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Cities with Mosquitoes: A Political Ecology of *Aedes Aegypti's* Habitats

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ABSTRACT: Both urbanisation and climate change have been linked to the ecological success of *Aedes aegypti*. These mosquitoes, which breed in stored and stagnant water, are the primary vectors of dengue, chikungunya and Zika, diseases that have been increasingly affecting populations in the Global South. Addressing this problem requires a wider understanding of habitats favourable to the breeding of *Aedes aegypti* as they are made and remade in the city. Through interviews and archival work documenting the histories and routines of water storage, this exploratory study examines the formation of suitable mosquito habitats in six neighbourhoods of Maputo, Mozambique. The paper has been inspired by debates on urban political ecology to delve into the transformations that water undergoes once it is stored in and around homes. We document the interrelatedness between socio-economic characteristics (in contexts of unequal urbanisation) with physico-chemical changes of stored water, as it becomes a suitable mosquito habitat.

KEYWORDS: Stored water, habitats favourable to *Aedes aegypti*, political ecology, Maputo, Mozambique

INTRODUCTION

The particular ecology and life cycle of the *Aedes aegypti* mosquito favours its abundance and prevalence in urbanising areas (Gubler, 2011). These mosquitoes breed in stored and stagnant water and need human density to feed; they are the primary vectors of dengue, chikungunya and Zika, diseases that have been increasingly affecting populations in the Global South (Beaty et al., 2016). When a mosquito feeds on the blood of an infected person, that mosquito becomes a vector; it will remain infected with the respective virus and continue transmitting the disease to healthy people for the rest of its lifespan (Paixão et al., 2017). Viewed from the life cycle of *Ae. aegypti*, these diseases are transmitted when humans to bite and breeding sites are available. Female mosquitoes use human blood to produce eggs; they then lay these eggs inside water containers, above the water line (Beaty et al., 2016). Research has also warned that climate change may increase the proliferation of the mosquito *Ae. aegypti* in new areas as rising ambient temperatures can affect the temperature and distribution of stagnant water (Hunter, 2003; Githeko et al., 2000).

Studies on public knowledge about, attitudes towards, and practices regarding vector-borne diseases have been criticised for treating water "simply as a neutral and generic medium for mosquito breeding"

(Harris and Carter, 2019: 336). Treating water as a generic medium for mosquito breeding overlooks the fact that water distribution reflects and reinforces power relations and is charged with political and cultural meaning (Gandy, 2008; Zwarteveen et al., 2017); moreover, taking that approach does not consider the specific material characteristics that make only some water attractive to mosquitoes. Scholars have explained how *Ae. aegypti* larvae will only thrive when mosquitoes can access stagnant water with appropriate aquatic conditions in terms of temperature and organic material content (Christophers, 1960; Overgaard et al., 2017; Gubler, 2011; Romero-Vivas et al., 2006). Although *Ae. aegypti* can reproduce in stagnant water found in solid waste and drainage infrastructure, there is documentation of the way in which storage containers for domestic water contribute to higher percentages of the total *Ae. aegypti* pupal population (Romero-Vivas et al., 2006; Romero-Vivas and Falconar, 2005; Lutomiah et al., 2016).

This calls for a more precise understanding of *Ae. aegypti*'s habitats as they are made and remade in the city; what is specifically required is an account of both the socio-economic dynamics informing patterns of water distribution and storage and the biophysical characteristics that make some stored water more attractive to these insects. Through qualitative work that documents the histories and routines of water storage and the ecological characterisations of water containers, this study examines the formation of suitable mosquito habitats in six neighbourhoods of Maputo, the capital city of Mozambique, where the presence of *Ae. aegypti* was reported in 2015 and 2016 (Abílio et al., 2018; Kampango and Abílio, 2016). We focus on the particular conditions that influence the formation of habitats favourable to *Ae. aegypti*, such as the availability of stored water, the existence of specific water characteristics, and the proximity of humans.

The paper has been inspired by debates on urban political ecology to delve into the transformations that water undergoes once it is stored in and around households. We document the interrelatedness between socio-economic characteristics (in contexts of unequal urbanisation) and physico-chemical changes of water, as it transforms into suitable mosquito habitats only once it gets stored.

EXPLORING STORED WATER THROUGH URBAN POLITICAL ECOLOGY

Political ecological analyses are empirical research-based explorations that aim to explain linkages in the condition and change of socio-environmental systems, with explicit consideration of power relations (Rademacher, 2015; Peet et al., 2011). It is an approach that studies the relationships between humans and their biophysical environment; according to Robbins (2012: 94), "Non-human objects (elk, ice-makers, fungi), as well as human beings themselves, contain and are constituted by their relations to other things. So too, they are always becoming something else, precisely through their relating".

An urban political ecology approach understands the production of urban natures to be uneven, deeply political, and highly contested processes (Swyngedouw, 2004; Gandy, 2002; Rademacher, 2015). In this paper, we follow calls to put the active capacities of biophysical processes at the centre of political ecological analyses. We aim to distance ourselves from studies in which the social and discursive politics of access and control over resources takes centre stage while biophysical ecological implications receive little explicit attention (Walker, 2005; Braun, 2005; Gabriel, 2014). Our approach, instead, calls for an explicit recognition of materiality, that is to say, an acknowledgement that the biophysical environment is not composed of "pre-given substrates" (Bakker, 2012: 621) that may facilitate or constrain social action; instead, the materiality of resources interacts with human actions, frequently producing unintended consequences that may be sources of unpredictability and unruliness. Political ecology should therefore account for a co-production of socio-natures in which humans and non-humans alike participate, "albeit unevenly, and subject to dynamic and evolving constraints" (Bakker and Bridge, 2006: 19).

Taking these approaches into account, we remain conscious of power relations and inequalities and understand the connections of these power relations to the biophysical environment. Political ecological works have analysed different socio-ecological processes that produce uneven water distributions in the city. Authors documenting everyday life in the urban South have described the ways in which power relations influence the flow and pressure of water throughout different neighbourhoods, and the ways in which communities outside of formal networks manage to obtain water (Anand, 2011, 2017; Gandy, 2008; Von Schnitzler, 2017; Acevedo-Guerrero, 2019). While these analyses have concentrated on portraying the uneven distribution of infrastructure and water quantity, others have focused on the political ecology of water quality (Sultana, 2011; Boakye-Ansah et al., 2016). Rusca et al. (2017: 138) have highlighted the need for studies on the quality of water in the Global South, arguing that an interdisciplinary approach that underlines the entanglement of politics and power, and the physico-chemical and microbiological contamination of drinking water, "can further our understandings of both uneven distribution of water contamination and the conceptualisation of inequalities in the urban waterscape".

In this paper, we contend that studies on the political ecology of urban water quality and distribution could benefit from incorporating a question about the ability of stored water to serve as a habitat for mosquitoes. In order to examine the formation of favourable mosquito habitats, we use mixed methods to delve into the transformations that water undergoes once it is stored in and around homes. We draw attention to the characteristics of water itself; we consider not only the ways in which these characteristics can reflect the socio-economic inequities in cities, but also the ways in which they can reinforce inequities. This implies an acknowledgement of the different materialities of water as possible sources of unpredictability, unruliness and resistance to human intentions (Bakker, 2010). Water, for example, is a flow resource; it is not easily bounded above or below ground and is a substance through which externalities such as pollution are easily diffused (Bakker, 2004, 2010). Stored water, under specific conditions, also provides mosquitoes with a place to lay eggs, grow and develop through their water stages (egg, larval and pupal) (Higa et al., 2015). We document the interrelatedness of socio-economic inequities and the physico-chemical changes of water, as it transforms into suitable mosquito habitats only once it is stored. The paper aims to contribute to political ecological accounts of water urbanisation in the Global South through the inclusion of the role of stored water and mosquitoes.[1] It also aims to contribute to studies on public knowledge about, attitudes towards, and practices regarding, vector-borne disease; such studies have been criticised for their indifference to the social and environmental histories of specific places (Harris and Carter, 2019; Mulligan et al., 2012).

METHODOLOGY

Using mixed methods to document water storage practices

New understandings of the (re)emergence of vector-borne diseases need to consider multiple agents and their persistent interactions (Wilcox, 2005; Padmanabha et al., 2010). This study looks at household-level factors that produce habitats favourable to mosquito breeding (see Nading, 2014; Pinto Garcia, 2016). Our study addresses water storage practices as they are affected by failures in service continuity (see DuChanois et al., 2019; Kumpel and Nelson, 2016); it also characterises habitats favourable to the breeding of *Ae. aegypti* by documenting water storage practices and by analysing some characteristics of stored water itself. This assessment aims to describe the context in which habitats favourable to *Ae. aegypti* might emerge.

It is important to mention that this is not an entomological study and that it focuses on the *possible emergence* of habitats. We draw on the latest entomological survey carried out in Maputo, in which researchers describe the aquatic conditions that contribute to an increase in the numbers of pupal-stage

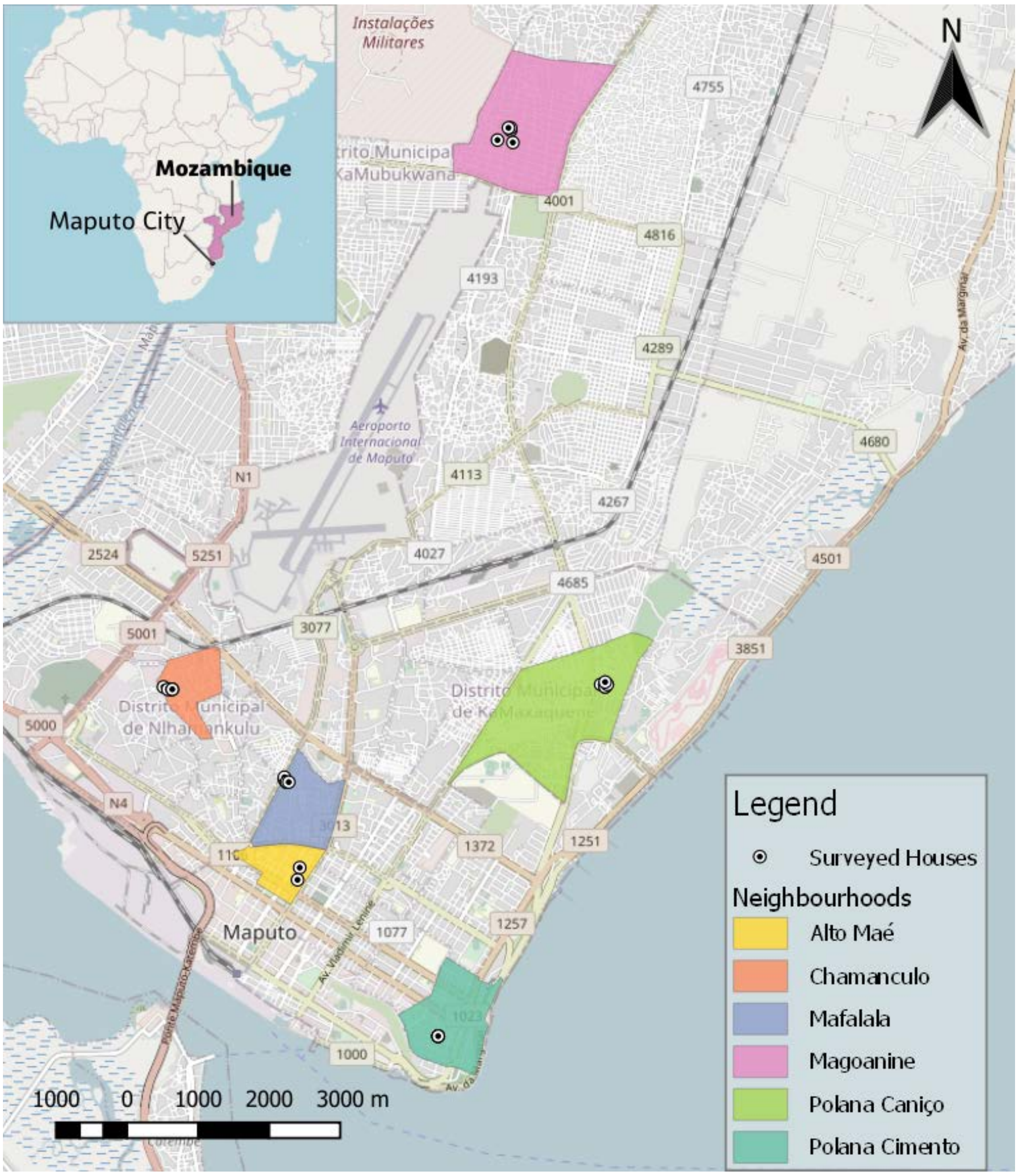
[1] It is important to note how, besides a detailed account of water storage practices and of stored water itself, there is a need for studies that account for the changing behaviour, distribution and population dynamics of insects as they interact with water (see Gandy, 2019).

Ae. aegypti (see Abílio et al., 2018); we also draw on entomological and epidemiological literature on Mozambique and on the Global South in general.

Study area

Specific neighbourhoods of Maputo were chosen and visited based on recent accounts of *Ae. aegypti* sightings and infestations in the city (Abílio et al., 2018); we also aimed to capture a range of socio-economic characteristics, selecting neighbourhoods with high incomes including Alto Maé (AM) and Polana Cimento (PCI*),* and also including lower-income areas such as Chamanculo (CH), Mafalala (MAF), Polana Caniço (PCA), and Magoanine (MG). All areas were visited between November 2017 and February 2018 (Figure 1).

Figure 1. Study area.



Source: Authors

One of the authors has lifelong experience in Maputo and this greatly facilitated the engagement with research participants and with observations grounded in first-hand experience. Participation in this study was voluntary and all participants provided verbal informed consent. All information was kept anonymous and outcomes were used for research purposes only. This study was approved by the president of each block (*chefe de quarteirão)* as well as by the ethical committee of Eduardo Mondlane University.

Data collection

Primary data was gathered during field research in Maputo. Water storage practices were documented via direct observation of water storing habits and through semi-structured interviews with residents in the study area. The economic accessibility of Maputo's water storage tools was assessed by querying market prices of water containers in the commercial areas of the city. The emergence of habitats favourable to *Ae. aegypti* was also characterised via a water container inventory and a temperature assessment of tap and stored water.

The container inventory involved the identification and recording of type, size, material, condition, length of time in use, and household location of water storage containers. Water temperature was measured and recorded during three consecutive visits to each surveyed household; water temperature in all water storage containers in each household was also measured and an average temperature was entered into the report for each of the visits. Measurements were performed using a calibrated electrical conductivity (EC) meter (Greisinger GHM 3400 Series). All measurements took place between 6 and 10 am.

Analysis and integration of results

Data coming from direct observation and in-depth interviews was analysed by summative-content analysis and was contextualised within the history of urbanisation of each neighbourhood. The current unit value of used storage tools was determined by a modified Ross-Heidecke method of valuation; according to this method, an estimation of the economic value of a storage tool was made by taking into account the time it had been in use, its observable condition, and the cost price of a new one (Hincapie, 2015). The temperature of stored and tap water was compared within and between neighbourhoods using one-way analysis of variance (ANOVA). Significant groups of analysis were drawn from Tukey and Fisher tests (n = 78). Interval plots showing neighbourhood means and standard deviations were drawn using a confidence interval of 95% with $\alpha = 0.05$.

WATER AND UNEVEN URBANISATION IN MAPUTO

Urbanisation histories

Mozambique's southern coast became urbanised in the process of developing its ports for ships bringing goods from Europe and for transporting inland resources arriving by rail from the Transvaal network and via the Victoria Falls Bridge (Newit, 2017). In 1799, the Portuguese officially established themselves in what was then known as Delagoa Bay, and in 1898 the city of Lorenço Marques was declared the capital of Mozambique (Jenkins, 2000; Pestana et al., 2014). The city was divided between European and indigenous settlements with Xilunguini, Xchangana[2] for the neighbourhoods inhabited by Portuguese and other Europeans and KaMpfumu, Xchangana for those controlled by the natives. Urbanisation occurred under prescriptive European notions of how the bay swamps should be drained and transformed; this

[2] In Maputo, the most widespread language is Xchangana. Though Portuguese is Mozambique's official language, the country has more than 50 different languages, corresponding to different ethnic groups (Pestana et al., 2014).

resulted in constant expansion of the Xilunguini areas at the expense of the KaMpfumu lands (Honwana, 2017).

The Xilunguini, which today comprises four neighbourhoods including PCI and AM, was built according to a model of a European city; it eventually received the name of "cement city". It consisted of single-family houses and the use of cast iron and masonry for the house façades (Fernandes and Mendes, 2012). Along with the characteristic exterior construction of family compounds and state buildings, the city's water and electricity network was laid out systematically, starting from the train station and port square and going as far as the Rua de Circunvalação, located two kilometres north of the bay (Fernandes and Mendes, 2012). In the eyes of white colonisers, this transformation of the swampy area of the bay changed the city from a "small colonial settlement" into what was described at the time as "one of the most beautiful and fashionable African cities, proud for its cosmopolitan atmosphere and pavement cafes" (Pestana et al., 2014: 76).

While these expansions, refurbishments and developments were taking place in the 'cement city', informal indigenous settlements were starting to develop beyond KaMpfumu lands and beyond the city's limits (Jenkins, 2000). Most Africans residing in Maputo were unpaid labourers working in the railways, ports and in domestic services, in the city centre (Jenkins, 2000). These labourers lived in backyard shacks adjacent to Portuguese homes or in peripheral areas of the city. Native homes outside the cement city grew rapidly and unevenly; small homes were built using readily available reeds from the newly dried swamps or zinc roofs and corrugated tin walls (Fernandes and Mendes, 2012). In 1940, following rising concerns from the ever-growing periphery, the colonial administration launched a project to construct a 'model neighbourhood' that followed the cement city layout. This neighbourhood, known as Munhuana and later as Mafalala (MAF), was built with the intention of providing a "hygienic space" where "the benefits of the civilised colonization could be easily shown to the indigenous communities" (Fernandes and Mendes, 2012: 7).

Migrants from the northern parts of the country who came seeking work settled not only in the so-called model neighbourhood of MAF*,* but also in informal settlements adjacent to it, Chamanculo and Polana Caniço; their native customary behaviours directed household configurations. Officially land tenancy was only granted to the *assimilado*[3] head of the family, but with the arrival of new family members to the city, plots of land were divided into smaller quartiers. This trend changed the original radial outline of neighbourhoods and redrew them into intricate alleys; there, individually owned land transformed into common spaces where families gathered to share meals, discuss political issues, or engage in cultural activities (Jenkins, 2009; Fernandes and Mendes, 2012). The expansion of the cement city's periphery thus followed both European plans and social structures that were mainly guided by local customs such as the passing on of land through the matrilineal line (Fernandes and Mendes, 2012).

World War II had diverse effects on Mozambican history, bringing more than 160,000 Portuguese immigrants into Maputo (Jenkins, 2000). Throughout the 1960s, the fascist Estado Novo regime in Portugal kept military control over Mozambique and confronted the Mozambique Liberation Front (Frelimo), a movement which was fighting for the country's independence. By the early 1970s, the Frelimo insurgency had mobilised an army of approximately 7000 people and had taken control of some parts of central and northern Mozambique. In 1974, the Portuguese leftist *Carnation Revolution* overthrew the Estado Novo regime and, in Mozambique, independence was declared in 1975 (Nylen, 2014; Newit, 2017). The capital's name was changed to Maputo, honouring one of the country's most significant chiefdoms (Newit, 2017).

[3] From the 1910s to the 1960s, *assimilado* was the status given to certain African men of the colonial Portuguese Empire; it was a designation that indicated they had reached a level of "European civilisation". The Legislative Decree No. 39.666, Of May 20, 1954 defined the requirements African men had to fulfil to acquire this status; they included: conversion to Catholicism, having stable employment, and knowing how to read and write Portuguese. Implementation of the assimilado status gave rise to much confusion, and the requirements often included ramdom requisites such as wearing European clothes and shoes (Newit, 2017; Pestana et al., 2014).

Soon after independence, the Mozambican National Resistance (Renamo) led an armed campaign against Frelimo; this resulted in a 16-year civil war that impoverished, killed and displaced millions of Mozambicans, many of whom found refuge in Maputo (Nylen, 2014; Emmerson, 2013; Andersen et al., 2016). After independence in 1975 the urbanisation of Mozambique accelerated, especially during the years of the civil war; low-income neighbourhoods, in particular, received large numbers of displaced people during that period (Vivet, 2015). War, forced displacement, and a lack of investment in Maputo's infrastructure resulted in inoperative drainage systems, a major solid waste crisis, inadequate water and sanitation services, and deficient land planning that was characterised by informal land tenure and speculation (Sumich, 2008; Honwana, 2017).

Since the signing of a peace agreement in 1992, six democratic elections for presidency and legislature have been held and Frelimo has maintained national power in all of them (Andersen et al., 2016). After the war, government and international donors focused their attention on rural reconstruction and, in line with global trends, decentralisation policies have transferred planning responsibilities to municipalities (Monteiro et al., 2017). In the last two decades, a number of development projects have been implemented in Maputo to extend water, sanitation, transportation and energy infrastructure to previously peripheral neighbourhoods (Monteiro et al., 2017). Maputo aims to be a city of development, growth and private investment, as shown by its high contribution to the national gross domestic product (40%); however, it is also a city with important spatial inequalities, as an imbalanced growth path has disproportionally benefitted higher-income neighbourhoods (Bowen and Helling, 2011; Gradín and Tarp, 2019). Economic growth thus benefits primarily economic and political elites; most of Maputo's neighbourhoods face youth unemployment and those that do have jobs are employed in the informal sector. The 2017 census identified a population of 1,101,170 inhabitants in Maputo of which more than half were living under the poverty line, that is, on less than US$1.90 a day[4] (National Institute of Statistics INE, 2017). The city also has the highest Gini coefficient (which measures income inequality) in the country (0.582) (Gradín and Tarp, 2019). Approximately 70% of the city's population currently lives in informal settlements characterised by high density and insufficient access to infrastructure (Ahlers et al., 2013).

Wealth and water in Maputo

Contemporary Maputo maintains decentralised leadership structures, with a democratically elected city mayor collaborating with an executive council and a number of neighbourhood bodies.[5] The socio-economic conditions of Maputo's neighbourhoods translate into spatial inequalities. Central neighbourhoods in what used to be called the cement city, such as PCI and AM, accumulate high income and have good access to water services, development opportunities, commercial activities, leisure, and spaces holding high symbolic value for the city and the country (Chavana, 2009). PCI is an upper class neighbourhood with buildings and gated communities where expats and political and economic elites live; it is also an economic and cultural hub of the city, being home to university departments, restaurants, museums, art galleries, shopping malls, high schools, hospitals and hotels. AM is a densely populated neighbourhood which, besides being home to many upper- and middle-income families living in houses and apartment buildings, hosts multiple malls, office buildings, churches and schools.

Beyond the central, former cement city, neighbourhoods display different characteristics. CH and MAF, adjacent to the cement city, are the densest and most populated neighbourhoods in Maputo. There, houses are usually made from corrugated tin, wood and artisanal cement blocks; basic services are not fully available and, while water pipes are laid above ground, sanitation infrastructure overflows

[4] All monetary values have been converted to 2020 US dollars.
[5] The city is divided into seven districts; districts are comprised of several neighbourhoods (*bairros communais*) which are run under the supervision of a director. In each neighbourhood, blocks of 50 to 100 houses are grouped into *quarteirãos*, each one led by a chief, or *chefe de quarteirão* (Ginisty and Vivet, 2012).

regularly. PCA, in contrast, has recently gained more access to basic services, but residents fear that prices in the area will increase with the advance of housing developments and gated communities. Further away from the city centre, peri-urban MG is less dense, hosts extended-family plots and self-built infrastructure, and has enough space for people to own horticultural urban gardens.

Current policies and regulations are evidence of the country's efforts to provide water and sanitation in urban areas. The Delegated Management Framework, introduced in 1998, gave way to decentralisation and private sector participation (Tutusaus Luque, 2013); under this framework, the Ministries of Public Housing and Finances contracted water supply and distribution to a private entity, the Water Supply Investment and Asset Fund, or FIPAG, which in turn manages water provision through smaller municipal entities; Aguas de Regiao de Maputo (AdeM) supplies water to Maputo (see Schwartz et al., 2015; Barca-Alves, 2015). The Council for Regulation of Water Supply was also created in 1998, to regulate water supply operations as well as of consumer tariffs, quality of services, and water network expansion (Water and Sanitation Program, 2011). These interventions have, however, fallen short in their response to the problematic of having a fragmented infrastructure; the old cement city and its adjacent neighbourhoods are serviced by AdeM while a growing lower-income periphery relies on different types of solutions to obtain water (Ahlers et al., 2013). Maputo's water services can be described as a mosaic of arrangements, with public, private, formal and informal water provision occurring in different urban spaces (Ahlers et al., 2014; Ahlers et al., 2013).

The city receives water from various suppliers and sources; some comes from the Umbeluzi River and some from the Pequenos Libombos Dam, while yet another source is the Great Maputo aquifer system (Tutusaus Luque, 2013). About 55% of Maputo's households receive tap water via piped networks and, of these, 16% have water inside their houses and the remaining 39% have backyard or outside taps; 29% of Maputo's households have flush toilets connected to septic tanks, while 36% use latrines. While metropolitan Maputo requires 260,000 cubic metres of water per day (m^3/day), the Umbeluzi treatment plant has a maximum capacity of only 240,000 m^3/day; moreover, between 35 and 40% of water is lost due to leaks along the distribution network, which is comprised of 1154 km of water pipes and 7 distribution centres (MOPH and FIPAG, 2011).

The 2014-2017 drought in the Umbeluzi River Basin critically lowered the water levels in the Pequenos Libombos Dam; AdeM has, as a consequence, been providing intermittent service, with its clients receiving water in their taps for less than five hours per day, if at all (Galaitsi et al., 2016). An intermittent water supply is both a cause and a symptom of what has been called the "spiral of decline"; this refers to a situation where the lack of 24/7 water service provision discourages end users from paying for water services; this, in turn, hinders the financial viability of water utilities, which become no longer able to operate and maintain water infrastructure; this again creates the conditions for poor service delivery (Subbaraman et al., 2015; Galaitsi et al., 2016). Users of intermittent water supply also risk being exposed to increased microbial contamination and microbial regrowth during stagnant periods (Bivins et al., 2017) because, ultimately, intermittency forces people to store water inside and around their homes, where water safety levels tend to drop after a few days of compromised service (see DuChanois et al., 2019; Galaitsi et al., 2016).

The void left by AdeM in peri-urban areas of the city is filled by independent water providers and water tankers, which usually sell groundwater; the latter thus constitute an alternative actor in the urban water-provision scheme. These independent water providers deliver water on a full cost recovery basis and are demand responsive (Ahlers et al., 2013). Neither the water services they provide nor their tariffs are actively regulated and therefore services can be intermittent and the prices they charge can be higher than the volumetric fees charged by the centralised water utility (Jimenez-Redal, 2014; Schwartz et al., 2015).

WATER STORAGE PRACTICES AND HABITATS FAVOURABLE TO THE BREEDING OF AEDES AEGYPTI

Socio-economic conditions and intermittent water supply shape water storage practices

Residents of PCI and AM have readily available water taps and sewerage networks. MAF, CH and PCA – neighbourhoods where water services were extended after people settled – are characterised by intricate alleys and constant subdivision of land into smaller and smaller plots. Most of them have water taps located outside their homes; in CH, for example, half of the population has a water tap on their land, while the other half uses communal water taps or buys water from neighbours. Despite having water mains available in the neighbourhood, some households cannot afford the cost of installing the connecting infrastructure, that is, buying the pipes, hoses, taps and meters, and paying for installation and connection. Further away from the city centre, independent providers and water tankers provide water services; in MG, for example, people depend on independent providers to source and sell local groundwater.

All neighbourhoods, regardless of their income status and location, experience water intermittency. Water taps run dry at different times in most neighbourhoods as AdeM periodically announces rationing campaigns, and service continuity thus remains uncertain. In MG, water services can be intermittent and also less predictable. In all of Maputo's lower- and middle-income neighbourhoods, availability of water services is restricted to certain hours of the day and certain days of the week and there is thus a widespread need to store water. Practices of water storage vary, however, depending on a household's ability to afford the different storage tools; we witnessed the resulting differences in the material characteristics and placement of the storage container. In what follows, we describe containers in terms of their relative cost, their characteristics (whether they have a lid, and their storage capacity), and their placement within or near the household.

Residents of Maputo store water in bottles, uncovered bowls, plastic jerrycans, buckets with and without lids, barrels with lids, and closed tanks. The use of uncovered bowls and open jerrycans, open or closed buckets, and barrels with lids occurs mainly in lower-income neighbourhoods that are located on former indigenous lands; the use of closed water tanks is less widespread and is concentrated in higher-income neighbourhoods that are located in the former cement city. Table 1 summarises the different characteristics of Maputo's water storage practices.

From our visits to CH, MAF, PCA and MG we identified a notable reliance on buckets (with and without lids) and jerrycans. These typically hold between 15 and 20 litres and once filled with water are mainly located indoors. While some buckets were found with their respective lids, jerrycans were always found open. Another everyday container is the barrel, which is used less commonly but is relevant due to its relatively large storage capacity of up to 200 litres. Barrels are usually made of tin or metal, are commonly found without a lid, and are stored inside kitchens and bedrooms. Other less prevalent containers include bowls and re-used water bottles, both usually found open and placed indoors in kitchens and living rooms. While the unit value of bottles, bowls, buckets and jerrycans oscillates between US$0.13 and US$5, barrels are more expensive, with a unit value of US$17.87.

Residents of CH, MAF and PCA store water mainly during early morning hours, before water 'runs out' at around 8 am. In peri-urban MG, communities store water bought from small-scale infrastructure providers, refilling their storage devices from communal taps at any time of the day. Since residents in these neighbourhoods tend to store water in small quantities, storage tasks take longer and are performed by more than one person in the family, usually mothers and daughters.

Table 1. Catalogue of water storage containers found in Maputo.

Type	Photo	Storage capacity (litres)	Placement in household	Prevalence	Use
Bottles with caps		3	Backyard, kitchen, main room and bedroom	4/91	Cooking and drinking
Uncovered bowls		6	Backyard, kitchen and latrine	17/91	Bathing, cleaning, cooking and drinking
Open plastic jerrycan		20 to 25	Main room, backyard, kitchen and latrine	23/91	Cooking, drinking, cleaning, flushing, and storage
Uncovered bucket		10 to 25	Main room, latrine, backyard and kitchen	12/91	Flushing, bathing, cleaning, cooking and drinking
Covered bucket		10 to 25	Main room, back yard and kitchen	18/91	Flushing, bathing, cleaning, storage, cooking and drinking
Barrel with or without lid		210	Backyard, kitchen, main room and bedroom	12/91	Storage, cleaning, bathing, cooking and flushing
Closed tank		Less than 1500	Rooftop and next to the house	5/91	Storage, cleaning, cooking, bathing and flushing

The use of vertical and horizontal water tanks was found to be less widespread. Tanks usually made of polyethylene hold up to 1500 litres, are fully covered, and are usually located on rooftops and next to the house. Residents from wealthier neighbourhoods such as PCI and AM use these large tanks to store water in bulk, thus bypassing dry taps when service is cut off. The tanks are connected to the household water infrastructure through hoses, and water therefore flows from the taps. These containers require a significant investment as the unit value of water tanks is US$217, which does not include installation fees. In both PCI and AM, service is frequently cut off at 9 am. Storage tasks involve opening and closing a hose, which takes little time and can be performed by fewer people. Buildings with several apartments will sometimes hire a man to both guard the door and perform water storage activities, which may include treating the stored water with commercially sold chlorine.

The widespread use of jerrycans, bowls and buckets in CH, MAF, PCA and MG indicates that these areas have an overall lower water storage capacity. The largest amount of water is stored in the least frequently used storage containers (that is, tanks), which are mostly located in higher-income neighbourhoods. Higher storage capacity thus has to do with the ability to invest in larger closed systems; furthermore, only some houses have house plots large enough or rooftops strong enough to hold large tanks. Household characteristics and the capacity to afford particular storage containers therefore influence how close stored water is to the people using it; while jerrycans, bowls and buckets are placed in close proximity to humans (in bedrooms, main rooms, kitchens and latrines), storage tanks are located further away (on rooftops or outside the home). The varied forms of water storage are also influenced by the legacy of informal urbanisation; memories of the days when water access was much more difficult prompt residents of MG to store multiple water containers, even if cuts are not frequent.

> I came to live to MG a long time ago. At the beginning I had to fetch water and carry it in metal bidons. Ten years ago, my neighbour dug a well and began his (water) business. Since he knew me for all of his life he was kind to let me connect to his well for free. Today we have the water tap, water is very clean (…). I keep a barrel in my room, just in case there is a cut. I store water so we never run out of it (Personal Interview, 20 December 2017).

These water storage features are evidence of the various forms of water access in the city. The large water tanks found in high-income areas signal a type of storage that is focused on maintaining quantities sufficient to compensate for the ubiquitous intermittence; the bottles, bowls, jerrycans and buckets found in lower-income areas reflect habits of storage resulting from the everyday endurance of intermittencies, fragile materials, and human closeness to the water. In this way, we see how urbanisation histories and socio-economic inequities influence storage practices such as container selection. In the next section we will see how, in addition to influencing these practices, they also have some influence on the characteristics of water itself.

Water storage and habitats favourable to mosquitoes

The occurrence of habitats favourable to the breeding of *Aedes aegypti* responds to the convergence of numerous factors. *Aedes* mosquitoes need stagnant water to undergo immature and mature development; in cities like Maputo, where water services are intermittent, stored water can become a habitat that favours their development (Barrera et al., 2011). *Ae. aegypti* uses pockets of water found in solid waste and drainage infrastructure; however, previous studies have shown that storage containers for domestic water contribute to higher percentages of the total *Ae. aegypti* pupal population (Romero-Vivas et al., 2006; Romero-Vivas and Falconar, 2005; Lutomiah et al., 2016). Successful breeding by *Aedes* mosquitoes will depend on stored water availability, the presence of specific water characteristics, and the nearness of humans. Although this study did not entail entomologic surveillance, it aimed to understand the formation of possible habitats that possess these characteristics.

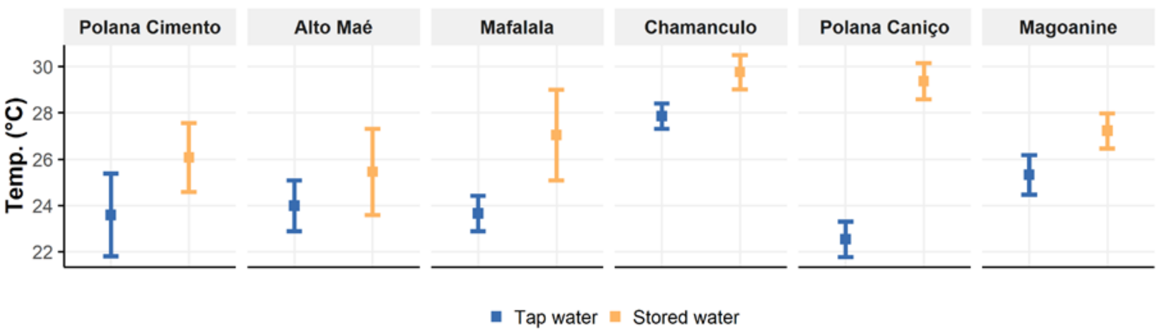
Viable aquatic habitats for *Aedes* mosquitoes require particular conditions of organic material, and temperature (Barrera et al., 2011). In order to conduct our investigation, we first focused on the presence of open containers whose characteristics with regard to organic material, and the presence of mosquitoes rendered them favourable habitats for the reproduction of *Ae. aegypti* (Lutomiah et al., 2016; Romero-Vivas et al., 2006). We found that particularly in *CH, MAF, PCA and MG,* open water storage containers such as bottles, bowls, jerrycans, buckets and barrels made it easy for *Aedes* mosquitoes to breed and become adults.

Second, we noted temperatures since this parameter is pivotal for the successful completion of the *Ae. aegypti* life cycle (Reinhold et al., 2018). Research shows that water temperatures below 10°C and above 45°C prevent or kill the life cycle of the mosquito; furthermore, water between 23°C and 32°C provides *sufficient* habitat conditions for the developmental stages of the mosquito and that, within this range, temperatures around 29°C offer the *optimal* conditions for egg, larval, pupal and mosquito development. Recent research has shown that temperatures of up to 30°C promote a shorter development time from hatching to adult emergence (Gubler, 2011; Overgaard et al., 2017; Gopalakrishnan et al., 2013; Reinhold et al., 2018)

We measured the temperatures of tap water arriving to urban households as compared to that of stored water (Figure 2). The assessment of tap water in the six neighbourhoods of the study showed that CH has the highest tap water temperature (27.85°C ± 0.99°C); this was significantly higher than that of the remaining sites of study, among which there was no statistical difference. Stored water in CH and PCA had the highest temperatures (29.76°C ± 1.34°C and 29.37°C ± 1.4°C, respectively); conversely, stored water temperatures in PCI and AM were the lowest (26.07°C ± 2.3°C and 25.45°C ± 1.77°C, respectively), and were significantly different from those found in the other areas of study (F-value 7.71; $p < 0.05$).

Figure 2 shows the variation in temperature of stored water from area to area, and the difference in temperature between tap water and stored water. It is worth noting that water temperature is linked to size of container, that is, the larger the storage device (large tanks of 500 to 1500 litres) the lower the temperature of the water stored. Stored water in Chamanculo (CH) approaches 30°C, which offers the optimal conditions for egg, larval, pupal and mosquito development; this is consistent with on-site identification of *Aedes* mosquito carcasses and with previous studies on *Aedes* distribution in Maputo (Abílio et al., 2018; Kampango and Abílio, 2016; Massangaie, 2016).

Figure 2. Interval plot of temperature means in six neighbourhoods of Maputo City.



Note: Individual standard deviations were used to calculate intervals; a 95% confidence interval was assessed for means in each neighbourhood; significant differences were assessed using Tukey tests, significance α = 0.05.

Finally, we also documented container placement. Habitats favourable to *Ae. aegypti* will emerge when water storage containers are in close proximity to humans. Mature pupae will emerge from the water, break the pupal skin and ingest air to expand their abdomens. After this eclosion, females need sugar intake and avidly take several blood meals; these provide the proteins and lipids needed for yolk synthesis and formation (Briegel, 2003 ; Rodhain and Rosen, 2001). *Aedes* mosquitoes exhibit day-biting behaviours in alignment with human household activity, that is, in the early morning (5 to 10 am) and in the late afternoon (3 to 8 pm). They take shelter and feed inside households, though they are known to move between indoor and outdoor spaces (Reinhold et al., 2018). The typical flight range of these mosquitoes is short (less than 100 metres) and the dispersal of adult *Ae. aegypti* averages from 30 to 50 metres per day. Females rarely visit more than two or three houses in their lifetime (Getis et al., 2003); therefore, in neighbourhoods such as *CH, MAF, PCA and MG,* where water is stored inside bedrooms and kitchens – places where humans spend significant time – the ubiquitous availability of both humans and water containers may increase the likelihood of high numbers of adult mosquitoes and pupae (Getis et al., 2003; Barrera et al., 1996).

It is important to highlight the way in which histories of urbanisation and socio-economic inequities influence not only the storage practices, but also the characteristics, of water; the most affordable containers such as open jerrycans and buckets, which we found in the households of low-income neighbourhoods such as CH, present favourable habitats for mosquitoes. Water stored in such containers holds organic material, and registers the optimum temperature for mosquito breeding; moreover, the close proximity of both humans and open water containers inside these homes may increase the likelihood of high numbers of adult mosquitoes and pupae. In this sense, the characteristics of this stored water both reflect and reinforce histories of urbanisation and socio-economic inequalities. The presence of *Ae. aegypti* infestations also increases the likelihood of dengue outbreaks; when affecting populations that have historically faced structural inequalities in their access to health and formal labour, these outbreaks can leave them in positions of even greater vulnerability (see Human Rights Watch, 2017; Nading, 2014).

CONCLUSIONS

Ae. aegypti-borne diseases such as dengue, chikungunya and Zika have emerged as important public health threats throughout the Global South, especially in Latin America, Southeast Asia and the Western Pacific (Cecilia, 2014; World Health Organization, 2017). Mozambique and other urbanising African countries have experienced a growing number of cases and a wider geographical spread (see Abílio et al., 2018; Higa et al., 2015; Amarasinghe et al., 2011). Studies have shown climate change and rapid urbanisation to be creating even more suitable habitat conditions for *Ae. aegypti* (Sorensen et al., 2017; Gubler, 2011).

This exploratory article aims to understand the conditions that are favourable to mosquito reproduction; it hopes to open paths to exploring alternatives to controlling mosquito reproduction that are not based solely on the prohibition of generic domestic storage, but instead recognise the diversity of storage practices and the histories behind each storage routine and container. We have documented interconnected processes. First, we examined the historical journey of infrastructural development; this started in colonial Maputo with the building of the cement city and the uneven layout of water infrastructure, and has been reinforced more recently by the lack of investment in low-income neighbourhoods. Second, we considered the everyday routines of water service intermittency that are caused by both the fragmented access to infrastructure and the recent droughts that have affected the utility's reservoir. Third, we looked at the diverse and heterogeneous water storage practices; these practices comprise not only storage routines, but also places of storage (within and around the house) and the variety of water containers. Finally, we explored the different processes taking place inside the container itself.

We focused on the political ecology of stored water in Maputo, that is, on an analysis of the socio-environmental characteristics of water storage with an explicit consideration of relations of power. Everyone stores water in Maputo, but communities store water differently depending on their socio-economic dynamics. Lower-income areas engage in labour intensive water-collecting activities, and store water inside and outside their houses in bottles, bowls, jerrycans and buckets. The large water tanks that are found in high-income areas signal a type of storage that is less labour intensive, where water is stored in bulk in closed containers; commonly, as tanks are usually on the roof, families do not see, or live in proximity to, stored water.

We also delved into the transformations that water undergoes once it is stored, noting how, if left open, containers can accumulate organic matter and breed the larvae of *Ae. aegypti*. We also documented the changes that water temperature undergoes in particular storage containers, in some cases reaching high temperatures (29°C to 30°C) and thus offering the optimal conditions for egg, larval, pupal and mosquito development. Finally, we documented how female *Ae. aegypti* – whose flight range is under 100 metres – may benefit from the proximity of water storage containers to humans. In this sense, the characteristics of stored water in Maputo not only reflect socio-economic inequality, they can also worsen it. Following calls to to put the active capacities of biophysical processes at the centre of political ecological analyses, we gave explicit attention to the characteristics of stored water and to the role that they can play in reinforcing community vulnerabilities (Gabriel, 2014). The thriving of *Ae. aegypti* increases the risk of dengue, chikungunya and Zika outbreaks, which can cause populations in already vulnerable contexts to become even more vulnerable.

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