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Aedes Aegypti—Insights on the Impact of Water Services

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Abstract Epidemics in general and dengue in particular surcharge the health services and the economy. However, the fighting actions are circumscribed to the health sector despite the known positive economic impacts that the investments in water supply and sanitation services (WSS) may cause on society and public health. Besides the fact that urban WSS infrastructure is closely linked to disease prevention, in Brazil, the user's perception and demand are very few and many institutional aspects, like the integration between local WSS, health, environment, and development of city councils, need to be improved and better aligned. In this way, disease control and vector density reduction remain challenges to be overcome. This article addresses the need for greater institutionalization of urban WSS relating them to health aspects from official data. It concludes that the negative impacts of lacking universal access to WSS on dengue and other mosquito diseases are dispersed in all cities, regions, and populations regardless of their degree of development. Furthermore, contrary to what is normally emphasized, the analysis carried out shows that the lack of urban stormwater management systems may be an important component of WSS in preventing the proliferation of dengue disease.

Plain Language Summary From the outbreak of COVID-19, the importance of public health services has been highlighted. However, there are many other diseases that deserve attention as those that arise from the presence of mosquitoes and that are directly related to climate and its changes. This study seeks to correlate data, in Brazil Dengue epidemics with the existing urban infrastructure, especially those related to water supply and sanitation service (WSS), because their absence or insufficiency, and incompleteness propitiates the emergence and proliferation of mosquitoes. The conclusion is that in all urban areas, rich or poor, the problem exists and correlates with the WSS infrastructures. The subject deserves further study and verification in detail of the existing and missing infrastructure and its correlation with the incidence rates of Dengue, Chikungunya and Zika diseases.

1. Introduction

With the pandemic of Coronavirus Disease 2019 (COVID-19), health issues have gained prominence all over the world. The pandemic changed all existing priorities and strengthened the public policies of all countries world-wide, including the provision of essential public services, such as stormwater and water supply and sanitation services (WSSs). Although the impact of this pandemic on public health and the economy of different countries and regions is very high, the impact of other diseases should also be assessed, namely dengue fever, leptospirosis, malaria, and others (Brady & Smith, 2021).

Dengue fever is classified by the World Health Organization (WHO) as one of the 17 neglected diseases, treatable and not curable, with old diagnostics methods and inadequate treatments (WHO, 2017). For these reasons, dengue fever demands investments and developments to become simpler and more effective to treat but it has not aroused much interest from the pharmaceutical industry. In several countries in South America, Africa, and Asia, such as Brazil, this is a major disease, impacting substantially the health of the population and the economy.

The main dissimilarities between a neglected disease and COVID-19 is that the former mainly affects the countries with low or average income and whose contamination is less widespread around the world. Furthermore, it is mainly associated with the lack of WSS in developing countries. In Brazil, dengue fever is an endemic disease and has the highest incidence, in absolute numbers, but there is no specific treatment or vaccine (Rosenblatt, 2020), nor clear seasonal disease forecast information (DiSera et al., 2020).

In the recent (2019) Brazilian epidemic, the existence of Dengue, Chikungunya, Zika, and urban Yellow Fever (YFV) demonstrated the presence of the vector mosquito—*Aedes Aegypti*. In urban areas, these vectors find available water for their breeding sites from two distinct origins related to WSS issues. First, the open buckets and containers used in periods of intermittent rainfall or irregular water supply (Caprara et al., 2009); and second,

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in rainwater puddling sites due to problems in stormwater management systems (Akanda et al., 2020; Seidahmed et al., 2018).

This research will discuss the incidence of *Aedes Aegypti*-related diseases and the availability of urban WSS, using Brazil as a case study. In this country, urban WS coverage reached 84% (93% in urban) in 2020 (Brasil, 2021a), however, a relevant share displays a poor quality of service: untreated water, lack of continuity (195.6 thousand systematic interruptions of six or more hours), and high-water losses of 40% (Brasil, 2021a). The situation of wastewater is even worse: 55% of the total population has wastewater collection (63% in Urban) and only 47% is treated. The figures for urban waste are not better: 92% of the population has waste collection, but just 59% is disposed of adequately. The panorama is worse if the rural population is included since it still represents around 15% of the total population (ABRELPE, 2020).

Urban WSS and solid waste are under the responsibility of Brazilian municipalities that plan and can provide directly or delegate them to a State or private companies. With less or more autonomy and corporatization, a contract must be signed between the municipality and the operator, being regulated by an external independent authority (Narzetti & Marques, 2021a).

Table 1 shows the heterogeneity of WSS and urban solid waste availability in the country. While the South and Southeast regions display coverage levels and quality of service similar to those in high-income countries, the North and Northeast show numbers closer to low-income countries.

A low level of investment explains the gap. Brazil, with 213 million inhabitants in 2021, according to the Brazilian Institute of Geography and Statistics (IBGE), invested in the last years US\$ 2,400 million/year, or under 1 US\$/month per capita. To obtain universal access to the WSS until 2030, however, it requires three times more, according to the National Plan of Basic Sanitation, or somehow an even higher amount (Pinto et al., 2015).

In Brazilian municipalities, stormwater management is not institutionalized, relies on municipal budget allocations and do not have skilled staff (Novaes & Marques, 2022). Of the 73 regulatory agencies with responsibility for WSS regulation, just one regulates stormwater management, that is, the Water, Energy and Basic Sanitation Regulatory Agency of the Federal District (ADASA), in Brasilia. These constraints often lead to uncertain and unpredictable programs, which hinders planning and preventive actions.

These official indicators, which show an adverse situation, did not significantly improve in the last 2 years and are much worse since they do not include a large part of the peri-urban population (Narzetti & Marques, 2021b). Furthermore, most of the municipalities are not endowed with urban stormwater management, which is a service of intermittent use. Indeed, its importance is contingent on rainfall and other local characteristics, such as topography, impervious areas, and WSS budget and city policies.

This article assesses the importance of urban WSS coverage in mitigating the proliferation of the Aedes Aegypti mosquito and consequently Dengue fever, Chikungunya, and Zika. Particularly, we analyze the impact of urban stormwater infrastructure, a scarcely researched issue.

In Brazil, the States of São Paulo (SP), Paraná (PR), and Rio de Janeiro (RJ) are highly urbanized and wealthy (with more impermeable areas), with high rates of WSS coverage, highlighting a very high number of dengue cases. Thus, to understand the extent of those facts, we use data from Brazilian government institutions such as the Minister of Health, Ministry of Regional Development, and IBGE, to correlate urban WSS and *Aedes Aegypti*-related diseases. Such an assessment focusing on urban stormwater infrastructure and other WSS variables at the municipal level, including 4,100 Municipalities (89% of the population), as far as we know, has never been exploited, being innovative and bringing contributions to the literature.

After this introduction, Section 2 highlights urban WSS and health considerations. Section 3 details the methodology used. Section 4 analyses and correlates the Dengue, Chikungunya, and Zika cases with urban WSS infrastructure and other variables discussing the results obtained. Finally, Section 5 displays the concluding remarks and some policy implications.

2. WSS and Public Health

Cairncross and Feachem (2018) proposed a classification of infectious parasitic diseases that are potentially determined by the environment, which they called Diseases Associated with Poor Sanitation (DAPS). The term

Table 1
Water Supply and Sanitation Service and Solid Waste Services by Region

Regions	South	Southeast	Northeast	Midwest	North	Total (% or 10^6 inh.)
Waste collection (ABRELPE, 2020)	95%	98%	81%	94%	81%	92%
Water supply (WS) (Brasil, 2021a)	91%	91.3%	74.9%	90.9%	58.9%	84.1%
Wastewater collected (Wtc) (Brasil, 2021a)	47.4%	80.5%	30.3%	59.5%	13.1%	55.0%
Wastewater treated (Wtt) (Brasil, 2021a)	46.7%	58.6%	34.1%	58.5%	21.4%	47%
Total pop. (10^6) (Brasil, 2011)	27.3	80.3	53.08	14.05	15.86	190.59 (210.72[a])
Pop. without WS (10^6)	2.46	6.98	13.32	1.27	6.51	**30.30 (33.50[a])**
Pop. without Wtc (10^6)	14.35	15.65	37.00	5.69	13.78	**85.76 (94.82[a])**
Pop. without Wtt (10^6)	14.55	33.24	34.98	5.83	12.46	**101.01 (111.68[a])**

Note. The bold values are aproximated values of the sum of the horizontal rows, meaning the total of inhabitants without services in 2011 and 2019.
[a]Estimated population—Brazilian Institute of Geography and Statistics (IBGE)—14 November 2019.

should be understood in the context of lack or insufficient sanitation (water services), in addition to poor housing conditions. The DAPS are classified as follows: (a) fecal-oral transmission diseases (e.g., diarrheal); (b) vector-borne diseases (e.g., dengue); (c) water transmitted diseases (e.g., leptospirosis); (d) diseases associated with hygiene (e.g., conjunctivitis); and (e) geohelminths and taeniasis. This classification can contribute to the creation of health protection programs, as well as to the assessment and development of public sanitation policies (Siqueira et al., 2017).

Aedes Aegypti mosquitoes are responsible for transmitting Dengue, Chikungunya, YFV, and Zika. Zika infection in pregnancy women is associated with baby microcephaly risk (Brady et al., 2019), and to protect the population, the socio-economic conditions that favor the presence and proliferation of vectors must be understood (Johansen et al., 2016).

WHO mentions poor WSS as a serious life threat and stated that, for each dollar invested in treated water and wastewater collection, 4.3 dollars are saved in terms of health expenditures (WHO, 2014). The global incidence of dengue increased in recent decades and half of the world's population is at risk, WHO estimated 100–400 million infections each year (WHO, 2020) with significant costs (Lee et al., 2019) and a major economic impact, particularly in developing countries (Oliveira et al., 2019). From 2001 to 2009, diarrhea and dengue were responsible for more than 93% of hospitalizations caused by DAPS in Brazil and the average annual costs of hospitalizations were responsible for more than 3% of total Brazil's Single Health System (SUS) expenditures involving hospitalizations (Teixeira et al., 2014).

For example, Campinas municipality has 1.2 million inhabitants, 794 Km^2, Gross Domestic Product (GDP) 13573 US\$/capita, according to IBGE (Brasil, 2020). This municipality follows a recurrent pattern of urbanization in Brazil and Latin America where inequality in the distribution of services among social groups, living in different intra-urban spaces, provides favorable conditions for vector proliferation (Barreto, 2017; Johansen et al., 2016). There were dengue fever outbreaks in 2007 and 2014. The improper urban waste disposal and the irregular and non-universality of WS are common features in Brazilian urban centers (Brasil, 2021a, 2021b).

2.1. Aedes Aegypti/Aedes Albopictus/Culex

Arboviruses are diseases caused by an arbovirus transmitted by arthropod vector bites, mostly mosquitoes, and ticks. In Brazil, arbovirus is found in two families and two main genera of medical importance: Flaviviridae (Flavivirus) and Togaviridae (Alphavirus). The genre Flavivirus has many specimens of arbovirus and those that present greater relevance and clinical importance for public health are: Dengue virus (DENV), Zika virus (ZIKV), YFV, and West Nile virus (WNV). Likewise, for the genre Alphavirus, the species of main relevance are Chikungunya virus (CHIKV) and the Mayaro.

DENV is an urban arbovirus of greater relevance in the Americas, transmitted by female mosquitoes mainly of the species *Aedes Albopictus* and *Aedes Aegypti*, a daytime mosquito that multiplies in standing water deposits

accumulated in backyards and inside houses, and has an etiologic agent with four distinct serotypes: DENV 1–4, and 18 genotypes (Brasil, 2020c), meaning that it is possible to be infected four times, increasing the risk of developing severe dengue and likely to contract the hemorrhagic form.

WHO estimated that nearly 3,200 million people worldwide had a high probability of catching the disease. Every year DENV infects around 390 million people, of which 96 million have clinical manifestations, and 20 thousand end up dead (Oliveira et al., 2019).

CHIKV first appeared in America in 2013, which caused an epidemic wave in many countries of Central America and Caribbean islands, and has three genotypes: West African, East-Central-South-African (ECSA), and Asian-Caribbean. In Brazil, until now the Asian lineage and ECSA were detected and now every state registers native transmission. CHIKV can also manifest an atypical or severe form and a high number of deaths are observed.

In the first half of 2015 another virus transmitted by *Aedes Aegypti*, ZIKV was first identified in Northeast Brazil. After that, the virus spread in the Americas, except in Chile and Canada. Until now, there are known two virus genotypes: one African and another Asian (Brasil, 2020c).

The simultaneous circulation of DENV, CHIKV, ZIKV, and, on a smaller scale, also by YFV and WNV, in addition to another arbovirus, constitutes a great challenge for Brazilian health assistance and surveillance, including timely identification actions of suspected cases (the disease symptoms are very similar), clinical and laboratory diagnosis and in triggering control actions (Brasil, 2020c).

Since the urban arbovirus shares several similar symptoms with other diseases, there is an additional challenge to initial clinical detection, making it difficult to adopt adequate clinical management. This issue often leads to an increase in the occurrence of severe forms of the disease and, eventually, to an increase in the number of deaths (Fonseca et al., 2019).

2.2. Dengue Fever

Disease found in tropical and sub-tropical climates (Viana & Ignotti, 2013), mostly in urban and semi-urban areas with variations in risk influenced by city elevation (Watts et al., 2017) rainfall, temperature (Siraj et al., 2017), relative humidity, and unplanned urbanization (WHO, 2020).

In 2012, an outbreak on the Madeira islands, Portugal, resulted in over 2,000 cases. Mainland Portugal and 10 other countries in Europe detected imported cases and now autochthonous cases are observed on an almost annual basis in many European countries. Dengue is the second most diagnosed cause of fever after malaria among travelers returning from low and middle-income countries (WHO, 2020).

In 2020, several countries reported increases in the number of cases: Bangladesh, Brazil, Cook Islands, Ecuador, India, Indonesia, Maldives, Mauritania, Mayotte (Fr), Nepal, Singapore, Sri Lanka, Sudan, Thailand, Timor-Leste, and Yemen. The occurrence of vector-based diseases is closely related to climate variations and thus to global warming. Hotter summers, higher humidity, and changes in precipitation regimes are expected with greater frequency and intensity and consequently with an increase in the geographical dispersion of vectors and the risk of these diseases (Khedun & Singh, 2014).

Dengue prevention and control depend on effective vector control measures, and community involvement can improve vector control efforts substantially (WHO, 2020). A vast majority of cases are asymptomatic or mild and self-managed, so the actual numbers of dengue cases are under-reported or are misdiagnosed as other febrile illnesses. There is no specific treatment for dengue and severe dengue, and the disease can rapidly evolve from a feverish state to more severe conditions. Among its complications are neurological and cardiorespiratory changes, liver failure, gastrointestinal bleeding, and pleural effusion. Severe dengue is a potentially fatal complication, due to plasma leaking, fluid accumulation, respiratory distress, severe bleeding, or organ impairment (WHO, 2020).

In 2019, until the end of August, 1,544 thousand probable cases were registered in Brazil (Brasil, 2020c), far exceeding (more than seven and half times) the 2018 registered number of 205 thousand cases.

In 2020, until the 50th week, 979 thousand probable cases were reported (466 cases/100 thousand habitants). The distribution of cases by region was: Midwest (1,200 cases/100 thousand); South (934 cases/100 thousand), Southeast (376 cases/100 thousand), Northeast (261 cases/100 thousand) and North (120 cases/100 thousand). The number of probable cases, however, is probably underestimated due to COVID-19 impacts, namely on health care seeking behavior (Brasil, 2020c).

In 2022, until the 10th epidemiological week, 161 thousand probable cases occurred in Brazil (incidence rate of 75/100 thousand). In comparison with 2021, there was an increase of 44% for the same period (Brasil, 2022a).

The greatest dengue fever incidence areas coincide with developed states: SP (Human Development Index (HDI) = O.783; GINI Index (GINI) = 0.45); Goiás (HDI = 0.735; GINI = 0.45) and Minas Gerais (MG) (HDI = 0.731; GINI = 0.46). Municipalities like São Caetano do Sul (HDI = 0.862; GINI = 0.360) and Assis (HDI = 0.805; GINI = 0.42) in SP present highs levels of dengue fever. Disease deaths in 2019, were 782 and the major lethality ratio (deaths/100 cases), occurred in the Midwest (0.08%) followed by the South region (0.06%), and the highest lethality is over 60 years old, especially over 80 years old, with greater relative risk when compared with the range of 1–4 years old.

Seasonal variation in temperature (Ogashawara et al., 2019) and rainfall influences the dynamics of the vector and the incidence seasonality of the disease (Viana & Ignotti, 2013) that occurs in Brazil in the first half of the year when there is a higher incidence of cases.

2.3. Chikungunya

Chikungunya is a viral disease transmitted to humans by infected mosquitoes. The disease shares some clinical signs with Dengue and Zika and can be misdiagnosed, and this is the reason why there is no real estimate for the annual number of people globally affected. Mostly, it occurs in Africa, Asia, and the Indian subcontinent, a major outbreak in 2015 affected several countries of the Americas, and sporadic outbreaks are seen elsewhere too (WHO, 2020a). The proximity of mosquito breeding sites to housing is a risk factor for Chikungunya, but deaths are very rare and mostly related to other existing health problems. There is currently no vaccine or specific drug against the virus, so the treatment is focused on relieving the symptoms (WHO, 2020b). Lethality rates for those over 80 and under one-year-old are higher than for other groups, and during the 2018–2019 period, there were 76 thousand cases (2018) and 110 thousand cases (2019) recorded in Brazil (Brasil, 2019).

Chikungunya caused, in 2019, in Brazil, 92 deaths, and the major ratios occurred in the Midwest region (0.09%), followed by the Southeast and Northeast (both with 0.07%), and concerning Zika it was three deaths, to laboratory criteria, at Paraiba State.

In 2020, Brazil has reported 80 thousand probable cases (38 cases/100 thousand inhabitants). The southeast and northeast regions present the highest incidence rates (102 cases/100 thousand and 13 cases/100 thousand, respectively). Until the 26th epidemiological week, 72.8% of Chikungunya notifications occurred (58 thousand probable cases), and the incidence rate was 28 cases/100 thousand inhabitants. The states of Espírito Santo (ES), Bahia (BA), and Rio Grande do Norte (RN) stand out. Between the 27th and 50th epidemiological weeks (2020), 27.2% of Chikungunya's probable cases were reported (22 thousand cases), an incidence rate of 10 cases/100 thousand inhabitants. During this period only the state of Sergipe (SE) presented an incidence rate above 100 cases/100 thousand inhabitants.

2.4. Zika

Zika virus disease is caused by a virus transmitted primarily by *Aedes* mosquitoes, which bite during the day. Symptoms are generally mild and include fever, rash, conjunctivitis, muscle and joint pain, malaise, or headache and typically last for 2–7 days. Most people with Zika virus infection do not develop symptoms. Zika virus infection during pregnancy can cause infants to be born with microcephaly and other congenital malformations, known as congenital Zika syndrome. Infection with Zika virus is also associated with other pregnancy complications, including preterm birth and miscarriage. An increased risk of neurologic complications is associated with Zika virus infection in adults and children, including Guillain-Barre syndrome, neuropathy, and myelitis (WHO, 2018).

Until August 2019, it registered 9.8 thousand probable Zika cases in Brazil, well above 2018 (6.7 thousand cases) and in 2020 (7.2 thousand cases) until the 49th week (3.4 cases/100 thousand). Northeast presented the highest incidence rate (9.1 cases/100 thousand), Midwest (3.7 cases/100 thousand), and North (2.0 cases/100 thousand). The state of Bahia (BA) has 49% of Brazilian cases.

Important cases in pregnant women, by the effects (fetuses' microcephaly) with 1.6 thousand probable cases were registered (447 confirmed). The distribution by states is according to the Online Notifiable Diseases Information System (Brazil, 2019): RJ, 43% (192); ES, 15% (66); MG, 10% (47); Alagoas (AL), 7% (32); Paraíba, 3% (16) e Mato Grosso do Sul (MS), 3% (14).

An overview of the detection rates and spatial distribution in Brasil, in 2019, shows Dengue, Chikungunya, and Zika spreading (Brasil, 2020c). However, due to the Severe Acute Respiratory Syndrome Coronavirus 2 worldwide epidemic outbreak, most resources were directed to control the COVID-19 disease, restraining the battle against other types of diseases and viruses. There is an urgent need to make the shift, and promote resources to fight the urban arboviruses, especially in tropical regions and in areas where the *Aedes Aegyptis* mosquito has been frequent.

3. Methodology

In this section, we briefly describe all the variables used in this research, their sources, as well as all the steps performed to shed some light on their possible relationships. After the merging of all required data sets, we were able to include 4,100 municipalities in the analysis, that is, 73.6% of the 5,570 Brazilian municipalities, covering 89% of the population. The analysis involves the assessment of correlation coefficients between variables to summarize data and build a diagnostic able to guide further analyses and future policies. The analyses were implemented in R software, version 4.1.2 (R Core Team, 2022), using the R packages "PerformanceAnalytics" (Peterson et al., 2020) and "DataExplorer" (Cui, 2020), and the data set used is stored on Mendeley data repository (Novaes & Pinto, 2022).

The literature confirms through systematic reviews on the epidemiological areas of interest, the associations of temperature and precipitation with Dengue fever, and, similarly, to other *Aedes Aegypti* vector-borne diseases (Li et al., 2020). A few even focus on the analysis of those factors over a specific territory (e.g., for Brazil see Viana & Ignotti, 2013). Particular papers focus on non-climate/weather factors, such as the urbanization degree (Lowe et al., 2021), but fail to provide a nationwide perspective. To account for those pitfalls, the variables used are described as follows:

- The *Aedes* variable is related to the Dengue fever, Chikungunya, and Zika disease cases, that occurred during the 2019–2021 period. The source is the Department of Informatics of the Unified Health System (DATASUS) data set (Brasil, 2022).
- The *ac_sw* variable considers urban roadways (km) without natural, or built, drainage systems. The source is the National Sanitation Information System—SNIS (Brasil, 2021c) data set on urban drainage and stormwater management.
- The *ac_ws* variable covers WS irregularity or total urban population at water risk, that is, with a high probability of finding themselves with poor or nonexistent WS. The source is the nationwide water security index data set (Brasil, 2020b).
- The *ac_ww* variable includes the urban population without wastewater services. The source is the SNIS wastewater services data set (Brasil, 2021a).
- The *idhm* variable is the municipal HDI, a statistic composite index of life expectancy, education, and per capita income indicators. The source is the continuous national sample survey of households 2020, which updates the census data set (Brasil, 2021).
- The *Gini* variable is the Gini index, which is a measure of statistical dispersion that highlights income or wealth inequalities within the population. The source is the continuous national sample survey of households 2020, which updates the census data set (Brasil, 2021).
- The *pib_cap* variable is the GDP per capita of each municipality. The source is the local GDP data set 2010–2019 (Brasil, 2020).

The WS irregularity data is considered without specifying how many hours or days events occur. Besides that, different areas of the municipalities show specific degrees of irregularity according to their different physical

Table 2
Brazilian Municipalities Grouped According to Their Climate and Urban Population Density Characteristics

Climate	Description	Urban population density	Municipalities
Af	Tropical rainforest climate	Lower	94
Af	Tropical rainforest climate	Higher	40
Am	Tropical monsoon climate	Lower	198
Am	Tropical monsoon climate	Higher	62
As	Tropical dry savanna climate	Lower	400
As	Tropical dry savanna climate	Higher	125
Aw	Tropical savanna, wet	Lower	716
Aw	Tropical savanna, wet	Higher	219
BSh	Hot semi-arid (steppe) climate	Lower	225
BSh	Hot semi-arid (steppe) climate	Higher	46
Cfa	Humid subtropical climate	Lower	855
Cfa	Humid subtropical climate	Higher	147
Cfb	Temperate oceanic climate	Lower	311
Cfb	Temperate oceanic climate	Higher.	39
Cwa	Monsoon-influenced humid subtropical climate	Lower	243
Cwa	Monsoon-influenced humid subtropical climate	Higher	84
Cwb	Subtropical highland or temperate oceanic climate with dry winters	Lower	227
Cwb	Subtropical highland or temperate oceanic climate with dry winters	Higher	69
		TOTAL	4,100

and socio-economic characteristics (Diniz, 2019). Irregularity are factors that can accentuate inequalities within municipalities, and diseases are often identified with location within cities. However, WS irregularity is the main factor that leads to higher water risk, that is, the population at risk of poor or non-existent WS (Brasil, 2020b).

Finally, since *Aedes Aegypti* vector-based diseases are localized, they are difficult to analyze under aggregated data. Thus, to assess the previous variables across comparable territories, we split the data into climatic zones according to Köppen's climate classification (Alvares et al., 2013) and urban population density. In the last parameter, municipalities were categorized as having a *lower* or *higher* urban population density depending on whether they had until 2,000 hab/km^2 or more, respectively. Those 18 groups cover the number of municipalities outlined in Table 2.

4. Results and Discussion

The results achieved can be analyzed by considering: first, the nationwide correlation matrix in Figure 1; and second, the correlation maps (Figure 2) for each cluster of Table 2. The nationwide correlation matrix provided the results outlined in Figure 1. In Figure 1, on the upper side of the diagonal, we present the pairwise correlation values, with p-values significance levels analyzed ($p < 0.001$ it is represented by ***, $p < 0.01$ it is represented by **; $p < 0.05$ it is represented by *) On the lower side of the diagonal, we display the bivariate scatter plots with a fitted line.

The overall results point to a strong correlation between the number of cases (var. *Aedes*) and the WS (var. *ac_ws*) and wastewater services (var. *ac_ww*) variables, respectively corr. = 0.58 and corr. = 0.33. However, when we disaggregate the data, we find interesting results. In Figure 2, we highlight the results for each pairwise comparison with the number of cases (var. *Aedes*). In this figure, we labeled the municipalities with an urban population higher than 1 million.
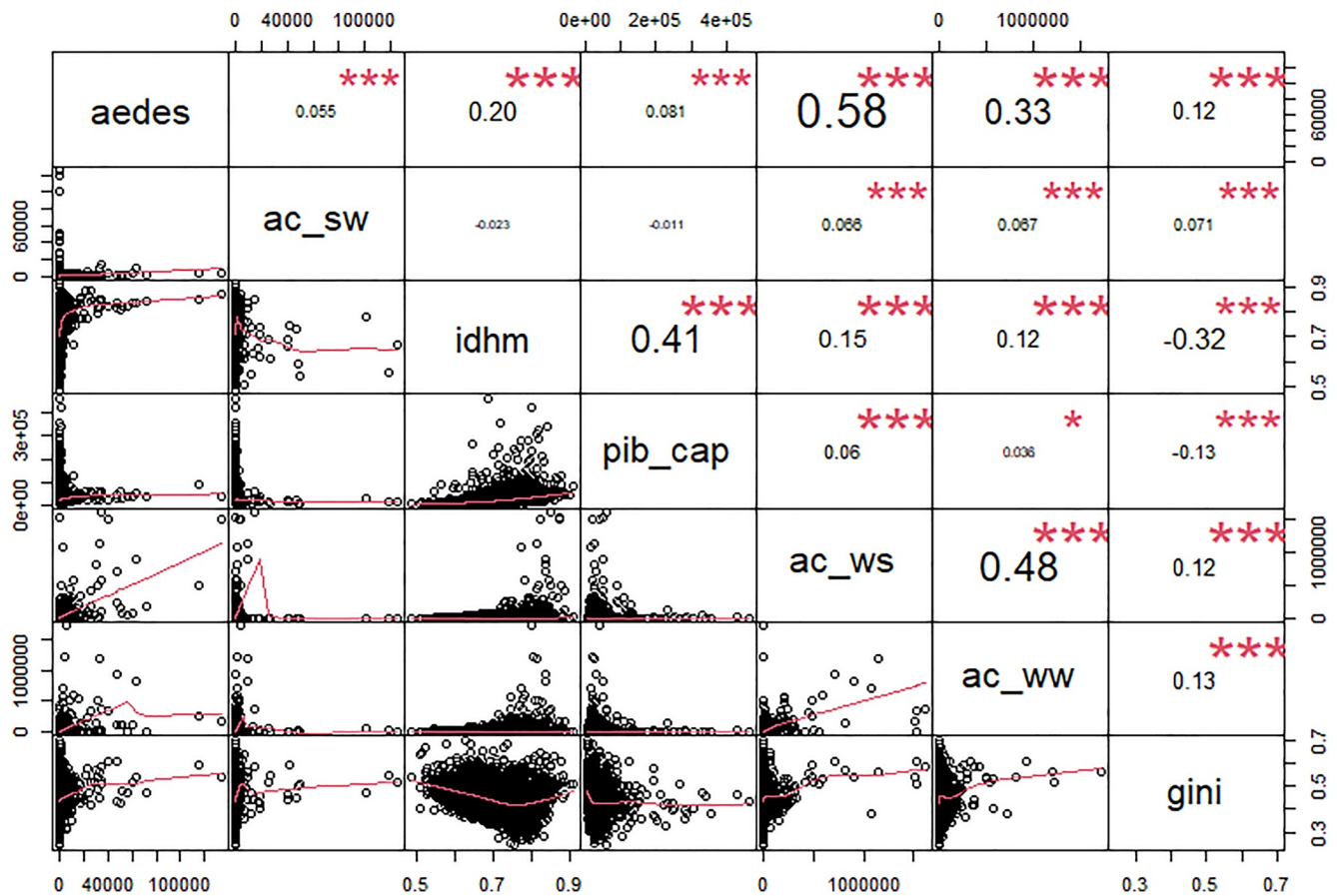
Figure 1. Nationwide correlation matrix of all variables for the 4,100 Brazilian municipalities.

The first conclusion reached, however, is that in the municipalities with high population densities, there is a positive correlation between *idhm* and the number of disease cases, or the bigger the *idhm* the greater the number of cases for three climates (Figure 2b): Am (0.52), Af (0.53), and As (0.57).

The correlation between the number of disease cases and the WS irregularity or total urban population at risk, with poor or nonexistent WS services, also for the municipalities with a high population density, is stronger in more climates (Figure 2d): Am (0.68), Af (0.93), As (0.93), BSh (0.55), Cwb (0.95), and Cfb (0.71).

The correlation, for the municipalities with high population densities, between the urban roadways (km) without natural, or built, drainage systems are, for all the studied climates (Figure 2a): Am (0.73), Af (0.85), Aw (0.75), As (0.75), BSh (0.58), Cwb (0.93), Cfa (0.65), Cwa (0.58), and Cfb (0.99).

Several Brazilian municipalities with WS services have direct or indirect municipal management structures (55%) and in the remaining (45%) there is no municipal structure to manage stormwater management services (Brasil, 2019a, 2020a, 2021). Furthermore, municipal councils of WSS and healthcare are far from the degree of "deliberative effectiveness" desired, with lower social participation than expected and promoted by each sector legislation (Souza & Heller, 2019).

An interesting case is the situation of RJ, with significantly lower cases in recent years, which may be explained by a resilient effect due to: an increase in knowledge about the disease and mosquitoes breeding sites, improved health, and sanitary government teams responsible for fighting and prevention initiatives. Some studies highlight that there may be a natural time/territorial displacement (Xavier et al., 2017), for example, in 2019, between March and June, there were 30 thousand disease cases and in 2020, in the same period, little incidence with just 216 disease cases. The lower number of 2020 disease cases, however, can be in part attributed to the greater
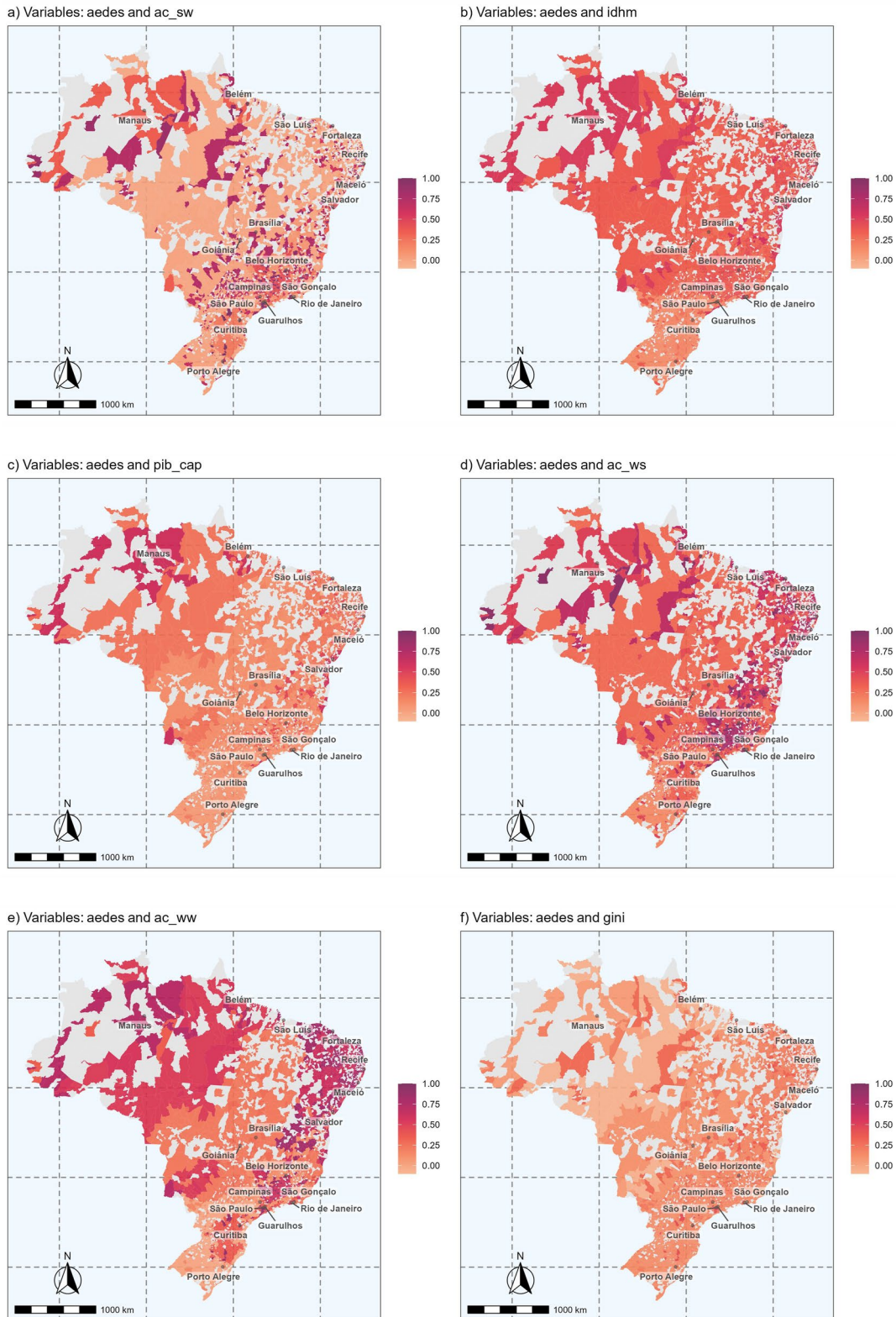
Figure 2. Correlation maps of all Aedes pairwise comparisons for the 18 clustered territories.

presence of people at home due to the COVID-19 pandemic, which promoted great care in their home environments (G1. Globo, 2020).

The case of the water utility of São Paulo State Water and Sanitation Company (SABESP) is another interesting one. During the pandemic in SP (Portal do Governo de SP, 2020), SABESP provided free domestic water reservoirs to the most vulnerable, in partnership with private enterprises. This initiative can be followed and incorporated into public policy, which may allow extending its scope to rainwater reservoirs, as a large urban stormwater management experience, with the inclusion of vulnerable people.

There are, however, several contradictory aspects of the coexistence of Dengue, COVID-19, and measures such as lockdowns and social distancing (Brady & Wilder-Smith, 2021). While social isolation in 2020 has led to a reduction of dengue in some countries like Brazil and Colombia, in several others like Paraguay, Bolivia, French Guiana, and Suriname, there were increased outbreaks. It is expected that in places where surveillance and measures to combat the mosquito have been reduced, the presence of the vector will increase and consequently the related diseases. The reduction in dengue-related activities may have led to underreporting and the similarities in various symptoms contributed to confusing diagnoses, deaths, and notifications.

5. Conclusions

The presence of the *Aedes Aegypti* vector in cities is closely linked to WSS, for example, due to water storage elements, either man-made or natural ones. We sought to analyze the population under a high WS risk, which may lead to the use of temporary storage, either from rainwater or supplied water. Afterward, we assessed the existence of drainage elements in public urban roadways, highlighting the existence (or not) of stormwater infrastructures, which may allow the presence of puddles, that is, breeding grounds for the *Aedes Aegypti* mosquito. Similarly, municipalities with a higher amount of urban population without wastewater services often imply a comparable deficit in terms of drainage infrastructure, allowing to shed some light on the impact of faulty drainage services in *Aedes* vector-based diseases. Additionally, the GDP per capita, the HDI, and the Gini index were verified, to try to relate the already known poor income distribution and inequalities with the study findings. Indeed, the results achieved do not imply causality, but rather guide a probable incidence.

In most variables, as the WSS status quo, a proxy is used to indirectly question the assumptions initially made. Service quality aspects are important, like irregular WS or rainwater use, which require standardizations to enable the implementation of alternative ways toward WSS universalization, overcoming the persisting issue of incomplete urban infrastructures. From this point of view, the SABESP initiative, also triggered by the presence of COVID-19, of providing water tanks for free, with the participation of private companies, provides a possible solution. Even if the installation costs are borne by the customers, it seems an interesting public policy, not only to combat dengue and other diseases but to increase access to WSS.

Preventing future epidemics should be the way forward. The development of vaccines is a complex and time-consuming issue to be solved through research, that should be integrated with health and WSS policies, allowing to save resources and efforts. By building and managing more effective infrastructure, there is a reduced proliferation chance of mosquitoes, viruses, and diseases. Despite possible limitations, the strategic integration of prevention and vaccination resources, while adjusting the benefit-cost ratio, should bring greater welfare.

The absence of data related to urban stormwater management in the official (audited) databases is a limiting issue, and indicative of the lack of institutionalization of the subject in municipal, state, and federal structures, including the issue of permanent resources. Indeed, it is fundamental to the formalization of those databases as the SNIS-Stormwater, in a disaggregated way, of drainage and stormwater management data, such as, for example, the incompleteness of data regarding urban infrastructures in several territories. The lack of disaggregated data by neighborhood and income brackets, instead of states and municipalities, prevents the detailed identification of places with irregular WS, absence of reservoirs, lower network pressures, the prevalence of the mosquito, and the disease. This constraint is also an issue for policy making. Thus, to improve the quality of the results achieved, it is important to increase data collection activities throughout most Brazilian municipalities.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Data Availability Statement

The data set supporting the conclusions of this research can be found in Mendeley Data Repository. Files are attached in Novaes, Carlos; Silva Pinto, Francisco (2022), "Data from statistical analysis of Dengue Brazilian Cases," Mendeley Data, V1, https://doi.org/10.17632/jc5tz588f6.1.

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