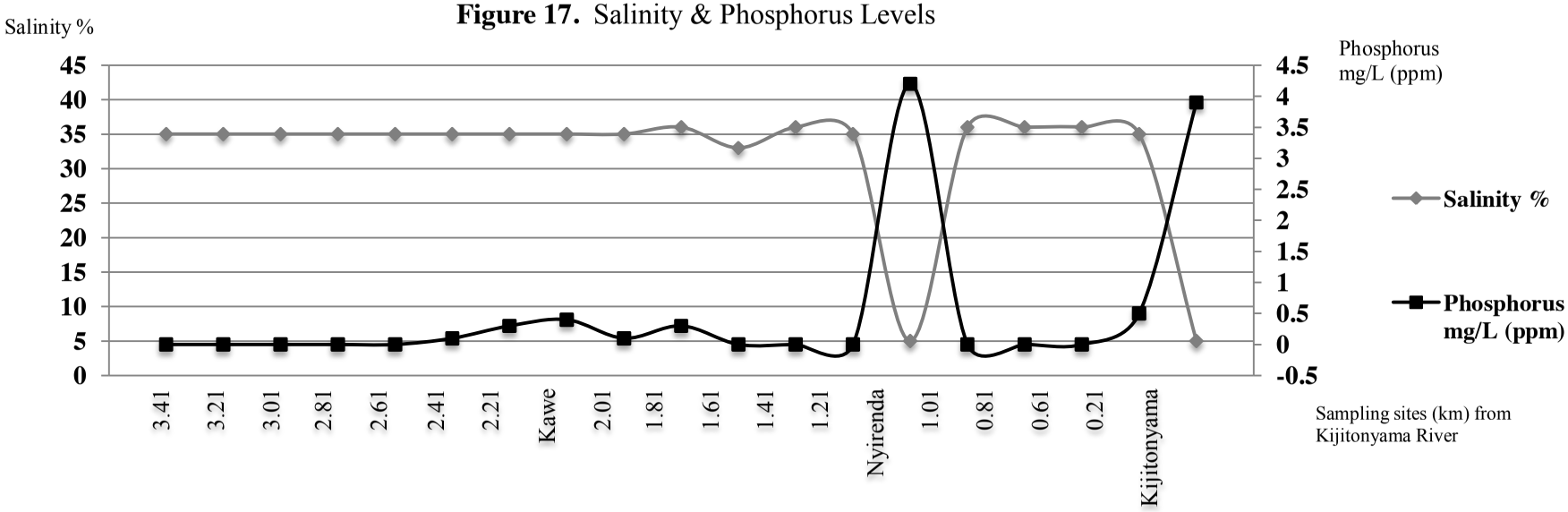


Figure 18. Concentration of *Escherichia coli*

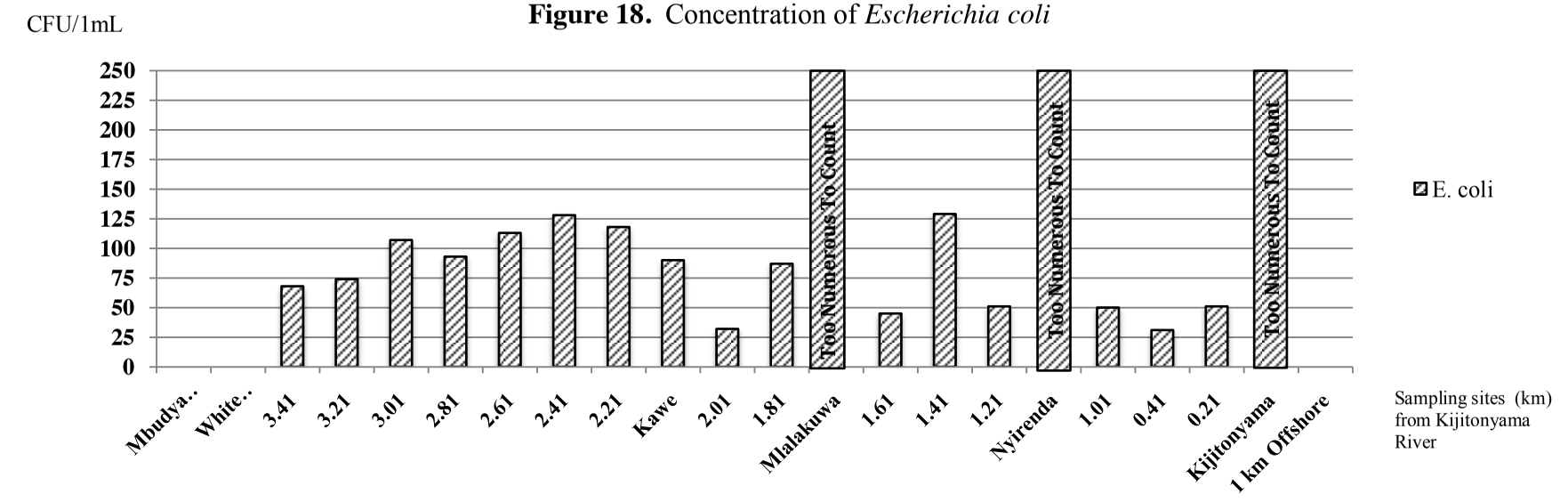
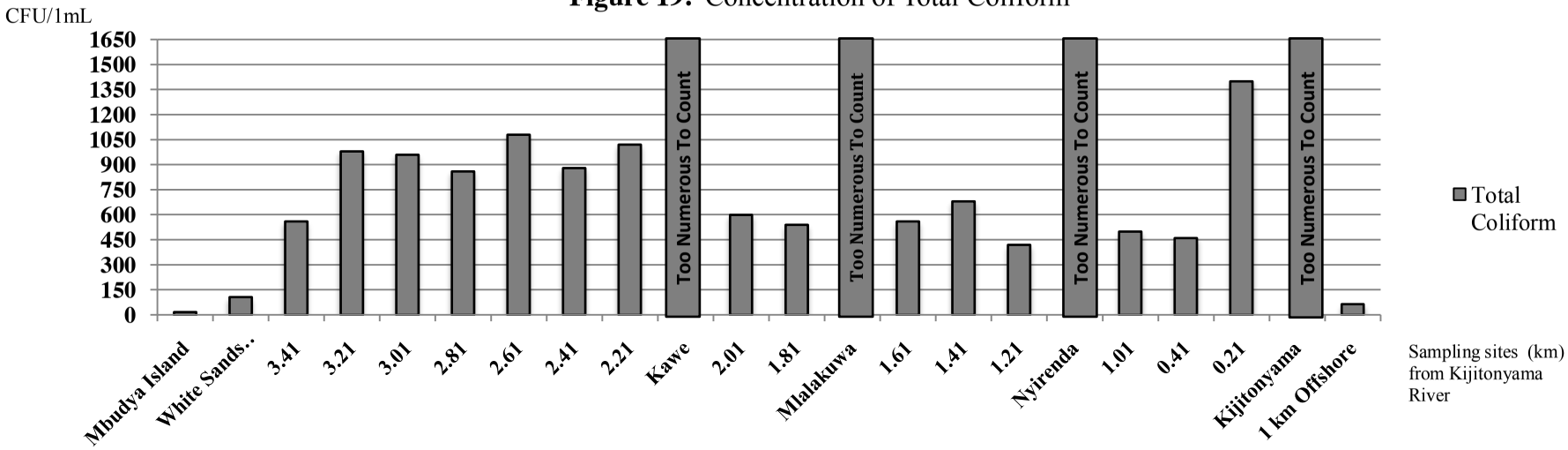


Figure 19. Concentration of Total Coliform



4. DISCUSSION

This study found that flooding is the hazard of key importance in understanding the vulnerability and resilience of the ecology of Msasani Bay and the livelihoods of people of the surrounding areas. Floodwaters contained increased microbial loads due to pollution by sewage and industrial wastewaters, surface runoff, stormwater overflows and resuspension of sediments; therefore levels of coastal marine and terrestrial pollution were significantly elevated during, and following, periods of rainfall. Accordingly, this section discusses the factors impacting the vulnerability and resilience of the SES of Mssasani Bay.

4.1 Factors Impacting Vulnerability

Wisner et al. (2003) postulated that vulnerability is in fact not determined by natural forces, but more so by social systems and power; that political and economic systems "decided how groups of people vary in relation to health, income, building safety, location of work and home, and so on" (2003: 7). To address disasters, the underlying factors (such as the root causes) and their causal relations must be focused on in order to enable change to occur and thus bring about a reduction of vulnerability.

As a tool for addressing the vulnerability of the SES, Wisner et al.'s (2003) 'Pressure and Release' model facilitates a discussion of underlying factors via a temporal progression through interlinked processes. Figure 5 illustrates the situation surrounding Msasani Bay whereby the annual disaster of floods comes about each year because of the existing cumulative effect and gradual development of root causes, dynamic pressures and unsafe conditions: the progression of vulnerability. It is reasonable to posit that 20–30 years ago, prior to major changes in Dar es Salaam's city landscape, these system dynamics did not occur as they do in their current form and therefore vulnerability was not experienced so prominently by the environment and the people in surrounding areas.

4.1.1 Disaster

Disaster is the intersection at which natural hazards and vulnerabilities meet (Wisner et al. 2003). Pressure mounts to the SES of Msasani Bay from hazards and vulnerabilities, creating a release (note similarities to the 'release' phase in the Adaptive Cycle model) in the form of

the destruction of lives and livelihoods, the spread of diseases, and a major loss of biodiversity. These three disasters are locally and historically based and accordingly will be examined throughout the following discussion of the PAR model and in the succeeding section 4.2 of Factors Impacting Resilience.

4.1.2 Unsafe Conditions

Physical Environment

My research was conducted with a focus on streams and rivers, all of which were visibly polluted. Sources of sewage and industrial wastewater pollution in the Kijitonyama River included neighbouring households, the Mikocheni waste stabilisation ponds (receiving industrial wastewater and household sewage), and private and DAWASCO *maji taka* lorries that emptied their load into the river. Results from household and fisher interviews revealed the origin and extent of sewage pollution in water bodies. Low income households were particularly exposed to hazards via the river, as some were located just centimetres from the bank and others situated up to only 20 metres away. It was common for children to play throughout the area, playing both in and around the river. As described in the 3.Results section, fishers also regularly came into contact with materials and hazardous substances in Msasani Bay. Additionally, bathers and tourists in the bay were exposed to the significant health risks posed by the water's contaminants.

Annual flooding added another dimension to the risk of fishers and households. The physical location of households during the rainy season (annual floods) involved significant numbers of individuals being directly exposed to floodwater pathogens on a daily basis: 70% of respondents stated they came into contact with floodwaters. Respondents told of their homes being flooded not only by the rising river level, but also by refuse blockages, or their domestic sewerage pipes that led directly to the river for wastewater disposal. The low income households that were flooded stated that they lost time and money each rainy season due to floods, for example in removing both water and the contaminated mud that remained throughout their homes. Fishers' workplaces were inundated with worsened pollution for an extended period, also putting these individuals at extreme health risk. The following paragraphs explain the results of water samples and what they mean in terms of human and ecological threats. The section 4.1.2 Health, discusses the impacts of these unsafe conditions on the community.

The water samples collected in Msasani Bay were also an indicator of sewage, through the analysis of faecal indicator bacteria *E. coli* and TC and the nutrient P. The levels found present in and around river outfall sites revealed high contamination. A correlation between the levels of faecal bacteria indicators and nutrient concentrations was observed at all sites. Although all samples analysed for TC displayed contaminated results (albeit few colonies) this could have been caused by a number of factors such as surface runoff, soil, or sediments, amongst others. As expected, sampling results furthermore showed (Figure 17) an increase in the P concentrations attributed to the high concentration of sewage and wastewater from rivers. In contrast, a drop in P concentration was found in seawater samples likely due to dilution. Higher salinity levels in seawater had a consistent inverse relationship with lower P concentrations, until a considerable drop in salinity (for example, in the rivers) was accompanied by a substantial increase in P (see Figure 17).

According to the WHO guidelines for safe recreational waters (2003), conditions that are biologically plausible to contract from sewage polluted recreational waters include enteric illnesses such as gastroenteritis, ear infections, eye infections, acute febrile respiratory illness (AFRI), general respiratory illnesses, skin symptoms, infectious hepatitis, *Salmonella paratyphi*, and typhoid. It is interesting to note that in a large portion of interviews with households, and especially fishers, respondents indicated their experience with such listed illnesses. Risks posed to those who utilise Msasani Bay are threefold. Firstly, rivers "discharging into an enclosed bay can be considered to present a higher risk than one discharging directly into open sea" (WHO 2003: 77). Secondly, there is an increased risk from (river) outfalls in Msasani Bay discharged directly onto the beach above the low water level. Thirdly, the low level of treatment: the untreated state of sewage discharged into recreational areas "presents a serious risk to public health" (WHO 2003: 78). In addition to the presence of sewage, moreover, hazardous industrial wastewater was indicated in responses from numerous actors. Categories of particularly exposed people were low income households and fishers whose homes and workplaces were situated in close proximity to these polluted rivers, drains and seawater.

Although the WHO guidelines for safe recreational water environments were updated in 2003 to use intestinal enterococci as the measure of water quality, on a country basis, numerous States have their own guidelines that include the use of *E. coli* (or TC) as the indicator of risk.

The bathing water directive of the Scottish Environment Protection Agency states that 95% of microbiological samples of *E. coli* should not exceed 2000 CFU/100 ml (SEPA 2014). The guidelines for Canadian recreational water quality state that a single sample should not exceed 400 CFU/100 ml (Health Canada 2012). Health Vermont states that *E. coli* bacteria density should not exceed 235 CFU/100 ml (2012). Samples collected throughout this study (see Appendix 2) are compared to these three guidelines, and thus only two samples meet the criteria of recreational water quality: Mbudya Island and White Sands Hotel taken on 26 October 2014, outside of Msasani Bay. All other sample locations were deemed unsafe for bathing and recreational use by a wide margin. It is logical to conclude that the risk potential to human health through exposure to sewage polluting the four rivers in this study and their discharge into Msasani Bay is exceedingly high. When microbial water quality assessment is combined with sanitary inspection, samples collected can be classified as extremely hazardous or "exceptional circumstances" that require urgent action (WHO 2003: 84). Few studies have concluded similarly the excessive microbial levels of pollution in the coastal marine environment adjacent to urban areas in Dar es Salaam (Machiwa 2010). Although numerous other studies have indicated that further research is necessary so as to deliver conclusive findings of similar trends (Abbu & Lyimo 2007; Lyimo 2009).

Local Economy

Income levels are critically low in large portions of Dar es Salaam's urban society, with the wealth gap widening between high and low income earners. Interviews with fishers revealed their reliance on catch and the pessimistic outlook for their livelihoods in the case that fish should become increasingly difficult to obtain. Additionally it was depressing to witness the low prices obtained by the sale of fish, representing meagre remuneration for their hard work. Households also faced pressures to their financial capability from increasing water and food prices, poor health, education costs and population pressures affecting unemployment. As with fishers, households' livelihoods were liable to disruption through a myriad of ways: the immediate threat of floodwater in the home, sick family members, or the inability to travel to work or school in times of floods. Moreover, low income disadvantages them in relation to unexpected costs such as medicine or the replacement of assets destroyed by floods, and reduces the capacity of families to afford improved housing (both the physical dwelling and its location).

Low income is compounded by the lack of assets, such as owning houses, held by marginal populations. Results revealed high income households own their own home in 70% of cases, compared to just 35% of low income households. Fishers also face difficulties with their lack of access to common property assets, despite beach access and the right to fish being enshrined in Tanzanian law.

Social Relations

The lack of active public debate in Dar es Salaam at the time of fieldwork can be traced back to the root causes of vulnerability, although it has become an unsafe condition in the 21st century. Its foundations lie perhaps in three possible conclusions: urbanisation whereby, as residents are not locals to the area, they lack connection with it and hence participation in issues that affect them; or, as Governments have increasingly become less tolerant to opposition and contestation of their policies and actions, public debate has eroded; or that as environments have become more polluted, the public has become more passive or pessimistic about any possibility of improvement to the situation. A household respondent stated, "when local Government meetings are called, people don't go to give feedback". As such, this lack of public debate in the city is a weakening factor for the community since debate is a driver of action, and action is acutely required on the issue of the flooding of polluted environments in Dar es Salaam, and more specifically, surrounding Msasani Bay.

The social composition of Dar es Salaam includes marginal groups who are at particular risk to flooding and its effects. High risk is posed to residents in unplanned settlements who experience flooding impacting their entire existence. These occupants were poor and had little choice but to live in risky locations. Results demonstrated that a significant portion of low income households encountered floodwaters inside their homes, and that if residents did not experience floodwaters directly this way, they likely came into contact with these polluted waters by nature of their location and daily activities, such as travelling to work or school. The ensuing health consequences are discussed in the section 4.1.2 Physical Environments and will also be discussed in following sections. Fishers can be considered at risk on two counts: results showed that they suffered the effects of polluted floodwaters due to their daily exposure in Msasani Bay which received contaminated riverine waters, and secondly, their livelihoods relied upon the functional integrity of the marine ecosystem.

Public Actions & Institutions

Health

Through investigation of the winners and losers in relation to sewage and wastewater discharges, this study's findings confirm, "wastewater management is a key component of health risk management" (Corcoran et al. 2010: 41). The unplanned, un-serviced, and hazardous residential areas in Dar es Salaam (such as the research site for low income households) have limited drinking water supply, poor sanitation, sub-standard housing, overcrowding, and lack organised solid waste collection (Mwakitalu et al. 2013). Results showed that the impact of frequent contact with contaminated floodwaters of the Kijitonyama River was that residents experienced a broad range of diseases and sicknesses directly linked to their exposure to sewage (as listed by WHO, 2003 in 4.1.2 Physical Environments section). The prevalence of stagnant water and waterlogging in home areas increased disease and insect vectors, such as cholera, diarrhoea, typhoid, dysentery, and malaria or dengue fever. Moreover, "respiratory illnesses often become more prevalent in the aftermath of slow-onset floods, and take a toll, especially among very young children, babies and the elderly" (Wisner et al. 2003: 221).

My study results are in agreement with those of other studies (for example, del Ninno et al. 2001; Kunni et al. 2002) that have indicated flood-affected people encountered increased disease and health problems. Del Ninno et al. adequately summarised the experience of those who encountered floodwaters in their homes, by stating, "carrying on regular activities, such as cooking eating, cleaning, going to work or school, and even sleeping, became more difficult" (2001: 72). Pervasively, sick family members that cannot work constitute both a loss of labour and financial support, they (or the carer) provide: "especially during attempts to recover after a hazard event, [it] can be a significant element of the disaster" (Wisner et al. 2003: 221). Compounding hazardous exposure, low economic groups typically have poor existing health due to financial pressures. Extra time and money spent on flood-related impacts can further exacerbate health problems through stress and extra hours worked to finance the household's losses.

The health impacts to interviewed fishers were typically less severe than households (if severity is classified by incidence of water-borne diseases). A reason for this could be the

die-off of pathogens in riverine waters when exposed to sunlight and salinity on entering Msasani Bay. Studies (Bouvy et al. 2008, and Winfield & Groisman 2003, in Rochelle-Newall et al. 2015) however, suggest, "it is probable that *E. coli* and other FIB [faecal indicator bacteria] can persist and even proliferate in tropical environments, particularly those with high temperatures" (Winfield & Groisman 2003, in Rochelle-Newall et al. 2015: 3). Although, it appears temperature is not the only determining factor to indicator bacteria. Survival of *E. coli* cultures showed remarkable inactivation at high levels of solar radiation (Chandran & Hatha 2005). Accordingly, it appears that "light penetration in the water column plays an important role in determining survival" (Rochelle-Newall et al. 2015: 6). It is therefore plausible to conclude that, firstly, the point where the fisher entered and exited the bay (water samples indicated the various amplified points of contamination) determined their exposure to the concentration of sewage and wastewater. Secondly, important to note is that despite fishers' extensive contact with turbid and contaminated waters close to the shore, they spend the majority of their time outside of the shallows, in deeper, less polluted, clearer water.

Town Planning

The issuance of building permits represented a considerable problem for Dar es Salaam. Flooding in Mikocheni and Msasani in recent decades can be attributed to poor urban planning. The Structural Adjustment Programmes (SAPs) of the 1980s in Dar es Salaam (economic austerity measures) created an environment where municipal councils could raise funds through unscrupulous issuance of building permits. This study's findings concur with observations reported in the grey literature and numerous newspaper articles.

A report conducted for NEMC (Kayombo 2007) (summarised in 1.2 Literature Review section) indicated Nyirenda River's problems, which exhibit significant similarities to the Kijitonyama River (despite a lack of studies conducted there) and no doubt other locations throughout the city. These include the following circumstances: houses built very close to the river, owners allowed to fence borders of plots thus diverting the natural course of the river, or narrowing and restricting its flow, and increases in stormwaters or industrial flows resulting in overflows to adjacent houses. Dar es Salaam newspapers frequently featured articles that articulated the blocking of river courses draining into the Indian Ocean in Mikocheni and Msasani. Articles typically attributed resultant flooding to affluent developers and residences; this was also the perception held by households and fishers.

My research results revealed that town planning was of great concern to actors throughout the study. Households expressed their exposure to hazardous floodwaters during the rainy season and low income households showed concern for the lack of services and access to their residences; fishers observed that rivers joining the ocean often overflowed their banks in peak rains; health clinics noted drain and sewerage overflows; industries stated that industrial area planning was a matter of concern, while they considered peripheral residential areas to be even more disturbing; institutions, specifically DAWASA also had much to say on this issue:

> "The Municipality issues permits to build in those swamp areas [*Bonde la Mpunga*, Shoppers Plaza area]. In 1987 there was nothing there, no buildings, no houses but good natural flow of water. In approximately 2000 the construction emerged. They imported materials to fill in the area. When it floods there are big problems. It's all about the use of the area, that's why it's as bad as it is."

This statement corresponds with those of a NEMC spokesperson who similarly iterated this impression of the poorly planned *Bonde la Mpunga* and permits that were haphazardly issued. A newspaper article stated it similarly:

> "in 1979, *Bonde la Mpunga* was mostly virgin wetland used for paddy farming. The 1979 Dar es Salaam Master Plan correctly designated the area as hazardous land for building… Years after, residential houses emerged and by 1992, the city council together with the Ministry Of Lands and Human Settlements Development prepared and approved a local subdivision plan. The area became prime development destination, especially for wealthy developers who were able to fill in the wetland for development of their structures. Another factor is that up to that time the land was not legally owned by any individuals due to its status as hazardous land. The city was thus able to transfer title to the wealthy developers. In the course of their economic calculations, the authorities turned a blind eye to the ecological function of the urban wetland as water sink for the city" (IPP Media 2014).

When asked if there should be more partnership between the municipality and DAWASA, and whether these issues should be shared problems, the DAWASA spokesperson answered:

> "the reason is the land use problems. There's buildings going up without permits, or with permits also, these buildings block the stormwater drains to the sea and the floods are worse, in Mikocheni area… Stormwater and sewage is a problem. We are working with the municipality on this. We cannot raise the sewage system so there are remaining obstacles. We're trying to force and remind council to get rid of these obstacles. The municipality gave the permits, the Ministry of Land comes in, approves the permits, people have banks loans already so then people just following existing planning system – do as they please".

Furthermore, when asked if they were to take action with one stakeholder and issue, which would it be, DAWASA spokesperson stated:

> "this is a cross-cutting issue, but I would start with those who issued the permits. People have ownership titles, deeds, permits. These need to reassessed – how did they get them? Also NEMC needs to better enforce their Environmental Impact Assessment certificates".

There is a strong case from these selected descriptions that flooding in Mikocheni and Msasani is a socially constructed issue. Some may ascribe the worsening annual floods to climate change; however research results and grey literature support the conclusion that these specific flooding problems are far from a naturally occurring event that worsens with time. Town planning issues extend to the haphazard sewerage and wastewater system in Dar es Salaam, systemic problems that persisted in 2014. These will be analysed in a temporal context, in the 4.1.4 Root Causes section.

4.1.3 Dynamic Pressures

Lack of Effective Local Institutions

Dar es Salaam sewerage and wastewater institutions may be considered ineffective for two reasons. Firstly, ineffective administration, via their roles and bureaucracy, and secondly, their lack of financing renders them ineffective in their capacity: activities and projects. As shown in Figure 3, the structure of sewerage and wastewater institutions is intended to be one of synergistic cooperation. The overlap between these groups formally exists to create a system of checks and balances where one institution aids another by way of support and mutual interests. My research results, however, indicate that in reality these organisations operate at a distance from one another. Figure 20 indicates this separation.

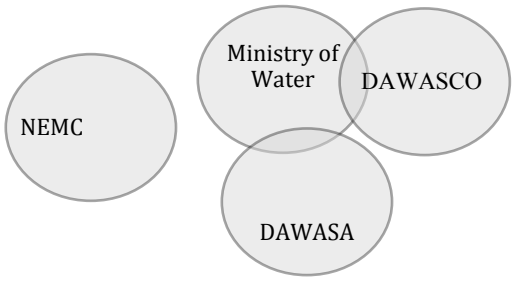


Figure 20. Apparent Sewerage and Wastewater Institutional Administration

Core functions of the institutions, such as the essential services of sewerage provision and treatment are not coordinated adequately due to such decentralisation, and furthermore, effective policy and action is impeded. The disconnection between these functional units has allowed responsibility to be passed from one organisation to another and a clear lack of accountability has developed in these key institutions. An informal interview with the

Ministry of Water revealed that although the Ministry controls DAWASA and DAWASCO, it does not participate actively in the management of the sewerage and wastewater system, merely functioning as a report collector and information disseminator. Moreover, the institutional architecture between DAWASCO and DAWASA is almost identical to the one that existed between DAWASA and the previous private operator (Pigeon 2012; Triche 2012). This has fashioned a culture of mistrust between the two, whereby DAWASCO rejected the supervisory authority of DAWASA and reported directly to the Ministry of Water, which prompted DAWASA to monitor DAWASCO's performance via an external auditing company, costing US$120,000 annually (Pigeon 2012). Although the situation has somewhat improved (Pigeon 2012), results of this study indicated that DAWASA is still not completely aware of DAWASCO's performance on the ground. For example, the DAWASA spokesperson stated that the Mikocheni stabilisation ponds were properly maintained by DAWASCO, despite numerous interview respondents across actor groups and visual observation that indicated the ponds had not been treated, and hence ceased efficient functioning, since approximately September 2013. Newspaper articles also supported these functional problems between the two organisations (Kessy 2014).

It is interesting to note that from a discussion with a Ministry of Water employee that there appeared to be no review by the Ministry of the performance of the country's utilities. Additionally another study found "coordination of data reporting lacking… managers were often unable to retrieve internal and published reports… there appeared to be no single audited set of operational and commercial data that was shared by DAWASA and DAWASCO" (Triche 2012: 35). Contrary to this, UNEP et al. (2009) noted that at the end of every year, urban water and sanitation authorities evaluated key performance indicators to verify utilities' performance, although it is unclear whether this is inclusive of the Ministry of Water, or only DAWASA.

My study's results reflected this lack of administrative effectiveness, as households, fishers, industries and health clinics indicated their scepticism to or distrust of the institutions. Industry generally felt let down by Government institutions. In relation to NEMC for example, aside from frequent audits, an industry stated "at the moment NEMC and consultants come and it's all just talk, nothing is done, we're yet to see any action… NEMC has all these action plans but some things are out of [their] control". Contradictorily, NEMC had a more positive attitude: "we do a lot with industry; establish what are the problems, what

they need help with and advice; what were the conditions placed upon them; what's being done to meet these conditions. We deal with compliance on the ground". Speaking of the four institutions more generally, an industry respondent stated, "there's also a lot of bureaucracy. The Government doesn't function because it's so decentralised, so they're solely independent, they impose what they need to operate".

Institutional ineffectiveness and lack of priority for sewage and wastewater treatment facilities are brought into focus by their public communications. Organisations' websites, reports and Government legislation (e.g. Tanzania EMA 2004) often feature rhetoric citing 'water and sanitation': however in reality water supply and upgrade projects dominate both funding and operations, with sewage and wastewater plans remaining unfulfilled. The body of literature and newspaper articles confirm that while institutions have made infrastructure improvements in the provision of water, sewerage developments have lagged behind (Pigeon 2012). A factor constraining overall institutional capacity is the lack of adequate finances.

Activities and infrastructure projects and upgrades are severely inhibited by the lack of funding available. NEMC clearly expressed this deficiency: "campaigns are not possible, there are too many budget constraints, it's really difficult. [We are] not sure if we get funds so we just plan our activities accordingly and then implement them [as we can]". Results across-the-board indicated this problem. When discussing planned infrastructure projects for the city's sewerage, DAWASA stated: "they're still in the planning stage. The bottleneck is financials, who will finance these projects? There's not enough money for that". The interview respondent considered that infrastructure projects could eventuate quite quickly if funding were available.

In terms of DAWASCO, limited funding and infrastructure expansion can be attributed to accumulated debts. The corporation's organisational capacity is severely inhibited by its significant economic losses, by some accounts as high as 230% of their asset value, or 15 billion Tanzanian shillings (Pigeon 2012; Daily News 2014; Triche 2012). Although, "of the debt, the Government owes DAWASCO 10.5 billion [shillings] with the country's security organs top on the list of debtors" (Daily News 2014). Other factors, such as the dilapidated state of sewerage infrastructure, can act to compromise the effectiveness of DAWASA and DAWASCO. Several studies listed the dire state of infrastructure in the 1990s and 2000s (Mgana 2003; Pigeon 2012; UNEP et al. 2009), although despite multi-million dollar

international projects (like the DWSSP), results of this study and current newspaper articles indicate the situation has not changed.

City projects (such as the DWSSP) that do not deliver intended and expected outcomes, can further reflect the ineffectiveness of local institutions, though perhaps poor leadership and corruption play a greater role. Additionally, institutional capacity and integrity is jeopardised when higher Government bodies override an institution, undermining and rendering it functionally redundant. A spokesperson for DAWASA told of this scenario in reference to NEMC's attempted foreclosure of an incompliant industry ('21st Century Industry'):

> "In the case of Morogoro a year ago, NEMC issued a notice requesting [environmental performance] parameters. NEMC has the mandate to close an industry or factory, so they ordered closure of this industry, and within a week the Government overturned the decision. They said no [it cannot be closed], a number of people will lose their employment. Industry was not meeting the effluent standards but the Government said no, you can't close this industry".

Lack of Education

It is widely accepted that investment in education and health enhances development, reduces poverty and improves environments. "Understanding of the links between wastewater and health, ecosystem functioning and the potential benefits of wastewater reuse in contributing to development and improved wellbeing" (Corcoran 2010: 68) plays a vital role in changing the sewage and wastewater pollution scenario in and around Msasani Bay.

"Countries that don't invest widely in education find it hard to attract foreign investment in businesses that depend on a skilled labor force" (Stiglitz 2006: 46). An industry respondent noted this lack of skilled workforce in Dar es Salaam; whereby university graduates do not have the academic rigor or experience required for immediate employment in technical industries, in comparison to India for instance. Interview results for households and a fisher suggested that improvements in education, both in schools and for the community, would improve waste management and their surroundings.

Health clinics expressed concern that a lack of recognition of the linkages between sewage and health effects likely increased the risk of people exposing themselves to polluted environments. The Crona et al. (2000) study (in 1.2 Literature Review) highlighted this relationship:

> "the fact that many respondents perceived a general risk related to sewage but did not link it directly to human health could signal existence of the type of systematic under-estimation of risk referred to as unrealistic optimism (Radcliffe and Klein, 2002; Weinstein, 1980). Unrealistic optimism has also been seen to affect response to a risk (Becker and Maiman, 1975; Janz and Becker, 1984) and thus has implications for the vulnerability of unrealistically optimistic individuals" (Crona et al. 2000: 236).

My research showed similar results, whereby all household respondents were aware of the risks posed by their proximity and contact with the polluted Kijitonyama River or floodwaters, although when asked about the beach and waters of Msasani Bay, only 65% believed the Bay's waters to be unclean and unsafe for human contact, and one third used the beach for recreational activities such as swimming. From this it is evident that general community education is required, but also specific education of the bay's hazardous waters and the direct effect of pathogen exposure to human health.

Forces of dynamic pressures on the macro scale include the rapid urbanisation, population growth, and increasing industrial pollution, leading to an increase in water pollution and decline in marine productivity. These issues have either been considered previously or are analysed in the 4.2 Factors Impacting Resilience section. The discussion will now address the root causes in the progression of vulnerability.

4.1.4 Root Causes

Limited Government Financial Capacity & Corruption

The third objective of this study, 'what are the reasons sewage is discharged in its current locations and untreated state?', can be largely answered by the absence of substantial Government funding for sewerage systems, and corruption.

Corruption is frequently referred to in both grey and academic literature on Tanzania. The early years of independence were marked by low national corruption (Pigeon 2012), although with the economic and political change of the late 1970s and 1980s there were substantial increases. In late 1995, President Mkapa launched an anti-corruption campaign in which the Warioba Commission was created to report on State-sector corruption (Briggs & Mwamfupe 2000). The report published in 1996 presented overwhelming levels of corruption that instigated wide-spread change; although apprehension surrounds "what is actually known [and if it] is only the tip of the corruption iceberg" (Briggs & Mwamfupe 2000: 806).

As interview results have displayed, corruption appeared present across numerous actors and Government bodies. The 4.1.2 Town Planning section discussed the problems of dubious permits issued to developers and wealthy land owners who are permitted to construct buildings in hazardous locations and peripheral walls that block drainage. NEMC experienced a challenge to their capacity through a higher Government department overruling their authority and undermining their environmental responsibilities. The undermining of an organisation with such an important role sends a clear message to industries and the public: the environment comes second to economic activities in Tanzania[2]. A DAWASA spokesperson reflected on the reasons for such actions:

> "members of parliament represent certain constituents. It depends on their interests. There have been complaints about industry from people but at the end of the day it depends on influence of industry to members of parliament, who they know, how much power they have, determines how the Member of Parliament will react, and subsequently Government ministries and NEMC. In favour of [the] industry's interest depends on how much the industry contributes to [the] Government in tax money".

An extension of corruption at the industry level is that organisational positions of power are sometimes held by industrial interests, for example the former Chairman of NEMC was also the founder and executive chairman of IPP Limited, one of the largest industrial and media conglomerates in East Africa.

Nationally, Tanzania has a history of financially mismanaged, externally funded development projects. Such projects are typically misconceived and come with misguided conditions (Stiglitz 2006), creating the climate for corrupt practices to occur. The DWSSP is one example amongst dozens or perhaps hundreds of projects with misspent funds that should have contributed meaningful and lasting impacts to State plans or infrastructure. Concomitantly, if the scale of corruption exists to the extent suggested or further, it seems apparent why the Government does not have sufficient funds for necessary services and resources, such as those provided by DAWASCO, let alone being able to fund vital infrastructure upgrades.

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[2] Since field research was completed in November 2014, NEMC has closed down 21st Century Industry on 20 February 2015 for continually defying orders to improve the standard of wastewater treatment and reduce air pollution of their textile operations, to the appropriate level of compliance. This indefinite foreclosure comes after repeated warnings since 2006 from NEMC, the Municipality, Morogoro District and Regional Commissioner's Offices, the Vice President (Environment) and the Prime Minister (Mhagama 2015; Rweyemamu 2015).

Poor Leadership & Leadership's Lack of Political Will

Given the previous section, Government was fully aware of the problems that existed in relation to water pollution and its associated issues. Corruption, however, weakens leadership; one of several reasons for poor leadership and low political will. Where politicians and institutional executives became dishonest in their actions, their complicity impeded their ability and propensity to make the 'right' decisions and to act in the national interest. As a result, they delivered weak leadership, perpetuated and reaffirmed by other complicit individuals in their close environment. From this, fragmented and superficial action followed.

Perceptions of weak leadership and the lack of political will to deal with water pollution are widespread. Examples occur throughout this study's findings, in addition to literature and newspaper articles. Household and fisher respondents were particularly dissatisfied with the Government's absence of leadership on the issue of water pollution: whether sewage, industrial wastewater, or solid waste. In the Kayombo (2007) report for NEMC, the local Government in Mikocheni ward indicated that it had struggled to receive support on attempting to deal with industrial wastewater discharges into the Nyirenda River. Moreover, the accounts from household and fisher respondents told of Government and its institutions doing very little to improve sewerage and polluted waterways, and discrepancies existed between what was said by institutions in relation to the Mikocheni stabilisation ponds, and industrial compliance monitoring. Another illustration of this is that Government lacked accountability to its citizens in terms of addressing or meeting the basic tenets of the EMA. These principles comprised the right to a clean, safe and healthy environment and the duty to protect the environment (Tanzania. EMA 2004), all of which were poorly adhered to. The principles exemplified Government policy measures that appeared comprehensive, but in practice amounted to little more than rhetoric.

An additional factor reinforcing poor leadership and minimal political action was because people have not demanded more of their leaders. As considered in previous sections, the lack of active public debate and environmental leadership reflected low levels of education and awareness amongst the populace. By way of example, research results showed that polluted waters from rainy season flooding impacted low economic groups most heavily; however political protest did not result. In more highly educated societies, avoidable human-instigated

'disasters' usually invoke activism among 'aware' citizens. The lack of political will amongst leadership may be in part ascribed to this lack of empowerment and environmental awareness among disadvantaged citizens.

Weak Regulatory Framework

Despite "sectoral pieces of legislation relevant to the protection of marine and coastal environment[s] ...Tanzania lacks a coherent policy that addresses the issue of pollution" (UNEP et al. 2009: 49). Current policies and institutional structures in place have been inept in relation to the efficient and valuable functioning of regulatory frameworks. The absence of an updated master plan since the 1979 version was undoubtedly a factor that contributed to the city's regulatory and planning confusion, amongst other factors such as large population growth through urbanisation. Research findings support the contention of a weak regulatory framework that had implications for all actor groups. Industry interviews indicated that the compliance regulations for industrial wastewater effluents were unrealistic for Tanzania as there was no incremental progression in stringency. Further, existing frameworks poorly communicated to the public prevent them from actively partaking in their own futures. A respondent from one of the Mikocheni offices interviewed, stated that without environmental education for citizens, the construction of future infrastructure would be wasted. Similarly, the schools interviewed expressed parallel sentiments, as did NEMC: "people are not aware of what the EMA wants them to do and the roles of the Government".

Structural Adjustment Programs

Tanzania's economy in the 1980s was impacted by World Bank and International Monetary Fund imposed market fundamentalism and macroeconomic reforms. Economic reforms commenced in 1981, followed by the Structural Adjustment Programme (SAP) in 1982 and the 1986 Economic Recovery Programme (following Nyerere's resignation in 1985) (Briggs & Mwamfupe 2000). The structural adjustment measures saw the IMF impose neo-liberal austerity measures on Tanzania as conditionalities to their development loans. The country's education and health levels suffered significantly due to these budget cuts. Moreover,

> "structural adjustment policies often lead to a deterioration of the situation for those with the least resources to adapt to the changed economic circumstances. To the extent that poverty in many regions of the world is the primary cause for environmental degradation, increased poverty caused by structural adjustment policies can lead to further environmental damage" (Hansen 1988, in Wisner et al. 2004: 86).

When evaluating this study's findings and the literature surrounding infrastructure and development projects, it is easy to see the historical influence of the SAPs and how they have shaped Tanzania's political and cultural norms of today.

Low Social Awareness & Participation

Low social awareness and participation contribute to the large number of factors that affect the vulnerability of the SES to varying degrees. Two factors that contributed to low social awareness and participation include the lack of education and disillusionment at the lack of institutional effectiveness and performance. There was also differential vulnerability between actors; low income households have limited opportunities as they experience more pressures on their livelihoods, as do fishers, whereas higher income households have a greater capacity, for awareness and participation. However, actors are not helpless individuals who lack agency. "Just because neighbourhoods have been disenfranchised in the past does not mean they are unwilling or unable to be an important part of the process" of change (Morrow 1999, in Wisner et al. 2003: 84). Household and fisher respondents were fairly optimistic about the use of education as a tool for local action at the community level, so as to pressure local and municipal Governments to take action. One fisher summarily expressed the idea of much needed grassroots activism in Mikocheni and Msasani:

> "We must start taking care of our houses, cherish begins at home. If everyone in the neighbourhood takes care of the environment there is no need to complain because everyone has a special place to put their rubbish. No need to wait until the rain comes to put your rubbish into the streams".

As Mehta writes: "local people are capable of resolving their own problems and do not need massive subsidies or external solutions" (2011: 6).

4.2 Factors Impacting Resilience

Superficially, the SES of Msasani Bay appears resilient. Every year floods create devastation for the people and marine environment, which then exhibit endurance and resilience in adapting to contaminated floodwaters with elevated microbial loads. A resilient system is one that continues to function by its successful incorporation of change (Holling 1986). Seemingly the Msasani SES does this annually; the bay receives these polluted waters and

naturally treats them to a less-contaminated state with a degree of productivity: households cope with contaminated floodwaters in their homes and streets without contracting diseases in epidemic proportions; fishers adapt their techniques and fishing locations so as to continue generating income for their families; health clinics absorb the increased numbers of patients; and industries go about their "business as usual" with floodwaters in the streets. While disturbances to the system often serve to reduce vulnerabilities, discreet thresholds exist that, when crossed, cause the SES to collapse and transform into an alternate state in which key functionalities of the system are lost. The system's dynamics however require deeper analysis in order to fully understand the complexities and variabilities of gradual and sudden changes that occur each year.

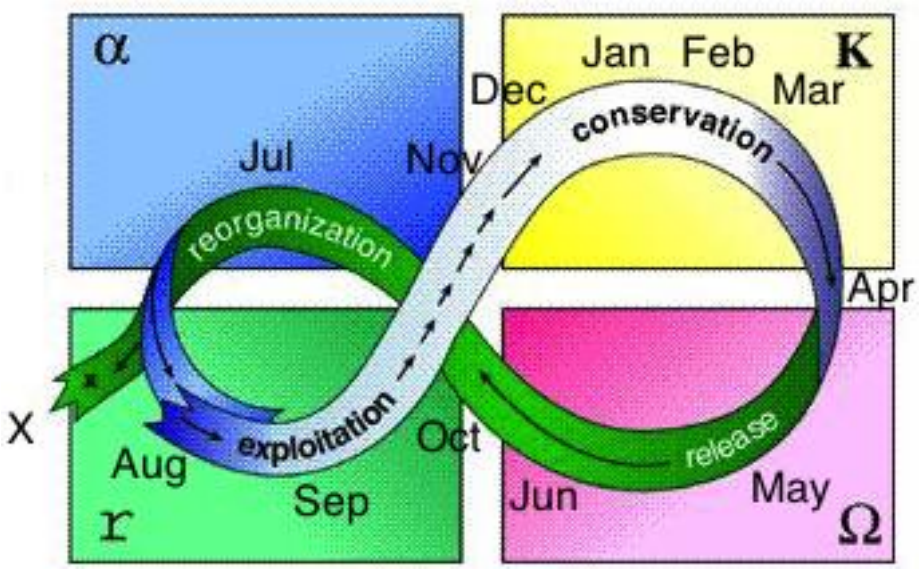

Figure 21. The Adaptive Cycle of Msasani Bay (Adapted from Holling 1986)

To illustrate factors that impact resilience in the SES, Holling's (1986) Adaptive Cycle model is used to guide this discussion. The model in Figure 21 is based on the hazard of annual floods so as to draw parallels between the concepts of resilience and vulnerability and to emphasise the flow of events between the four phases of the SES functions. These phases include exploitation, conservation, release and reorganisation, and can be explained in terms of months of the year when these phases occur. The key factor that drives the SES through the adaptive cycle is the annual rainy season (in March-April-May) floods carrying pollutants into the water bodies. Key variables that serve as indicators of the focal systems' changes over time (Resilience Alliance 2010) include the destruction of lives and livelihoods, the

spread of diseases, and a major loss of biodiversity; the same three that indicate 'disaster' in the 'pressure and release' vulnerability model.

The exploitation phase at the beginning of the foreloop commences in August after the reorganisation following the rainy season. Interviewed fishers described this system phase as the period when the bay typically became clean again in terms of turbidity, colour and visible pollutants. During the time after initial reorganisation, seagrasses (mainly *Thalassodendron ciliatum, Thalassia hemprichii* and *Syringodium isoetifolium*) and macroalgae (*Chaetomorpha crassa* and *Laurencia papillosa*) typically recovered in the bay when turbidity had decreased, the latter species thereby supplying bait for fishers. Other macroalgae (e.g. *Ulva* spp. and *Enteromorpha* spp.) are considered indicator species for nutrient enriched pollution (Teichberg et al. 2010), and these have become excessively abundant in the bay, but are not suitable as bait. A recent phenomenon however described by fisher respondents was that bait macroalgae have become difficult to find (e.g. *Chaetomorpha crassa* and *Laurencia papillosa*): "the macroalgae were supposed to grow now, but until now there are no algae found in the bay". Macroalgae play an important role in the SES, and it is interesting to note that their existence in the bay is, as of recently, no longer stable. As for environmental changes in the bay, all fishers noted clear differences, with one respondent stating: "the ocean is supposed to be clear now, the tides should clean it". When asked why it is supposed to be clean at this particular point in time (October), the fisher responded, "because it is the dry season". During this exploitation phase, the health of residents usually improves as widespread vectors of diseases have largely subsided after the rainy season, though some household respondents did not notice a correlation between season and sickness, nor did fishers distinguish periods of increased illness, although the health clinics did observe seasonality of sicknesses.

From August, continuing until approximately February, the SES gradually changes to a higher level of organisation and connectedness. The slow-flowing streams (rivers) are slowly accumulating polluted liquid and solid waste once more. By March, the system has progressed deep into the rigid conservation phase, and accordingly quickly experiences a collapse and a flip to the backloop and the release phase when rainy season floods begin during March. The three key system variables, the destruction of lives and livelihoods, the spread of diseases, and the major loss of biodiversity, originate from this release phase. The

SES generally recovers during July: the bay reorganises after the destruction, for instance, the excess amounts of nutrients and faecal coliform are absorbed; the sick have generally fought off their illnesses; the houses are cleared from water and mud once again; and fishers work in a slightly less turbid and polluted environment. However, "slow changes of the type expected might be so successfully absorbed and ignored that a sharp, discontinuous change becomes inevitable" (Holling 1986: 295). My findings have indicated that these slow, seasonal changes, may indeed be absorbed in the short-term, but there is the potential for these to incur a sharp shift that jolts the entire SES into a more permanent state of dysfunction.

The three key system variables that act as indicators of change in the SES are increasingly present throughout all phases of the Msasani adaptive cycle. The destruction of lives and livelihoods affects economically disadvantaged actors, by threats to their assets and income-earning potential. In terms of households, people's belongings are threatened, often with little chance of saving possessions and protecting dwellings, and their earning potential is susceptible to changes during this time. Threats to fishers' assets are posed in the macroalgal bait and seafood availability, general ecosystem functioning, and resultant variability of income. Households, fishers and health clinic respondents told of significantly heightened pollution of waterways and the increasingly worsened scale of flooding. Poor planning measures combined with urbanisation and unplanned settlements have led to the poorly situated, disadvantaged population's amplified susceptibility to the spread of diseases. These contracted illnesses have not yet reached epidemic levels, as the social system at present remains able to absorb these disturbances.

The third key system variable of major biodiversity loss occurs when the system crosses a threshold (system boundary) and flips into an alternate state: "crossing a threshold involves a change in the nature and extent of feedbacks associated with a key variable" (Miller et al. 2010: 11). This threshold transition has occurred in Msasani Bay perhaps more than once over the past few decades, and my study's findings indicate that another, near-future transition to an alternate further-degraded state is entirely plausible. Fishers and residents, past and present, described the substantial loss of corals in the bay some 20 to 30 years ago with the increase of industrial activities and introduction of sewage and wastewater discharge outlets. During that period the bay transitioned to an alternate state with the disappearance of relatively robust coral genera such as *Pavona* and *Porites*, in addition to large-scale fish die-offs where hundreds washed up onto the beach in subsequent years. Since then, other species

that have departed from the area include fish such as mudskipper (*Periophthalmus*), tuna (bonito and yellowfin), manta rays and dolphins. All fishers described that there was a significant reduction in desired fish species in Msasani Bay.

My findings indicate that macroalgal bait availability and catches of fish are reducing (the latter from outer waters of the bay), and there are visible symptoms of changes in the ecosystem, for example large quantities of opportunistic fast-growing green macroalgae washed ashore. In addition, the social system (for instance households) is under increasing annual pressure during the release and reorganisation phase.

4.3 Summary of Msasani Bay Social-Ecological System

This discussion has evidenced that when subject to disturbances, ecosystems can exceed critical thresholds that may flip the system into a different ecological state (Folke et al. 2002a). However, what is unclear from these shifts is whether the erosion of nature's support capacity will lead to even further vulnerability of the social system in Msasani Bay. The three key variables of 'disaster' in the 'pressure and release' vulnerability model (Wisner et al. 2003), and of change indicators in the resilience adaptive cycle (Holling 1986) have significant implications for the sustainability of the SES. The multi-scaled assessment has facilitated a more comprehensive account (Miller et al. 2010) of the impacts of sewage and wastewater pollution, through discussion of the socio-political factors involved, and the ecological aspects of system functioning in Msasani Bay, further supported by faecal coliform and nutrient analysis. This discussion of slow and fast ecological changes and a contextual, historical institutional analysis provides a way in which to better understand the social dimensions of the SES.

What is needed to reconceptualise the SES's management is to remove the human simplification of the landscape and seascape (Gunderson & Holling 2002), and recognise the interdependencies between the two systems. Moreover, complexity and diversity of the system must be fostered so as to reorganise and renew current conditions (Folke et al. 2002b; Berkes et al. 2003). From a better understanding of the system's diversity, adaptation and learning could be encouraged (Folke et al. 2002b) whereby social-ecological memory could be enhanced and the likelihood of effective response improved. In the same way, improved

education could stimulate engagement and broaden effective participation in the community (Simonsen et al. 2014).

With the same complexity of the SES of which it manages, governance of the Msasani Bay SES should be multi-tiered and polycentric to enhance the variety of response and reduce uniformity of regulation (Ostrom 1998). Management legislation (and more importantly, wastewater treatment) should be localised to the district or ward level so as to improve effectiveness of governmental institutions and attempt to service those locations that are most at risk (Ostrom 1998). Furthermore, national and regional institutional roles and responsibilities should be redefined so that realistic and area-specific policy can be formulated and implemented, and environmental remediation is available to households, fishers and other actors who depend upon its functionality. Learning to manage and live with the inevitability of change and uncertainty (Folke et al. 2002b; Berkes et al. 2003) increases the viability of the human-environmental system in Msasani Bay, whereby vulnerability can be reduced and resilience enhanced.

5. CONCLUSIONS

This study has illustrated the impacts and complexities of the sewage and wastewater situation in Msasani Bay, Dar es Salaam. Its historical and contemporary analysis of the effect of discharges on coastal ecosystems and human communities has demonstrated the presence of serious water pollution of the bay. By not prioritising ecosystem health and allowing haphazard sewage and wastewater discharges, the Government and its institutions have failed in their roles and responsibilities to protect citizens' rights to a clean, safe and healthy environment. This has meant that water pollution levels in rivers and the Bay are excessive, and when combined with the annual hazard of floods, Msasani Bay's SES experiences significant pressures that challenge its effective functioning. This has given rise to three key system variables that indicate the heightened vulnerability and low-level of resilience of the SES. Categorised in this study as lives and livelihood destruction, diseases spread, and a major loss of biodiversity, the variables indicate changes past and present, representing the increasingly perilous future of the system if left unaddressed.

Tanzania's post-Independence political and economic circumstances have evidently imposed constraints on its Government's ability to function efficiently in terms of providing basic sewerage and wastewater services and addressing the effects these have on the functional integrity of its ecosystems. Thus to ensure the future viability of the Msasani Bay SES, it is critical to address issues of corruption, inadequate town planning, ineffectiveness of sanitation services and environmental monitoring, and unrealistic policies. Short-term and disconnected thinking have limited the capacity of leadership and governmental institutions to look beyond current conditions and to instead focus on the underlying causes of water pollution. This way of thinking has resulted in inappropriate investments and misspent funds. In light of this, it is essential to reduce the rigidity of institutional frameworks for sewerage and wastewater and develop polycentric governance for collective action and transparency, with particular focus on investments in location-specific sewerage systems. The present situation of sewage and wastewater pollution in Msasani Bay (and throughout other areas in the city) deserves much higher prioritisation than it currently receives. The population's wellbeing and the ecosystem's sustainability depend on it.

5.1 The Way Forward

This study has provided evidence of high vulnerability and limited resilience of the human community and marine ecosystems in Msasani Bay. So as to absorb disturbance, to adapt and manage future adversity, it is essential that citizens and various levels of government come together to develop social-ecological memory and build the resilience that enhances a sustainable SES. The following recommendations are drawn from my interpretations of the challenges that face the system.

Firstly, there is an acute need for more studies to be conducted, most importantly on this topic, but also in this location. Due to the lack of data on water quality in Msasani Bay and also Dar es Salaam, longitudinal studies with data recorded over frequent time intervals would provide a better understanding and facilitate monitoring of water quality levels. Such statistics could supply governmental departments and institutions, such as the Ministry of Health and Social Welfare, with greater access to information and increased potential to determine and communicate (in collaboration with other Government ministries) the safety of beaches and rivers for public access.

Secondly, simple, robust, low cost technologies, such as natural systems (i.e. constructed wetlands) have potential for areas of Dar es Salaam. Constructed wetlands have high treatment performance, and when coupled with ponds, virus removal efficiency is high (Kivaisi 2001; Jenssen 2013a). If all relevant factors are considered, such systems may be suitable. These factors could include porous media and plants selected, wastewater inputs (domestic only), and location of the system in terms of soil type, neighbouring communities, and the area size required. During the rainy season in Dar es Salaam, sewage overflows are especially common, and improved drainage is therefore essential. Natural treatment systems also present a viable alternative as overflow contingency mechanisms: "due to the unpredictable flow of wastewater, most conventional purification systems are not suitable. The use of vegetated wetlands provides an alternative for collecting overflow water and purifying it" (Jenssen & Vatn 1997: 324). Natural systems have the greatest potential in the surrounds of the city (less densely populated areas) and on sizeable private plots inner city. It may also be favourable to construct shared systems among neighbours and even wards or villages. Natural system projects should be driven solely by communities under guidance and

support of local expertise, with potential for knowledge growth through research exchange, both in-country and internationally. Lessons learned from past projects should also be taken into account, for example 'Pumpsea' project that tested mangrove potential for domestic sewage filtration with the main component in Tanzania, although this project was unfortunately not followed through. In summary, investment in ecosystem services is known to produce significant long-term economic savings in wastewater treatment.

Thirdly, the reuse of wastewater for fertiliser is drastically underutilised internationally. There is particular potential for closed loop nutrient recycling in tropical climates such as Tanzania, due to the low residence time of wastewater before agricultural re-usage. The value of plant nutrients discharged to sewers, such as nitrogen and phosphorus, represents an economic loss (which could thus easily be transformed into a gain), but more importantly, the likely adverse effects on the environments that receive these enriched wastewaters (Jenssen 2013b). Water pollution into the SES of Msasani Bay underscores the necessity for better practices and increased innovation for domestic wastewater treatment and reuse.

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APPENDICES

Appendix 1: Household Demographics

Low Income	1	2	3	4	5	6	7	8	9	11	12	13	14	15	16	17	18
Age	30	32	30	37	34	35	32	19	45	24	28	21	35	28	18	33	22
Gender	M	M	M	F	F	M	F	F	M	M	F	F	F	F	M	M	F
# of People in Household	4	4	15	9	-	25	5	6	N/A	3	2	8	3	5	2	8	7
Time in Current Home	0.5	32	24	14	3	35	13	19	10	2	0.4	6	3	3	0.5	3	4
Tenant vs Owner	T	T	O	O	T	O	T	O	O	T	T	T	T	T	T	T	O

High Income	10	19	20	21	22	23	24	25	26	27
Age	67	31	70	53	52	60	69	40	22	48
Gender	F	F	F	M	M	M	F	M	M	M
# of People in Household	4	3	3	3	10	4	3	4	10	6
Time in Current Home	30	1.2	10	15	5	20	17	1	1	5
Tenant vs Owner	O	T	O	O	T	O	O	O	T	O

Appendix 2: Water Sampling Tables

	25 October: 5 Pre-Test Samples					26 October: 4 Comparative Samples			
Sample	1	2	3	4	5	1	2	1	2
Location [1]	Kijitonyama	0.2	0.4	0.6	0.8	Mbudya[2]	Mbudya	WS Hotel[3]	WS Hotel
Ecoli[4]	TNTC	TNTC	TNTC	TNTC	TNTC	0	0	1	0
TC (1sq)	-	-	-	-	-	-	-	-	-
TC Total	TNTC	TNTC	TNTC	TNTC	TNTC	17	17	104	110

[1] Location in km from Kijitonyama River [2] Mbudya Island [3] White Sands Hotel, Kunduchi [4] CFU/1 ml

27 October: 20 Samples for Salinity, P, *E. coli* & TC Analysis

Sample	1	2	3	4[2]	5	6	7	8	9	10
Location	Kijitonyama	Kijitonyama	0.21	0.61	0.81	1.01	Nyirenda	1.21	1.41	1.61
Ecoli[3]	TNTC	TNTC	51	*	*	25	TNTC	51	129	45
TC (1sq)	-	-	70	*	*	25		21	34	28
TC Total	TNTC	TNTC	1400	*	*	500	TNTC	420	680	560

Sample	11	12	13	14	15	16	17	18	19	20
Location[1]	1.81	2.01	Kawe	2.21	2.41	2.61	2.81	3.01	3.21	2.41
Ecoli[3]	87	32	90	118	128	113	93	107	74	68
TC (1sq)	27	30	76	51	44	54	43	48	49	28
TC Total	540	600	1520	1020	880	1080	860	960	980	560

[*] Discarded Sample [1] Location in km from Kijitonyama River [2] Note sample 0.41 km not collected [3] CFU/1 ml

	28 October: Mlalakuwa River Samples				6 November: Additional Samples					
Sample	1	2	3	4	1	2	3	4	5	6
Location[1]	Mlalakuwa	Mlalakuwa	Mlalakuwa	Mlalakuwa	Offshore 1 km	Offshore 1 km	0.41	0.41	Kijitonyama	Kijitonyama
Ecoli[2]	TNTC	TNTC	TNTC	TNTC	0	0	30	32	TNTC	TNTC
TC (1sq)	-	-	-	-	-	-	18	28	-	-
TC Total	TNTC	TNTC	TNTC	TNTC	42	88	360	560	TNTC	TNTC

[1] Location in km from Kijitonyama River [2] CFU/1 ml

Appendix 3: Interview Guides

Household Interview Guide

Age Female / Male

1. How long have you been living in your current house? Do you rent or own it?
2. How many people live here permanently?
3. Can you tell me about the sewage system in your house:
   -type of toilet?
   -connected to the central sewerage system?
   -does the toilet water go in same pipe as the greywater (toilet vs rest of house)?
4. Would you prefer to be connected to the city sewerage system (if not already)?
   -Why/ why not?
5. Can you afford to pay to be connected to the city sewerage system?
6. Are you concerned about the sanitation of your household and ward?
   - Do you think it affects your family's health?
7. What do you think about this stream (HERE)?
8. Have you ever experienced flooding in your house? Can you tell me about it?
   -How often?
   -For what duration?
   - Severity?
   - How long has this been the case?
   -Do you think that affects your family's health?
9. Does your household come into contact with flooding in this ward during the year? i.e. do you walk through it? (IF APPLICABLE)
10. Which period in the year is your family normally sick?
    -increase in rainy season?
    -what kind of sickness?
    -why do you think this is?
11. Have you ever seen anyone dumping liquids (sewage, chemicals etc) into a river/ ocean / stormwater drain?
12. Do you think there would be social or environmental benefits to (better) treating wastewater in Mikocheni/Msasani?
13. Do you use the beach in Msasani Bay?
    -What for? E.g. recreation, fishing?

14. What is your opinion of the water there? Is it clean? Safe?
    Was it always like this?
15. Does the water change at different times of the year?
    -Which period appears to be cleaner/safer/dirty/less safe?
16. Are there any indicators you look for in assessing the safety of the water?
17. If the situation stays the same, will you continue using your current sewage system?
18. Can you think of any improvements to the Kinondoni wastewater systems?
19. Would education make a difference?

Fishers Interview Guide

Age Female / Male

1. How long have you been fishing in this area? Where do you fish?
2. What is your opinion of the water in Msasani Bay? Is it clean? Safe?
   -was it always like this?
3. Does the water change at different times of the year?
   -Which period appears to be cleaner/safer?
   -Which period appears to be dirty/less safe?
4. Are there any indicators you look for in assessing the safety of the water?
5. Have the fish changed over the last 10 years?
   -In what way? >>quantity/quality (appearance/taste)??
6. Do you notice any other marine changes? i.e. algae?
7. Do you have alternative fishing locations?
8. Do you sell the fish you catch or take it home to your family?
9. If take home, has anyone ever gotten sick from eating fish (etc)?
   -can you tell me about that
10. Have you ever seen anyone dumping liquids (sewage, chemicals etc) into a river/ ocean / stormwater drain?
11. What do you think could be done to improve the rivers/drains in Msasani/Mikocheni?
12. Can you think of any improvements to Kinondoni wastewater systems?

Industry Interview Guide

Company Position Female / Male

1. How long has the business been located here?
2. What type of sewage system do you have onsite? /Connected to central system?
3. Are there Government requirements that regulate your wastewater output?
4. Is it expensive to comply?
5. Are the requirements possible?
6. Do you think that the Government is doing enough to help you manage your wastewater?
7. If Government enforced/made stricter the requirements, what kind of an impact would compliance have on your business?
   -would you be able to comply (treating wastewater) without increasing your prices
   -could you remain competitive?
8. Have you considered upgrading your facilities (to *better* treat wastewater)?
9. Would more modern technology improve your wastewater output?
10. Are these technologies available? Expensive? Impractical?
11. Have you ever experienced flooding onsite? When? Frequent?
12. Do you think there is a problem with **household** sewage and wastewater discharges in this area (Mikocheni/Msasani)?
13. Do you think the Government should improve the Wards' wastewater system?
14. What do you see as the most challenging issues for wastewater in Msasani Bay area?
    - Social - Environmental

Health Clinics Interview Guide

Company Position F / M

1. What is your opinion of the water in Msasani Bay? Is it clean? Safe?
   -was it always like this?
2. Does the water change at different times of the year?
   -Which period appears to be cleaner/safer?
   -Which period appears to be dirty/less safe?
3. Do you think contact with this water affects people's health?
4. Can you tell me about flooding in the Mikocheni area:
   -Is it a regular problem? Frequency?

-Do you think it affects people's health?

5. Which period in the year is generally worse for people's health?

   -Increase in rainy season?

   -Typical sicknesses?

6. Do you think there are there environmental problems that result from the current sewage and wastewater discharges into Msasani Bay?

   -What?

   -Do they impact on people's health?

7. Are there social problems that result from these poorly treated discharges? E.g. jobs
8. Is the sanitation of the Msasani Bay area concerning?

   - Do you think it affects people's health?

9. What do you see as the most challenging issues for sanitation and wastewater in Msasani Bay area?
10. Do you think education would make a difference?

DAWASA Interview Guide

1. I saw on Monday there was a newspaper article about the plan to construct 3 sewage treatment plants to process 80% of the city's wastewater in Mbezi Beach, Kurasini & Janwani. (Article written in January 2010 stating same thing)

   a. Can you tell me the timeframe for when these 3 plants will be built?
   b. Do you know the technology that will be utilised? The article mentioned a bio-digester?
   c. Are there any additional plans for sewage treatment in the city?

2. Can you tell me about the current system for wastewater in Kinondoni?
   d. Some problems with the wastewater treatment ponds in Mikocheni. Can you tell me about that?
   e. What are the reasons for disuse?
   f. I understand that unlawful wastewater discharges are an issue. Does non-compliance come from industry or residential?
   g. What do you believe are the main reasons for this?
   h. Is there community concern?
   i. Are there environmental problems that result from the current sewage and wastewater discharges into Msasani Bay?
   j. Are there social problems that result from these discharges?

   k. Can you tell me about the system for industries in Mikocheni? (Sewage & WW)
   l. Have you had discussions with them?

m. What attitudes did you encounter?
n. What concerns do they raise?
o. Do they comply?
p. What is the level of compliance?
q. Why?

3. What do you think about the Environmental Management Act 2004?
   r. Is it applicable to DAWASA?
   s. Are there any problems with it?
   t. Is it relevant for Tanzania? (copied EU regulations?)
   u. Do you have adequate resources to be able to implement these policies?

4. Is there a problem with sewage and WW when it floods in Mikocheni?
   v. What is DAWASA'S role in the road and drainage upgrade at Mikocheni Shoppers Plaza for instance?

NEMC Interview Guide

1. What is the role of the directorate?
2. Do you have enough resources to be effective/implement?
3. What do you think about the Environmental Management Act?
   -any problems with it?
   -is it relevant for Tanzania (too developed/European)?
4. What does your directorate focus on/campaigns?
5. Are there any programs or campaigns carried out in Kinondoni?
   -RE wastewater/sewage
6. Is there industry awareness?
7. Is there the potential for industry to collaborate with you?
8. What do you know about the current sewage system in Kinondoni?
   -problems?

Appendix 4: Selected Photos of Field Sites


Industrial Wastewater in the Mikocheni B Light Industrial Area

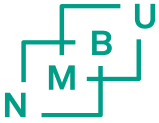

Msasani Bay, algae, and discoloured waves from industrial wastewater in Nyirenda River

Kijitonyama River, separating the low and high income households

Kijitonyama River mouth, Msasani Bay

A Mikocheni waste stabilisation pond in a state of disrepair

Photo Credits: Wilson 2014



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