Hamburg University of Applied Sciences
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Emerging Mosquito-borne Diseases and the Potential of Integrated Strategies

A situation analysis of the latest Zika outbreak in Rio de Janeiro 2015/2016

Master Thesis

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"It is safe to say that most emerging arbovirus diseases follow ecological modifications. It is naïve to think that humans will stop building cities and dams, or stop entering and destroying the forest. We can, however, learn more about risk and risk management; and we must continue to support environmental and health assessments, and begin to believe our scientifically based predictions and act on them."

(Shope 1977, p. 22)

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Abstract

Introduction Factors such as climate, environment, along with a setting's infra-structural, socio-economic and political characteristics are known to influence the spread of mosquito-borne diseases. In 2015 and 2016, Brazil became an increasingly affected country with epidemiological hot spots in the populous south-eastern regions including the municipality of Rio de Janeiro. In order to improve vector control and outbreak response in tropical metropolises it is important to better understand the complex ecology of urban mosquito-borne diseases and their primary vector *Aedes aegypt*i as parts of a human-urban transmission cycle.

Methods An information-rich case study was conducted following a mixed-methods approach to investigate the *Zika outbreak scenario in Rio de Janeiro 2015/2016* from multiple perspectives. The findings derived serve as a basis for a comprehensive situation and hazard analysis considering the latest mosquito-borne disease outbreaks in Rio de Janeiro that follows two established tools applied to the field of emerging infectious diseases – a multi-perspective "Situation and Influencing Factors Analysis" and the "Hazard Analysis and Critical Control Points" technique.

Results Looking at the case of Rio de Janeiro 2015/2016, environmental and climatic conditions could be identified as a fundamental basis for the spread of urban mosquito-borne diseases, with a particular focus on the initial and final epidemiological trend. Demographic, socio-economic, and infrastructural vulnerabilities may furthermore influence the extent of an outbreak that could be identified in the centered areas of the city. Based on these findings, integrated vector control and outbreak management strategies are needed that take the peculiarities of an affected setting into account following the achievements, challenges and lessons learned during the *Zika outbreak scenario in Rio de Janeiro 2015/2016*.

Conclusion This thesis explores the potentials of integrated knowledge, methodology and experiences as one solution approach to be able to point out not only risk factors and vulnerabilities, but also resources and solution approaches to develop an adequate response to MBD outbreaks within tropical metropolises like Rio de Janeiro.

Keywords Mosquito-borne diseases, Zika virus, Brazil, Urban transmission, Outbreak response, Integrated strategies

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Abbreviations

ARBOV	Arbovirus
AP	Health Programmatic Area in Rio de Janeiro
BP	Brazilian Portuguese
CF	Chikungunya fever
CHIKV	Chikungunya virus
DENV	Dengue virus
DHF	Dengue haemorrhagic fever
DSS	Dengue shock syndrome
EIP	Extrinsic incubation period
HACCP	"Hazard Analysis and Critical Control Point" concept
IBGE	Instituto Brasileiro de Geografia e Estatística
ICICT	Instituto de Comunicação e Informação Científica e Tecnologia em Saúde, Fiocruz Rio de Janeiro
IgM	Immunoglobulin M
MBD	Mosquito-borne disease(s)
MRJ	Municipality Rio de Janeiro
OMS	Organização Mundial de Saúde/World Health Organization
PAHO	Pan American Health Organization
PROCC	Programa de Computação Científica, Fiocruz Rio de Janeiro
RNA	Ribonucleic acid
RT-PCR	Reverse transcription polymerase chain reaction
SES	Socio-economic status
SIFA	"Situation and Influencing Factors Analysis" concept
VBD	Vector-borne disease(s)
WHO	World Health Organization
ZIKV	Zika virus

1. Introduction

In 2015 and 2016, the Americas experienced an extensive outbreak of a hitherto neglected tropical arthropod-borne virus, which likely infected about 700,000 people in northern, central and southern countries and territories by the end of 2016: the Zika virus (PAHO/WHO 2016). Originally circulating in sylvan environments and transmitted by wild mosquitoes to nonhuman primates, the Zika virus made its way to warm, humid and urban settings. Worldwide, the virus may affect human beings wherever an abundant population of a compatible vector and suitable mosquito habitat are present (Weaver et al. 2016, Foster, Garret & Meltzer 2016). According to the World Health Organization (WHO), more than 80 countries and territories have reported mosquito-borne Zika virus transmission since 2007, stating both laboratory confirmed cases and autochthonous transmission (WHO 2017a).

Particularly Brazil became an increasingly affected country, presenting favorable habitat for potential vectors due to its tropical climate conditions and environmental variety (Mendes & Moraes 2014). Along with a setting's infrastructural, socio-economic and political characteristics, those factors are known to influence the spread of vector-borne diseases by having direct and indirect impacts on the survival and distribution of pathogens and their carriers (Becker, Pluskota, Kaiser, & Schaffner 2012, De Oliveira Mota, Terzian, Rodrigues Silva, Estofolete & Nogueira, 2016, Pereda & Alves 2016). In Brazil, mosquito-borne diseases (MBD) have become a major public health concern not only in rural, but notably in urbanized areas. One of the primary vector is the mosquito *Aedes aegypti* that transmits the arboviruses Zika (Faye et al. 2013), chikungunya (Leparc-Goffart, Nougairede, Cassadou, Prat & De Lamballerie 2014), dengue (Simmons, Farrar, Nguyen & Wills 2012) as well as urban yellow fever (Jentes et al. 2011) and whose spread in Brazil poses a serious challenge to the country's health system. Although mosquito-borne pathogens have caused ongoing outbreaks since the resurgence of dengue fever in 1981 (Osanai et al. 1983), the rapid spread of the Zika virus in Brazil linked up with severe congenital and neurological complications led to a situation of International Public Health Emergency in February 2016 (WHO 2016a). Like dengue and chikungunya fever, Zika illness is mostly a mild and self-limited disease causing akin symptoms such as rash, fever, malaise, and other painful discomforts (Brasil, et al. 2016, Wilder-Smith, Ooi, Vasudevan, & Gubler 2010, Staples, Breimann, & Power

2009). Aproximately 80 % of infected individuals seem to remain asymptomatic, which altogether complicate to detect an ongoing outbreak and to control transmission effectively. In addition, a small number of cases can develop severe complications calling attention to the burden of MBD. An approved antiviral or vaccine is available neither for DENV, nor for ZIKV and CHIKV, so the effective treatment and prevention of such arbovirus infections and their complications remain difficult.

Particular attention needs to be directed to areas where beneficial conditions, a wide-spread manifestation of a potential vector and a high density of a susceptible and unprepared host population can lead to an explosive spread of mosquito-carried pathogens. However, a profound understanding of a wide range of determinants explaining transmission dynamics – from the impact of climate conditions to the mode of action of herd immunity – requires further investigation (Schmidt-Chanasit & Schumacher 2016). Favorable due to its tropical conditions, an increasing population growth and various artificial mosquito breeding sites, the municipality Rio de Janeiro represents such a vulnerable setting (Neiderud 2015). Due to the emergence of Zika in 2015, chikungunya in 2016 and the seasonal occurrence of dengue since 1986, the city faces not only one, but three co-circulating arboviruses of major public health concern. Yet, the diverse nature of influencing factors presents a main challenge to combat the distribution of the vector as well as arbovirus emergences. However, investigating the course of MBD from multiple perspectives can help to identify vulnerabilities of an affected area and thus may lead to more targeted points of public health prevention activities and outbreak response.

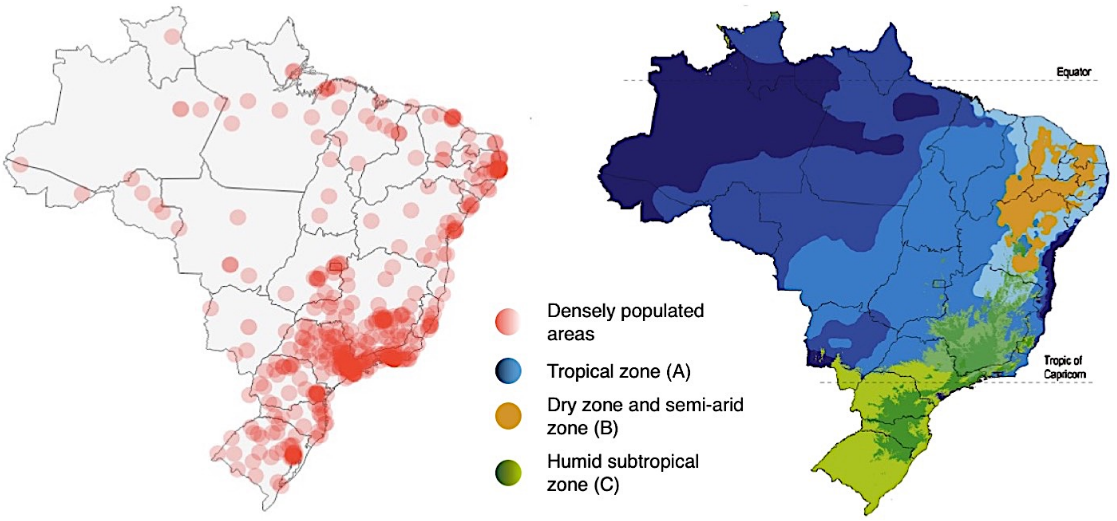
In order to improve vector control and to adequately counter the rapid spread of arboviruses, it is important to take the complex ecology of MBD into account. Both considering the characteristics of an affected setting and learning from the achievements, challenges and lessons learned during the latest outbreaks in Rio de Janeiro may furthermore support the development of effective MBD outbreak management. This thesis aims to investigate the latest MBD emergences in Rio de Janeiro in 2015/2016 following a multi-perspective situation and hazard analysis. A comprehensive literature review to identify contributing factors for the occurrence of MBD epidemics as well as a descriptive case study of Rio de Janeiro city in 2015/2016 form the basis of the inquiry. The identification of multifactorial determinants of promoting and inhibiting nature may help to develop a hazard profile for MBD transmission and to give recommendations for a targeted outbreak response and MBD management.

2. Background

Brazil – an overview about the country's profile and public health

The Amazon rainforest, the Brazilian highlands, vast coastlines as well as several hydrographic regions: Brazil encompasses numerous geographical dimensions distributed across an area of 8,514,877 km^2. Occupying almost half of the South American continent, Brazil is the fifth largest country in the world considering both area and population (Meyer 2010). Today, Brazil has an estimated population of approximately 211 million people, distributed among sparsely populated areas in rural regions and densely populated metropolises of up to 10 million inhabitants like Sao Paulo, Rio de Janeiro, Salvador and Brasilia (World Population Review 2017). Illustrated in Figure 1a, approximately 85 % are living in urbanized areas, around 45 % within cities greater than 100,000 inhabitants, and almost 30 % of the urban population is living in slums according to the World Health Organization (WHO 2009a, WHO n.d., WHO 2015a).

Divided into five overall regions (North, Northeast, Southeast, South and Center-West), the country consists of 26 several states and the Federal District of different economic, cultural, and demographic profiles (PAHO 2012). Five different ethnicities can be found among Brazil's population (white, black, mixed white and black ancestry called mulatto, Asian, and indigenous) and more than half of the Brazilians are considered middle-class. However, the level of income inequality and poverty, especially among women and several ethnic groups (mulatto, black and indigenous population), remain high in the Northeast, North, and Center-West. Social disparities associated with limited access to public services may furthermore foster high crime rates particularly in the cities' impoverished areas (Central Intelligence Agency 2017). Although Brazil experienced improvements in income distribution, inequalities and extreme poverty due to economic growth during the past decades (PAHO 2012), since 2013 the country has observed a shrinking economic development, growing unemployment and inflation causing major public disturbances, especially in Brazil's metropolises. The political crisis had reached its climax in 2016, when Michel Temer became president with the impeachment of Dilma Rousseff in May 2016, followed by the country's financial crisis in June 2016 (Central Intelligence Agency 2017).



1a: Distribution of densely populated areas
Source: 2017 World Population Review
(http://worldpopulationreview.com/countries/brazil-population/)

1b: Climate classification of Brazil
Source: Alvares et al. 2014, p. 717
(edited with software GIMP 2.8.20)

Figure 1: Brazil's population density and climate classification

Induced by the environmental diversity, Brazil is characterized by subtropical and tropical climate with hot and humid conditions, but also wet and dry seasons. Following Köppen's climate classification of Brazil (Alvares, Stape, Sentelhas, De Moraes Goncalves & Sparovek 2014), three primary climate zones can be described (Figure 1b). Firstly, a tropical climate in the north-western parts presenting specially wet conditions, and north-eastern areas with drier seasons (A zone). Secondly, a semi-arid climate characterized by dry conditions due to low latitude and altitude present in the north-east (B zone). And thirdly, a humid subtropical climate mainly occurring in the southern regions, where temperature ranges between hot, temperate and cool (C zone). With one of the world's largest economies, a constantly growing population as well as the Amazon as the planet's biggest ecosystem, Brazil became notably affected by climate change effects during the past decades (WHO 2015b, Central Intelligence Agency 2017): the country is confronted with an uprising trend in minimum and overall surface temperature, especially observed in urbanized areas (De Lucena, Rotunno Filho, De Almeida França, De Faria Peres & Xavier 2013). Furthermore, in 2015 and 2016 Brazil was facing torrential rainfall and floods in the south and droughts in the northern areas caused by one of the strongest El Niño events ever recorded. In the future, the incidence of extreme weather conditions is predicted to increase, especially in large urban centers, putting the country at the risk of being affected by serious health hazards, changes in morbidity pattern and economic losses (Caminade et al. 2016, PAHO 2012, WHO 2015b).

Besides the social profile and climate fluctuations, other environmental factors must be considered when it comes to human security in Brazil. Although all municipalities were connected to water supply and sewerage system as well as to waste disposal services in 2008, especially rural and poorer areas have access to general sewage system and septic tanks only and are lacking in adequate waste management. Almost a third of untreated sewage is still released directly into freshwater sources, while in half of Brazilian municipalities solid waste was disposed in irregular open-air dumps (PAHO 2012). Thus, inadequate water supply, sanitation and hygiene pose a serious risk to the country's population health.

Due to the its environmental variety, Brazil furthermore provides ideal conditions for the circulation of yet neglected tropical diseases of significant concern to public health: arthropod-borne viruses (arboviruses). Identified as an essential influencing factor for the transmission of vector-borne arboviruses, tropical and subtropical climate conditions appear to be suitable for several carrier species such as mosquitoes, sandflies, bugs, and ticks (McMichael, Haines, Slooff & Kovats 2003, Tabachnick 2013). In Brazil, a variety of pathogens like viruses, bacteria, and parasites can be transmitted to vertebral hosts by blood-feeding vector insects distributed all over the country's natural ecosystems (Barreto et al. 2011, WHO 2016b). Mainly mosquito-borne diseases (MBD) have become a major public health issue, especially in areas where large and densely populated urban settings have been infested by an anthropophilic mosquito population (Hales, Weinstein, Souares & Woodward 1999, McMichael et al. 2003). Besides malaria, which is one of the most concerning VBD worldwide, arbovirus infections like yellow fever and dengue pose a serious global health concern due to their rapid development and increasing health burden (WHO 2016c, Mendes & Moraes 2014, WHO 2017b). As for MBD, for many VBD a vaccine is missing and a lack of adequate treatment, but also increasing drug resistance represents a major health care issue (WHO 2014). Overall, infectious diseases significantly rank among Brazil's health challenges, while at the same time rates of non-communicable diseases such as diabetes, high blood pressure and cardiovascular diseases are growing. A detailed survey about the country's health and risk profile can be found online provided by WHO and PAHO Global Health Observatory data (http://www.who.int/gho/countries/bra/country_profiles/en/).

2.1 Mosquito-borne diseases in Brazil

Although in Brazil autochthonous mosquito-borne epidemics like malaria, yellow fever or dengue have been prevalent for more than 70 years (Nunes et al. 2012, Dick et al. 2012, Oliveira-Ferreira et al. 2010), the recent Zika outbreak has been challenging the country's health system causing suspected cases in all 27 federal units of Brazil. During 2014 and 2016, even three MBD of major public health concern were co-circulating, particularly affecting densely populated areas: the Zika virus (ZIKV), for the first time recognized in 2015 (Faria et al. 2016); chikungunya virus (CHIKV), introduced in 2014 (Azevedo, Silva Oliveira & Da Costa Vasconcelos 2015), and four different serotypes of dengue virus (DENV 1-4) causing seasonal outbreaks since 1981 (Osanai et al. 1983). The principle vector responsible for the latest urban arbovirus emergences in 2015 and 2016 is the female mosquito *Aedes aegypti* (Yellow fever mosquito), a well-adapted urban species of the genus *Aedes* which mainly feeds on human hosts and to lesser extent on domestic mammals. In addition, its relative *Aedes albopictus* (Asian tiger mosquito) is also compatible to transmit all three arboviruses, however, more present in rural areas and preferring domestic and wild vertebrates, but also human beings for blood-meals (Enfissi, Codrington, Roosblad, Kazanji & Rousset 2016, Do Reis, et al. 2010, Abushouk, Negida & Ahmed 2016, Leparc-Goffart et al. 2014). In addition to Brazil, more than half of the world's population share their habitat with capable mosquito species and, thus, are at risk to be affected by MBD once a pathogenic agent emerges (Kraemer et al. 2015, WHO 2017c).

2.2 The primary vector *Aedes aegypti*

Besides ZIKV, DENV, and CHIKV, *Aedes aegypti* is able to transmit urban yellow fever virus, Venezuelan equine encephalitis virus and the Mayaro virus (Marcondes & Ximenes 2016). Having its origins in Africa, the mosquito spread and established in South America, sub-Saharan Africa, Southern Asia and Australia (Kraemer et al. 2015, Braks, Honório, Lourenço-De-Oliveira, Juliano & Lounibos 2003) where it can be found in tropical urban and densely populated settings living indoors as well as outdoor (Marcondes & Ximenes 2016, Braks et al. 2003). Environmental changes, urban growth and international travel and trade may contribute to the continuous vector spread, which causes ongoing challenges for surveillance and control all over the world (CDC 2016a, Kraemer et al. 2015, WHO 2016d).

Highly vulnerable but also adaptable to external conditions, the mosquito's development is mainly influenced by environmental factors such as meteorological determinants (temperature, rainfall, humidity), landscape quality (urbanized environment), stability of blood sources and suitable living and breeding habitat (human-occupied territory) (Piovezan, Rosa, Rocha, De Azevedo & Von Zuben 2013, Powell & Tabachnick 2013, Kraemer et al. 2015, Morin, Comrie & Ernst 2013). Passing four life stages (egg, larvae, pupa and adult), the development from the egg stage to adult flying mosquitoes takes 8 to 10 days with promoting thermal conditions between 21-30 °C (Honório, Codeço, Alves, Magalhães & Lourenço-de-Oliveira 2009). The life span of adult *Aedes aegypti* mosquitoes generally lasts three weeks depending on the availability of blood sources and environmental factors (Joy, Arik, Corby-Harris, Johnson & Riehle 2010). With warmer temperature, their biting activities increase, the mosquito reproduction accelerates and egg as well as larvae development can speed up. In contrast to that, temperatures lower than 20 °C and above 35 °C can restrict mosquito activities, development and survival (Wu, Lu, Zhou, Chen & Xu 2016, Fagundes Gomes, Araújo Nobre & Gonçalves 2012). Artificial items that accumulate water during prolonged rainfall (e.g. garbage items), but also uncovered tanks for water storing during dry periods create essential breeding habitat in close vicinity to human living area (Powell & Tabachnick 2013, Kraemer et al. 2015). As sip-feeders, female mosquitoes repetitively suck blood from multiple hosts to mature their eggs (Amuzu, Simmons & McGraw 2015). Confined by *Aedes aegypti*'s relatively short flight range (no more than 400 meters around the site where it was born) and preferred biting activity during daytime (especially early morning and before dusk), the vector has ideally adapted to human habitat (WHO 2016e). As a result of this so-called domestication process, *Aedes aegypti* is able to shift its complete life cycle indoors, which makes the mosquito less dependent on external climatic conditions (Parham et al. 2015, Wu et al. 2016).

2.3 Anthropod-borne viruses

Arthropod-borne viruses (arboviruses) comprise pathogens that require a blood-feeding carrier that transmits the agent to vertebrate reservoir hosts (WHO 1985). As for MBD carried by *Aedes aegypti*, female mosquitoes act as hematophagous arthropods transmitting arboviruses to human hosts during their blood meal. While infected *Aedes aegypti* mosquitoes are able to pass the virus to a susceptible human host, infected humans can also serve as a source of the virus for uninfected mosquitoes that suck the host's blood and then start to distribute the virus by biting multiple people during their life cycles (WHO 2016e). Experimental studies have shown that arboviruses can be transmitted vertically, that is, from adult female mosquitoes to her offspring. Although pathogens can survive for only a few generations without horizontal transmission (vector-host), vertical transmission enables arboviruses to persist in the eggs during hot, dry or cold conditions (Thangamani, Huang, Hart, Guzman & Tesh 2016).

From a public health perspective, viruses of the family *Bunyaviridae* (e.g. Rift Valley fever), *Flaviviridae* (dengue, yellow fever), and *Togaviridae* (e.g. chikungunya, Venezuelan equine encephalitis) are classified as the most important human pathogens mainly occurring in tropical regions (Gubler 2001a). Considering the latest emergence of arboviral diseases caused by urban *Aedes aegypti* mosquitoes in Brazil, three pathogens are of increasing concern: resurgent dengue virus and the newly recognized Zika and chikungunya virus. All three arboviruses are able to infect and replicate within both vertebrate and arthropod cells (Schmaljohn & McClain 1996). Particularly, large urbanized areas located in tropical climate are at risk to be affected by MBD epidemics due to their high population density, socioeconomic diversity, disparate land use and often insufficient infrastructure and health care system (Kraemer & Khan 2010). However, such influencing factors and their level of impact can differ considering the location and the interval of a particular cycle.

2.3.1 Dengue virus and dengue fever

During the 17th century, the first suspected dengue-like epidemics occurred in the Americas following the etiology of reported outbreaks (Brathwaite et al. 2012). The first viral isolation of DENV was reported in the North of Brazil in 1981 (Osanai et al. 1983). To date, DENV is prevalent in almost all regions of Brazil presenting a periodical pattern within a year due to the impact of temperature and precipitation on mosquito abundance and vector capacity (Ximenes et al. 2016). The clinical manifestation called dengue fever (DF) is caused by one of the four serological DENV types of the family *Flaviviridae* (Jelinek 2010). The infection by one DENV serotype leads to life-long immunity against that subtype, while a recurrent infection with another serotype can develop a severer and life-threating form of DENV infection like dengue haemorrhagic fever (DHF) and dengue shock syndrome (DSS) (WHO 2016e). Similar to ZIKV and CHIKV, DENV infection is an undifferentiated febrile illness with clinical features like fever, painful disorders and symptomatic rash, but may also be asymptomatic (Jelinek 2010). A more detailed overview about DF syndrome is given in Table 1. Especially older children, adults and immune-compromised individuals are at risk. The incubation period in humans can vary from 3 to 12 days, while the viremic phase of DF lasts 4-5, sometimes up to 12 days. During this viremic phase, a female *Aedes aegypti* mosquito can be infected by taking a blood-meal from a contagious human host, which also applies to ZIKV and CHIKV. To prevent further spread of the disease, infected individuals should avoid mosquito bites and apply protective measures for at least one week after infection (Jelinek 2010). Based on the ecological characteristics of MBD, thermal conditions can accelerate or inhibit DENV development. The period of DENV replication inside *Aedes aegypti* called extrinsic incubation period (abbreviated EIP), within which the mosquito becomes able to transmit the virus via saliva, is 8-12 days (Gubler 1997, WHO 2009b). The fastest viral replication (extrinsic replication rate, abbreviated EIR) was reported at 30 °C, a low virus load inside *Aedes aegypti* occurred at 26 °C (Morin et al. 2013; Fibriansah et al. 2013, Chan & Johansson 2012).

2.3.2 Zika virus and Zika illness

Like DENV, the ZIKV is a *Flavivirus* of the family *Flaviviridae* (Ioos et al. 2014). Originally circulating in sylvan environments and passed from mosquitoes to nonhuman primates, the ZIKV made its way to densely populated urban settings affecting human beings wherever a potential population of a compatible vector is present (Weaver et al. 2016; Foster et al. 2016). Since the first detection in Uganda in 1947, only isolated outbreaks with a small number of notified cases have occurred in Africa and Asia. Since 2007, major ZIKV epidemics have been reported in Gabon, Central Africa (Grard et al. 2014), throughout Oceania and the Pacific including Yap Island and French Polynesia (Duffy et al. 2009, Pettersson et al. 2016), followed by Cook Island (Roth et al. 2014), Easter Island (Tognarelli et al. 2016), and New Caledonia (Dupont-Rouseyrol et al. 2015). In 2015, the ZIKV reached Brazil as the first affected South American country (Campos, Bandeira & Sardi 2015), rapidly spreading across the Americas (CDC 2017a).

In contrast to DENV and CHIKV, ZIKV can not only be passed by mosquito bites, but also from human to human through body fluids via blood transfusion (Musso, Stramer & Busch 2016, Musso & Gubler 2016), sexual contact (Musso et al. 2015), and maternal-child transmission (Besnard, Lastère, Cao-Lormeau & Musso 2014). After the detection of Zika virus

RNA in other body fluids like saliva, urine, and breastmilk, the research on potential transmission routes is still going on. Infected people may develop Zika virus illness, which is mostly a mild and self-limited disease causing undifferentiated symptoms that share similarities with DENV and CHIKV infection (cf. Table 1). Approximately 80 % remain asymptomatic (Brasil et al. 2016). Yet, the development of a reliable case definition based on the symptomatic appearance to clearly distinguish Zika illness from dengue and chikungunya fever remain challenging. The incubation period in humans ranges from 3 to 12 days, the course of symptoms generally lasts for 4 to 7 days (Mo, Salada & Tambyah 2016). A study suggests that first-time ZIKV infection may prevent reinfections (Osuna et al. 2016). However, information about the longevity of immune response and its potential to induce herd immunity are lacking and long-term follow-up assays are needed to conduct serological investigations (Keener 2016). Based on the latest research findings, a small number of cases can develop severe complications. ZIKV infection is linked with congenital complications and infantile cases of microcephaly (mother-to-child transmission in the womb) as well as neurological disorders among adults including Guillain-Barre syndrome (Krauer et al. 2017, McGrath et al. 2017, Brasil et al. 2016). Due to the risk of birth defects and the potential transmission through body fluids, pregnant women as well as women and couples planning to get pregnant are classified as vulnerable groups. Furthermore, studies suggest that pre-existing DENV immunity (presence of DENV antibodies) may enhance ZIKV infection (Paul et al. 2016). As for DENV, the mosquito becomes able to transmit ZIKV after approximately 10 days (EIP). A higher temperature indicates a more rapid virus development, reporting a high load of infectious ZIKV particles in *Aedes aegypti* saliva at 27 °C. But in contrast, at 18 °C the transmission of infectious particles has not been detected yet (Heitmann et al. 2017).

2.3.3 Chikungunya virus and chikungunya fever

The *Alphavirus* CHIKV, a member of the family of *Togaviridae*, is the third mosquito-borne arbovirus of major public health concern causing urban epidemics in Brazil since 2014 (Faye et al. 2013, Enfissi et al. 2016). Mainly circulating in tropical and subtropical regions, the CHIKV was originally found in Tanzania, Eastern Africa, in 1953 and has followed the global path of ZIKV and DENV to areas where the potential vectors *Aedes aegypti* and *Aedes albopictus* are present (Azevedo et al. 2015). In comparison to ZIKV and DENV, *Aedes* *albopictus* has proved to be the more effective vector which is also present in temperate climate zones (Löscher & Prüfer-Krämer 2010). Today, CHIKV has been identified in countries in Africa, Asia, Europe, the Indian and Pacific Oceans as well as in the Americas including Brazil (CDC 2016b). In about 70 % of infected individuals, CHIKV infection may cause chikungunya fever (CF) which is clinically characterized by an akin febrile syndrome like DENV (cf. Table 1) (WHO 2016e). After an incubation period of 2 to 7 days, in most cases CF symptoms resolve in approximately 2 weeks. However, severe forms of CHIKV infection can develop painful arthralgia in 88 % of symptomatic cases persisting for one month and up to years (chronic arthralgia/arthritis). Further serious but less common manifestations are gastrointestinal disease, neurologic complications, cardiovascular disease, haemorrhagic manifestations, and death. Vulnerable groups for severe CF are infants and young children, elderly people and patients with co-morbidities, autoimmune diseases or pre-existing joint concerns (Goupil & Mores 2016). The incubation period of CHIKV within *Aedes aegypti* is approximately 2-6 days (Manore, Hickmann, Xu, Wearing & Hyman 2014) and may accelerate with elevated temperature of 28 °C, where transmission efficiencies are reported to be higher. In contrast, the virus load was low in mosquito saliva at 20 °C. However, such investigations have focused *Aedes albopictus* mosquitoes from Europe, expecting changes in EIP inside *Aedes aegypti* in Brazil to be similar (Vega-Rúa et al. 2015).

Table 1: A general view on the clinical manifestation of DENV, ZIKV, and CHIKV

Clinical signs*	DENV	ZIKV	CHIKV
Fever (duration)	≥ 38 °C (4 to 7 days)	low or absent ≤ 38 °C (1-2 days)	> 38 °C (2-3 days)
Skin rash	occurs from the 4th day in 30-50 % of cases	occurs on the 1st or 2nd day in 90-100 % of cases	occurs 2 to 5 days in 50 % of cases
Muscular pains	+++	++	+
Joint pains	+	++	+++
Intensity of joint pain	mild	moderate	severe
Joint swelling	rare	frequently, mild	frequently, moderate to severe
Conjunctivitis	rare	in 50-90 % of cases	in 30 % of cases
Headache (frequency, intensity)	+++	++	+
Pruritus	mild	moderate to intense	mild
Complications**	Haemorrhagic fever, Dengue shock syndrome	Microcephaly, Congenital anomalies, Neurological complications	Poly-arthralgia, Neuro-invasive complications

* Frequency of the most common clinical signs and symptoms of ZIKV infection in comparison to DENV and CHIKV following the second observation of the Federal University of Pernambuco (provided by Carlos Brito, Professor of the Federal University of Pernambuco, December 2015; updated: 22nd January 2016)

** Following the findings of section 2.3.1 to 2.3.3

2.4 The Zika outbreak scenario in Rio de Janeiro, Brazil, 2015/2016

In January 2015, an increase of cases affected by an acute viral exanthematic illness has been recognized in Rio de Janeiro for the first time. In most of the patients, descending skin rash, mild arthralgia, and low-graded fever were reported. Based on syndromic investigations, the viral disease that was previously described as an unusual presentation of dengue could be identified as ZIKV infection (Brasil et al. 2016). As ZIKV is closely related to DENV, a differentiation between both *flaviviruses* following the clinical manifestation, but also through serum antibody tests (IgM), is still difficult. A case confirmation can be realized best by the detection of viral genome via laboratory examination (RT-PCR) in blood fluids of affected patients (Yin, Salada & Tambyah 2016). With an early documentation of Zika disease, Brasil et al. (2016) provided the first report of circulating ZIKV in Rio de Janeiro city. Following the latest findings of Ayllon et al. (2017), the first ZIKV affected *Aedes aegypti* mosquitoes could be collected in Manguinhos neighbourhood in April 2015. For this area, ZIKV introduction is suggested during May and November 2013, much earlier before the first case of human Zika virus infection was detected.

Until April 2016, most Zika diagnoses were registered in the populous southeast regions of Brazil including the state of Rio de Janeiro, which reported about 157 cases per 100,000 inhabitants and thus more than triple the national average (Reuters 2016, Bowater 2016). In addition to the increase in ZIKV incidences and the rapid spread across Brazil, the country also registered a rising number of cases of microcephaly among newborns and other severe adverse pregnancy and infant outcomes in October 2015. In November 2015, Brazil declared the National Public Health Emergency (WHO 2017d). With the continuing ZIKV spread across the Americas and the occurrence of clusters of microcephaly and neurological disorders (Brasil et al. 2016, Krauer et al. 2017) the WHO classified Zika an “extraordinary event” and declared the Public Health Emergency of International Concern in February 2016 (WHO 2016a). From that date, ZIKV infection became an internationally notifiable disease. In 2015, the city also recognized increasing cases of CHIKV infection (Souza et al. 2017). Together with seasonal DENV outbreaks that occur in Rio de Janeiro since 1986 (Ximenes et al. 2016), the co-circulation of three arboviruses posed a serious challenge to the city’s health system. Combined with the gaps in knowledge about Zika and the risk of global arbovirus spread due to mass gathering events like Rio carnival (February 2016) and the Summer Olympic Games (August 2016), Rio de Janeiro city can particularly be seen as the Achilles’ heel in the fight against MBD in Brazil.

2.5 MBD research and control: a bio-socio-economic issue?

Following the theoretical principle of VBD research and outbreak response described by Ellis and Wilcox, "the ecological dimension of vector-borne disease research and management is a pervasive element because this issue is essentially an ecological problem with biophysical, social, and economic dimensions" (2009, p.155). Looking at Rio de Janeiro, the metropolis seems to hold suitable conditions to promote the spread of MBD within a short time as it happened with Zika in 2015/2016. To better understand MBD dynamics and vector ecology may improve strategies to reduce the risk of exposure to arthropod-born agents (Liang, Gao & Gould 2015). Especially integrated approaches involving both biological and social sciences present a promising measure for vector and MBD management according to WHO (2004). To avail of the essential knowledge and methodology of several disciplines (e.g. public health, epidemiology, demography, social science, medicine, ecology, geography, meteorology, environmental science) is thus a valuable gambit to explore scientific questions about complex challenges within a specific context (Mauser et al. 2013, Gray 2008). In that respect, it is to ask:

a. *What lessons can we learn from the latest arbovirus outbreaks in Rio de Janeiro city 2015/2016 considering large, urbanized and densely populated areas promoted by tropical climate conditions as a hot spot for emerging MBD transmission?*
b. *How can integrated knowledge, methods, and tools contribute to the improvement of vector control and MBD outbreak response?*

A better understanding of the city's temporal and spatial vector-host-pathogen dynamics and the impact of environmental, socio-economic and infrastructural conditions within the setting's resources and limitations may help to respond to MBD transmission more effectively. Within a two-step investigation process, this thesis pursues four key objectives:

(1) a basic ecological understanding of emerging MBD within an urban transmission cycle
   a. … to learn about the ecological dimension and influencing determinants of MBD and their health impacts and challenges from multiple disciplines' perspectives
   b. … to descriptively investigate the interaction between the vector-pathogen-human epidemiological dynamics and primary eco-bio-social determinants in Rio de Janeiro during the period 2015/2016, taking the city's profile and the situation of Public Health Emergency into account

(2) the application of integrated knowledge and methodology following the achievements, challenges and lessons learned in Rio de Janeiro with the purpose
   a. … to explore the setting's peculiarities and situational factors that mainly influenced the latest arbovirus outbreaks in Rio de Janeiro city 2015/2016 aiming to identify strengths, weaknesses, opportunities and threats
   b. … to determine hazards and resources at the sight of MBD transmission looking at two municipal areas of Rio de Janeiro affected to different degrees

The primary outcome of this research may help to identify spatial, temporal as well as situational weak points and risk factors leading to the (re-)emergence and rapid development of MBD in the city of Rio de Janeiro. On the other hand, it also presents resources and points of public health action in order to improve the development and targeted implementation of effective MBD control strategies. The findings derived could help to improve multi-sectoral communication and strengthen evidence-based development of health policies in the fight against MBD.

3. Methods

The following section presents an overview about the study rationale, methodological aspects and the datasets used for this thesis.

3.1 Study design

An in-depth understanding of the ecology of vector-pathogen-host interaction related to the development of MBD within urbanized and densely populated areas forms the basis of this thesis. Therefore, a descriptive case study of the *Zika outbreak scenario in Rio de Janeiro 2015/2016* was conducted following a mixed-methods approach. The study inquiry includes (1) a comprehensive review on the past and current literature, (2) a quantitative and (3) a qualitative research approach. The key findings were evaluated to identify risks and resources aiming an effective response to emerging MBD outbreaks in metropolitan settings. The assessment follows two established tools, which are modified to the field of emerging infectious diseases epidemiology: (4) the *Situation and Influencing Factors Analysis* (abbreviated SIFA), originally applied in the field of social marketing for public health programs, and (5) the *Hazard Analysis and Critical Control Points* concept (abbreviated HACCP), widely used in food production systems.

(1) The comprehensive literature review was conducted screening not only academic sources, but also public health reports to gather information regarding (a) the vector *Aedes aegypti* and its properties, (b) arboviruses circulating in Rio de Janeiro transmitted by *Aedes aegypti,* (c) factors that may influence the spread of MBD in metropolises or rather megacities, and (d) public health activity and potential strategies to combat the spread of MBD. Different search terms related to MBD ecology and development were used separately and in combination to screen references provided by scientific databases (Pubmed, LIVIVO) as well as web-based (Google Scholar):

*Mosquito-borne diseases**		
*Vector-borne diseases**	+ *Outbreak*	+ *Brazil*
Zika/Dengue/Chikungunya	+ *Ecology*	+ *Rio de Janeiro*
Arbovirus	+ *influence**	
*Mosquito**		
Aedes aegypti		

Inclusion criteria were set for

a. access to free articles and full text version,
b. sources available in English and German linked to the field of medicine and health,
c. relevant past and current ecological studies representing a basic understanding of vector-transmitted diseases development, and
d. the latest research findings focusing on Brazil published during the past 10 years.

The findings derived are based on both a quantitative and a qualitative literature analysis.

(2) The quantitative inquiry focuses on the spatio-temporal description of determinants identified in the literature analysis, that may influence the spread of arboviruses in tropical, urbanized and densely populated settings. To investigate the interplay between MBD emergences and probable influencing factors for the case of Rio de Janeiro city, the number of notifications of the suspected cases of ZIKV, DENV and CHIKV infection were used to create a monthly epidemiological overview from October 2015 to September 2016. During this 12-months period, all three arboviruses were reported to cause suspected infected cases among Rio de Janeiro's population based on the first and only available dataset. Emphasized to influence the development of MBD, the following variables were investigated:

a. the distribution of *Aedes*-positive breeding sites based on the Larval Index Rapid Assay (LIRAa) surveillance from October 2015 to September 2016,
b. climatic conditions and weather phenomena from October 2015 to September 2016,
c. the environmental characteristics of Rio de Janeiro city,
d. socio-economic characteristics and living conditions within different communities,
e. the city's basic and public services (basic supply, health care, education), and
f. the temporal trend of internationally published news reports (following the Twitter-Hashtag #Zika) as well as the Google trend for the queries "Zika", "Dengue", and "Chikungunya" to give an idea of the development of public interest.

(3) The qualitative approach was used to create a multi-disciplinary picture of the Zika emergence situation in Rio de Janeiro 2015/2016 involving different disciplines' perspectives.

The information gathered are based on the experiences as well as expertise and knowledge of ten specialists from the fields of

a. medical sciences and health care
b. entomology,
c. environmental and climate sciences, and
d. public health action.

Field observations in the expert's work life as well as contemporary materials amplified the data collection. All findings are presented within a qualitative framework reporting the most important messages developed during the case study in Rio de Janeiro city.

Based on the descriptive investigation of the literature review, quantitative analysis and qualitative evaluation, a situation (SIFA) and hazard analysis (HACCP) was conducted. This approach follows the application of two tools:

(4) the *SCOPE* concept of the ECDC's technical document *Social marketing guide for public health programme managers and practitioners* ("Analyzing situation and influencing factors", Task 2, cf. ECDC 2014). This tool was chosen to receive an in-depth understanding and insight into the complex challenge of emerging MBD outbreak scenarios considering the case of Rio de Janeiro city; and

(5) the *Hazard Analysis and Critical Control Points* concept (Edmunds, Hunter, Few & Bell 2013, Krumkamp et al. 2009) applied to the outbreak of emerging mosquito-transmitted diseases in Rio de Janeiro city 2015/2016. This approach was implemented to investigate two differently affected areas (a severely affected community and a less affected community) and to assess the progress of outbreak response based on the lessons learned during the 2015/2016 MBD emergences in Rio de Janeiro. Key influencing factors identified within the quantitative and qualitative analyses were taken into consideration to develop solution approaches and targeted messages for future public health activity.

3.2 Case definition and setting description

Based on the study rationale, the setting chosen to investigate the case of emerging MBD outbreaks, associated influencing factors of different qualities and their impact on arbovirus epidemics is the city of Rio de Janeiro, Brazil. Due to the introduction of Zika in 2015, chikungunya in 2016 and the seasonal occurrence of dengue since 1986, the city faces not only one, but three co-circulating arboviruses of major public health concern. On the one hand the latest outbreaks enabled to investigate first hand experiences as well as to establish a detailed situation report regarding the fight against MBD from a Brazilian perspective. On the other hand, the co-circulation of three different types of arboviruses and the lack of profound knowledge about the rapid spread of ZIKV and its severe consequences turned up challenging. Furthermore, a wide range of online data bases, often not easy to find and hard to understand, aggravated the search for reliable and topical information. However, as a large and densely populated municipality at major risk, the city's climatic, environmental and infrastructural profile appeared to be favorable for a descriptive case study to investigate presumed drivers for the rapid spread of mosquito-borne diseases following the example of the Zika in 2015/2016. With the Fundação Oswaldo Cruz (Oswaldo Cruz Foundation, known as Fiocruz) Rio de Janeiro owns one of the leading science and technology health institution in Latin America based in Manguinhos, an impoverished community in the north of Rio de Janeiro city. Despite activities like research development as well as information and communication in health, science and technology, the Fiocruz institution also focuses on the provision of health care and the production of vaccines, drugs, reagents, and diagnostic kits (Fundação Oswaldo Cruz 2017) – important measures to face the spread of MBD not only in Rio de Janeiro, but worldwide. The collaborating institution gave access to various fields of research and professionals, an insight into the situation regarding the city's public health challenges and its characteristic communities, as well as achievements, obstacles and perspectives in the sector of case management, transmission and vector control of MBD. A broad collaboration with national and international partners provided opportunities for multilateral investigations.

3.3 The quantitative inquiry and datasets included

The following table presents the datasets included within this thesis as well as their referable sources, collected between 2004 and 2017. All information corresponds to the findings derived from the literature review.

Table 2: Overview about the datasets included

Variable	Data description/Source
Epidemiological dataset	Suspected cases of ZIKV, DENV, CHIKV/ arbovirus infections in total (2015/2016) (Rio de Janeiro health secretariat database provided by PROCC Fiocruz)
Climatic dataset	Spatio-temporal information about minimum/maximum temperature, precipitation (2015/2016) IRI Data Library provided by PROCC Fiocruz (http://iridl.ldeo.columbia.edu/)
	Temporal information about extreme weather events (2015/2016) São Cristóvão meteorological station (http://alertario.rio.rj.gov.br/info-estacoes/)
Environ-mental dataset	Area description in km^2 (2017) Thomas Brinkhoff: city population Brazil (https://www.citypopulation.de/php/brazil-rio.php)
	Coastline extension in km (2015) Instituto Municipal de Urbanismo e Pereira Passos (IPP)/ Diretoria de Informações da Cidade (DIC) (http://portalgeo.rio.rj.gov.br/pcontrole/content/out/content.asp?gcod=279)
	Average elevation above sea level in m (2004) IPP/DIC (http://portalgeo.rio.rj.gov.br/pcontrole/content/out/content.asp?gcod=279) Geologica e hidrografia da cidade do Rio de Janeiro, Educação Pública (http://www.educacaopublica.rj.gov.br/oficinas/geologia/hidrografia_rj/06.html) Wiki OpenStreetMap (http://wiki.openstreetmap.org/wiki/Rio_de_Janeiro_(city)/Morros_do_Rio)
	Environmental/infrastructure description (2017) Allocation of bays, lagoons (2009), rivers (2005) Google Maps/Software R version 3.3.2 (R libraries RgoogleMaps, maptools, ggmap mapdata) Secretaria Municipal de Urbanismo (SMU), IPP, Diretoria de Informações Geográficas (DIG) (http://portalgeo.rio.rj.gov.br/amdpgint_ms.asp?gtema=0&gcod=1) Prefeitura da Rio de Janeiro/Instituto Pereira Passos/Armazém de Dados (http://pcrj.maps.arcgis.com/apps/webappviewer/index.html?id=eb90b035ecea4615bf1404de54be23dd/http://pcrj.maps.arcgis.com/apps/webappviewer/index.html?id=7606de2873ee441fae431368967ef56b)
Mosquito dataset	Aedes aegypti infestation rapid survey/ Levantamento Rapido de Indice para Aedes aegypti (LIRAa) Predominant breeding sites of Aedes aegypti (2015-2017) Prefeitura da Rio de Janeiro (http://prefeitura.rio/web/sms/exibeconteudo?id=2815394)
Community/ socio-economic dataset	Population (2010, 2015/2016); basic demographics (age, gender, ethnicity) (2010) IBGE - Censo Demográfico 2010 (http://portalgeo.rio.rj.gov.br/amdpgint_ms.asp?gtema=0&gcod=1) Estimated population size 2015 and 2016: Prefeitura da Cidade do Rio de Janeiro 2013 (http://portalgeo.rio.rj.gov.br/estudoscariocas/download/3255_Proje%C3%A7%C3%A3oPopulacional2013-2020_CidadedoRiodeJaneiro_m%C3%A9todoAiBi.pdf)
	Housing quality (2010); number of permanent residents per household (2010) Level of income among the working population (2010) Number of analphabets per age group (2010) IBGE - Censo Demográfico 2010 (http://portalgeo.rio.rj.gov.br/amdpgint_ms.asp?gtema=0&gcod=1)

	Public and domestic garbage disposal (2010) Water supply within private households, sanitation within private households (2010) IBGE - Censo Demográfico 2010 (http://portal-geo.rio.rj.gov.br/amdpgint_ms.asp?gtema=0&gcod=1)
	Proxy: overview allocation of educational services/schools and health care services (2016) Prefeitura da Rio de Janeiro/Instituto Pereira Passos/Armazém de Dados (http://pcrj.maps.arcgis.com/apps/webappviewer/index.html?id=8397b3b090794488995be72c05e3ec61/http://pcrj.maps.arcgis.com/apps/webappviewer/index.html?id=747b6bf0c45e402cb95482f32a50c14e)
	Proxy: overview distribution of Favelas in Rio de Janeiro without numbers (2016) Prefeitura da Rio de Janeiro/Instituto Pereira Passos/Armazém de Dados (http://pcrj.maps.arcgis.com/apps/webappviewer/index.html?id=5529d644feff4d92a30bd38565f6c460)
Public news/ Twitter posts/ Google Trend dataset	International news coverage, research findings, and public declarations/alerts (a) via Twitter related to the Hashtag "#Zika" (online publications 2015-2017) Healthmap (http://www.healthmap.org/zika/#; http://compepi.org/project/zika-timeline/) (b) via STAT newsletter "Zika in 30 seconds: What you need to know today" (2016/2017) STATnews (https://www.statnews.com/series/zika-update/) (c) via "Zika history" presented by the WHO digital timeline (2015-2017) WHO (http://www.who.int/csr/disease/zika/en/)
	Google search interest for (a) search term "Zika", (b) search term "Dengue", (c) search term "Chikungunya" provided by Google Trend © for Rio de Janeiro state (1st March 2015 to 22nd May 2017) Google queries related to the search term (1st March 2015 to 22nd May 2017) (https://trends.google.com/trends/)

Almost all datasets were available for Rio de Janeiro's 162 districts and have been aggregated for the ten Health Programmatic Areas (Áreas Programáticas), since this was the most appropriate way to obtain a complete data set based on the permission of the Rio de Janeiro health secretariat. By this it was possible to describe the epidemiological, entomological, environmental, socio-demographic as well as infrastructural characteristics of each Programmatic Area (AP).

Epidemiological dataset

The epidemiological data used in this analysis was obtained from the Rio de Janeiro health secretariat presenting every notified suspected case of Zika, dengue, and chikungunya disease per month for the year 2015 (January to December), and 2016 (January to October). The dataset includes aggregated information about the International Classification of Diseases tenth revision (ICD-10), the epidemiological month of notification, and the geographic allocation in Rio de Janeiro city following the ten Health Programmatic Areas (AP). Case notifications with missing information about temporal and spatial classification were excluded. Information about suspected cases are discussed in total numbers as well as in relation to the investigated area's inhabitants number based on the estimated population size

2015/2016. The epidemiological overview is displayed individually for ZIKV, DENV and CHIKV infections as well as for arbovirus infection (ARBOV) on total. Data preparation was realized by the Programa de Computação Científica, Fiocruz Rio de Janeiro.

Climatic and environmental dataset

Resulting from the literature review, temperature, rainfall and the occurrence of extreme weather events (temperature extremes, torrential rainfall, scarcity of rainfall) were chosen as main influencing climate variables. The data analysis was based on two datasets:

(1) Spatial climate information for each AP were derived from satellite data for the duration October 2015 to September 2016 using the IRI Data Library for monthly day and night surface temperature of Southern America (“USGS LandDAAC MODIS 1km 8day version_005 Terra SSA”) and monthly precipitation data (“UCSB CHIRPS v2p0 monthly global precipitation”). Data arrangement was supported by the Programa de Computação Científica, Fiocruz Rio de Janeiro.

(2) Temporal climate information (January 2015 to October 2016) were acquired from one meteorological station located in São Cristóvão, AP 1.0 (http://alertario.rio.rj.gov.br/info-estacoes/), which measures temperature and precipitation every 15 min. Information about extreme events were examined by calculating the number of days per month with (a) temperature > 35 °C (lower maximum limit), (b) temperature > 40 °C (upper maximum limit), (c) temperature < 20 °C (minimum limit), (d) precipitation level > 30mm (extreme rainfall), and (e) precipitation level zero (no rainfall). The extreme events follow the description of crucial climate drivers and limiting values stated in past and current literature (Fagundes Gomes et al. 2012, Honório et al. 2009; Gubler et al. 2001b, Becker et al. 2012). The calculation was performed in Microsoft ® Excel ® 2013. Data preparation was supported by the Instituto de Comunicação e Informação Científica e Tecnologia em Saúde, Fiocruz Rio de Janeiro. The dataset is displayed in Table A1 in Appendix 1.

(3) Besides meteorological parameters, further environmental characteristics were derived from several databases (cf. Table 2). Datasets were available for coastline extension (in km), altitude above sea level (in m) as well as a descriptive overview about bays, lagoons and rivers distributed over the city. The average elevation was calculated following the basic altitude of Rio de Janeiro city (5 m above sea level) and the mean altitude value of

all identified plateaus within each programmatic area. Based on information taken from Google Maps © and digital maps provided by Prefeitura da Cidade do Rio de Janeiro (2013), the overall city structure of Rio de Janeiro could be described concerning the infrastructure and environmental characteristics prepared by software R version 3.3.2 (R libraries RgoogleMaps, maptools, ggmap and mapdata) and software GNU Image Manipulation Program (GIMP) version 2.6.11 and 2.8.20.

Mosquito dataset/ Larval Index Rapid Assay ("LIRAa") surveillance

Information about the entomological surveillance of the primary vector *Aedes aegypti* were taken from the *Aedes aegypti* infestation rapid survey/Levantamento Rapido de Indice para *Aedes aegypti* (LIRAa) prepared for Rio de Janeiro's ten APs. Originally developed by the Health Surveillance Secretariat of the Brazilian Ministry of Health, this method aims to identify the vector infestation rates as well as predominant breeding sites of *Aedes aegypti* on a municipal level. Therefore, the city was divided into 251 so called strata, which consists of 8,100 to 12,000 properties and can be represented by the ten Health Programmatic Areas (Prefeitura do Rio de Janeiro, n.d.). As the Larval Index Rapid Assay intends a quarterly entomological surveillance, data was available for October (18^{th} to 24^{th}) 2015 as well as March (13^{th} to 19^{th}), May (29^{th})/June (4^{th}), and October (16^{th} to 22^{nd}) 2016. To realize a monthly examination, missing follow-up observation values were replaced by the values of the last observation. The LIRAa index indicates three levels of alert: an infestation index less than 1 % classified as "Tolerable", an index ranging from 1 to 3.99 % indicating an "Alert", and an index higher than 3.99 % classified as "At Risk". Table A2 in Appendix 1 presents the complete dataset including the replaced monthly value of missing observations. Information on infested containers are divided in five categories: Group (A) containers for household water storage; Group (B) movable containers; Group (C) fixed containers; Group (D) discarded containers; and Group (E) natural containers.

Community information and socio-economic dataset

The Instituto Brasileiro de Geografia e Estatística (IBGE) and the Prefeitura da Rio de Janeiro provided information about various community and socio-economic parameters for Rio de Janeiro's ten APs. Based on the 2010 census, data could be extracted for population size, basic demographics (age groups, gender, ethnicity), housing quality, number of permanent residents per household, level of income among the working population as well as the number of analphabets per age group as one variable representing a crucial ability to get access and to understand health information. The census also presented information about the public and domestic garbage disposal as well as an overview about the form of water supply and sanitation within Rio de Janeiro's private households. Information about the population size relevant for the investigated season could be gathered from the Population Projection Report 2013-2020 (cf. Table 2). To present reliable measurements of the investigated population within the quantitative approach of this thesis, the mean value of the 2015 and 2016 estimated population size was calculated (Lins, Pessoa da Silva, Carneiro da Silva & Guimaraes Ferreira 2013, p. 13). Information about population density, demographic characteristics, housing quality, household size, level of income, number of analphabets, and allocation of basic supply is presented in proportion (%) to the population size of 2015/2016. The proportion of each variable in relation to the population size in 2010 (census 2010) is assumed to be the same in 2015/2016. Furthermore, data could be identified regarding the allocation of educational and health care services available for 2016, though the dataset is presumed to be incomplete considering the population size of 6.5 million inhabitants. However, the set was included to provide a proxy of the situation in Rio de Janeiro, supplemented by information taken from the qualitative analysis.

Public news, Twitter posts and Google Queries dataset

To give an idea of the influence of public interest and the development of public health reports, a trend analysis was conducted following essential research findings, public health announcements and news reports associated with the Zika virus outbreak in Brazil 2015/2016. Information were taken from three sources with an emphasis on Brazil:

a. *Healthmap*, which presents all collected online reports based on an open source Twitter analysis following the hashtag *#Zika* from March 2015 until May 2017 (English and Brazilian references),
b. the scientific newsletter of *STAT* following the reports of the section *Zika in 30 seconds: What you need to know today* from February 2016 until May 2017 (online publications in the field of medicine and public health presented in English)
c. the Zika history provided by the WHO digital timeline focusing on the duration March 2015 (beginning of the Zika outbreak in Brazil) until May 2017 (end of Public Health Emergency of National Concern in Brazil).

Information were included not only relevant for Rio de Janeiro city and state, but throughout Brazil since the latest news, findings and MBD management efforts on a country's level may also affect actions taken on a municipal level. An impression of the level of interest and public concern regarding MBD emergences in Rio de Janeiro could be developed following the results of a Google Trend analysis (https://trends.google.com/trends/) for the queries "Zika", "Dengue", and "Chikungunya" as all three diseases were co-circulating in Rio de Janeiro 2015/2016. The Google Trends analysis was conducted on a web-search basis considering all categories of interest for Rio de Janeiro state from 1st March 2015 to 12th May 2017. The evaluation also presents favored Google queries related to "Zika", "Dengue", and "Chikungunya" identified by Google Trends. The findings are described in the form of relative search interest ranging from 0 to 100 (the number of calls in relation to the total search-volume of a specific query within a particular setting and duration).

3.4 The qualitative inquiry

Based on the findings of the literature review and first results of the epidemiological quantitative analyses, the qualitative approach draws on multiple sources of data collection for an information-rich case study recommended by Creswell and Poth (2017). Data was gathered by (a) expert conversations, (b) field observations, and (c) contemporary materials.

(a) Participants for expert conversations were recruited from different fields of research who are/were working in the field of mosquito-borne arbovirus control in Rio de Janeiro, Brazil, and beyond. Eligibility criteria were experiences in research or field work linked to MBD and climate issues in Brazil (i.e. laboratory work, data collection in the field, medical consultation, community work, project coordination) as well as proper communication skills in English or German as these were the languages spoken in the research team. Ten experts from the field of medical sciences, entomology, environmental and climate sciences as well as the public health sector were consulted individually (person-to-person, Skype, telephone call or email survey) and information were evaluated anonymously to ensure the privacy and data protection of all participants. All sessions followed a conversation protocol (cf. Appendix A8.1 and A 8.3) and, if permitted from participants, were audio-recorded for further analyses. The agreement on conversation procedure, data storing and privacy was ensured by giving informed consent prior (cf. Appendix A8.2) to each consultation following the approval of the Fundação Oswaldo

Cruz (ICICT), and the FTZ-NK, University of Applied Sciences Hamburg. Records were transcribed with the aid of "oTranscribe" online HTML5 app (http://otranscribe.com/). Five overall categories could be deduced which were similar to the foci of the literature analysis. Each category could be divided into 2 to 3 subcategories, the subcategories were furthermore distinguished in a total of 46 thematic codes. A detailed overview including the results is presented within Appendix 6. Data was analyzed and refined using the approach of a summarizing qualitative content analysis based on Mayring (2012) and Kuckartz (2008) (Dresing & Pehl, 2013).

(b) Five observation sites emerged where two researchers participated in large part as observers integrated into the research setting: (1) physician's consultation with mothers and/or fathers and their children; (2) entomological laboratory observation; (3) inspection of virologists' laboratory and equipment; (4) participation in the field of microbiological mosquito control program ("Eliminate Dengue"); (5) participation in team meetings to improve case management of co-circulating arboviruses and virus surveillance of hard-to-reach communities. Information were collected using an observation minute (cf. Appendix A8.4). Time for a conjoint field note session right after the observation was scheduled to reflect the information gathered and the individual impressions in form of a narrative description captured in a categorical matrix (1-5).

(c) Additionally, contemporary field materials (protocols, findings sheets, photographs, news, magazines, newsletter, presentations and posters presented on the "Latin American Symposium on Climate Change and Health" and "Zika Symposium" in Rio de Janeiro in 2016) were screened to develop a more detailed description of the situation of co-circulating arboviruses and climate challenges in Rio de Janeiro city.

A framework was developed representing the key findings of the qualitative inquiry. The aim was to focus on information that identify key drivers, challenges and resources/solution approaches concerning emerging MBD outbreaks and control strategies in a setting like Rio de Janeiro city and to learn from the involved professional perspectives and their experiences during the *Zika outbreak scenario 2015/2016*.

3.4 Analysis of the situation, influencing factors, and hazards

Tool (A): Situation and influencing factors analysis (SIFA)

To better understand determinants that may impact the dynamics of MBD in time and place, a situation and influencing factors analysis (SIFA) was conducted. Originally developed to implement or evaluate social marketing approaches as a part of communicable disease prevention activities and public health programs (ECDC, 2014), one of the document's tools was chosen to investigate the situation of the spread of MBD diseases in Rio de Janeiro city. Activities combined in "Task 2 – Analyzing situation and influencing factors" were tailored accordingly to the study design and applied in an appropriate way to describe strengths and weaknesses (tool 4), influencing contextual issues (tool 5), barriers and challenges (tool 6), competing health and community issues (tool 7), evidence-based strategies and MBD control efforts (tool 8 and 9) as well as sources, partners and stakeholders who may contribute to effective MBD outbreak control (tool 10 and 11). The evaluation followed the resources provided within the technical document (ECDC 2014, pp. 44-51).

Tool (B): Hazard Analysis and Critical Control Points technique (HACCP)

Primary, the HACCP concept was developed to set public health oriented standards with the aim to improve food-safety practices by identifying and controlling biological, chemical and physical hazards and risks associated with food production. In detail, "the approach […] was to set targets for pathogen reduction based on what was judged achievable with available science and technology, and to require establishments to meet the limits on a consistent basis" (Hulebak & Schlosser 2002, p. 549). Besides the prevention of foodborne diseases, this systematic assessment tool is widely applied to various fields of action like animal health and welfare (Noordhuizen & Metz 2005), health care and infection control (Baird, Liddell, Mitchell & Sneddon 2001) as well as emerging infectious diseases outbreaks aiming to develop a rapid outbreak response (Edmunds et al. 2013, Krumkamp et al. 2009). Originally, the concept consists of seven main principles (National Advisory Committee on Microbiological Criteria for Foods 1998):

i. to conduct a hazard analysis
ii. to determine critical control points (CCPs)
iii. to establish critical limits for the identified CCPs
iv. to establish monitoring procedures

v. to develop corrective actions
vi. to establish verification procedures, and
vii. to develop record-keeping and documentation procedures

However, to evaluate and assess emerging health threats and outbreak management systems, the first three principles are of main importance (MacLehouse, 2013). Based on the descriptions of Edmunds et al. (2013, p. 2), Hulebak and Schlosser (2002, p. 550), Krumkamp et al. (2009, p. 22) and MacLehouse (2013, p. 122), Table 3 presents the first three defined principles of an HACCP following the case of an emerging infectious disease outbreak scenario:

Table 3: HACCP principles used to evaluate an emerging infectious disease outbreak scenario

HACCP	**Principle 1: Conduct a Hazard Analysis**	**Principle 2: Identify Critical Control Points in the Process**	**Principle 3: Establish Critical Limits for each identified CCP**
Aim	To analyze all hazards and risks that can be associated with a public health concern	To develop points, steps, or procedures at which control may be applied and hazards can be prevented, eliminated, or reduced	To establish criterion that must be met for each preventive measure associated with a CCP to control identified hazards and risks
Action	Create a flow chart of stages involved within the scenario/ process in question and validate the flow chart based on the literature, through liaison with experts or surveys to those involved during the outbreak	Critical review of the scenario/process to highlight stages which can adopt mitigation strategies for hazards	Ascertain critical limits for the CCPs identified and use these to generate recommendations for the improvement of the overall outbreak scenario/ management process

Within this thesis, the HACCP principles 1-3 were applied to the study case of the Zika virus outbreak scenario in Rio de Janeiro 2015/2016. First, a hazard analysis was conducted (Principle 1). A flowchart was drawn to identify hazards and risks during an MBD emergence, which is predicated on the results of the literature review, quantitative inquiry and qualitative content analysis. The establishment and evaluation of CCPs (Principle 2 and 3) followed the findings identified in the SIFA, statements derived from the expert conversations as well as solution approaches ascertained within the literature analysis.

4. Results

4.1 Comprehensive literature analysis: key findings

An in-depth understanding of the complex body of MBD ecology forms the basis of this thesis. Therefore, a comprehensive literature analysis was conducted reviewing the past and current literature that includes clinical and experimental studies, review articles, case studies and academic commentaries. Also, technical public health reports and science news articles were screened to gain the best knowledge available as information (particularly about Zika as a hitherto neglected vector-borne disease) has been published quickly since the latest emerging arbovirus outbreaks. Literature was included which met the inclusion criteria and contains information about the fields of vector ecology and MBD ecology following the title, abstract and/or conclusion. Based on that, 65 sources were reviewed, published between 1963 and 2017. Articles about mosquito-transmitted arboviruses and *Aedes* mosquitoes prevalent in Brazil were limited to the time span of 2007-2017 to gain the latest information possible. Seven articles published earlier than 2007 (1967-2006) were included that provided highly valuable information about the ecological perspective on MBD, especially concerning DENV as well as arbovirus outbreaks in Africa and Asia. Thirty-four sources specifically focus on vector ecology, 31 are mainly about mosquito-transmitted diseases or rather the agents' ecology, 24 cover the impact of climate on MBD, 14 discuss environmental influences, 7 mainly focus on anthropogenic issues and 7 further studies report about the topic of vector and disease control. A list of the included references can be found in Appendix 2c.

Considering the purpose to identify factors that influence the development and spread of MBD eight thematic fields could be identified:

a. epidemiological factors
b. biological factors
c. ecological factors
d. environmental factors
e. climatic/meteorological factors
f. socio-economic factors
g. anthropological/societal factors, and
h. political, historical and economic factors.

The most frequently cited and thus more profoundly explained determinants are climate (56 out of 65 sources) and environmental parameters (43), the impact of vector ecology like density, behavior, and development (44), human host characteristics such as population density, human behavior, or immune status (40), socio-demographic conditions (29) and the investigated setting's infrastructure (27). Also, the agent's properties like transmission dynamics and development (23) as well as the impact of vector and MBD control measures (24) were more frequently investigated. Rather less examined or of minor importance seem to be political, historical and economic factors (4), the impact of globalization (6), and technology and industry on a local and global level (2). However, issues like urbanization (21), population growth (11), and human movement (17) related to the globalization trend seem to gain increasing attention and are more often described in contemporary research articles. Almost all identified influencing factors could be distinguished in local and global parameters. A summarizing framework can be found in Appendix 2a.

Particularly useful for this thesis, three sources provided a detailed basic plan that illustrates the complex vector-host-pathogen interaction taking the established influencing factors into consideration (cf. Appendix 2b):

a. *The ecological dimensions of vector-borne disease research and control* (Ellis & Wilcox 2009)
b. *Challenges in predicting climate and environmental effects on vector-borne disease epi-systems in a changing world* (Tabachnick 2013)
c. *Irregular water supply, household usage and dengue: a bio-social study in the Brazilian Northeast* (Caprara et al. 2015)

All three articles distinguish between three primary dimensions that are interacting with each other within an overall epidemiological system: the vector, the pathogen, and the host effected by environmental conditions. Figure 2 integrates the main ideas of Ellis and Wilcox (2009, p. 158f), Tabachnick (2013, p. 947), and Caprara et al. (2015, p. 126), supplemented by the factors identified within the literature analysis of all 65 sources.

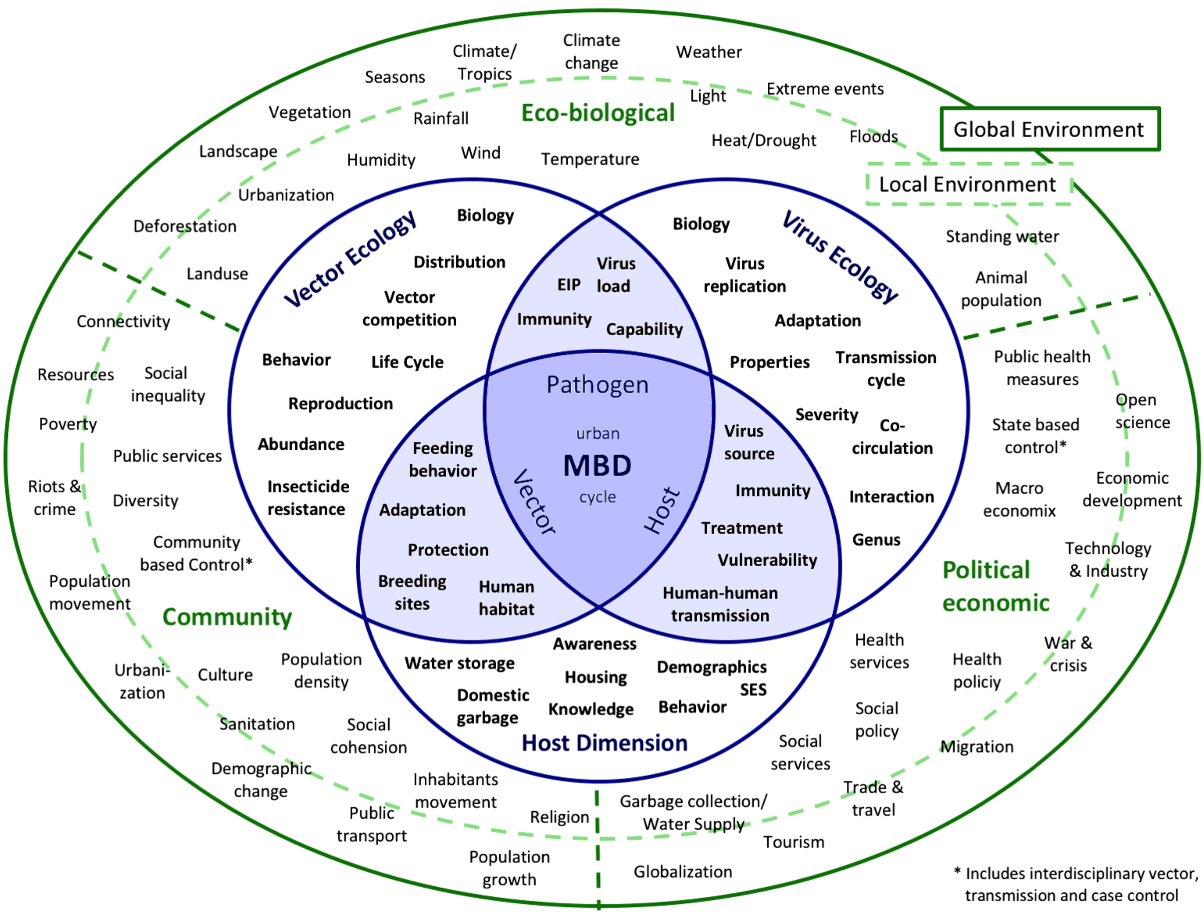


Figure 2: MBD ecology - summarizing results of the comprehensive literature analysis

As one of the most susceptible domain to external influences, the vector's ecological dimension (*Vector Ecology*) is particularly dependent to environmental parameters due to the mosquito's missing innate regulation system and dependence to suitable human living area (*Host Dimension*) since human beings are the main blood source of *Aedes aegypti* mosquitoes. Depending on the characteristic of each influencing factor, the identified determinants may be either promoting or restricting for the development of MBD. While warm and humid weather conditions, an increased vector-host contact, the availability of artificial breeding places, and the susceptibility of vector and host may trigger the spread of MBD, cool and dry climatic conditions, improved water supply, proper housing conditions and herd immunity among the human host population can restrict vector abundance and virus circulation.

Furthermore, the application of control measures, the improvement of vector and virus surveillance as well as health education and public empowerment are pointed out essential in the fight against MBD, following the review article "Zika Virus: Epidemiology, current phobia and preparedness for upcoming mass gatherings, with examples from World Olympics and Pilgrimage" by Nahla K. Ibrahim (2016) which serves as the fourth key source of valuable input for this thesis. Although this review mainly focuses on ZIKV, public health approaches for future outbreak preparedness and response can be applied to all three arbovirus diseases circulating in Rio de Janeiro city. In addition to Figure 2, Table 4 presents a comprehensive summery of the influencing factors, distinguished in MBD promoting or rather risk factors, and components of restricting or protective impact.

Table 4: Promoting and restricting factors influencing the spread of MBD

Factor	Promoting/Risk Factors	Restricting/Protective Factors
Natural Environment	• Tropical climate (humidity, elevated temperature, prolonged precipitation especially during summer) • Extreme weather events (flooding/drought) • Urbanization/urban environment/deforestation • Standing water (rivers, lakes, bays) • Global warming/increase of minimum temperature	• Hot/cold temperature, extreme weather events • Winter season (cold temperature, dry conditions) • Wind, higher altitude and latitude • Climate change creating unsuitable habitat: shift of vector population
Urban Ambience	• Population growth/high density, human movement • Lack of infrastructure, water supply, waste management • Lack of access to public (health) services • Resource-poor settings	• State-based preventive and control measures • Improved infrastructure and sanitation • Public (health) education and public empowerment
Community Ambience	• Poor-quality housing, high number of residents/household • Poverty, social inequalities, demographic change • Lack of domestic garbage collection and adequate water management/sanitation and hygiene • High level of neighborhood connectivity, public movement	• Wealthy community, adequate water supply, (environmental) sanitation and hygiene • Community-based application of preventive and control measures, community empowerment • Allocation/access to adequate public (health) services
Human host-related Conditions	• Newborns/children, elderly, co-morbidities/autoimmune diseases, level of susceptibility and immunity • Pregnant women (ZIKV severe consequences) • Lower socio-economic status, low education level • Human risk behavior/increased vector-host contact (*water accumulation in household containers/domestic waste during rainy season/water storage during dry season (artificial breeding sites), lack of protective measures like application repellent, nets, protective clothing, …)*	• Application/installation of personal protective measures, household vector and transmission control: avoiding mosquito bites and control for breeding sites • Knowledge and awareness concerning MBD transmission and *Aedes aegypti* control
Vector-related Conditions	• High mosquito density in densely populated urban settings with tropical conditions (hot spots) • Climate dependency (elevated temperature, breeding water caused by rain but also artificial water storage) • Domestication, proximity to human habitat • Vector behavior: – *Sip-feeder during daytime, feeds from multiple humans* – *Short flight distance, living habitat close to humans* • Adaptation, insecticides resistance	• Competitive vector species (*Aedes albopictus*) • Biologically adapted mosquitoes not able to reproduce or to transmit pathogens (vector control) • Integrated vector control (biological, chemical, physical; however, risk of insecticides resistance • Entomological surveillance (adult mosquito and infestation surveillance)

Virus-related Conditions	• Susceptible host population, capable vector population, first emergence within a suitable environment • Probability of asymptomatic infection (DENV, ZIKV) • Faster replication with elevated temperature (EIP) • Arbovirus co-circulation/arbovirus co-infection • Virus adaptation/modification • Lack of diagnostic tools and antiviral treatment/vaccine	• Availability of diagnostic tools/trained professionals • Adequate symptomatic treatment • Herd immunity of host population, vaccination • Epidemiological surveillance, early warning system (sentinel, syndromic, electronic
Political, economic Conditions/ Global Perspective	• Lack of (financial) resources and infrastructure • Lack of political will/political and financial crisis, war • Natural disasters/extreme weather events • Increased trade and travel (global spread of vector/virus) • Mass gathering events in affected areas • Globalization, urbanization, population growth, demographic change • Human movement and migration	• (Social and health) Policy making • (Interantional) health education and travel advice/ establishement/maintenance of travel medicine • Educational materials (public, television, social media) • Resource-/risk-oriented preventive/control measures • Research and development of new products (diagnosis, treatment, vaccine) (Ibrahim, 2016) • Strengthening of international and multidisciplinary open science community for international collaboration and public health action • Financial support and commitment

Overall, four main risk factors appear to be crucial for emerging arbovirus outbreaks:

a. a wide-spread distribution and high density of a capable domestic *Aedes aegypti* mosquito combined with ineffective vector control (Pepin et al. 2015),
b. suitable tropical-like climate conditions presenting elevated temperature and humidity as well as accumulated standing water (natural or artificial) that creates breeding sites close to or inside human habitat (Lana, Carneiro, Honorio & Codeco 2012)
c. a susceptible host population living in urban and densely populated areas with a lack of adequate infrastructure and access to public (health) services (Barreto et al. 2011)
d. an emerging virus affecting both vertebrate and arthropod cells that is yet poorly understood and hardly preventable due to a lack of sustainable protection measures, adequate treatment and preventive strategies (Gubler et al. 2001b)

In contrast, environmental factors may decline MBD and vector development*:*

a. restricting hot and cold thermal conditions that influence both vector and virus survival (cf. paragraph 2.2 and 2.3)
b. heavy precipitations and flash floods that harm eggs and larvae (Zahouli et al. 2016)
c. vector competition between *Aedes albopictus* and *Aedes aegypti* (considering the availability of food), especially in suburban and rural areas (Piovezan et al. 2013).

Following the literature, the implementation of effective physical, chemical, and biological vector control (WHO, 2004) combined with public health educational programs (Ibrahim, 2016) and the frequent application of protective measures (prevent mosquito bites and control for mosquitoes inside and outside according to CDC (2017b) are by now the most promising health promotion strategies to combat the spread of MBD. An adequate epidemiological and entomological surveillance is highlighted essential to detect early arbovirus transmission to create an alert surveillance system for control and prevention of future outbreaks (Ibrahim, 2016).

4.2 The quantitative analysis:
A descriptive profile of Rio de Janeiro city

The municipality Rio de Janeiro (MRJ), the capital of the state of Rio de Janeiro, is located in the Southeast of Brazil (longitude -22.9035, latitude -43.2096) with an area of approximately 1,200 km^2. Following the latest estimations of 2016, Rio de Janeiro has a population of about 6,320,000 inhabitants, with a population density of almost 5,500 people per km^2 (Brinkhoff 2017). After Sao Paulo, the city is thus the second-most populous municipality in Brazil. It is subdivided into a total of 161 districts, called Bairros, which can be combined into ten Health Programmatic Areas (AP) that serve as an administrative structure for public security and health care planning (Prefeitura da Cidade do Rio de Janeiro 2014). A more detailed overview is given in Figure 4A, Appendix 3.

Figure 3 presents a spatial description following the overall structure of the city distinguished into the ten different APs. This map will furthermore serve as a key feature for the following sections. AP 1.0, 3.1, 3.2, and 3.3 represent the center of Rio de Janeiro city and is predominantly characterized as urbanized and well-infra-structured. In contrast, AP 2.1, 2.2, 4.0, and 5.1 to 5.3 may be described as decentered and shaped by the city’s environmental diversity. The displayed surfaces and landscape give an idea of the environmental characteristics of each AP.

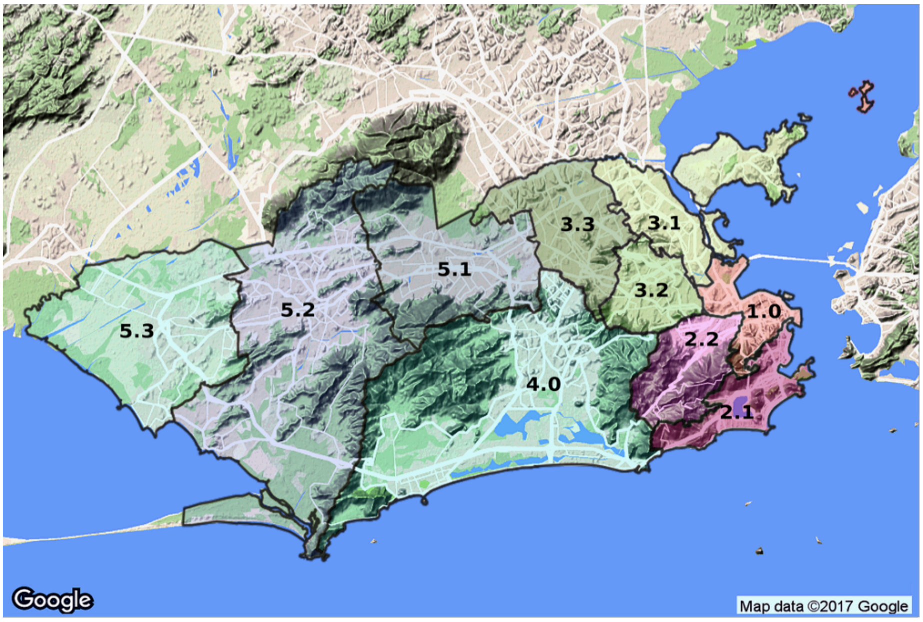


Figure 3: Spatial description of Rio de Janeiro city, created with software R version 3.3.2 and GIMP 2.6.11

Additionally, Table 5 describes the basic characteristics of the different APs following the area, the population size and density based on the 2010 census, as well as the population size and density based on estimates for 2015/2016.

Table 5: Basic characteristics of Rio de Janeiro following the area, population size and density

AP	Area (km^2)	Population 2010	Density** 2010	Population 2015/2016*	Density** 2015/2016
1.0	34.4	297,976	8,662	312,183	9,075
2.1	46.25	638,050	13,796	641,676	13,874
2.2	54.94	371,120	6,755	373,089	6,791
3.1	86.23	886,551	10,281	899,633	10,433
3.2	41.37	569,970	13,777	572,071	13,828
3.3	76.96	942,638	12,248	948,390	12,323
4.0	294.4	909,368	3,089	1 018,992	3,461
5.1	116.07	671,041	5,781	676,491	5,828
5.2	287.97	665,198	2,310	703,297	2,442
5.3	161.7	368,534	2,279	395,922	2,449
MRJ	1,200.3	6 320,446	52,656	6 541,741	5,450

* Mean value of the estimated density 2015 and 2016
** Population density: number of inhabitants per km^2

A major part of the city is bordered by the sea, with the Atlantic Ocean to its south, Guanabara Bay on the east and Sepetiba Bay on the west side. AP 2.1, 4.0 and 5.3, together with 1.1 and 3.1, are thus described as coastal zones. Furthermore, three massifs located in the north (Gericinó-Mendanha massif), the east (Tijuca massif) and the west (Pedra Branca massif) affect Rio de Janeiro's topographic profile. Besides those massifs, the city is situated on lowland level around an average altitude of approximately 20m (Dereczynski, Silva & Marengo 2013). Illustrated in Figure 3, the larger areas in the middle of the city – AP 4.0 and 5.2, but also 5.1 and 2.2 – are mainly formed by Rio de Janeiro´s mountain terrain and urban forests.

Located in an Atlantic tropical climate, the coastal length together with the topographic conditions of the city are deeply impacting the local climate, making the northern and western districts warmer and drier than the southern and downtown areas (Dereczynski et al. 2013). During the year, a warm and rainy summer season and a cold and dry winter season can be observed. During the summer months from November to April average temperature between 24 and 27 °C occur, while during the winter season from May to October the monthly mean temperature ranges between 21 and 24 °C (Honório et al. 2009, Dereczynski et al. 2013). Additionally, an overall change in temperature, which may be associated with global climate change, can be observed. Over the last 30 years, a clear trend in urbanization together with an increase in minimum temperature as well as a rise in overall surface temperature was illustrated in the literature, expecting a higher percentage of warm days and nights in the city Rio de Janeiro for the 21st century (Dereczynski et al. 2013, De Lucena et al. 2013). Observations further indicate an increase of torrential rainfall events for next decade together with the occurrence for longer dry and shorter wet seasons.

The following sections of chapter 4.2 describe the MBD scenario 2015/2016 (considering the epidemiological and entomological surveillance) with respect to environmental, climatic, infrastructural and socio-economic properties of Rio de Janeiro city's ten APs in more detail. The presented information is related to the identified influencing factors based on the literature analysis (cf. Table 4) to descriptively examine the impact of

a. climatic conditions and weather patterns linked to tropical climate;
b. the environmental characteristics concerning the topographic profile, level of urbanization, infrastructure and allocation of basic supply within the city; and
c. the socio-economic conditions considering the demographic characteristics, education (analphabets), income, housing conditions, and household size.

4.2.1 The spread of emerging MBD in Rio de Janeiro 2015/2016

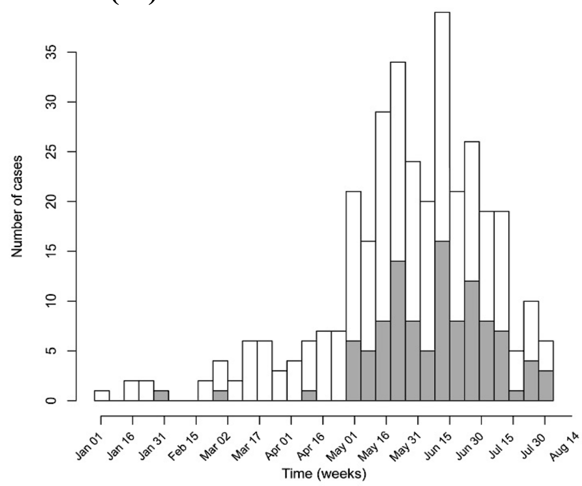
Following the Fiocruz clinical surveillance for confirmed (gray) and non-confirmed (white) ZIKV infected cases (Brasil et al. 2016), Zika was first detected in January 2015. However, looking at the clinical surveillance of suspected cases provided by the Rio de Janeiro health secretariat, ongoing ZIKV circulation was recognized at a later date (Figure 4a and 4b). The major outbreak was reported from September 2015 to July 2016. As described within section 2.4 and illustrated in Figure 4b, not only ZIKV, but also suspected DENV and CHIKV cases have been reported between October 2015 and October 2016. The numbers of the suspected cases for each virus is presented in Table 6.

Following the temporal trend from October 2015 to September 2016, the epidemiological development of all three arboviruses (yellow line) resembles the pattern of a continuous common source outbreak, though the first suspected cases were reported from March to July 2015. During this event, Rio de Janeiro's population have been exposed to the same potential source of infection, affected *Aedes aegypti* mosquitoes, prolonged over a period of approximately 14 months. Between September 2015 and October 2016, 86,385 cases of suspected arbovirus infection were reported to the health secretariat of Rio de Janeiro city. Most of the suspected cases were notified as Zika (38,221 notifications) and dengue (34,330 notifications), while only a sixth of all reported notifications was suggested to be chikungunya (13,834 notifications). An initial minimum of 598 suspected cases was notified in October 2015, the maximum peak of 20,554 suspected cases in April 2016, followed by a final minimum of 524 suspected cases in October 2016. Considering each virus report separately, Zika, counting 44 percent of all reported cases, represents the majority of arbovirus notifications with an initial minimum of 12 suspected cases in September 2015 and a maximum value of 7,138 suspected cases in March 2016. Zika circulation seems to start contemporaneously with dengue, but with a steeper slope at first forming a plateau-like shape with no precise individual peak. A declining trend was recognized from March 2016 onwards. The proportion of dengue notifications counts for 40 percent of all suspected arbovirus cases and presented an initial minimum of 563 suspected cases in October 2015 and its peak with a maximum of 10,835 suspected cases in April 2016. The curve of dengue cases increased more steadily presenting the highest peak of the three arboviruses development in April 2016. From April to October 2016 the dengue curve decreased to its lowest level.

Figure 4a:
ZIKV development in Rio de Janeiro Jan 2015 to Aug 2015 provided by Brasil et al. (2016, p. 6)

Figure 4b:
Arbovirus development in Rio de Janeiro Jan 2015 to Oct 2016 based on the health secretariat surveillance (author's database)

(4a)



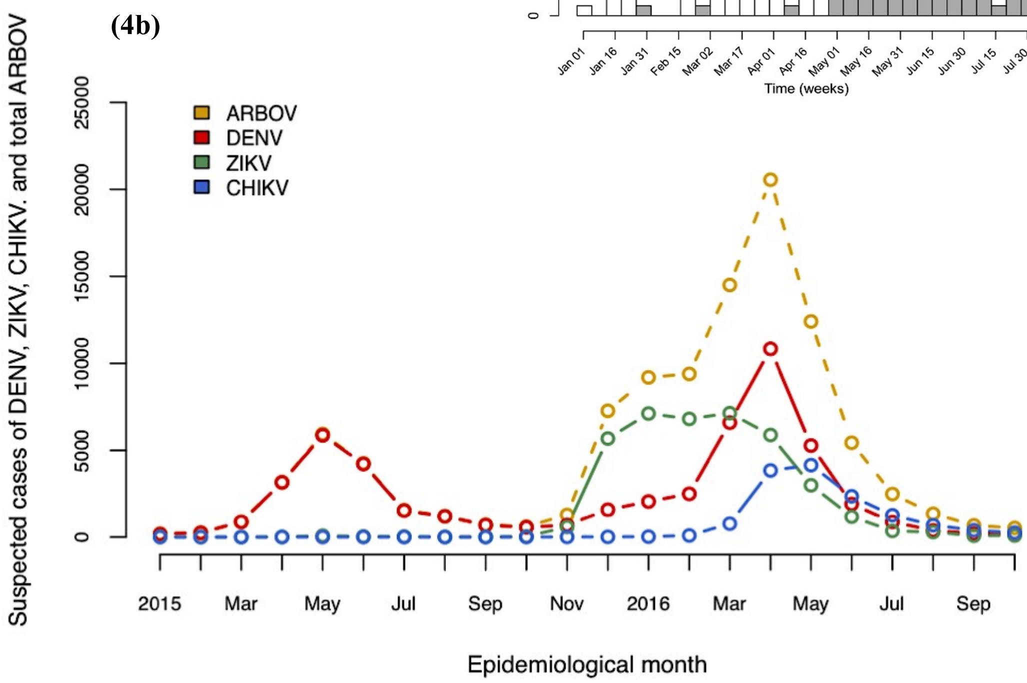
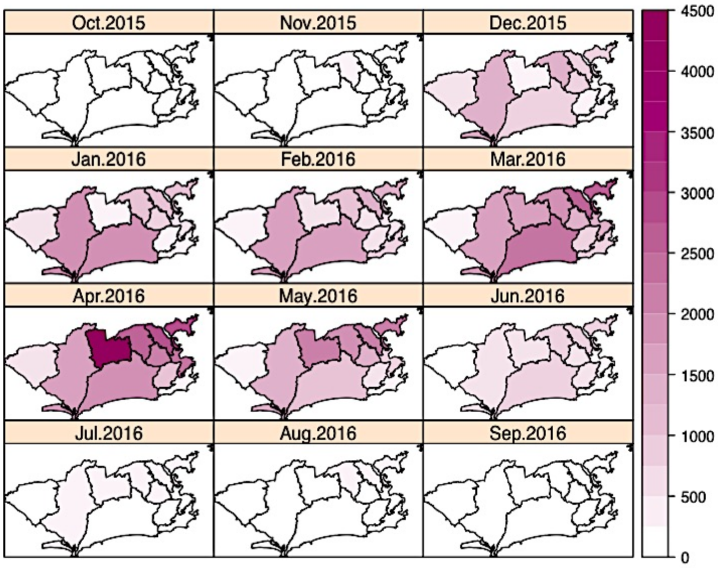


Table 6: Temporal Perspective - Suspected cases in total numbers displayed for ZIKV, DENV, CHIKV, and arbovirus infected cases (ARBOV), Rio de Janeiro Sept 2015/Oct 2016

Virus/Time	Sep 15	Oct 15	Nov 15	Dec 15	Jan 16	Feb 16	Mar 16
ARBOV	702	598	1283	7,272	9,195	9,396	14,503
ZIKV	12	33	581	5,678	7,116	6,808	7,138
DENV	690	563	693	1,582	2,055	2,496	6,595
CHIVK	0	2	9	12	24	92	770
Virus/Time	**Apr 16**	**May 16**	**Jun 16**	**Jul 16**	**Aug 16**	**Sep 16**	**Oct 16**
ARBOV	20,554	12,409	5,438	2,486	1,352	673	524
ZIKV	5,883	2,988	1,173	355	289	78	89
DENV	10,835	5,277	1,912	871	380	201	180
CHIVK	3,836	4,144	2,353	1,260	683	394	255

Chikungunya virus made up 16 percent of all suspected arbovirus infections, with an initial minimum of two suspected cases in October 2015 and a maximum of 4,144 suspected cases in May 2016. Chikungunya seem to have started later than the other two viruses, likely due to its first emergence in 2015/2016. An increase in suspected cases can be observed starting in February, peaking in May and afterwards following a decreasing development till October 2016. The development of all three diseases declined from July to October 2016 to a minimum of 524 suspected cases of arbovirus infection (ZIKV=89, DENV=180, CHIKV=255). This is also the time when the field investigation of this study project ended.



5a: Suspected cases of ARBOV in total numbers

5b: Suspected cases of ARBOV per 10,000 inhabitants

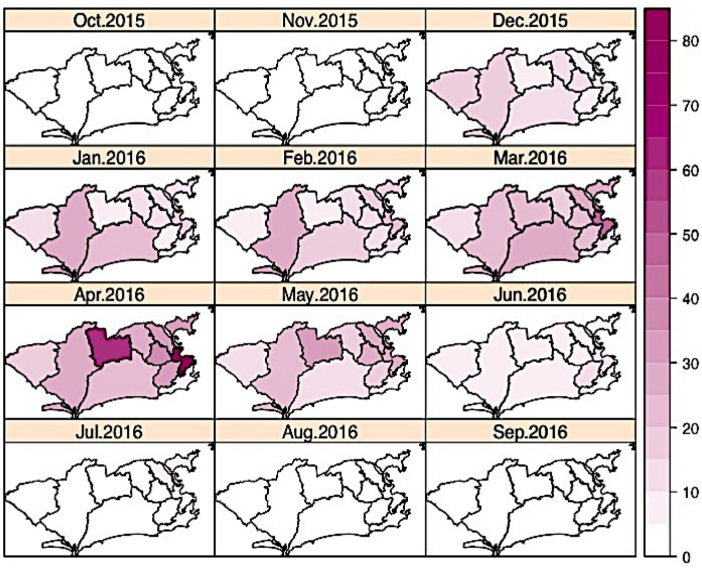


Figure 5: Spatio-temporal perspective - the spread of arbovirus diseases following the notified suspected cases of ZIKV, DENV, and CHIKV in a) total numbers and b) cases per 10,000 inhabitants

The maps (Figure 5) present the spatial distribution of arbovirus infections in total (ZIKV, DENV, CHIKV) from October 2015, indicating the beginning of the co-circulation of all three viruses (cf. Table 6), to September 2016 presented in total numbers of suspected cases as well as the number of suspected infections per 10,000 inhabitants. A spatial overview for ZIKV, DENV, and CHIKV is illustrated in Figure A5, Appendix 4.

Investigating the co-circulation of ZIKV, DENV, and CHIKV as one arbovirus challenge (cf. temporal perspective), the spread of ARBOV across Rio de Janeiro caused alerting numbers of suspected cases from December 2015 until June 2016, thus for 7 months of the investigated 12-months duration (Figure 4 and 5). Two paths of distribution can be illustrated, describing the development of arbovirus circulation in total as well as per 10,000 inhabitants: firstly, from December 2015 until February 2016, the viruses started to spread area-centrically, especially circulating within the largest of the ten areas (3.3, 4.0 and 5.2) with more than 12,000 cumulative cases among ≈ 2.6 million inhabitants until February 2016. The highest portion was notified as Zika. District 5.1 seemed almost non-affected, reporting just about 1,600 notifications by that time. Also, the western (AP 5.3) and eastern region (AP 1.0 - 3.2) of Rio de Janeiro remained less concerned. Since March 2016, initiating the second trend, those areas previously less affected notified an increased number of suspected cases, highlighting AP 4.0 (23 cases per 10,000 inhabitants) and 3.1 (29 cases per 10,000 inhabitants). Following the total numbers, the most affected area was AP 5.1 in April 2016 reporting 4,266 suspected cases (63 cases per 10,000 inhabitants), almost all of them stated as dengue. Considering the cases per 10,000 inhabitants, also AP 1.0 presented a high number of suspected cases especially in March (43 cases per 10,000 inhabitants) and April 2016 (78 per 10,000 inhabitants). While the circulation started across larger and more decentered districts (AP 3.3, 4.0, 5.2) and there the number of notifications decreased since March 2016, especially those areas in the northeast of Rio de Janeiro (5.1, 3.1, 3.3, 1.0) remained affected until May 2016, mostly reporting dengue and chikungunya infection. Similar to the temporal analysis, the number of suspected cases of all three diseases started to decrease concurrently between April and June 2016 until August 2016, where less than 1,500 cases were reported.

4.2.2 The distribution of Aedes aegytpi across Rio de Janeiro 2015/2016

Figure 6 illustrates the distribution of *Aedes aegypti* and presents the local vector infestation rate related to the classification of alert. It also describes predominant breeding places of *Aedes aegypti* summarized for 2015 and 2016.

Since this information is based on an incomplete monthly dataset (cf. methods) conclusions must be drawn with caution. However, following the alert scale of the LIRAa infestation index, all areas present a higher mosquito infestation during the summer season (November to April) with an index value ranging from 0.3 (tolerable) to 1.4 (alert). The highest values were reported for AP 3.3 (index 1.4), for AP 1.0 (index 1.3), and AP 3.1 (index 1.2) from October 2015 to February 2016. Less affected were AP 1.0, 2.1, and 5.3 (index 0.6). None of the areas reached an index value higher than 3.99 (risk).

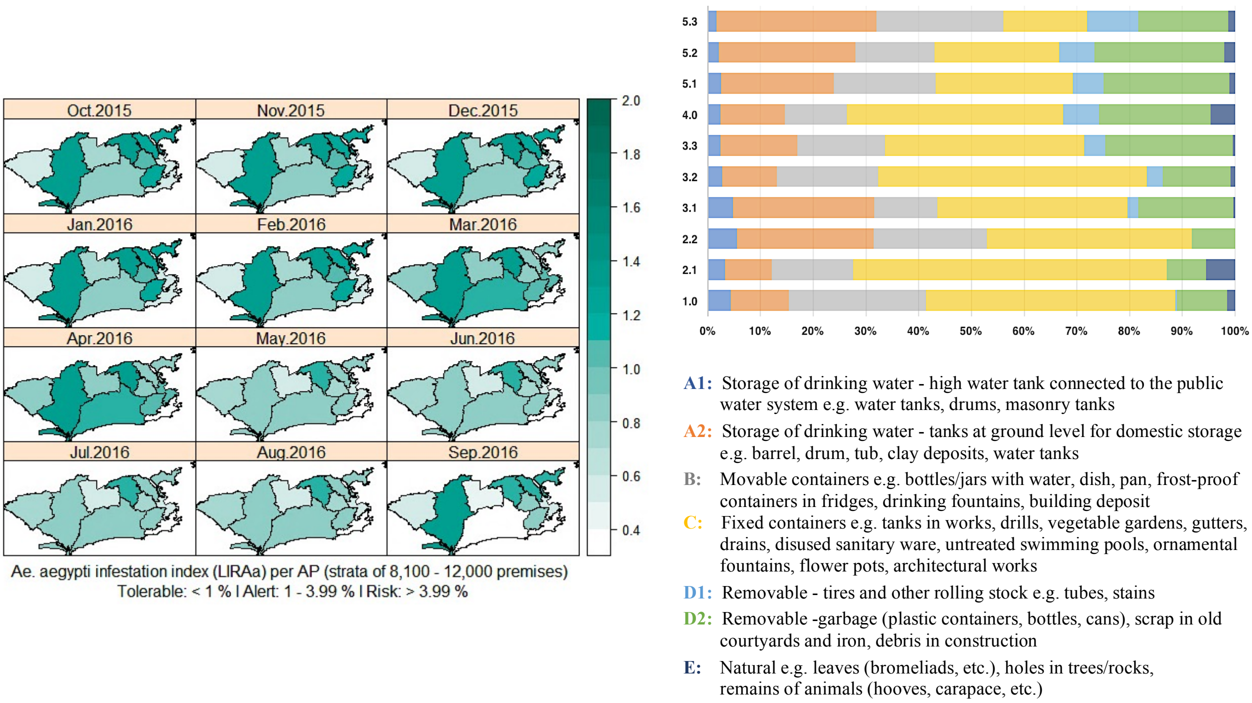


Figure 6: Spatio-temporal perspective – the distribution of *Aedes aegypti* and predominant breeding places based on the LIRAa infestation index for Rio de Janeiro 2015/2016

In contrast, during the winter months (May to October) a lower infestation index was recognized ranging from 0.1 (tolerable) to 1.1 (alert) across the city. The lowest values were notified in AP 2.1 (index 0.1), 1.0, and 5.1 (index 0.5) during May and September 2016. Looking at the predominant breeding sites of *Aedes aegypti*, the most preferred places are fixed containers like tanks, gutters, drains, swimming pools or flower pots (C). However, in area AP 5.2 and 5.3 mosquito larvae could be found in tanks for domestic water storage at ground level (A2). In AP 1.0, 2.1, 3.2, and 5.3, also movable containers (B) like bottles, drinking fountains, and basins served as breeding habitat. Removal vessels like garbage items and scrap (D2) could be identified as infested by mosquito larvae in AP 3.3, 4.0, and 5.1. Breeding places of minor infestation were tanks for water storage at higher a level that are connected to the public water system (A1) and natural items like leaves and holes in trees and rocks (E).

4.2.3 The descriptive analysis of identified influencing factors

Following the evidence of the past and current literature, environmental, infrastructural, and socio-economic conditions may be crucial drivers for the distribution of mosquitoes and their carried pathogens DENV, ZIKV, and CHIKV. Hereafter, a detailed description of Rio de Janeiro's characteristics will be investigated.

4.2.3.1 Environmental profile of the study area Rio de Janeiro

Rio de Janeiro is mainly characterized by urbanized environment in the north-east, decentered urban districts with agricultural focus in the west, as well as forested areas combined with three massifs in the north, east, and center-west (Figure 7).

Figure 7: Spatial perspective – the environmental profile of Rio de Janeiro
Source: Prefeitura da Cidade do Rio de Janeiro (2017), edited with software GIMP 2.8.20

Especially AP 3.1 to 3.3, but also 1.0 are described as centered and highly urbanized, associated with a high population density (almost 10,000 inhabitants/km^2 within each AP) and well-developed infrastructure. In contrast, AP 2.2, 4.0, 5.1, and 5.2 are shaped by Rio de Janeiro's forests and plateaus. As presented in Table 5, such areas have a lower population density (less than 5,000 inhabitants/km^2 in each AP) than those districts in the north-east of Rio de Janeiro. The altitude of these regions along with a dense forest vegetation make them less habitable for people, but also *Aedes aegypti,* which prefers urbanized habitat with close vicinity to humans (Figure 8). According to Cetron (2016), an elevation higher than 2,000 m above sea level is associated with a minimum likelihood (≈ 1%) for MBD transmission. More than 200 different plateaus can be found in AP 4.0 and 5.1, some of them with an altitude higher than 1,000 m.

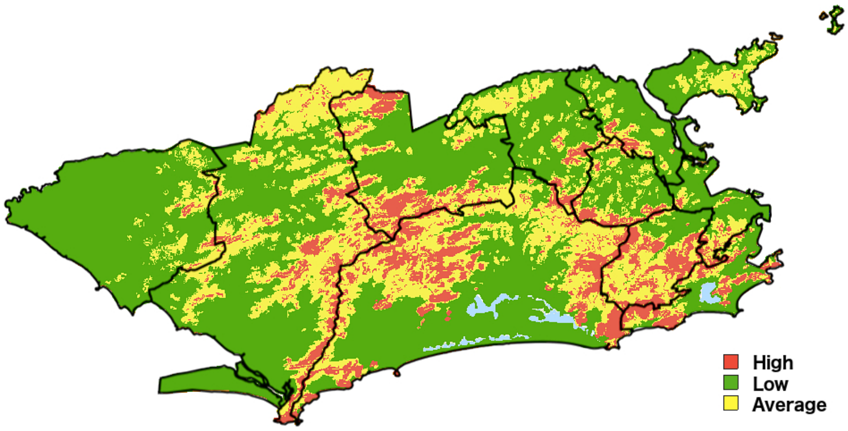


Figure 8: Spatial perspective – the elevation profile of Rio de Janeiro
Source: Prefeitura da Cidade do Rio de Janeiro (2017), edited with software GIMP 2.8.20

AP 2.2, southern parts of 4.0 and 5.3, as well as AP 1.1 and 3.1 are furthermore known as coastal areas close to the Atlantic Ocean and surrounding bays. The largest coastal zones are Praia da Barra da Tijuca in AP 4.0 (length=15.53 m), Praia da Marambaia in AP 5.2 (length=10,97 m) as well as Praia de Copacabana (length=3.04 m), Praia de Ipanema (length=2.14) and Praia de São Conrado (length=2.19 m) in AP 2.1. In addition to the direct proximity to the sea and bays, almost 300 river courses form the hydrographic system of Rio de Janeiro. The highest portion of rivers can be found in AP 4.0 and 5.2. The areas AP 2.1 and 4.0 furthermore hold lagoons in the south of Rio de Janeiro. As mosquitoes require standing water to breed and thus replicate, primarily in warm ambient temperature, Rio de Janeiro's bays, rivers, and lagoons may serve as breeding habitat for *Aedes aegypti*. Figure 9 gives an idea of the distribution of natural water surfaces.

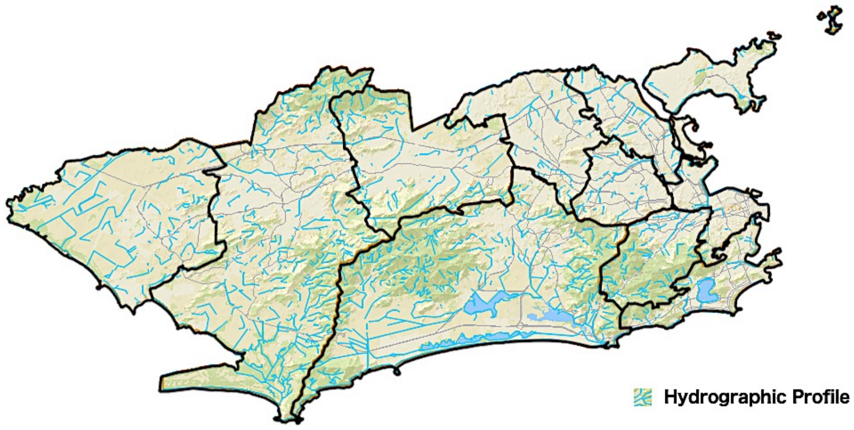


Figure 9: Spatial perspective – the distribution of water areas in Rio de Janeiro
Source: Prefeitura da Cidade do Rio de Janeiro (2017)*, edited with software GIMP 2.8.20*

Referring to the findings of the literature review, three environmental determinants may fundamentally influence the development of mosquitoes and MBD: firstly, the presence of natural water areas like bays, lagoons, and rivers; secondly, the level of altitude; and thirdly, the proximity to the coast influenced by oceanic climate cycles (cf. chapter 4.1, Table 4). Looking at the previous maps (Figure 7-9), all of them are of major importance considering the environmental profile of the study area Rio de Janeiro.

4.2.3.2 Climatic conditions and seasonal weather patterns

As described in section 4.2, Rio de Janeiro is characterized by an Atlantic tropical climate and a diverse environmental profile impacting the local climate. Considering the occurrence of local weather patterns and seasonal changes, climatic conditions need to be investigated temporally and spatially. Based on the findings of the literature analysis, especially elevated temperature and increased rainfall are crucial for the development of mosquitoes and circulation of anthropod-borne viruses (Paz & Semenza 2016, Vasconcelos et al. 2001). However, both determinants in the event of extremes may also restrict the activity and survival of *Aedes aegypti* and arboviruses, thus, the transmission of MBD (Yang, Macoris, Galvani & Andrighetti 2011).

Looking at maximum and minimum temperature (Figure 10), two thermal phases could be observed: a warmer period from October 2015 to April 2016 (end of winter to summer) and a colder period from May to September 2016 (end of summer to winter).

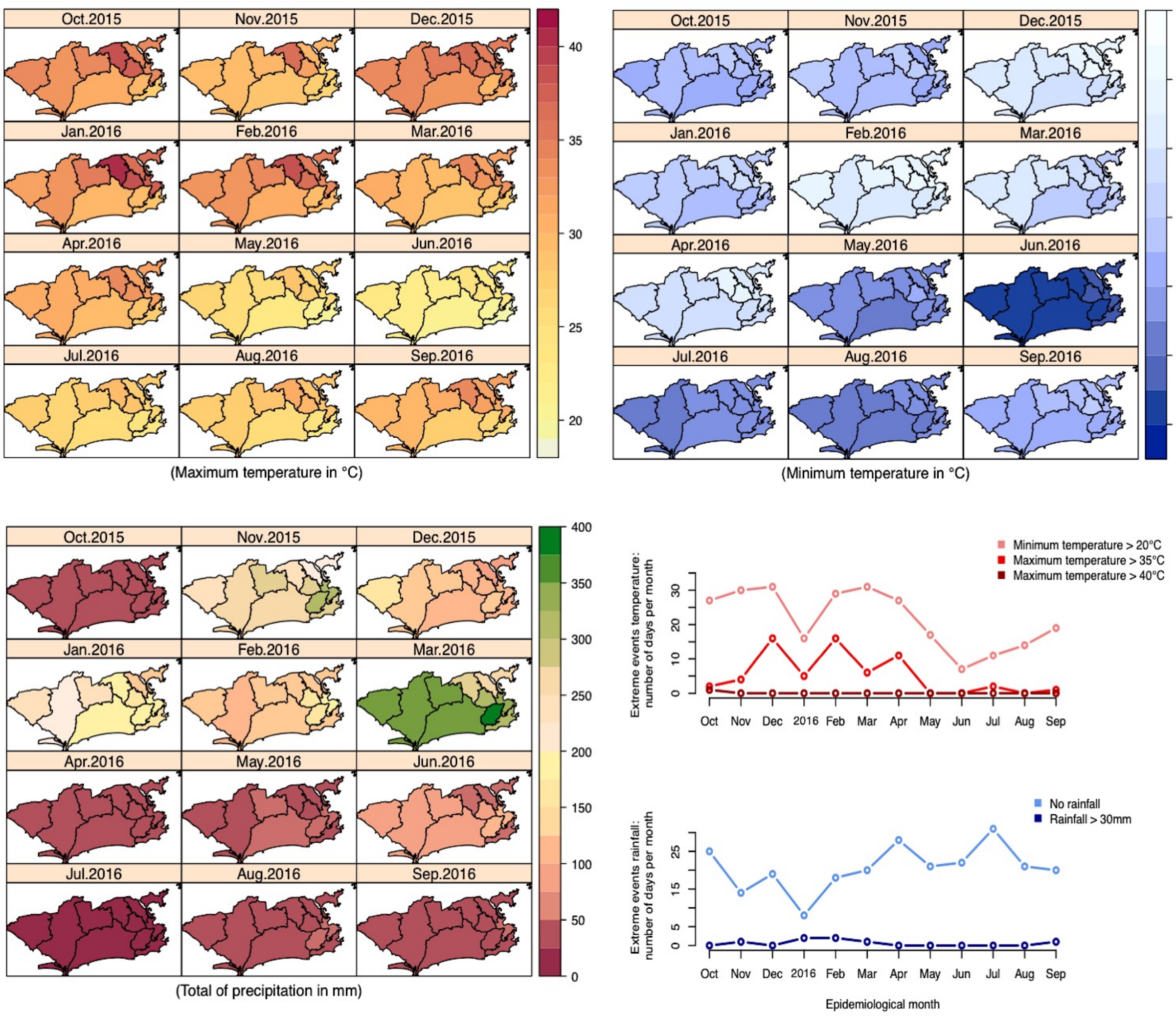


Figure 10: Spatio-temporal perspective – the development of temperature, rainfall and the occurrence of extreme weather phenomena in Rio de Janeiro 2015/2016

For maximum temperature, the highest average was recorded in January 2016 (Tmean=34.4 °C) with AP 3.3 as the hottest district (T=40.6 °C), followed by 1.0, 3.1, 3.2, and 5.1 with temperatures above 35 °C. The lowest maximum value occurred in June 2016 (Tmean=22.4 °C), whereas the previously stated districts still present temperatures higher than the average (T=23.1-24.2 °C). October and December 2015, as well as January and February 2016 have been the warmest months on average (T=33.7-34.4 °C). Concerning the development of minimum temperature, the coldest month was June 2016 (Tmean=16.8 °C), when all districts reported a temperature lower than 20 °C. However, district 1.0, 2.1, 3.1, and 3.2 again indicated slightly warmer conditions (T > 17 °C) than the others. The highest minimum values occurred in December 2015 and from February to April 2016 (T=23.2-25.4 °C).

Looking at rainfall patterns (Figure 10), two seasons could be observed: a wet and a dry season. Starting in November 2015, the wet season lasted until March 2016, with November 2015 (total rainfall=2,660.74 mm) and March 2016 (total rainfall=3,341.38 mm) as the rainiest months within the displayed 12-months cycle. The highest level of precipitation was recognized in the AP 2.2 and 1.0 (rainfall > 1,500 mm), followed by 5.1, 5.3, 4.0 and 5.2 (rainfall > 1,350 mm). In contrast, the more desiccant areas within this period were 3.1, 3.3, and 2.1 with an amount of rainfall less than 1,300 mm. A contrary season with drier conditions lasted from April to September 2016, with a totalized rainfall amount less than 900 mm per month. Since precipitation was also low in October 2015 (rainfall < 400 mm), dry conditions may be presumed lasting from April to October 2016.

The interacting pattern of temperature and precipitation induce a wet and warm summer season as well as a cold and drier winter season, as described by Dereczynski et al. (2013). This interplay could also be observed in extreme weather phenomena. With an increase of minimum temperature (T > 20 °C) and maximum temperature (T > 35 °C), a decrease in the number of days with no rainfall on the one hand, and a slightly increase in the number of days with torrential rainfall (rain > 30 mm) was recognized. Such conditions present most suitable circumstances for mosquito and pathogen development, based on the findings of the literature analysis. Considering the restricting impact of both hot and cold temperature on the survival of mosquitoes and arboviruses (cf. section 2.2 and 2.3), more days with hot conditions, but also a drop in maximum and minimum temperature may inhibit mosquito activity and virus replication. Both events were observed in October 2016 (start of the increasing trend of minimum temperature > 20 °C, higher number of days with maximum temperature > 40 °C), in December 2015/February/April 2016 (peak in the trend of maximum temperature > 35 °C), and May/June 2016 (drop in minimum temperature > 20 °C and maximum temperature > 35 °C). A scarcity in rainfall was recognized in October 2015, April 2016 and a peak in July 2016. Increased rainfall could be observed from December 2015 to March 2016.

4.2.3.3 Rio de Janeiro's population characteristics

As presented in section 4.3.2.1, the population density is considered a main influencing factor for the transmission of mosquito-borne arboviruses. However, also housing conditions and socio-economic properties play an important role when it comes to MBD emergences (Rocklöv et al. 2016). To give an overview about the distribution and thus concentration of Rio de Janeiro's population, Figure 11 presents the population density (2015/2016) per AP.

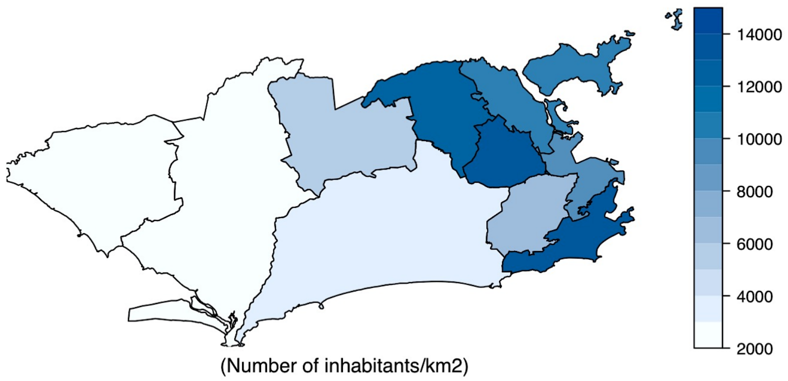


Figure 11: Spatial perspective – the population density in Rio de Janeiro 2015/2016

Furthermore, Table 7 gives an overview about the demographic characteristics of Rio de Janeiro's population. The information presents the proportion (%) of sex, age group, and ethnicity among the population of each area following the 2010 census dataset. For further debate on the 2015/2016 MBD emergence scenario, the proportion (%) in relation to the estimated population size of 2015/2016 is assumed to be similar.

Overall, a slightly higher proportion of women in contrast to men was reported for each AP. Area 2.1 presents the highest number of female inhabitants (56 %). Concerning the age distribution, AP 2.1 and 2.2 are characterized by a larger number of elderly people (age 60 to 80^{+} years), while especially AP 3.1, 5.2 and 5.3 state a higher proportion of infants and children (age group 0-9 years and 10-19 years). The most reported age group for almost all APs was 20-29 years, only AP 5.2 and 5.3 indicate a younger mode of 10-19 years. The most common ethnicities in Rio de Janeiro are white (51 %) and so-called mulatto inhabitants (37 %). However, more than 50 % of the population's ethnic status is not declared. Inhabitants of black ethnicity present the third largest ethnic group (11 %). An ethnic minority are yellow, Asian, and indigenous ethnicities (each less than 1 %).

Table 7: Spatial Perspective – Demographic characteristics of Rio de Janeiro's population looking at the proportion (%) of sex, age groups, and ethnicity per AP and MRJ (based on the 2010 census)

AP	1.0	2.1	2.2	3.1	3.2	3.3	4.0	5.1	5.2	5.3
Proportion of sex (%)										
female	52.6	55.6	55.9	52.4	54.2	53.6	52.4	51.9	52.2	51.9
male	47.4	44.5	44.1	47.6	45.8	46.4	47.6	48.1	47.8	48.1
Proportion of age group in years (%)										
0 - 9	11.10	8.15	8.52	12.71	10.82	12.32	12.34	12.94	13.78	15.76
10 - 19	14.07	9.82	11.38	15.66	13.55	15.30	14.45	16.07	17.09	18.62
20 - 29	18.11	16.10	15.69	17.51	16.14	16.04	17.38	17.30	16.38	16.61
30 - 39	16.31	15.57	14.54	15.63	15.26	15.09	17.03	15.34	16.05	15.44
40 - 49	13.75	13.64	13.82	13.34	14.06	13.85	14.36	13.94	14.21	12.99
50 - 59	11.68	13.64	13.95	10.98	13.01	12.42	11.70	11.76	11.19	10.32
60 - 69	7.27	10.26	9.81	6.86	8.43	7.94	7.09	7.00	6.50	6.09
70 - 79	4.56	7.45	7.37	4.18	5.74	4.88	3.87	3.96	3.39	3.05
80^{+}	2.45	5.36	4.92	1.92	3.00	2.16	1.78	1.69	1.41	1.13
Ethnicity (%) *(*mixed black and white ancestry)*										
White	48,79	75,61	71,30	46,63	54,83	44,44	57,99	40,06	41,47	34,08
Black	13,30	5,09	7,31	12,40	12,25	14,36	8,92	14,09	12,15	14,46
Yellow	0,99	0,68	0,69	0,87	0,58	0,72	0,65	0,72	0,71	0,93
Mulatto*	36,74	18,47	20,59	40,01	32,20	40,41	32,33	44,90	45,57	50,42
Asian	0,18	0,15	0,11	0,09	0,13	0,08	0,11	0,08	0,10	0,11
Indigenous	<0.01	<0.01	<0.01	<0.01	0,00	<0.01	<0.01	0,15	<0.01	0,00
Not declared	48,79	75,61	71,30	46,63	54,83	44,44	57,99	40,06	41,47	34,08

Major differences could be recognized in the distribution of white and colored (black, mulatto) ethnicities: while a higher portion of white ethnic origin is located in AP 2.1, 2.2, and 4.0 (ranging between 58 and 76 %), the major portion of the colored population seems to be found in AP 3.1 to 3.3 as well as AP 5.1 to 5.3 (ranging between 45 and 65 %). Only AP 1.0 presents an almost balanced proportion of white (49 %) and colored ethnicity (50 %).

Two further characteristics could be identified as influencing factors in the literature when it comes to health protection and promotion against MBD: the ability to understand health information premised on basic education as well as the financial resources to afford protective measures (Messina et al. 2016, Ibrahim 2016). Thus, the quantitative analysis also focuses on the portion of analphabets among Rio de Janeiro's population as well as the distribution of minimum income (ranging from no income to R$ 510.00 minimum wage) and the median nominal income. In the literature, both determinants (low education, low income) are associated as health risk factors, which are described in Table 8.

Table 8: Spatial Perspective - Socio-economic characteristics of Rio de Janeiro's population looking at the proportion (%) of analphabets and low-level income per AP and MRJ (based on the 2010 census)

Factor/AP	1.0	2.1	2.2	3.1	3.2	3.3	4.0	5.1	5.2	5.3
Analphabets	6.56	2.87	3.22	6.77	3.77	4.41	5.30	5.39	6.05	7.66
Median income	8,309	29,590	7,119	7,500	14,951	15,880	8,740	4,970	4,070	1,500
No/Low income	51.83	33.03	35.89	56.69	48.64	54.83	45.48	59.47	59.76	66.48

For both, the proportion of analphabets (aged between 8 and 60^+ years) as well as the distribution of low-level income or no income status among Rio de Janeiro's working population (N=5,560,655 out of 6,320,446 total population) a similar allocation can be observed. AP 2.1, 3.2 and 3.3 can be described as more wealthy areas considering the median income (median nominal income > 10,000.00 R$). However, AP 3.2 and 3.2 present a high proportion of a low-level income population, indicating a higher level of social inequality within these APs. In contrast, the median nominal income in AP 5.1, 5.2 and 5.3 ranges from 1,500 to 5,000 R$, representing poor income conditions. In addition, the proportion of low-level income is high in these areas with more than 59 %.

A similar trend is given for the proportion of analphabets. While AP 2.1 and 2.2 present a smaller number of analphabets (33-36 %), all other areas report numbers higher than 45 %. In AP 3.1, 5.1, 5.2, and 5.3 the highest proportion of analphabets was identified, with a maximum of 66 % in AP 5.3. However, the distribution of analphabets among different age groups is not considered within this analysis. Altogether, AP 2.1 presents the best of the investigated socio-economic conditions, while AP 5.3 indicate the worst circumstances.

As mentioned before, also housing conditions and the household size are highlighted as important drivers for a high vector density and activity as well as the transmission of MBD (Neiderud 2015). While housing conditions in conjunction with a lack in water supply and garbage collection can contribute to an increase of mosquito density and arbovirus transmission (Honorio et al. 2009), also the number of residents living together may influence the spread of pathogens and abundance of *Aedes aegypti*. For instance, Rodrigues et al. (2015) found out, that a higher household density positively affects the female mosquito density.

For Rio de Janeiro, information about the housing conditions of permanent residents were provided by the 2010 census. The type of housing can be distinguished in houses, town-houses, and apartments that are considered as higher-quality housing, as well as poor-quality housing and poor-quality huts. The highest portion of poor-quality housing conditions could be identified in AP 1.0, 3.1, 3.3, 4.0, and 5.1 (more than 1,000 households). The maximum value was found in AP 4.0 (N=7,631). In contrast, for AP 2.2, 5.2, and 5.3 less than 800 private households with poor-quality conditions are reported. The average number of residents per household in Rio de Janeiro is three. The highest number was found in AP 5.3 (N=3.2), the lowest amount in AP 2.1 (N=2.5). To demonstrate the potential risk profile considering housing conditions and household density, Figure 12 illustrates the distribution of poor-housing quality and a high household size (more than 5 residents per private household) looking at each AP.

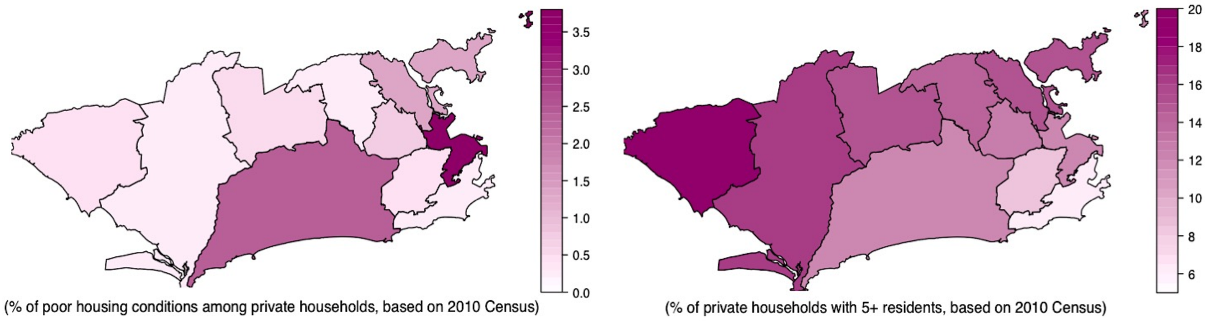


Figure 12: Spatial perspective – Poor housing conditions and high household density in Rio de Janeiro

Impoverished areas often present a particularly vulnerable setting for a high vector density, and thus increasing emergence of MBD (Barreto et al. 2011) due to a higher level of poverty, low income, and a lack of basic services like health care, water, sanitation, electricity and schooling (Hotez et al. 2008). Such conditions can especially be observed in Rio de Janeiro's urban slums, called *Favelas*, which exist in large numbers all over the city. According to the United Nations Human Settlements Programme (2003, p. 225), *Favelas* are "highly consolidated residential areas of self-construction on invaded public and private land and without infrastructure". In addition, other slum-like settlements can be found like *Loteamentons* (illegal subdivisions of land without planning rules or infrastructure), *Invasoes* (irregular occupation of public or private land), and *Cortiços* (a form of social housing within one location, or shared rooms in a single building) (United Nations Human Settlements

Programme 2003). Most of the slums and informal settlement are associated with urban insecurity, often dominated by criminal gangs that restrict community mobilization, mobility and the provision of services (La Rocque & Shelton-Zumpano 2014).

In 2010, nearly 1.5 million people were estimated to live in the slums of Rio de Janeiro (Cavallieri & Vial 2012). Furthermore, in Rio de Janeiro the worst health situation could be identified in areas with the greatest concentration of slums (Szwarcwald, Bastos, Barcellos, Pina & Esteves 2000). Since the city's slums present a highly suitable habitat for *Aedes aegypti* mosquitoes and thus a potential hot spot for MBD emergence, the distribution of *Favelas* displayed in Figure 13 (estimated status 2016) will be taken into consideration. However, information about the quantities of *Favelas* within each AP as well as their environmental, social, and infrastructural characteristics is not provided within this thesis.

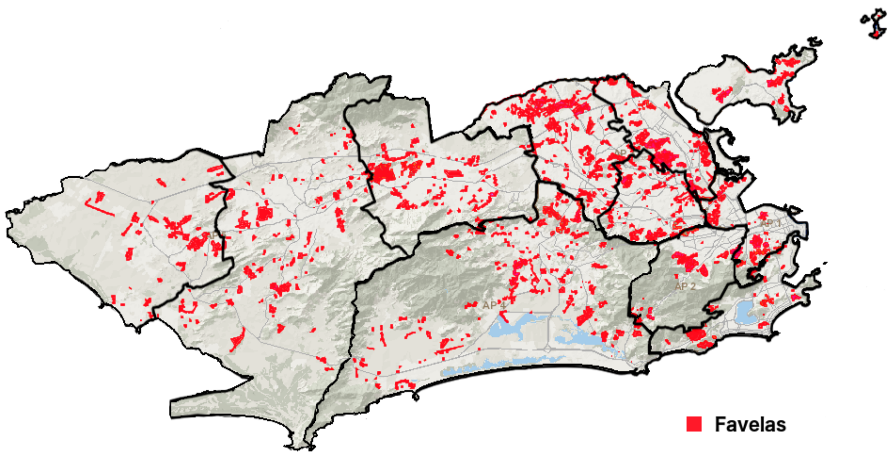


Figure 13: Spatial perspective – Overview about the estimated distribution of *Favelas* in Rio de Janeiro 2016
Source: Prefeitura da Cidade do Rio de Janeiro (2017), edited with software GIMP 2.8.20

Following the spatial description provided by Prefeitura da Cidade do Rio de Janeiro (2017), *Favelas* can be found all over the city. However, a higher amount is recognized in the APs 3.1, 3.2, and 3.3. On the other hand, large settlements exist in AP 1.0, 3.1, 3.2, 3.3, and 5.1. Smaller ones are allocated in AP 4.0, 2.1, and 2.2, all of them in close proximity to the forest and mountains, as well as AP 5.2 and 5.3.

4.2.3.4 The allocation of basic supply in Rio de Janeiro 2015/2016

Besides suitable climate and environmental conditions and a favorable human habitat, the setting's provision of access to piped water, proper sanitation, waste disposal service, the educational as well as the health care sector is also of importance when it comes to MBD emergences (Caprara et al. 2015, Hotez et al. 2008).

As presented in the introduction section, the connection to water supply, sewerage and garbage collection system remain challenging in some regions of Brazil. Although Brazil's metropolises benefit from improved basic supply since 2008 (PAHO 2012), in Rio de Janeiro, disparities in access to piped water, sanitation, and waste management could be observed following the 2010 census information. The table below describes the conditions of water supply[1], sanitation[2] and garbage collection[3] of each AP in Rio de Janeiro.

Table 9: Spatial Perspective – Provision of basic supply in Rio de Janeiro looking at water supply, sanitation system and garbage management as well as the sanitation drainage within each AP (based on census 2010)

AP	General network [1]	Pool/ Fountain on property [1]	Others [1]	Exclusive Bathrooms/ Sanitation [2]	No Bath-room/ Sanitation [2]	Domestic Waste (t) [3]	Public Waste (t) [3]
1.0	104,192	110	419	104,489	232	90,782	114,838
2.1	265,360	255	511	266,003	123	186,003	96,664
2.2	134,950	543	2,636	138,067	62	96,018	44,529
3.1	285,320	685	812	286,649	168	222,366	178,777
3.2	191,260	243	2,041	193,435	109	129,547	103,815
3.3	308,675	718	2,370	311,540	223	256,184	159,675
4.0	297,881	5,084	6,102	308,811	256	278,769	127,955
5.1	210,823	291	1,220	212,190	144	148,476	168,397
5.2	202,609	3,042	3,695	209,198	148	164,337	127,744
5.3	110,467	1,287	844	112,424	174	77,099	22,587

Less than 2 % of all investigated households (N=2,144,445) have access to poor water supply only ("Others"). Almost 50 % benefit from the connection to the general water network. Access to sanitation or exclusive bathrooms is provided for almost all households (N=2,142,806), less than 1 % are not connected. However, in some of the investigated households (N=3,532), drainage is realized by ditches, rivers, lagoons, oceanic or other inadequate systems only. Across the city, 1,639 households are lacking proper sanitation. Garbage collection is provided for all ten APs. The highest amount of public waste was collected in AP 4.0, 3.3 and 3.1. Domestic garbage was high in AP 3.1, 5.1 and 3.3.

Considering both, the highest amount of garbage has been found in AP 3.3 and 4.0. To better understand the distribution of potential risk factors in terms of water supply, sanitation and garbage collection, Figure 14 displays the allocation of poor water supply, poor/no sanitation, the amount of domestic garbage as well as public waste.

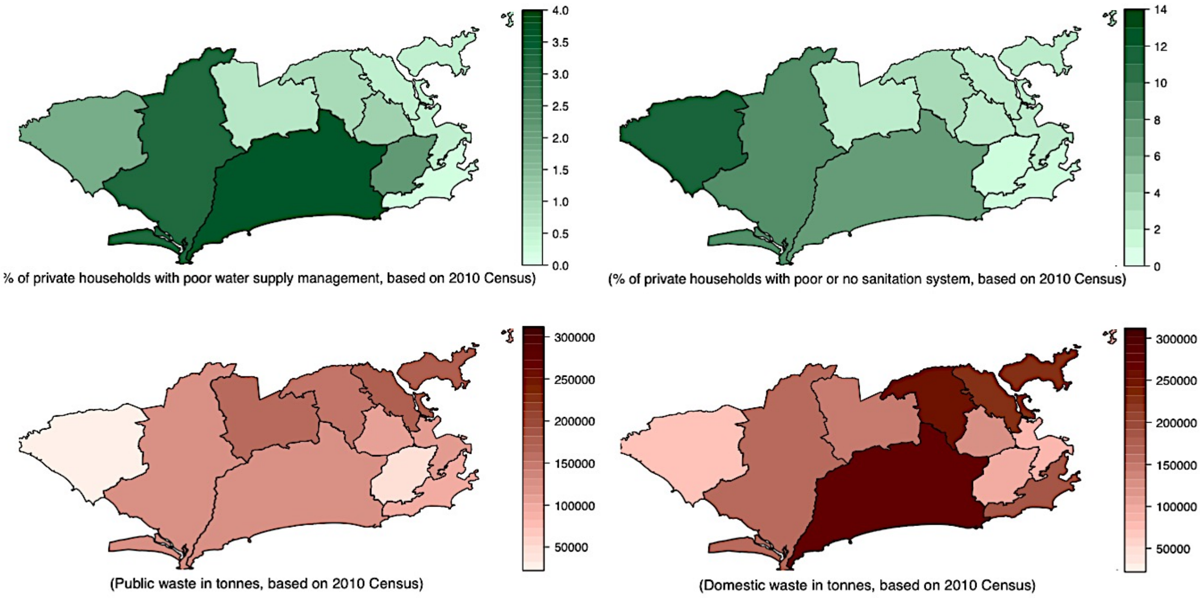


Figure 14: Spatial perspective – Overview about the water supply, sanitation and garbage collection system in Rio de Janeiro

Inadequate supply of piped water (cf. "Pool/Fountain on property" and "Others", total of 32,908 households) and a poor or no access to sanitation system only (total of 86,346 households) could be found in the more decentered areas AP 4.0, 5.2, and 5.3. Adequate water supply seems especially challenging in AP 4.0 and 5.2. A lack of proper sanitation could be identified in AP 5.3. However, inadequate water and sanitation management was only reported for a small number of all investigated households in Rio de Janeiro.

A final component of the descriptive profile of Rio de Janeiro is the allocation of public services like health care supply and educational facilities (Figure 15). Both sectors are important elements of an adequate public health infrastructure and provide essential resources in the fight against MBD (Gubler et al. 2001b).

Based on the information presented by Prefeitura da Cidade do Rio de Janeiro (2017), 444 major health care units and 1,933 educational facilities (kindergarten/child development, schools) were counted in 2016. Health care access is provided by municipal health units on the one hand (N=336), and state and federal health units on the other hand (N=108). Educational facilities can be distinguished into public services (N=1,542), state services (N=364), and federal services (N=27). For both, educational and health care supply, the centered APs in the north-east of Rio de Janeiro present a higher density than the decentered APs like 4.0, 5.1, 5.2, and 5.3.

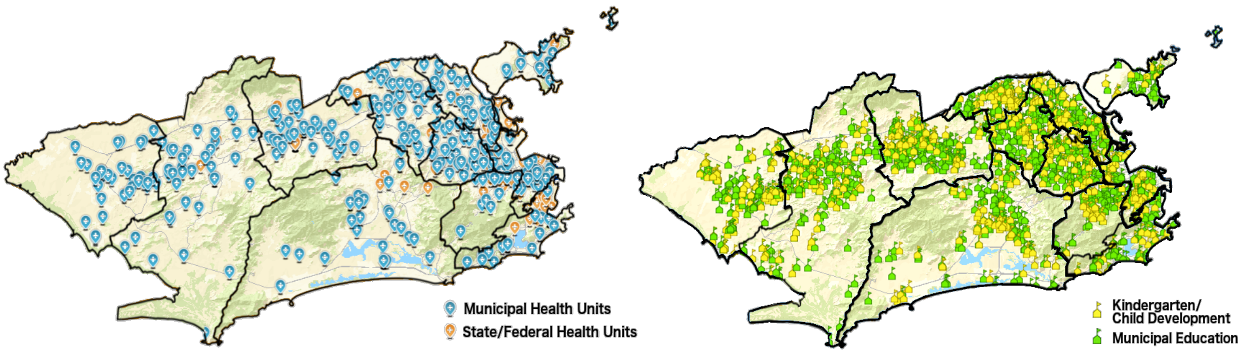


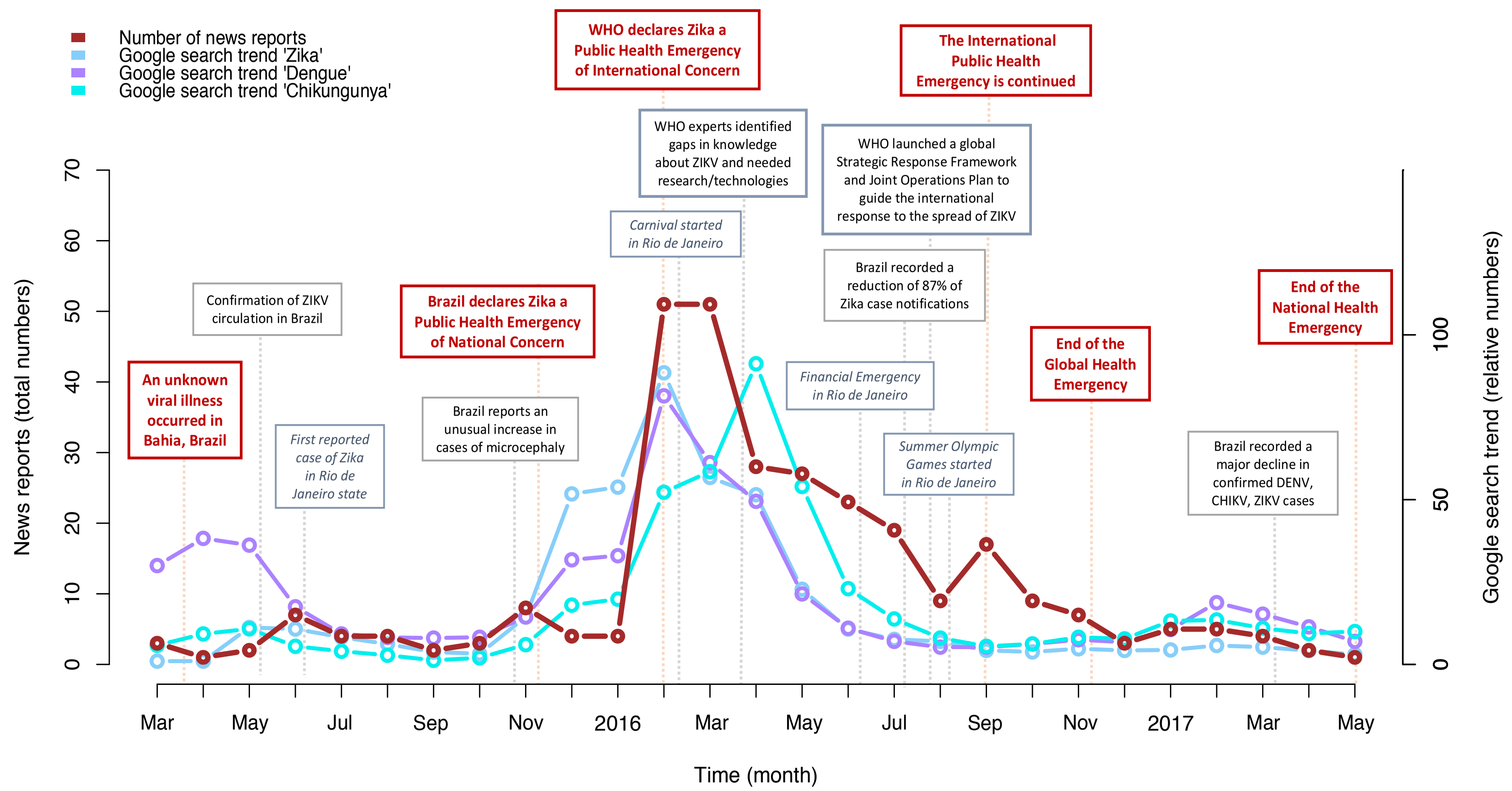
Figure 15: Spatial perspective – Overview about the allocation of health care and educational services in Rio de Janeiro 2016
Source: Prefeitura da Cidade do Rio de Janeiro (2017), edited with software GIMP 2.8.20

Taking the environmental profile into consideration, such differences could be explained by the major plateaus and thus inappropriate landscape. Especially in AP 4.0, educational and health care services seem lacking. In contrast AP 1.0, 3.1, 3.2, and 3.3 present a high density of both services.

4.2.4 Media attention and public interest during the Zika outbreak scenario

With the introduction of ZIKV in 2015 and its rapid spread across Brazil, an increasing public interest, but also scientific focus on the field of MBD could be observed. With the declaration of the National Public Health Emergency in November 2015 (WHO 2017d), and the International Public Health Emergency in February 2016 (WHO 2016a), not only the level of public health concern, but also international alert among the scientific and public health community reached a climax in early 2016. One of the most concerning research findings in 2015/2016 has been the evidence-based confirmation of the association between ZIKV infection and the occurrence of congenital health complications and neurological disorders like Guillain-Barré syndrome (Krauer et al. 2017, McGrath et al. 2017, Brasil et al. 2016). Even worse, Rio de Janeiro was not only challenged by circulating Zika virus, but three mosquito-transmitted diseases, naming dengue and chikungunya virus: “Zika isn’t the only mosquito-borne virus that should worry us” (Powell 2016). Additionally, due to the Summer Olympic Games held in August 2016, as well as Rio Carnival that is celebrated annually in February, Rio de Janeiro was especially emphasized as a metropolitan epicenter in the south-east of Brazil at risk to become a hot spot for global MBD spread.

As Jeff French (2016) explained in his report about the ECOM project (“Effective Communication in Outbreak Management: development of an evidence-based tool for Europe”), mass media and digital media play an important role in outbreak management and risk communication. During an epidemic scenario, media may have a spotlight effect that increase public risk perception. However, high media coverage usually occurs before the public needs specific advice regarding appropriate health action (French 2016). Furthermore, the media coverage of public health epidemics may develop by following major events like newly identified cases, alerting news and governmental actions instead of targeted public health guidelines (Shih, Wijaya & Brossard 2008). To consider the influence of media attention and public interest – especially in the case of a hitherto neglected MBD like Zika and the co-circulation of three arboviruses of major public health concern – this section describes the development of key news reports and governmental action associated with the Zika epidemic in Brazil (cf. methods). Furthermore, the level of public interest is presented in form of the Google search trend looking at the queries “Zika”, “Dengue”, and “Chikungunya” for Rio de Janeiro state from 2015 to 2017 (information available for Rio de Janeiro city only were not provided).



Google "Zika"	**Top 5 Google queries related to "Zika" search term (related proportion):** zika sintomas* (100), sintomas* (100), virus zika (85), sintomas* da zika (65), zika dengue (40) (sintomas [BP] = symptoms)
Google "Dengue"	**Top 5 Google queries related to "Dengue" search term (related proportion):** sintomas* dengue (100), sintomas* (100), mosquito dengue (75), mosquito (75), mosquito da dengue (65) (sintomas [BP] = symptoms)
Google "Chikungunya"	**Top 5 Google queries related to "Zika" search term (related proportion):** chikungunya sintomas* (100), zika (100), dengue chikungunya (80), dengue (75), dengue zika chikungunya (55) (sintomas [BP] = symptoms)

Figure 16: Temporal perspective – The level of public interest and public health attention in Rio de Janeiro state 2015/2016 (figure created with R 3.3.2 and Microsoft® Power Point for Mac 15.32)

Figure 16 illustrates the quantities of reports as well as Google search trends from March 2015 (first recognition of Zika) until May 2017 (end of the national public health emergency in Brazil). A detailed overview about relevant news reports can be found in Appendix 5.

Four peculiarities could be observed:

a. with the first case notifications in March 2015 (Brasil et al. 2016), an increasing trend in Google search could be observed. However, the most applied query was "Dengue". Considering Google as a digital source for health information in terms of symptoms and health complaints, the trend could be associated with the easily confusable clinical picture of Zika and dengue in a situation of lacking knowledge and uncertainty.

b. Previously to the declaration of the Public Health Emergency of International Concern (February 2016), the number of reports remained low. Right after the WHO declaration, the amount of publication sharply increased with a peak from February until March/April 2016. The Google search trend for all three diseases started to increase with the declaration of the National Public Health Emergency (November 2015), with "Zika" as the most applied query. "Zika" and "Dengue" peaked in February, while "Chikungunya" that caused first reported cases in Rio de Janeiro at a later date reached its peak in April 2016.

c. The level of public interest seems to follow the development of Zika, dengue, and chikungunya disease (Figure 4): at the end of the epidemic season in June 2016, both trends decreased to a minimum. With the WHO declaration to continue the International Public Health Emergency in September 2016, the numbers of reports raised again, but afterwards decreased until December 2016. With the start of the next season from January 2017 onwards, an increase in Google search trend and media coverage can be observed, however, clearly lower than in 2015/2016.

d. Public events and governmental action like Rio Carnival, the Summer Olympic Games, and Rio de Janeiro's financial crises do not seem to be of any major influence regarding both media coverage and Google search trend. Furthermore, positive reports like latest findings in research or the development of a strategic outbreak management framework could be observed together with a decreasing trend in public interest, though such information could be of valuable input to combat the spread of MBD in Rio de Janeiro. This decreasing spotlight trend supports the finding of Jeffrey French (2016).

As suggested by French (2016) and based on the findings of the ECOM project, the duration of high media coverage should be used to provide trustworthy and easy to access information in a continuous way through all phases of an outbreak. However, to be able to examine the influence of media content during the Zika outbreak in Rio de Janeiro goes beyond the scope of this thesis.

4.3 The Qualitative Analysis: Lessons learned and solution approaches from multiple perspectives

During the field work of this case study, ten specialists of different fields of research and the public health sector could be consulted to share their knowledge, experiences, and professional perceptions mainly focusing the *Zika outbreak scenario in Rio de Janeiro in 2015/2016*. Four participants are physicians, virologists or medical scientists, three of them are working in the field of entomology, two are staff members of public health programs (vector control, community empowerment, health education), and one participant is from the field of environmental and climate sciences. With all participants, conversations were conducted between December 2016 and February 2017 that followed a narrative guideline about the *Zika outbreak scenario in Rio de Janeiro 2015/2016* and approximately five question about the field of work of each expert (cf. Appendix A8.1). Every conversation lasted between 19 and 85 minutes depending on the arrangement with each conversation partner.

Seven narratives took place at the participants' workplace, two conversation were conducted via Skype or phone, and one in the form of an email survey. Nine conversations were complemented by a participating observation to be able to scrutinize open questions and shared experiences more accurately. Additionally, five participating field observations were conducted to gain first-hand impressions regarding the work and action of the participating experts' profession. Field materials that could be examined during the field research supplemented the findings of the qualitative inquiry.

The main emphasis of the experts' conversations was to develop an in-depth multidisciplinary picture of the achievements, challenges and lessons learned during the *Zika outbreak scenario 2015/2016*. Figure 17 highlights the key findings derived from the assertions of all participants involved. Statements could be made regarding identified risk factors *("We have* *all the conditions, welcome to Brazil"* expert's statement, December 2016), challenging factors *("There will always be new challenges"* expert's statement, December 2016), and multidisciplinary solution approaches *("We have to have an engagement of all approaches"* expert's statement December 2016*)*. A detailed overview of the previous steps of the qualitative content analysis is described in Appendix 6. The findings presented within this figure will be discussed in more detailed in section 5.3.2.

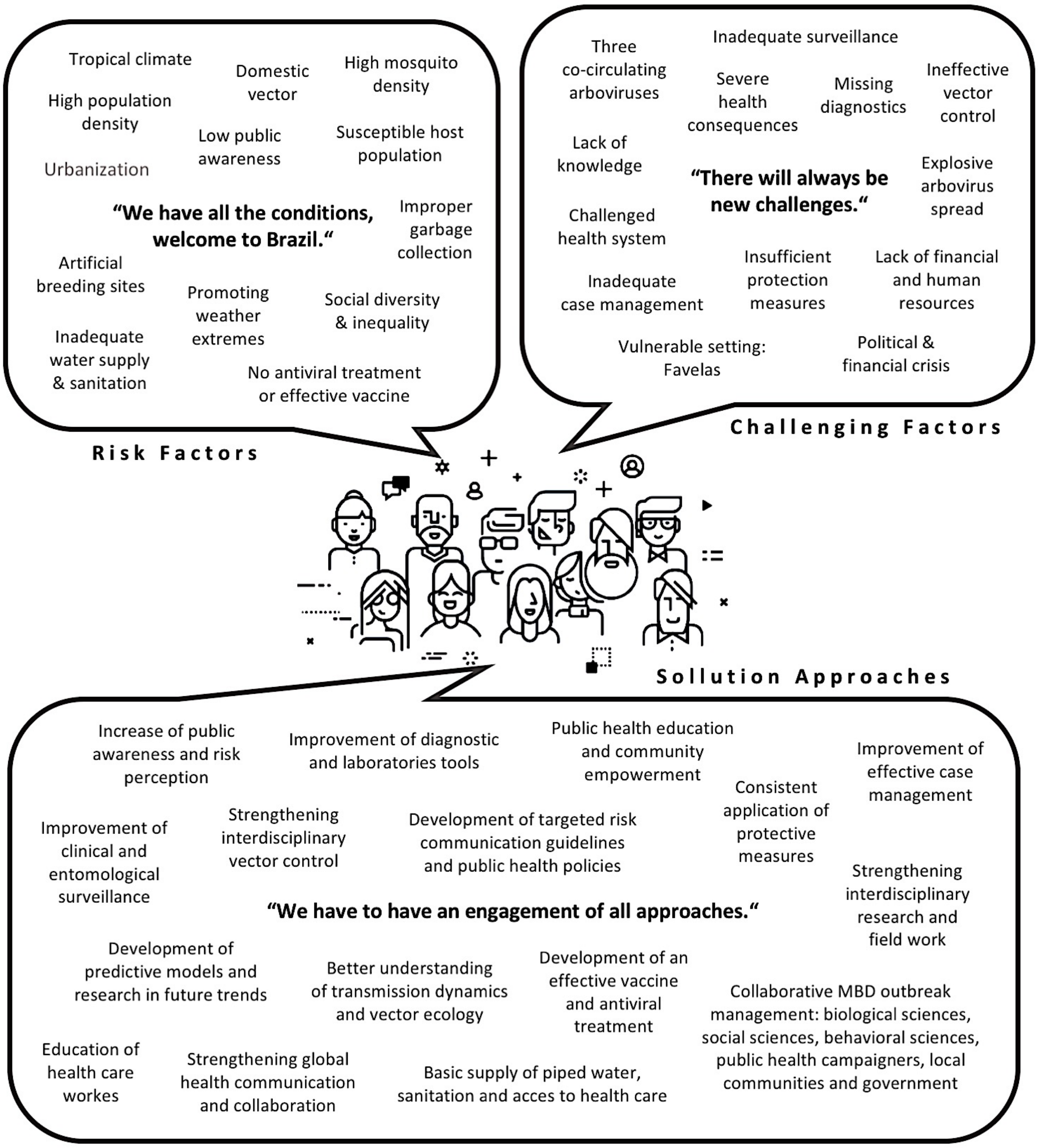


Figure 17: Lessons learned and solution approaches from multiple perspectives following the findings of the qualitative evaluation

Source of figure: https://www.sonarsource.com/solutions/deployments/team-grade/index/team-deployment.png

4.4 The situation and influencing factors analysis
Co-circulating mosquito-borne diseases in Rio de Janeiro city

Aiming an adequate management and response to the spread of infectious diseases, public health action should consider the ecological dynamics of an epidemic situation within a certain setting (Ellis and Wilcox 2009). As presented within the previous results (section 4.1-4.3), knowledge and field experiences gathered from biological, environmental, social, and behavioral sciences may help to develop integrated public health strategies that meet the complex characteristics of MBD in tropical metropolises like Rio de Janeiro city. With the application of selected tools of the ECDC Social Marketing guide (ECDC 2014), this section presents the results of a situation and influencing factors analysis (SIFA) to develop a better understanding about why MBD developed and spread as they did, temporally and spatially, in Rio de Janeiro 2015/2016. The analysis follows three major activities, inspired by the ECDC Social marketing guide (tools 4-11):

a. the conduction of a situation analysis to identify strengths, weaknesses, influencing contextual issues, opportunities and challenges in the fight against MBD (tool 4-7)
b. the identification of potential MBD control efforts figured out within the literature review, as well as the qualitative analyses of the conducted narratives (tool 8 and 9)
c. the identification of sources, partners and stakeholders who may contribute to effective MBD outbreak control (tool 10 and 11)

The findings of tool 4, 5, and 9 are presented below as these tools provide the most useful results for the following hazard analysis (HACCP). The findings of tool 6, 7, 8, 10, and 11 are presented in Appendix 7. The author's evaluation presents one way of data interpretation.

4.4.1 SWOT analysis (Tool 4) – Strengths, Weaknesses, Opportunities and Threats considering the Zika outbreak scenario in Rio de Janeiro 2015/2016

Original focus: *This tool will help you assess the strengths and weaknesses of your existing interventions and highlight what aspects of current work you may need to change* (ECDC 2014, p. 44)

Modification: *This tool will help to assess the strengths and weaknesses of the study area and highlight what aspects and characteristics need to be considered and addressed to combat the spread of MBD in Rio de Janeiro city*

Strengths of the setting

Natural environment:

- restricting hot and cold temperature/the occurrence of weather extremes
  - minimum number of days with minimum temperature > 20 °C (May-September 16)
  - high number of days with elevated temperature 35-40 °C (occurs from October 15 to February 16 in the centered APs, December 15 and February 16 in almost all APs)
  - drop in minimum and maximum temperature (all APs in June 16)
- scarcity in rainfall with restricting effect on *Aedes aegypti* development (from April to October, also APs 2.1, 3.1, 3.2, and 3.3 in March 16)
- winter season: cool and dry climatic conditions normally from May to October
- Higher altitude: less inhabitable for Rio de Janeiro's inhabitants and *Aedes aegypti* (present in large parts of AP 2.2 and 4.0)
- Increased wind: restrict *Aedes aegypti*'s flying ability (associated in coastal areas, AP 1.0, 2.1, southern 4.0, parts of 3.1, and 5.3)

Urban environment and development:

- improved infrastructure and access to piped water, sanitation and garbage collection system in comparison to rural/semi-rural areas of Brazil (infrastructure: especially in the centered APs; improved water supply and sanitation: APs 1.0 to 3.3, 5.1; improved waste management: APs 1.0, 2.2, 3.2, 5.2, 5.3)

Community ambience:

- (health) benefits among "wealthy" communities due to a higher socio-economic status/ financial resources (APs 2.1, 2.2), adequate housing and living conditions (APs 2.1, 2.2, 3.2, 4.0), basic education (APs 2.1, 2.2, 3.2, 3.3)
- allocation/access to public (health) services and educational facilities (APs 1.0, 2.2, 3.1, 3.2, 3.3)

Entomological perspective:

- low *Aedes aegypti* abundance/density (cf. LIRAa index, cf. APs 2.1, 4.0, 5.3)
- low probability of vector-human contact
- minimum number of available artificial and natural breeding sites (less natural breeding sites: APs 1.0, 3.2, 5.1, 5.3)

Epidemiological/health care perspective:

- early case detection of circulating Zika virus (Brasil et al., 2016)
- identification of vulnerable groups (infants, children, elderly, pregnant women, patients with co-morbidities/lacking immune response) and vulnerable settings (*Favelas*)

Public health perspective:

- risk communication and public health advice before MBD high season (end of winter/early summer) in easily accessible areas (e.g. public transport, digital and social media channels, …)
- increase in Google search trends congruent to the increase of case notifications

Weaknesses of the setting

Natural environment:

- summer season: warm and wet conditions from November to April
- warm and wet conditions, increased rainfall and temperature:
  - mostly stable temperature between 20 and 35 °C during summer
  (APs 2.1, 2.2, 4.0, 5.1, 5.2, 5.3) → increased replication of vector and pathogen
- increased rainfall during summer (APs 1.0, 2.2, 3.2, 5.1, 5.2, 5.3) → more breeding sites
- natural breeding sites/standing water (APs 2.1, 4.0, 5.3)
- scarcity of rainfall → increased water storage (APs 3.1, 3.2, 3.3)

Urban environment and development:

- high population density (APs 1.0, 2.1, 3.1, 3.2, 3.3)
- high level of urbanization/deforestation (APs 1.0, 3.1, 3.2, 3.3)
- high neighborhood connectivity/human movement (APs 1.0, 2.1, 3.1, 3.2, 3.3)
- lacking infrastructure and access to piped water, sanitation and garbage collection system (infrastructure: especially in the decentered APs; inadequate water supply and sanitation: APs 4.0, 5.2, 5.3; inadequate waste management: APs 3.1, 3.2, 3.3, 4.0, 5.1)

Community ambience:

- (health) risks among poor communities due to a lower socio-economic status/ financial resources (APs 1.0, 2.2, 3.1, 3.2, 5.1, 5.2, 5.3), poor housing and living conditions (APs 1.0, 3.1, 4.0), basic education (APs 1.0, 3.1, 5.3)
- high household size (APs 3.1, 5.1, 5.2, 5.3)
- inadequate access to public (health) services and educational facilities
  (APs 2.2, 4.0, 5.2, 5.3)

Entomological perspective:

- high *Aedes aegypti* abundance/density (cf. LIRAa index, cf. APs 3.1, 3.2, 3.3, 5.2)
- Inadequate vector control; ineffective/inconsistent control strategies
- maximum number of available artificial and natural breeding sites (high portion of larvae in domestic garbage/fixed pots: APs 1.0, 2.1, 2.2, 3.1, 3.2; high portion of larvae in water containers: APs 5.2, 5.3)
- adaptation/domestication of *Aedes aegypti*, development of insecticides resistance

Epidemiological/health care perspective:

- susceptible host population, lack of herd immunity and approved vaccine
- co-circulation of three arboviruses, sharp increase in infections and severe consequences
- undetected cases: probability of asymptomatic infection, patients do not seek for medical help since there is no effective treatment available
- inadequate case management due to a lacking antiviral treatment and probability of case confusion/misdiagnosis; lacking health care capacities
- lack of diagnostic tools as well as resources for case detection → inadequate surveillance
- areas with a higher proportion of vulnerable groups (infants and children, especially APs 1.0, 3.1, 3.3, 4.0, 5.1, 5.2, 5.3; elderly, especially APs 2.1, 2.2); pregnant women, patients with co-morbidities/lacking immune response) and vulnerable settings (*Favelas*, especially APs 1.0, 3.1, 3.2, 3.3, 4.0)

Public health perspective:

- inconsistent application of protective measures on an individual, community and state municipal level (e.g. repellents/clothing, protective housing installations, vector control)
- lack of public awareness and risk perception regarding an ongoing MBD threat and vector control; other health risks more relevant (water-borne diseases, violence/crime)
- lack of financial resources/governmental support on a community and municipal level
- math gathering events, especially in affected areas (Rio carnival February 2016)
- Rio de Janeiro's political and financial crisis, public disturbances
- media coverage mainly follows the public health alerts, not public interest

Threats to vector control and MBD outbreak management

Vector control:

- uncontrolled distribution of *Aedes aegypti* in whole Rio de Janeiro city
- lack of entomological surveillance (requires extensive financial and human resources)
- inconsistent application of protective measures on an individual and community level:
  - repellent: uncomfortable application (every 3-4 hours), expensive measure
  - long-sleeved clothes: uncomfortable during hot summer months
  - mechanical control: inconsistent application, especially in private households
  - insecticides: inconsistent application, increasing insecticides resistance of mosquitoes
  - missing alternatives for individual protection
- occurrence of extreme weather events:
  - flooding: creates new breeding habitat
  - scarcity in rainfall: leads to increased water storage, especially in areas without access to piped water
- inadequate housing and living conditions, especially among the poor: "MBD hot spots"
  - high vector abundance due to various artificial breeding sites (water storage, improper garbage collection, inadequate sanitation)
  - increased vector-host contact due to high vector abundance and population density/household density
  - often associated with a higher level of crime and loss of governmental control → lacking access to basic public services, health care, educational sector, hard-to-reach communities due to gang-controlled community structure
- *Aedes aegypti* ecology:
  - sip-feeder, feeds from multiple sources, container breeder, daylight-activity, short flight distance, eggs can survive over months during droughts, opportunistic egg laying
- lack of awareness and public empowerment among Rio de Janeiro's communities to take self-responsible action and to take care of domestic breeding sites
- Rio de Janeiro's political and financial crisis

MBD outbreak management:

- co-circulation of three arboviruses of major public health concern along with a rapid increase in severe health consequences following the initial infection → major challenge for Rio de Janeiro's health care system (financial/human resources, medical equipment)
- lack of evidence-based knowledge (ZIKV, CHIKV), high level of uncertainty
- inadequate clinical surveillance, missing clinical case description/akin clinical picture
- ZIKV: several transmission routes (vector-human, human-human)
- impoverished settlements and *Favelas:* hard-to-reach communities, lack of basic health care supply and access to the poorest → MBD hot spots
- missing antiviral treatment and effective vaccine, lacking health care capacities
- risk of virus modification/interaction, increase in severe health consequences
- vertical transmission of ZIKV within mosquitoes: adult female mosquitoes can transmit virus to their offspring
- mass gathering events that may enhance the spread of MBD
- Rio de Janeiro's political and financial crisis, mistrust in government and institutional authorities, increasing public disturbances and political riots, growing social disparities
- media coverage follows the public health alerts (especially February 2016) instead of the increasing google search trend/public interest in valuable health information

Opportunities to enhance vector control and MBD outbreak management

Vector control – based on the status quo and available resources:

- benefit from ecological knowledge about *Aedes aegypti*
- include restricting climatic conditions for vector control intervention planning
  → more effective during less suitable conditions for *Aedes aegypti*?
- strengthening biological vector control (less dependent on individual/community action)
- improvement of integrated vector control strategies (bio-mechanical-chemical control)
- increase of community involvement and public empowerment to clean breeding sites within their living area; engage neighbors to do so

MBD outbreak management – based on the status quo and available resources:

- strengthening interdisciplinary collaboration in health care and research
- improvement of the allocation and thus availability of diagnostic tools
- education of health care works and improvement of case detection based on the clinical picture and laboratory case confirmation → improve clinical surveillance
- develop targeted and understandable communication materials (risk communication)
- improve risk communication and public health education
- benefit from digital media trends: media coverage and provision of valuable health information should follow search trends and identified queries → classification of symptoms, clinical information about dengue, Zika, and chikungunya disease
- involve preferred digital platforms and print media to communicate trustworthy information through various channels

4.4.2 PESTLE analysis (Tool 5)

Political, Environmental, Social, Technological, Legal, and Ethical Issues

Original focus: *List the political, environmental, social, technical, legal and economic influences that may impact on the behaviour you are seeking to influence over the next five years. Then place them in order of likelihood and level of impact (10 = high, 1 = low). This will help you anticipate and plan for these probable changes and influences.* (ECDC 2014, p. 45)

Modification: *List the political, environmental, social, technical, legal and economic influences that may impact on the development of MBD and the consequential health burden in the future – based on the lessons learned during the Zika outbreak scenario in 2015/2016. Then place them in order of likelihood and level of impact* (10 = high, 1 = low). This will help to anticipate and plan for transmission dynamics within different epidemic phases and to address promoting influencing factors more targeted.*

(* *direct or indirect impact on vector and/or human host and/or virus development)*

Political	**Level of Impact**
• allocation of public services:	• host, 8
- infrastructure/public transport	- host/virus, 5
- water supply	- vector/host, 8
- sanitation system	- vector/host, 6
- garbage collection	- vector/host, 8
- allocation of/access to health care and basic medical supply	- host/virus, 7
- allocation of/access to educational sector	- host, 7
• shrinking economic development, growing unemployment, inflation (2014-2017)	• host, 6
• rise in public disturbances, political riots, level of crime	• host, 5
• lack of governmental control, especially inside *Favelas*	• host, 6
• eviction of *Favela* inhabitants ahead of the Olympic Games	• host, 3
• Health system emergency in December 2015 (Gaier, 2015)	• host, 6
• Summer Olympic Games in Rio de Janeiro August 2016	• host, 2
• impeachment of Brazil's president Dilma Rouseff due to corruption allegations in May 2016	• host, 2
• financial crisis in Rio de Janeiro city in June 2016	• host, 6
• degradation of public services	• host, 5
• Brazilian evangelist Marcelo Crivella became Rio's new major in October 2016	• host, 2
• declaration of the National and International Public Health Emergency (November 2015, February 2016)	• host/virus, 7

Environmental	Level of Impact
• summer season: warm and wet conditions	• vector/virus, 10
• elevated temperature (minimum/maximum)	• vector/virus, 9
• hot temperature and heat accumulation	• vector/virus, 7
• drop in minimum temperature < 20 °C	• vector/virus, 9
• increased/prolonged rainfall	• vector, 8
• torrential rainfall/flooding	• vector, 7
• scarcity in rainfall/droughts	• vector, host, 7
• climatic change: increase in minimum temperature during the year	• vector/virus, 6
• urban environment with a high population density	• vector/host, 10
• natural water areas (rivers, bays, lagoons)	• vector, 5
• altitude (topographic relief)	• vector/host, 6
• coastal areas associated with increased wind	• vector, 3
• forestation	• vector/host, 5
• urbanization trend	• vector/host, 6
• population growth	• vector/host, 6

Social	Level of Impact
• age, sex, and ethnicity	• vector/host/virus, 5
• health status (+/-)	• virus/host, 6
• herd immunity/susceptibility	• virus/host, 10
• pregnancy	• ZIKV/host, 6
• socio-economic status (+/-)	• host, 5
• basic education (+/-)	• host, 7
• income/financial resources (+/-)	• host, 5
• housing conditions (+/-)	• vector/host, 8
• access to piped/clean water	• vector/host, 8
• sanitation and sewage system (+/-)	• vector/host, 6
• domestic and public garbage collection (+/-)	• vector/host, 8
• household size (+/-)	• vector/virus, 6
• neighborhood connectivity/human mobility	• vector/virus, 6
• culture and religious beliefs of the community	• vector/virus, 4
• Behavioral components (individual and community level)	• vector/host/virus 9
- domestic garbage management (+/-)	- vector, 9
- (uncovered) water storage (+/-)	- vector, 9
- application of protective measures (+/-)	- vector, 8
- implementation of vector control (+/-)	- vector, 8
- level of awareness and risk perception (+/-)	- vector/virus, 8
• increase in social inequalities/gap between rich and poor	• vector/host/virus, 5
• growing popular discontent	• host, 2
• public mistrust in governmental institutions	• host, 3
• impoverished living area: slums, informal settlements	• vector/host/virus, 7

Technical	Level of Impact
medical equipment/diagnostic tools (especially RT-PCR)	host/virus, 9
adequate clinical surveillance	host/virus, 8
adequate case management	host/virus, 8
antiviral treatment (not available)	host/virus, 9
effective vaccine (not available)	host/virus, 10
entomological equipment/diagnostic tools	vector/virus, 9
adequate entomological surveillance	vector/virus, 9
well-equipped health units	host, 7
well-equipped laboratories	vector/virus, 7
multidisciplinary collaboration	vector/host/virus, 7
communication between public health, research, government	vector/host/virus, 7
international collaboration	vector/host/virus, 5
open science communication	vector/host/virus, 6
early outbreak detection/early warning system	virus, 9
transmission dynamics/outbreak predictions	virus, 7
risk communication and health advice via TV, radio, social media and print media in public areas at an early stage	vector/host/virus, 6

Legal	Level of Impact
public health policies for MBD outbreak management	vector/host/virus, 5
reporting obligation for ZIKV, DENV, and CHIKV infection	virus, 6
vector control on a municipal/governmental level (however, optional for inhabitants and communities)	vector, 3

Economic	Level of Impact
rising economic burden due to the explosive spread and severe health complications of arbovirus infection (DENV = short-term burden, ZIKV and CHIKV = long-term burden)	host/virus, 5
financial resources for research, health care supply, and public health activities	vector/host/virus, 6
human resources for research, health care supply, and public health activities	vector/host/virus, 6
financial crisis in Rio de Janeiro June 2016	host, 5

Based on the descriptive mixed-methods analysis only, the level of impact remains unclear for (a) coastline/proximity to the ocean, (b) quality of sanitation, (c) the allocation of health care units and educational services, and (d) the influence of sex, age and ethnicity.

4.4.3 Key lessons from the evidence summary (Tool 9)

Original focus: *This record will help you set out a summary from all that is known about how to plan and deliver interventions that are similar to the one you are planning. It will also give you a record of things to avoid doing* (ECDC 2014, p. 49)

Modification: *This record will help to set out a summary from all that is known about how to plan and deliver future MBD outbreak management and response based on the findings derived from the mixed-methods analyses. It will also give a record of things to avoid.*

Things to do

Medical and health care perspective

- to consider (and address if possible) proliferating factors on a community level:
  - high *Aedes aegypti* density + high population density = increased vector-host contact
  - increased temperature (summer season) = faster virus replication/spread
  - susceptible host population = rapid MBD spread
  - favorable environment: urbanized, low level of forestation, low altitude, standing water
  - favorable community profile: poor housing, high amount of impoverished settlements, poor socio-economic status, lack of basic education, low income, inadequate water supply and (domestic) garbage collection
  - vulnerable groups: infants/children, elderly, patients with co-infection/co-morbidity, ZIKV=pregnant women, inhabitants living in resource-poor settings
  - low level of risk awareness/perception and health education
  - lack of basic supply: water, sanitation, garbage collection, health care, educational sector
- to face major health care system challenges:
  - co-circulation of three arboviruses, increase in numbers of severe health consequences
  - health system emergency: lack of equipment, financial and human resources
- to improve case detection and case management at an early stage (clinical surveillance)
- to provide an area-wide availability of adequate diagnostic tools (PCR-tests)
- to improve diagnostic tools, laboratory equipment, and to educate health care workers
- to develop guidelines for adequate syndromic diagnosis (ZIKV, DENV, CHIKV)
- to improve risk communication and public empowerment for effective transmission control
- to identify MBD hot spots
- to develop a collaborating network in health care and medical research
- to strengthen field work and ecological research

Entomological perspective

- to consider (and address if possible) proliferating factors on a community level:
  - increased temperature and rainfall (summer season) = increased development, activity, and replication/higher mosquito density and biting activity
  - prolonged/torrential rainfall = water accumulation/increase in breeding sites
  - scarcity in rainfall = (uncovered) water storage/artificial breeding sites
  - inadequate access to water supply = water storage/artificial breeding sites
  - inadequate garbage collection = accumulation during rainfall/artificial breeding sites
  - favorable habitat: urbanized environment, high population density, poor housing, artificial breeding habitat; resource-poor settings
  - challenging ecology: human host, human habitat, sip-feeder, container breeder, opportunistic egg laying, blood meal from multiple sources
- to consider restricting conditions to enhance effective vector and breeding sites control:
  - low temperature, decreased rainfall (winter season) → especially focus containers
- to consider proliferating conditions for biological vector control (release of modified vector)
  - warm and rainy conditions (summer season)
  - avoid heat accumulation as well as months with a drop in minimum temperature
- to improve entomological surveillance and early virus detection within *Aedes aegypti*
- to gain a profound understanding of vector ecology within a certain setting
- to identify *Aedes aegypti* hot spots
- to develop integrated vector control strategies including bio-socio-economic influences
- to strengthen biological vector control
- to prevent the development of insecticides resistance in vector populations
- to improve risk communication and public empowerment for effective vector control
- to combine biological and social sciences to develop effective vector control strategies on a community level

Public health perspective

- to include knowledge about proliferating and restricting factors for targeted intervention planning regarding vector control and case management
- to especially focus on vulnerable groups and settings considered as hot spots
- to increase public awareness, health education and empowerment regarding vector control and MBD control, especially on a community level
- to involve communities for intervention planning and implementation
- to improve the access to basic supply, especially in impoverished areas
- to realize easy access to protective measurements (repellents, contraceptives, …)
- to develop targeted health information and guidelines for clinicians, patients and the public
- to strengthen a close collaboration between research and public health
- to develop and strengthen an integrated network (health care sector, entomology, climate and environmental sciences, public health sector, educational sector, government, …)
- to develop a global network for trend detection and early health warnings
- to strengthen real-time data sharing and an open science community

Things not to do

- do not trust in one solution approach only – instead develop integrated solution approaches
- do not focus on the macro level – instead, take action on the meso and micro level
- do not feel safe when having an effective treatment and vaccine – “there will always be new challenges” (expert’s statement)

Things to explore

- to develop an effective antiviral treatment and vaccine
- to develop innovative and cost-effective vector control strategies
- to identify potential risks and to assess them (vulnerable groups, vulnerable settings)
- to benefit from transdisciplinary research and public health strategies combining knowledge from biological and social sciences
- to identify popular communication channels among Rio de Janeiro’s population
- to investigate the impact of culture and community cohesion
- to develop an early MBD outbreak system and reliable predictive models

Following the findings of the situation and influencing factors analysis, a detailed overview about the determinants of major impacts, main challenges, but also resources of the study area Rio de Janeiro city could be developed. The evaluation furthermore highlights critical points where action and further research is needed. Within this analysis, statements could be formulated for (a) determinants of major, medium and minor importance following the findings of the mixed-methods approach of this study (especially tool 5); and (b) possible solution approaches based on the findings of the qualitative literature as well as the knowledge and experiences of the participating experts. Additionally, the SIFA tool emphasizes gaps in knowledge, but also weaknesses of the study inquiry

Tool 9 (“*Key lessons from the evidence summar*y”), which turned out as a centerpiece of the SIFA concept, summarizes key findings that need to be considered for effective MBD outbreak management and response. Tool 10 and 11 present potential resources and solution approaches to combat future MBD epidemics. The information presented serve as the basis of the following HACCP analysis looking at two communities of different characteristics.

4.5 The Hazard Analysis and Critical Control Points Concept: A tool to respond to emerging MBD outbreaks within a certain setting

The HACCP concept was applied to address the emergence of MBD on a municipal and community level considering the strengths and weaknesses of the investigated area. This method aims to identify potential hazards – from the first day of (undetected) arbovirus circulation until the turning point of an adequate outbreak management (principal 1) –, to establish critical control points for the identified hazards (principle 2), and based on that, to give recommendations for criterions and limits how to evaluate the (re)occurrence of MBD emerging epidemics within the process (Principle 3).

Within the scope of this thesis, the HACCP tool was applied to two communities that became diversely affected. The first one is AP 1.0 which recorded the highest amount of 220 suspected ARBOV cases per 10,000 inhabitants (6,871 cases in total) from October 2015 to September 2016 and is thus considered the most affected community. Secondly, a less affected area was chosen. With 90 suspected per 10,000 inhabitants only (3,534 suspected cases in total), AP 5.3 presented a modest amount of reported suspected ARBOV cases. Although ARBOV transmission was considered low in AP 5.3, effective MBD outbreak management is crucial within all APs due to the probability of further spread mainly caused by human mobility and community connection.

Within a first step, a basic profile of each AP is described following the findings of the sections 4.2 to 4.4. While AP 1.0 is located in the east of Rio de Janeiro with an estimated population density of 9,075 inhabitants/km^2 (312,183 inhabitants across an area of 34.4 km^2), AP 5.3 can be found in the west with a population density of 2,449 inhabitants/km^2 (395,922 inhabitants across 161.7 km^2). Following Figure 7, AP 1.0 is highly urbanized with foothills of the Tijuca massif in the south, whereas in AP 5.3 almost 50 % of the displayed surface is regarded as green areas. Both APs are in close vicinity to water areas (Guanabara Bay in the east, Sepetiba Bay on the west), with low altitude territory and less affected by Rio de Janeiro's massifs (Figure 8). In addition, in AP 5.3 several rivers can be found, whereas AP 1.0 holds only a small portion of the city's river system (Figure 9). As described within Rio de Janeiro's climatic profile, both APs experience a seasonal change in temperature and rainfall, indicating elevated minimum and maximum temperature from December 2015 to April 2016 and a maximum of precipitation in March 2016 (summer season). However, higher temperature and rainfall could be observed in AP 1.0 presenting an average maximum temperature of 30.77 °C, average minimum temperature of 22.10 °C, and total rainfall amount of 1,528.95 mm. In contrast, in AP 5.3 the average maximum temperature was 30.28 °C, the average minimum temperature 21.27 °C, and a total rainfall amount of 1,396.72 mm was recorded. Furthermore, AP 1.0 experienced increased rainfall not only in March 2016, but also November 2015. Additionally, the table below lists all the identified quantities of potential socio-economic risk factors based on the quantitative analysis.

Table 10: Key socio-economic risk factors based on the quantitative analysis

AP	Population	Area (km^2)	Population Density	Infants %	Children %	Elderly %	Analpha-bets %
1.0	312,183	34.4	9,075	2.30	10.99	14.28	6.56
5.3	395,922	161.7	2,449	2.97	14.79	10.27	7.66
AP	**Colored Eth-nicity %**	**White Eth-nicity %**	**Analpha-bets %**	**Median In-come R$**	**No/Low Income %**	**House-holds**	**5+ House-hold %**
1.0	50.04	48.79	6.56	8,309.00	51.83	104,721	12.42
5.3	64.88	34.08	7.66	1,500.00	66.48	112,598	19.08
AP	**Poor/No San-itation %**	**Poor Water Supply %**	**Poor Housing %**	**Domestic Waste (t)**	**Public Waste (t)**	**Health Units**	**Schools**
1.0	2.13	0.51	3.74	90,782	114,838	51	128
5.3	11.00	1.89	0.43	77,099	22,587	38	176

As a higher density of impoverished settlements was considered an important driver for the occurrence of MBD (cf. literature review Table 4 and SIFA tool 4 and 5), the hazard analysis also focuses on the distribution of Rio de Janeiro's *Favelas*. Across AP 1.0, large settlements exist which account for almost a quarter of the total area (Figure 13). In comparison, AP 5.3 only holds a smaller number of *Favelas* looking at the estimated distribution.

4.6 Community-based HACCP: identified hazards and solution approaches

To identify and evaluate the occurrence of hazards within the MBD outbreak and response process, a flowchart was developed. The presented details are based on the findings of the literature review, the quantitative inquiry and qualitative content analysis. Figure 18 describes the basic steps of the process ("PROCESS") related to the identified hazards ("HAZARDS"), potential points and measures of control ("CONTROL POINT"), and critical limits and monitoring approaches ("KEY APPROACHES & MONITORING").

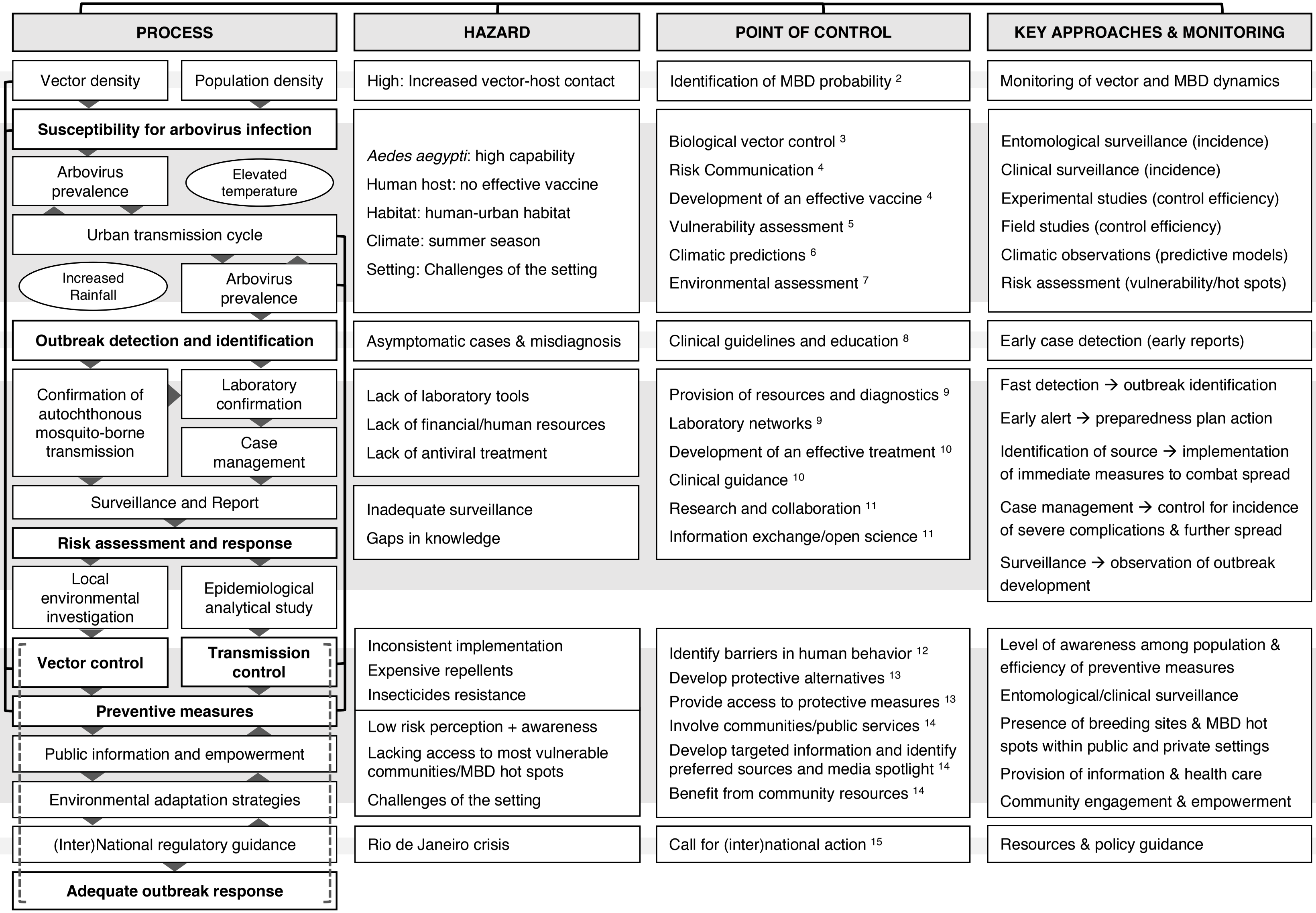


Figure 18: Hazard Analysis and Critical Control Points – Rio de Janeiro 2015/2016

(1) The urban transmission cycle

Two components for the occurrence of an arbovirus emergence within the study area Rio de Janeiro are essential: (a) the abundance of a capable urban vector (*Aedes aegypti*), and (b) a susceptible human host population. Once *Aedes aegypti* becomes infected during a blood-meal from a contracted vertebrate host, the vector is able to spread the virus to humans during its next blood-meal. Introduced into a suitable human-urban environment, the arbovirus may start to circulate within an urban transmission influenced by proliferating or inhibiting external conditions. During this phase, different hazards could be identified:

Hazard		Point of Control
A high density of *Aedes aegypti* and humans leads to an increased vector-host contact and thus a higher probability of MBD emergence.	**2**	A better understanding of local vector ecology and MBD transmission dynamics may help to identify the likelihood of MBD emergence within a certain setting.
Due to the high capability of *Aedes aegypti*, the mosquito species serves as a most suitable vector for arboviruses.	**3**	Biological vector control strategies may restrict the capability of *Aedes aegypti* (radiation, pathogenic fungi and bacteria).
Without an effective vaccine, the susceptibility of humans remain high until herd immunity is gained through recovering from arbovirus infection.	**4**	The development of an approved vaccine present an artificial measure to create herd immunity; until a vaccine is missing, risk communication needs to be intensified to combat the spread of MBD.
Highly urbanized and densely populated areas enhance vector abundance and thus create hot spots for the spread of MBD	**5**	A vulnerability assessment could help to identify and thus eliminate human-urban habitat hot spots.
The summer season present proliferating conditions (increased temperature, prolonged rainfall) for mosquito development, activity, and reproduction as well as arbovirus development and dynamics	**6**	Climatic models may help to predict the occurrence and development of MBD emergence within Rio de Janeiro following the spatio-temporal development of temperature, rainfall, and weather patterns.
The setting's properties may accelerate the development of MBD development presenting conditions of greater or lesser suitability.	**7**	An environmental assessment and, consequently, environmental adaptations could decrease the vulnerability of an affected setting and population.

Point 7 mainly depends on the properties of the investigated area referring to its weaknesses and threats based on the climatic, environmental and socio-economic profile (cf. SIFA findings tool 4). For a more detailed examination, Figure 19 illustrates the differences in the temporal development of arbovirus infection, the *Aedes aegypti* infestation rate (LIRAa index), and the pattern of climatic conditions looking at both AP 1.0 and 5.3.

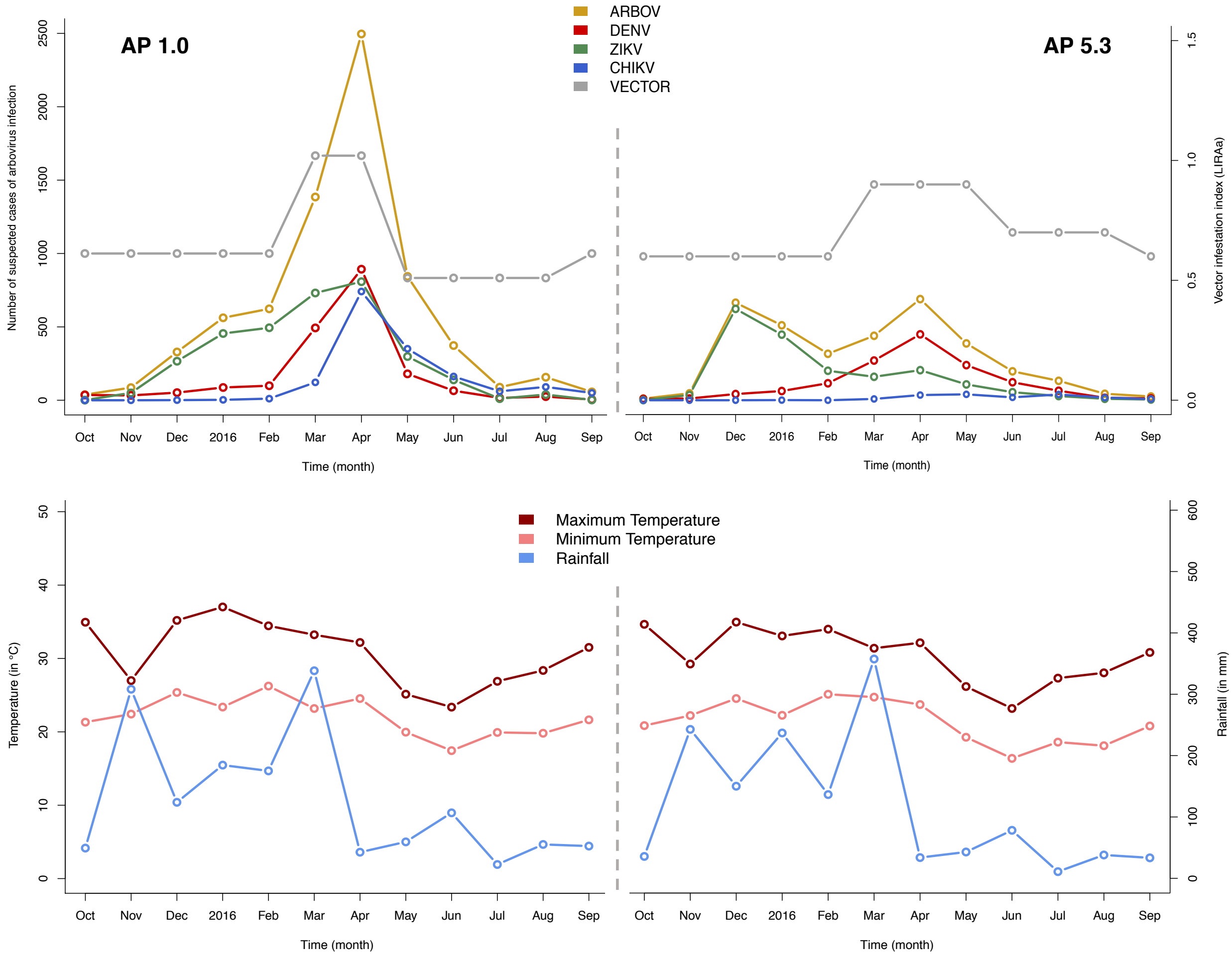


Figure 19: MBD outbreak dynamics in AP 1.0 and AP 5.3 associated with larvae infestation, temperature and rainfall

Both areas presented suitable climatic conditions (temperature higher than 20 °C and up to 35 °C as well as increased rainfall) from October 2015 to April 2016. The level and trend of larvae infestation was almost similar in both APs, with a moderate level from October 2015 to February 2016, and a peak from March to April/May 2016. From May to September 2016, a higher LIRAa index could be observed in AP 5.3. In AP 1.0, a major increase in rainfall could be observed in November 2015 and March 2016, however, with a drop in of maximum temperature in November 2015 (T=26.99 °C) and a hot peak in January 2016 (T=37.02 °C). In AP 5.3, increased rainfall was reported from October 2015 onwards with the highest amount in March 2016. Maximum and minimum temperature remained relatively stable from December 2015 to April 2016 compared to AP 1.0, indicating an increasing trend in October/November 2015 and a decreasing trend starting in April 2016. While in both APs an increasing trend in case notifications (ARBOV) could be observed starting in November

2015, AP 5.3 reached a first peak in December 2015, followed by a descent in reported cases and again a peak in February 2016 of a similar extend along with a growing LIRAa index value. MBD development in AP 1.0 increased steadily until February, when a steep rise was reported until April 2016 (nearly three times as much as AP 5.3) together with an increase of the LIRAa index (1.0). For both APs, a shrinking development in ARBOV cases as well as larvae infestation was recognized with a decrease in temperature and rainfall.

Table 11 summarizes risk factors identified for each AP, that may have influenced the varying MBD and larvae infestation development. For each factor the estimated level of impact (cf. SIFA findings tool 4) is stated.

Table 11: Challenging factors for the spread of MBD looking at AP 1.0 and 5.3

Challenges	AP 1.0	AP 5.3
Suitable human-urban habitat	• level of urbanization: high (10) • population density: high (10) • altitude: low (6) • proximity to open water (bay) (5) • public waste: moderate (8) • breeding sites mainly in garbage items and fixed containers (8) • agglomeration of impoverished settlements/*Favelas* (7)	• level of urbanization: low/moderate (8) • altitude: low (6) • existence of natural water areas (5) • proximity to open water (bay) (5) • sanitation/water supply: poorer (6/8) • increased water storage assumed (9) • breeding sites mainly in domestic water tanks and fixed containers (8) • moderate presence of impoverished settlements/*Favelas* (7)
Enhanced development of vector and virus	*Climatic factors: summer season* (10) • elevated temperature from December 2015 to April 2016 (9) • increased rainfall in November 2015, and January to March 2016 (8) *Infrastructural factors* • high level of human mobility and neighborhood connectivity (6)	*Climatic factors: summer season* (10) • elevated temperature from December 2015 to April 2016 (9) • increased rainfall from November 2015 to January 2016, in March 2016 (8) *Infrastructural factors* • not identified
Socio-economic risk factors	• poor housing conditions: highest (8) • high household size: moderate (6) • analphabets: higher amount (7) • poor income: > 50 % (5)	• high household size: highest (6) • analphabets: higher amount (7) • median income: low (7) • poor income: > 66 % (7) • public services: moderate density (5)
Total impact *	Mean value: 7.53 (N=15)	Mean value: 7.13 (N=15)
Public/ Communitiy	• public interest following Google: low/moderate until the peak of the outbreak (8) • risk awareness assumed low according to experts' experiences (proxy analysis) (8) • restricted access to impoverished areas due to crime and lack of governmental control (6)	

* the mean value of the estimated level of impact of each influencing factor (cf. SIFA findings tool 5) related to the total number of the identified local determinants

(2) Outbreak detection and identification

As soon as first infected patients with characteristic symptoms (Table 1) show up, an outbreak should be investigated. To identify a local MBD epidemic, an increase in the number of infected cases above what is normally expected in the population, as well as laboratory confirmation of virus load within infected patients and the local vector need to be detected. Furthermore, changes in the host's susceptibility as well as an increased host exposure caused by external factors may influence the extent of an epidemic outbreak (CDC 2012). An adequate case management and treatment of infected patients may decrease the risk of severe health complications and further spread of the disease. Entomological and clinical surveillance (abundance of *Aedes aegypti*, detection of infected *Aedes aegypti*, surveillance of infected suspected and laboratory confirmed cases as well as the occurrence of severe health complications and deaths) serve as a basis to monitor the outbreak development and dynamics. Based on the epidemiological information, a risk assessment is required to develop adequate and targeted outbreak response. During the *Zika outbreak scenario in Rio de Janeiro 2015/2016*, key hazards could be identified for the "Outbreak detection and identification" process:

Hazard		Point of Control
The akin clinical picture of dengue, Zika, and chikungunya impede a clear differentiation of the three febrile diseases. Furthermore, asymptomatic cases (DENV, ZIKV) complicated an adequate clinical surveillance.	**8**	The development of clinical guidelines and implementation of educational programs targeting health care providers may improve case detection following the syndromic picture as this is a crucial component in early outbreak detection.
The lack of laboratory/diagnostic tools as well as financial and human resources complicate local agent identification within patients as well as abundant mosquitoes.	**9**	The city-wide provision of medical tools as well as financial and human resources is required. National and international laboratory networks enable rapid diagnostic procedures independent to local resources.
An adequate antiviral drug to treat MBD and their severe complications remains missing.	**10**	Greater efforts are needed to develop an antiviral treatment (and vaccine). Until then, the development of clinical guidance is crucial to adequately manage MBD health burden based on a symptomatic treatment.
A lack in resources to conduct clinical and entomological surveillance complicate MBD monitoring and thus adequate outbreak response. Gaps in knowledge complicate the development of targeted strategies to combat MBD spread.	**11**	Closer cooperation in research and fieldwork is needed to realize adequate MBD surveillance. Real-time information exchange and open science may support to fill gaps in knowledge and develop evidence-based information.

(3) MBD control and preventive measures

Once an outbreak is identified, local environmental investigations as well as epidemiological analytical studies may help to develop targeted intervention strategies in terms of vector and transmission control. According to the findings of the literature review and qualitative content analysis, transdisciplinary strategies provide the most promising approach combining both biological and social sciences. Vector control (mechanical, chemical, and biological approaches) mainly aims to reduce vector abundance and density and to influence *Aedes aegypti*'s capability to carry DENV, ZIKV, and CHIKV. Applied in a consistent way, such strategies can not only influence the recent MBD epidemic, but can prevent future outbreaks by reducing *Aedes aegypti* population and making the vector less capable for arbovirus transmission. Until an effective antiviral treatment and vaccine are missing, transmission control mainly focuses on the avoidance of mosquito bites and elimination of vector habitat in close vicinity to human living area (application of repellent, long-sleeved clothes, screened windows and doors, cleaning of breeding sites). For both vector and transmission control the provision of health information and public empowerment, environmental adaptation strategies as well as national and international regulatory guidance serve as cornerstones of an effective MBD outbreak management and response. Integrated control strategies should furthermore benefit from the resources and opportunities of an affected setting (cf. SIFA findings tool 10 and 11, Appendix A7.4 and A7.5). During the phase "MBD control and preventive measures", the following hazards were recognized:

Hazard		Control Points and Measures
An inconsistent implementation of vector control measures and a lack of public awareness regarding the transmission MBD led to a high city-wide vector abundance and low risk perception regarding MBD and their severe complications.	**12**	Social and behavioral sciences could help to identify barriers regarding the consistent application of protective (behavioral) measures. Program evaluation, especially regarding vector control, may detect weaknesses and challenges in program implementation and consistency.
High prices for mosquito repellents impede the access to protective measures, especially for the poor communities. The development of insecticides resistance among *Aedes aegypti* mosquitoes contributes to ineffective vector control. Inadequate housing conditions, garbage management and artificial water storage may furthermore increase mosquito habitat within human living area.	**13**	The provision of inexpensive repellents and development of effective alternatives is needed to ensure a consistent application of protective measures, especially among the poorest. Adequate housing conditions, screened windows and doors as well as the avoidance of artificial breeding sites decrease vector density present in human living habitat.

A low level of public awareness regarding the risk and health consequences of MBD, vector control and protectives measures impedes community based control measures, combined with restricted access to the most vulnerable communities (especially inside *Favelas*) due to a lack of governmental control and high level of crime. Additionally, the investigated setting's properties may cause further challenges and obstacles.	**14**	The involvement of community representatives and public services like educational facilities may support the allocation of health information and thus increase public awareness and community engagement. Communication and behavioral sciences could also help to identify predominant communication channels and to develop targeted information materials for each community. Therefore, the challenges and resources of the targeted community needs to be taken into consideration.
Rio de Janeiro's political and financial crisis mainly restrict governmental support and the provision of financial resources. The declaration of emergency of Rio de Janeiro's health care system furthermore complicates the bottlenecks in health care supply.	**15**	To face the city's crisis, a call for national and international action is needed, especially to be able to address financial difficulties and thus restricted public health action and governmental guidance.

As for the challenges within AP 1.0 and 5.3 (cf. Table 11), local resources and opportunities could be identified to enhance the control of the determined hazards (Table 12).

Table 12: Potential resources for MBD outbreak response looking at AP 1.0 and 5.3

Resources	AP 1.0	AP 5.3
Human-urban habitat	• Low portion of water areas (5) • sanitation/water supply: improved (6/8) • predominant breeding sites (8)	• level of green areas: moderate (8) • population density: low (5) • waste collection: improved (8) • predominant breeding sites (8)
Restricted development of vector and virus	*Climatic factors: summer season* (10) • decreases temperature in November 2015, and May to August 2016 (9) • drop in temperature in June 2016 (9) • low rainfall in October 2015, and April to September 2016 (8) *Infrastructural factors* • central hub (distribution of public information and advice) (6)	*Climatic factors: summer season* (10) • decreases temperature in November 2015, and May to August 2016 (9) • drop in temperature in June 2016 (9) • low rainfall in October 2015, and April to September 2016 (8) *Infrastructural factors* • low level of human mobility and neighborhood connectivity (6)
Socio-economic risk factors	• less infants and children (5) • median income: moderate (7) • public services: high density (5)	• poor housing: low (6) • less elderly (5)
Total impact *	Mean value: 7.18 (N=11)	Mean value: 7.45 (N=11)
Public/ Community	• public interest following Google: high during the peak of the outbreak concurrent to the media coverage (based on proxy analysis) (8) • high level of social cohesion and cultural influences (4)	

* the mean value of the estimated level of impact of each influencing factor (cf. SIFA findings tool 5) in relation to the total number of the identified local determinants

5. Discussion

With the aid of the SIFA concept (especially tool 4, 5, 7, and 8), it was possible to critically discuss the interaction between the spread of MBD and the influence of different bio-socio-economic factors. The following section combines the findings of the literature review, quantitative inquiry and qualitative content analysis and discusses identified associations considering the influence of climatic and weather conditions, Rio de Janeiro's environmental profile, socio-demographic peculiarities and the provision of basic supply. Furthermore, potential resources and solution approaches are included in this discussion based on the lessons learned during the *Zika virus outbreak scenario in 2015/2016* and following the latest suggestions named in the literature (cf. SIFA tool 6, 9, 10, and 11).

5.1 The distribution of *Aedes aegypti*

As identified within the comprehensive literature review, metropolitan areas like Rio de Janeiro are considered as vulnerable settings when it comes to the spread of DENV, ZIKV, and CHIKV among the human population (Lima, Goulart & Neto 2015). One of the most important precondition is the abundance of a capable vector like the urban mosquito *Aedes aegypti* that lives in close vicinity to human living area and primary feeds from humans. In addition to suitable urban habitat and a stable blood source, tropical climate characterized by elevated temperature, rainfall and humidity serve as a fundamental basis for its survival, development and replication (Gomes, Nobre & Cruz 2012).

The findings of this case study contribute to this evidence. When looking at the distribution of *Aedes aegypti* larvae (Figure 6), the mosquito has been abundant all over the city. Even during the winter season (May to October) *Aedes aegypti* can be found, most predominant in the centered areas (AP 1.0, 2.2, 3.1, 3.2, 3.3) and AP 5.2. What is common for all of them, especially during summer, are elevated maximum and minimum temperatures, the presence of breeding water (formed by increased rainfall during summer, natural water areas, rivers and bays) a relatively low altitude, and a moderate to high level of urbanization in comparison to other APs. In contrast to the results of the literature research, the population density of each AP (Figure 11) seems less important for the presence of mosquito larvae when compared to the impact environmental factors. Only for an increased household size (5^{+}) an association can be observed. Less suitable seem to be elevated altitude shaped by Rio de

Janeiro's massifs in conjunction with afforested areas (especially AP 4.0) as well as the direct impact of oceanic climate present in AP 2.1 and 4.0. Based on the datasets and methods used, an association between socio-demographic conditions and the abundance of *Aedes aegypti* is difficult to evaluate, although there is evidence that poorer socio-economic conditions are linked to a higher density of domestic mosquitoes (Hotez et al. 2008). Mainly poor conditions of home and patio were described as key risk factors especially during the pre-rain and rainy season. In contrast, a lack of piped water that leads to an increase in water storage (often in uncovered containers and tanks) presents a hazard factor, especially during rainfall shortages (Ibarra et al. 2013). Both phenomena can be observed when looking at the predominant breeding sites. While areas with improper supply of piped water hold a higher number of mosquitoes in water tanks (e.g. AP 5.3), territories with improved supply but poorer housing conditions report larvae infestation inside fixed and movable containers like drills, gutters, sanitary ware, bottles and jars (e.g. AP 1.0).

As a consistent entomological surveillance was reported challenging following the statements of different experts, such numbers need to be discussed with caution and can also indicate a lack of proper larvae observation in those areas rated as less affected. A major obstacle seems the access to impoverished settlements and communities, where living conditions are presumed poor and the level of inequality and crime high. Such conditions can especially be found in AP 1.0, 3.1, 3.2, and 3.3. Furthermore, the quality of mosquito surveillance mainly depends on the methodology, equipment, available resources and durability of larvae collection, which was criticized by several experts and supported by missing observation values within the LIRAa index dataset. However, with the aid of the LIRAa index a general view on the interaction between mosquito abundance and climate conditions as well as predominant breeding places could be gained. Nevertheless, greater efforts and new strategies are needed to improve the quality and continuation of entomological surveillance.

5.2 The spread of mosquito-borne diseases

Circulating within an urban transmission cycle between domestic mosquitoes and human hosts, DENV, ZIKV, and CHIKV have been able to spread city-wide with the highest numbers of suspected infections in AP 1.0 and 5.1. As for *Aedes aegypti*, the three arboviruses can be associated with warm und wet climatic conditions during summer, obviously linked up with a faster mosquito development and increased biting activity (Ibarra et al. 2013). As sip-feeders taking multiple bites from various hosts, *Aedes aegypti*'s feeding behavior appears particularly challenging to control virus transmission once arbovirus load could be detected within the local vector population. Elevated temperature may furthermore accelerate arbovirus development inside mosquitoes but also human beings (cf. section 2.2 and 2.3). According to Neiderud (2015) as well as Hendrod and Bonsall (2016), the density of inhabitants and the close contact between people in urban areas can contribute to the rapid spread of infectious vector-borne diseases, creating favorable feeding conditions for urban *Aedes aegypti*. Such conditions were identified in AP 1.0, 2.1, 3.1, 3.2, and 3.3 that indicate a high population density, high level of urbanization, and a high level of human mobility (e.g. well-established local infrastructure, touristic hot spots, air ports). However, AP 2.1 remained the less affected area during the outbreak period 2015/2016, although it presents a suitable urbanized profile. Instead, AP 5.1 reported a high number of suspected cases, although it holds a lower population density but a higher portion of households with a large household size. Thus, and in contrast to the *Aedes aegypti* infestation index, the number of suspected cases may be associated with poorer socio-economic conditions and a lack in basic supply, strengthened by the study outcome of Caprara et al. (2009). For Rio de Janeiro, inadequacies in water supply (AP 4.0 and 5.2) as well as garbage collection (AP 3.1, 3.3, 5.1), but also inequalities in income (AP 3.1, 5.1, 5.2, 5.3), basic education in terms of reading ability (AP 1.0, 3.1, 5.2, 5.3), and housing conditions (AP 1.0, 4.0) possibly trigger the extent of an outbreak. However, AP 5.3, which holds the poorest conditions in terms of low income, high household size, and the portion of analphabets, was only affected to a minor extent in comparison to AP 1.0 and 5.1. Poor living conditions concentrated in urban slums, like Rio de Janeiro's *Favelas*, may furthermore create a most suitable environment to maintain infectious diseases transmission, supported by the finding of Barreto (2011). Those settlements can be found in AP 1.0, 3.1, 3.2, 3.3 and 5.1 following the *Favela* distribution and density (Figure 13). Here, also the number of suspected cases was reported high.

Within this study, the level of impact of demographic characteristics of each AP could not be determined. Although vulnerable groups could be identified for each arbovirus, highlighting infants, children, elderly, and patients with a weakened immune system (cf. section 2.3.1 to 2.3.3), an association is difficult to investigate by following the demographic properties of each AP. A more targeted assessment of the impact of these demographic parameters should follow the information about sex, age, ethnicity and co-morbidities of each reported case, which could not be covered on the basis of an aggregated dataset. However, considering the spatial socio-demographic analysis, poorer socio-economic conditions may be associated with inhabitants of colored ethnicities, whereas wealthier APs hold a higher portion of inhabitants with a white ethnicity. These findings contribute to the overall description about Brazil's socio-demographic profile (cf. p. 11).

Referring to the health system emergency in December 2015 (Gaier 2015), each community furthermore had to face major bottlenecks in medical resources (especially diagnostic tools) and health care supply to combat the spread of MBD. Although the centered APs hold a higher portion of health care units than the decentered APs, the reported number of suspected cases was higher within areas with appropriate allocation of health care facilities (Figure 15). However, this could also be linked to an improved access to health care supply leading to a higher number of inhabitants who sought for medical help when showing up symptoms in comparison to those areas where health care access is comparatively rare. Furthermore, the professional abilities and human resources to detect arbovirus infected cases following the clinical manifestation could be less developed in the decentered areas. In relation to each AP's population density, health care access considering per-capita provision can be assumed roughly equal (≈ 15,000 inhabitants on average per health care unit). However, with 1.48 units per km^2 AP 1.0 reported the highest density, whereas AP 4.0 with 0.7 units per km^2 holds the minimum. A city-wide improvement in diagnostic, medical, financial, and human resources is required to reduce the identified hazards and thus the risk for expanding MBD transmission not only by the provision of local resources, but also by nation-wide collaboration in health care, medical research and field work. As a resource identified within the literature review, the involvement of health care facilities and educational services may support the improvement of risk awareness and public health empowerment (Lima et al. 2015). Here again, the centered APs (AP 1.0 to 3.3) have a higher density of educational services when compared to the decentered areas (AP 4.0 to 5.3). The maximum was reported for AP 3.3 (4.12 schools/km^2), the minimum in AP 5.2 (0.88/km^2).

As for the LIRAa index dataset, using the suspected number of infected cases needs to be considered critically as these numbers might be influenced by different confounders. Due to the concurrent circulation of three arboviruses in Rio de Janeiro presenting an akin clinical picture and the lack of an adequate syndromic case definition (cf. Appendix 6), there is a high risk of misdiagnosis and case confusion of DENV, ZIKV, and CHIKV infection following the clinical manifestation only. To avoid the risk of misinterpretation regarding

DENV, ZIKV, and CHIKV dynamics, this study focuses on the total number of arbovirus infections (ARBOV) caused by *Aedes aegypti*, presuming a small number of ZIKV infected cases due to human-to-human transmission (cf. section 2.3.2). Therefore, all three arboviruses are assumed to be comparably dependent to external determinants. Furthermore, as presented by Brasil et al. (2016) the epidemiological trend of suspected ZIKV cases (white) and confirmed ZIKV notifications (gray) share a similar pattern at an early stage of the Zika outbreak (cf. Figure 4a, January to July 2015). Thus, a similar relation is assumed when looking at the trend of arbovirus infections in total. However, a sharp increase of suspected cases could be observed right after the declaration of the National and International Public Health Emergency in November 2015 and especially February 2016 along with an increase of media coverage and public interest following the Google Trend analysis (cf. 4b and 16). The public health alerts could also distort the epidemiological trend following the suspected cases only. On the one hand, a higher level of concern among Rio de Janeiro's population may have led people to seek for medical help although they perceived only mild symptoms. On the other hand, a higher level of awareness among health care workers may have result in a higher number of case reports following the clinical picture of their patients. In addition, in February 2016 Zika illness became a notifiable disease in Brazil. Both events could represent either an overestimation of arbovirus infections (including the risk of case confusion not only among DENV, ZIKV, and CHIKV, but also other febrile diseases), or obtained a more realistic display in comparison to previous outbreaks since patients and medical workers were more conscious of the ongoing threat. A retrospective laboratory analysis of the patients' serum samples could help to deal with these confounders, however, this approach requires enormous resources.

5.3 Rio de Janeiro: A situation statement from multiple perspectives

Overall, two epidemiological dynamics could be observed. Firstly, the initial and final trend of MBD development in Rio de Janeiro were mainly shaped by changes in temperature and rainfall that also influenced the spatial distribution and density of *Aedes aegypti* larvae (warming trend from November 2015 onwards along with increased rainfall until March 2016; in contrast, a drop in temperature in June 2016 and decreased rainfall from April 2016 onwards). Secondly, with the increase in temperature and thus faster replication of viruses as well as increased activity of *Aedes aegypti,* especially those areas became affected that hold a higher population density, a higher level of urbanization and increased human mobility. Also, vulnerabilities related to poorer socio-economic and housing conditions can be found that may have led to an intense peak within these areas (March/April 2016). However, environmental conditions of less suitability may inhibit MBD circulation like in AP 2.1 (proximity to the sea) and AP 5.3 (higher portion of green areas), though these areas could be classified at risk due to their socio-demographic and urbanized profile.

As long as an antiviral treatment and an approved vaccine against DENV, ZIKV, and CHIKV infection are missing, the control of these arbovirus diseases mainly relies on vector control and the consistent application of practical procedures to reduce the risk of exposure to mosquitoes and the probability of mosquito bites. Thus, keystones of effective control strategies are an improved awareness among health care providers and authorities, as well as a well-informed and empowered population (De Oliveira Mota et al. 2016). Interdisciplinary expertise on arbovirus diseases, vector ecology and the epidemiology of mosquito-borne infectious diseases may serve as a valuable resource for future intervention planning and public health action (Liang et al. 2015).

5.3.1 Lessons learned: vector ecology and climate dependency

Arising from the results of the literature review and qualitative content analysis, tropical climatic conditions not only serve as fundamental basis for the spread of urban MBD, but may also inhibit virus replication and mosquito activity in the form of extreme events (cf. section 2.2 and 2.3). This interplay of promoting and restricting impact associated with changes in rainfall and temperature could also be observed following the quantitative analysis of the study area Rio de Janeiro. These findings present a valuable insight to better understand and anticipate transmission dynamics, especially at the outbreak onset. An area-wide MBD transmission may be associated with a higher mosquito abundance caused by an increase in temperature and rainfall (development from November 2015 to March 2016), and mostly independent from socio-economic conditions of an affected region. Thus, climatic factors can mainly shape the magnitude of an arbovirus outbreak and can contribute to its time trend. The findings obtained are supported by the work of Barrera, Amador and MacKay (2011), who highlighted that inter-annual dengue epidemics can be associated with climate variability. Being premised on the advice of the experts from entomological and environmental sciences (cf. Appendix 6), to learn and benefit from climatic trend predictions and the forecast of weather extremes could help to anticipate mosquito development and thus to improve the efficiency of integrated vector control and early outbreak management. On the one hand, mechanical control for abundant *Aedes aegypti* may be especially effective when applied during less suitable climatic conditions (dry and cold season), supported by Padilla-Torres et al. (2013). On the other hand, right before and during the rainy and temperate season (summer season) the cleaning and elimination of aquatic breeding sites should be of major importance to avoid accelerated hatching of the eggs, faster development of larvae and thus an increased population of *Aedes aegypti*. With rising temperature – related to an increasing biting activity of mosquitoes and an accelerated replication of arbovirus in vector and host – practical protection becomes most important, though wearing long-sleeved clothes at temperature higher than 30 °C and the continuous re-application of repellents every three to four hours may be perceived as an inconvenient way of protection. Greater efforts are needed to increase the population's awareness to take care of vector breeding sites, to reduce the risk of exposure to mosquitoes and to understand the importance of vector control and practical protection in prospect for future MBD epidemics.

Another issue is *Aedes aegypti*'s ability to adapt to external conditions by benefiting from suitable human living habitat inside houses and patios (cf. section 2.2). Accumulated water in fixed vessels and containers or movable items like garbage and scrap provide various artificial breeding places, whereas inadequate housing conditions may create warm and humid indoor climate most comfortable for *Aedes aegypti* (Rao, Trpis, Gillett, Teesdale & Tonn 1973). Based on each community's characteristics, the mosquito is not only able to find its niches to develop, feed, and replicate in resource-poor settings (higher household density, poor housing, lack of protective measures, uncovered water storage, inadequate water supply and garbage collection), but also inside wealthier areas (standing water in pools, bromeliads, fountains, flower pots, architectural decorative elements). Thus, targeted adaptive strategies addressing human behavior and community empowerment are necessary. To name a few: the elimination of aquatic breeding sites taking predominant places into account, indoor measures like window screens, mosquito nets and air condition, and consistent mosquito control e.g. with larvicides and insecticides (Gubler et al. 2001b). By now, mechanical vector control is considered the most effective strategy if applied consistently. In the case of Rio de Janeiro, the achievements of such strategies mainly depend on the level of awareness, consistency of implementation and availability of resources on a community but also individual level, since governmental support in the form of financial and human resources was reported challenging, especially during the city's political and financial crisis (cf. Figure 17 and Appendix 6). In addition, mechanical and chemical strategies can mostly obtain short-term achievements only and may furthermore create new challenges like insecticide resistance among *Aedes aegypti* mosquitoes. A novel biological approach could be implemented which intends the release of laboratory adapted mosquitoes infected by the natural bacteria called Wolbachia (http://www.eliminatedengue.com/br/faqs). Transferred from male to female mosquitoes the bacteria reduce the vector's ability to transmit arboviruses such as ZIKV, DENV, and CHIKV by stopping virus replication inside the mosquito. Therefore, biological vector control approaches present an opportunity less depended to community action. To ensure a successful release and manifestation of modified *Aedes aegypti* populations, areas with most suitable environmental and climatic conditions should be selected. Once more, an environmental assessment and climatic predictions may be useful for the implementation of biological approaches. Although such measures also require the awareness and understanding of the involved communities to support the development and survival of these modified mosquitoes, suitable environmental conditions remain key drivers to ensure a stable population in a long-term perspective as discussed in section 5.2.

5.3.2 Lessons learned: the city's vulnerabilities and resources

Although increased efforts exist to take charge of *Aedes aegypti*, Rio de Janeiro is affected by an uncontrolled abundance of the domestic mosquito. Combined with a large and concentrated susceptible host population and a lack of practical protection, Rio de Janeiro's situation poses an increased risk for the development of MBD that have led to the co-circulation of three arboviruses in 2015/2016 (cf. Figure 17). According to Caprara et al. (2009), the socio-economic-environmental and cultural complexity of large metropolises influences not only the spread of MBD as presented in section 5.2, but also the achievements of control strategies. Although most of the surveyed experts emphasized that everybody could be at risk to get bitten by an infected mosquito, poorer socio-economic and living conditions, and a low educational level may be associated with a poorer health status and thus increased risk of exposure to MBD. Such challenging factors could also be detected following the second trend of MBD dynamics in Rio de Janeiro 2015/2016. In addition to the findings of the epidemiological development associated with climatic patterns, these results generate useful knowledge considering the rising trend of an epidemiological curve up to its peak. It seems that socio-economic and living conditions play an important role regarding the extension of an outbreak within areas that facilitate continuity and stability of an exposure. Here, arboviruses carried by urban *Aedes aegypti* can be seen as a continuous common source benefiting from summer season, resource-poor settings, and human hosts who are health, socially, and economically disadvantaged. Circulating between mosquitoes and humans, the agent may cause an outbreak until herd immunity is gained through recovering from arbovirus infection or until external conditions like climate, environment, vector control strategies, or protective measures restrict mosquito and virus development (cf. Figure 4, 5, and 10).

Rio de Janeiro's political and financial crisis in June 2016, but also the forthcoming Rio Olympics not only aggravated the challenging situation, but directed the public focus to other areas of need. Furthermore, aside from MBD, which are mostly experienced as a mild disease, health complaints caused by water-borne diseases, but also provoked by political riots, crime, and social inequality are perceived as more dangerous compared to the risk to get bitten by an affected mosquito. In the majority of cases, the application of protective measures like repellents, air condition and window screens are available for those who have the resources to afford them. Thus, resource-poor areas were pointed out as vulnerable settings leading to an increased density of domestic *Aedes aegypti*. What is furthermore challenging, according to the experts' experiences, are difficulties in gaining access to these vulnerable communities due to a higher level of crime, often absence of governmental control, as well as Rio de Janeiro's financial crisis mainly affecting the poorest of the city. Thus, local challenges but also resources need to be considered when it comes to MBD outbreak response and vector control.

A key finding was the interdisciplinary character of all suggested solution approaches: the main messages communicated by all experts to combat the spread of MBD and to counteract highly abundant *Aedes aegypti* were based on integrated action. Following the identified risks, challenges and solution statements presented in Figure 17, joint approaches should be:

a. to strengthen clinical and entomological surveillance, especially in highly vulnerable settings and among the identified risk groups (to control for MBD hot spots)

b. to develop integrated vector control strategies based on biological, mechanical, educational, and behavioral approaches involving knowledge about climate, weather patterns, environmental conditions and vector ecology

c. to improve the city-wide allocation of diagnostic tools and medical supply (antiviral treatment and vaccine) and to educate health care providers for early case detection
d. to provide fair access to repellents and to develop alternative practical protection and targeted health advice considering the differences of Rio de Janeiro's communities
e. to increase public empowerment and health education concerning MBD and *Aedes aegypti* on a community level and to benefit from available community resources
f. to strengthen the involvement of the governmental sector and to allocate resource-oriented assets (equipment, funding, human resources, guidelines, policies)
g. to strengthen interdisciplinary collaboration in research and public health, nationally and internationally (development of an open science community) and to increase the level of awareness regarding global epidemiological trends

5.4 Community-based attempt at a solution: The application of integrated knowledge, methods and field experiences

The findings of the previous discussion emphasize the importance to take the identified weaknesses and strengths of an investigated setting into consideration when it comes to MBD emergences. With a closer look at the epidemiological development in AP 1.0 and 5.3, an interesting pattern could be observed. As described in section 5.2, the onset and ending of the 2015/2016 outbreak may be linked up with climatic and environmental factors. While in both areas the rainy period in November 2015 led to an increase of cases in December 2015 (with a steeper slope in AP 5.3), AP 5.3 recorded a slightly decreasing trend until February 2016, whereas AP 1.0 slowly increased between November 2015 and February 2016. The maximum of suspected arbovirus cases between October 2015 and February 2016 was nearly the same in both areas. These differences may be associated with the spatial distribution of infected *Aedes aegypti* (not included within the scope of this thesis but suggested by Ayllon and his team in 2017); a drop in maximum temperature (T=26.99 °C) and immediately following rise (T=37.02 °C) presenting less stable conditions in AP 1.0; or a higher rainfall amount in AP 5.3. Following the solution approaches, especially during this period the cleaning of artificial breeding sites and consistent vector control remain crucial, as stable wet and temperate conditions promote the development and activity of mosquitoes and thus MBD (observed from February until April 2016). On this account, attention should be directed to previous months (like October 2015) with less suitable climatic conditions to ensure an effective reduction of *Aedes aegypti* especially living inside houses and patios. Differences need to be considered in terms of breeding sites (cf. Figure 6): inhabitants in AP 1.0 should concentrate on accumulated water within fixed and movable containers that serves as breeding habitat (e.g. gutters, containers, bottles, pools, fountains), whereas in AP 5.3 especially uncovered water storage tanks need to be controlled for larvae infestation.

Observed in both areas and congruent to the rainfall event in March 2016, the LIRAa index increased to its maximum level from March to April/May 2016. In both APs, the epidemiological curve reached its peak in April 2016, with a slight delay to the LIRAa index maximum. As stable elevated temperature may accelerate vector development and activity as well as virus replication and thus enhance MBD spread, especially during this period the application of measures to reduce the risk of mosquito bites is of major importance (repellents, long-sleeved clothes, vector control). While the peak in AP 5.3 was almost the same as in December 2015, the epidemiological curve in AP 1.0 described an explosive trend. Main issues that may have led to an increased outbreak in AP 1.0 in comparison to AP 5.3 are:

a. the population density associated with a higher vector density and vector-host contact
b. the level of urbanization and scarcity of green areas creating suitable vector habitat
c. a slightly higher mean temperature and increased rainfall during the summer season
d. a higher proportion of inhabitants affected by poor housing quality
e. a higher amount of public waste creating predominant *Aedes aegypti* breeding sites
f. a higher density of impoverished settlements (*Favelas*)

A poorer socio-economic status observed in AP 1.0 may be associated with a higher incidence of arbovirus infection, highlighting low income, a lack of basic education (here, analphabets), as well as poorer housing conditions. As these conditions can particularly be found in impoverished areas, a more frequent distribution of *Favelas* may have led to an intensified MBD transmission. Considering AP 1.0, amplified social disparities and the density of impoverished settlements with a higher agglomeration of inhabitants can be presumed to serve as hot spots when it comes to MBD emergences. Concerning this matter, AP 5.3 seems less affected. Instead, inappropriate sanitation and inadequate access to piped water result in domestic water storage that may lead to the creation of artificial breeding sites.

Especially in AP 1.0, stronger efforts are needed to reduce the risk of MBD transmission using adaptive strategies that focuses on the living conditions, human mobility, and increased vector-host contact. As a centered AP with a high density of health care facilities, educational services and traffic hubs, public services should be more involved to provide targeted health information and protection guidelines, for instance, in schools, hospitals, inside traffic stations or public transport, in museums, sport venues and parks, multiplied by health care workers, teachers, or public figures. Additionally, the provision of information and health care supply should follow the trend of public interest (e.g. Google Trend analysis) to ensure not only an adequate information coverage, but also to increase the sensitivity of health care workers regarding an ongoing MBD outbreak. Sample checks within vulnerable areas like AP 1.0 may furthermore help to improve early case detection and to control MBD at an early stage. The application of protective measures like repellents, long-sleeved clothes, but also screens for windows and doors remain an essential message for both APs to decrease the probability of vector-host contact. Concerning biological vector control, both APs hold advantages and disadvantages for the release of modified mosquitoes: while AP 5.3 presents more stable and balanced climatic conditions, AP 1.0 holds an appropriate human-urban habitat for a faster replication and development of mosquitoes.

Rio de Janeiro's cultural attitude and strong social cohesion may furthermore provide resources to engage communities in active vector and transmission control. Within the scope of this work, a cultural profile of the investigated APs was not developed. Social and communication sciences should be involved to identify predominant information sources, communication channels and key influencing factors of behavioral changes to strengthen community-based approaches, especially during a time of crisis and a lack of governmental control. Rio de Janeiro's urban slums pose a particularly challenging setting that is also highlighted in the literature (Ibrahim 2016) as well as by the consulted (Figure 17). As precise information about the structure, living conditions and culture within these impoverished settlements is lacking (following the 2010 census, population estimations 2015/2016, and environmental profiles), within this thesis *Favelas* are considered as vulnerable hot spots due to their poor socio-economic conditions as well as deficiencies in infrastructure, basic supply and public security following the results of the literature and experts' experiences. Further investigations are needed to better understand the ecology within these settlements (e.g. with the aid of ethnographic and participating case studies) and to be able to identify valuable resources that may support the communities living inside Rio de Janeiro's *Favelas*.

5.5 Study design, data reliability and field work

When Zika occurred in Rio de Janeiro in 2015 for the first time, knowledge regarding ZIKV and expertise in treatment and management of Zika illness were lacking. Together with seasonal resurgence of DENV since 1986 and the introduction of CHIKV in 2016, which is like ZIKV yet poorly understood, three co-circulating MBD challenged the city's population and health system. Highly affected by the urban vector *Aedes aegypti* and a naïve population to new agents, the tropical metropolis presented ideal conditions for the growth of MBD, but also served as a setting most suitable to better understand urban MBD dynamics. A comprehensive literature review, which provides valuable input as it presents results of studies on emerging issues (Jabbour 2013), gave a basic understanding of MBD development in tropical metropolitan areas and formed the investigative steps of the descriptive case study and following situation and hazard analysis. With the beginning of the project in August 2016, Rio de Janeiro had just experienced an immense outbreak of three MBD from 2015 to 2016. Thus, the field work, which started in October 2016, gave the opportunity to gain first-hand information, access to local data bases and to learn from the experiences of the involved experts. The quantitative description (section 4.2) could be complemented by the knowledge and field experiences of the consulted experts (section 4.3), which also offered the opportunity to discuss and assess the datasets included. Solution approaches identified within the literature review could be compared to the experts' suggestions following the achievements, challenges and lessons learned during the *Zika outbreak scenario 2015/2016*. However, the information gained from the qualitative content analysis are based on individual statements, even though from a professional point of view, and the author's evaluation only.

As epidemiological information about laboratory confirmed cases is lacking, the findings of this study are susceptible to errors of misdiagnosis, especially among DENV, ZIKV, and CHIKV. Thus, statements for each disease are difficult to make and might be influenced by misdiagnosis. Consequently, and due to the circulation of three arboviruses of public health concern during the investigated period, this thesis focuses not only on the spread of ZIKV alone, but the entirety of urban arboviruses transmitted by *Aedes aegypti*. Following the experts' experiences and advice, to better understand the ecology of MBD transmitted by urban *Aedes aegypti* and to investigate Rio de Janeiro's environmental and socio-demographic profile is particularly important as another forthcoming ZIKV epidemic in Rio de Janeiro appears unlikely to occur (due to herd immunity and based on the current evidence), but urban MBD emergences are expected to pose a serious challenge in the future.

Thus, to improve clinical surveillance of circulating MBD and to retrospectively investigate the reported suspected cases is essential to be able to detect, monitor and address future epidemics. Furthermore, information about *Aedes aegypti* infestation following the LIRAa index revealed considerable gaps in data collection and to investigate mosquito abundance and vector hot spots. Thus, an insight gained through the comprehensive literature analysis (highlighting Honorio et al. 2009) and based on the entomologists' statements enhanced the evaluation of *Aedes aegypti* abundance and dynamics in Rio de Janeiro. Locally acquired information about *Aedes aegypti*'s biting activity, development and reproduction as mentioned in section 2.2 could help to describe and assess the interaction of pathogens, mosquitoes and environmental conditions more accurately.

As information about Rio de Janeiro's environmental, climatic, infrastructural, and socio-demographic properties follow the open access online data base of the city's governmental authorities or were provided by experts from Fiocruz, it is assumed that the information gathered are comparable to other study outcomes and based on the most reliable information possible. However, not all information could be gathered in the form of quantities (e.g. area in km^2, altitude in m) and were, thus, amplified by further data sources. The data collection period of each included dataset ranges from 2005 to 2017 or was based on estimations for 2015/2016, which holds the potential of erroneous inferences. To address these weaknesses, the proportion of socio-economic characteristics as well basic supply (access to water supply, sanitation, garbage collection) was calculated following the 2010 census database (described in %) and juxtaposed to the population size and density of 2015/2016. Changes in the environmental profile were assumed to be low. Regarding the allocation of health care and educational services, the distribution of Rio de Janeiro's urban slums as well as the trend of public interest and media coverage in 2015 and 2016, it was difficult to make reliable statements since these databases held the highest potential of inadequacies. However, as these influencing factors were outlined in the literature, the information gathered allows a glimpse into the situation in Rio de Janeiro and give an impression for further investigations.

The instruments used for the comprehensive situation and hazard analysis (the ECDC's situation and influencing factors analysis and the Hazard Analysis and Critical Control Points technique) proved to be well-applicable to investigate risks and resources associated with an emerging MBD outbreak in the study area Rio de Janeiro. With the aid of the SIFA concept (tool 4 to 11), complex results could be generated that are not only valuable to assess the strengths, weaknesses, threats and opportunities in the fight against mosquito-transmitted arboviruses following the case of Rio de Janeiro, but also provided important input to critically discuss the strong and weak points of the datasets included as well as the study design and to give suggestions of improvement. Unexpectedly, the SIFA results yield further insights beyond the core of this thesis (cf. Appendix 7) and gave impressions for subsequent research. Applied to the findings of the SIFA instrument, the HACCP tool could be used to conduct a step-by-step hazard analysis following a MBD outbreak management flowchart from the onset of an emerging disease to an adequate outbreak response (cf. Figure 18). Based on that, hazards could be identified that need to be addressed from different points of action. The examination of AP 1.0 and AP 5.3 demonstrates the importance of setting-oriented field research and the necessity of community-based public health action and, therefore, comply with the solution concepts described in the literature (Lima et al. 2015). As a next step and to enhance the completeness and accuracy of the HACCP's final outcomes, an interdisciplinary evaluation should be conducted (e.g. by various experts, community representatives, stakeholders, and policy-makers).

5.6 Limitations of this study

Although the underlying concept of this study provided an in-depth insight into the emergences of MBD in Rio de Janeiro, this thesis reveals some limitations, including the described vulnerabilities of the datasets and tools. The findings of this study can only draw on the information available for 2015 and 2016, since this was the first time ZIKV and CHIKV have occurred in Rio de Janeiro. For more significant conclusions, the consideration period should be extended, though the number of cases of arbovirus infections might be smaller and interactions more difficult to investigate. Furthermore, the duration of the field research lasted from October to December 2016 and was realized by a team of two only, which mainly confined data collection on site. Further data selection depended on the availability of free access databases and willingness of requested experts to share their knowledge and experiences, as this project was not supported by any financial or further human resources.

Within the following six months, data could be prepared, cleaned and analyzed as presented within this thesis, but in the end offers more potential for further investigation. A statistical analysis (e.g. a linear regression analysis) to calculate the correlation between the development of MBD and the determined influencing factors could strengthen the outcomes of this study. Furthermore, statistical methods could help to smooth data that is prone to inaccuracies and thus create a more reliable information base. Here, the experiences and advice of the experts as well as the main outcomes of tool 8 ("Key data summary") of the SIFA concept generated useful information to be able to discuss and assess the limitations and inaccuracies of the quantitative inquiry.

Together with a better understanding of Rio de Janeiro's cultural characteristics (e.g. ethnographic field work, in-depth interviews, and participating observations) and the knowledge applied from social, behavioral and communication science, the presented findings may help to develop and implement more targeted public health strategies on a community level. A closer look at Rio de Janeiro's communities at a finer geographical scale (e.g. Bairros as presented in Appendix 3, a city block or household level) may enhance the analysis of local risks and resources and could serve as a basis to develop predictive models for future MBD outbreak dynamics considering time and place.

6. Conclusion

With the results of this thesis, a multi-perspective in-depth picture of the *Zika virus outbreak scenario in Rio de Janeiro 2015/2016* could be described. The aim was to investigate the potentials of integrated knowledge, methodology and experiences as one solution approach to be able to point out not only risk factors and vulnerabilities, but also resources and solution approaches to develop an adequate response to MBD outbreaks within tropical metropolises. The results describe the spatio-temporal development of the arboviruses DENV, ZIKV, and CHIKV, the distribution of their primary vector *Aedes aegypti*, and examine pathogen and vector dynamics in relation to the city's environmental, climatic, socio-demographic, and infrastructural profile. Contributing to the findings of the comprehensive literature review, environmental and climatic determinants – that is to say, changes in temperature and rainfall, the level of urbanization and demographic density, as well as the distribution of plateaus, green areas, rivers and their basins – serve as a fundamental basis for human-urban arbovirus transmission. On the one hand, changes in temperature and rainfall shaped the temporal magnitude and spatial pattern of the epidemiological MBD trend, starting with an increase in minimum and maximum temperature (Tmax>30 °C, Tmin>22 °C) as well precipitation (rain>200mm), and ending with a drop in minimum and maximum temperature (Tmax<25 °C, Tmin<20 °C) and a scarcity in rainfall (rain<100mm). Such associations may be explained by the impact of temperature and rainfall influencing *Aedes aegypti*'s development, activity and survival, as well as the influence of thermal conditions on arbovirus replication and viability. On the other hand, socio-demographic conditions and human living area, but also the provision of basic supply need to be considered when it comes to serious MBD trends, especially among the centered and often deprived areas in Rio de Janeiro. Based on the descriptive results and stated field experiences presented in this thesis, resource-poor settings with a higher population density characterized by poor housing conditions, a higher household size, as well as inadequate water supply and waste management can be seen as more vulnerable settings compared to areas that benefit from the impact of less suitable environment (e.g. oceanic climate, green areas, higher altitude), wealthier conditions, proper housing and a lower population and household density.

Highlighted as some of the most important anthropogenic factors are the level of basic education (i.e. reading ability), the access to information and health care supply, as well as private means to afford protective measures. These human and social resources are crucial to develop an adequate level of self-responsibility and health-awareness among Rio de Janeiro's communities and thus a well-informed population regarding MBD and their potential to cause severe health consequences like haemorrhagic fever, chronic arthralgia, neurological disorders or congenital complications. Among the city's diverse APs, *Favelas*, which are described as unstructured and often impoverished areas, pose a particular challenge in the fight against *Aedes aegypti* and urban MBD. However, a deeper understanding of the impact of socio-demographic and community vulnerabilities and the role of urban slums lays beyond the scope of this thesis. Further investigations are also needed when looking at Rio de Janeiro's demographic profile like sex, age, ethnicity and physical condition.

Learning from the findings of the situation and hazard analysis (SIFA and HACCP concept), within each AP of Rio de Janeiro characteristic risks and resources exist that should be addressed for future intervention planning. The information gained for AP 1.0 and AP 5.3 emphasizes the importance of community-oriented investigations and the development of risk and resource-based solution approaches. Here, a comprehensive situation and influencing factors analysis following the ECDC's social marketing guide (ECDC 2014) provides valuable input, complemented by a setting-oriented hazard analysis (HACCP) that substantially benefit from the SIFA framework. Furthermore, the observation of weather patterns and climatic predictions as well as environmental assessments could help to coordinate different vector control approaches more targeted, considering limited federal economic resources. In Rio de Janeiro, especially biological vector control approaches could serve as a most promising strategy taking the city's environmental and climatic profile into account. An increase in public empowerment, community-oriented public health action, and strengthened interdisciplinary collaboration in research and field work describe valuable resources identified within this study. However, the extent of an outbreak mainly depends on the susceptibility of the population, the infectious agent's properties, and the measures applied to control the spread of MBD at an early stage (Vasconcelos et al. 2001, Hales et al. 2002).

Considering the limitations of the thesis' study design and information base, all findings derived are based on a 12-months investigation only and may furthermore hold vulnerabilities based on the quality of the datasets included. For epidemiological examinations, the presented findings are based on the first and only possible data set available for ZIKV and CHIKV in Rio de Janeiro following the suspected numbers and aggregated information of arbovirus infection that holds the potential of erroneous description of MBD development. Due to co-circulation of three arboviruses of major public health concern presenting an akin clinical picture, the probability of misdiagnosis and case confusion was expected high. To reduce this risk, this thesis focuses on the spread of urban MBD transmitted by *Aedes aegypti* in its entirety considered as arboviruses rather than ZIKV alone. Furthermore, information based on 2010 census data may be inconsistent or prone to errors as access to Rio de Janeiro's communities (especially urban slums) was identified challenging. Changes in trends and development comparing Rio de Janeiro in 2010 and 2015/2016 also need to be taken into account. To use the proportion of socio-demographic characteristics (in %) instead of total numbers presents one solution to improve data quality. However, statements regarding Rio de Janeiro's environmental, socio-demographic, and infrastructural profile can only be as good as the quality of the datasets involved (cf. Table 2). Finally, the information included concerning media coverage and Google search trends can only be discussed as proxy as these numbers present a random amount of media reports based on the chosen sources as well as a ratio of called Google queries. Altogether, the datasets included provide a multi-perspective descriptive insight of the *Zika outbreak scenario in Rio de Janeiro 2015/2016* that could be critically reflected with the aid of the experts' conversations and field experiences.

As this study follows the author's descriptive exploration only, further statistical analysis could strengthen the value of the quantitative inquiry and thus reliability of the study outcome. Furthermore, to discuss the development of the HACCP flowchart and to evaluate the identified strengths, weaknesses, hazards and resources (SIFA concept) within an interdisciplinary team could improve the quality of main messages drawn from the situation and hazard analysis. However, this study serves as a novel approach to examine the progress of mosquito-transmitted arboviruses in tropical metropolises in relation to local climatic and weather conditions, a setting's environmental profile, as well as socio-demographic and infrastructural peculiarities. To combine integrated knowledge, methodology and local field experiences presents a promising strategy in the fight against future MBD epidemics. Based on the investigation of spatial, temporal as well as situational strengths and weaknesses, but also identified stakeholders and gaps in knowledge, targeted recommendations and public health guidelines may be developed to improve MBD outbreak management and vector control within a certain setting

7. References

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Declaration of Independent Work

I hereby declare that I have authored this thesis without any assistance, and that I have not used other than the declared sources and resources. Any material taken from other work, either as a quote or idea, have been indicated under “References”.

Hamburg, 22nd August 2017

Place, Date

[redacted]

8. Appendix

Appendix 1:
Supplementary materials – overview about the produced datasets (climate and vector)

Table A1: Monthly development of arbovirus infection (suspected cases) and the occurrence of weather extremes looking in Rio de Janeiro 2015/2016 (meteorological station AP 1.0)

Month/AP	ARBOV	DENV	ZIKV	CHIKV	Tmin > 20 °C *	Tmax > 35 °C *	Tmax > 40 °C *	No Rain *	Rain > 30mm *
Oct 2015	598	563	33	2	27	2	1	25	0
Nov 2015	1283	693	581	9	30	4	0	14	1
Dec 2015	7272	1582	5678	12	31	16	0	19	0
Jan 2016	9195	2055	7116	24	16	5	0	8	2
Feb 2016	9396	2496	6808	92	29	16	0	18	2
Mar 2016	14503	6595	7138	770	31	6	0	20	1
Apr 2016	20554	10835	5883	3836	27	11	0	28	0
May 2016	12409	5277	2988	4144	17	0	0	21	0
Jun 2016	5438	1912	1173	2353	7	0	0	22	0
Jul 2016	2486	871	355	1260	11	2	0	31	0
Aug 2016	1352	380	289	683	14	0	0	21	0
Sep 2016	673	201	78	394	19	1	0	20	1

* occurrence reported in the form of the number of days per month

Table A2: Monthly LIRAa Index observations in Rio de Janeiro 2015/2016 presented per AP

Month/AP	1.0	2.1	2.2	3.1	3.2	3.3	4.0	5.1	5.2	5.3	MRJ
Oct 2015*	0.6	0.6	1.2	1.2	1.0	1.4	0.9	0.7	1.3	0.6	1.0
Nov 2015	*0.6*	*0.6*	*1.2*	*1.2*	*1.0*	*1.4*	*0.9*	*0.7*	*1.3*	*0.6*	*1.0*
Dec 2015	*0.6*	*0.6*	*1.2*	*1.2*	*1.0*	*1.4*	*0.9*	*0.7*	*1.3*	*0.6*	*1.0*
Jan 2016	*0.6*	*0.6*	*1.2*	*1.2*	*1.0*	*1.4*	*0.9*	*0.7*	*1.3*	*0.6*	*1.0*
Feb 2016	*0.6*	*0.6*	*1.2*	*1.2*	*1.0*	*1.4*	*0.9*	*0.7*	*1.3*	*0.6*	*1.0*
Mar 2016*	1.0	0,3	1.0	0,9	0,9	1,3	1,1	0,8	1,3	0,9	1.0
Apr 2016	*1.0*	*0,3*	*1.0*	*0,9*	*0,9*	*1,3*	*1,1*	*0,8*	*1,3*	*0,9*	*1.0*
May 2016	0,5	0,1	0,9	0,8	0,7	1,1	0,9	0,5	0,9	0,7	0,8
Jun 2016*	*0,5*	*0,1*	*0,9*	*0,8*	*0,7*	*1,1*	*0,9*	*0,5*	*0,9*	*0,7*	*0,8*
Jul 2016	*0,5*	*0,1*	*0,9*	*0,8*	*0,7*	*1,1*	*0,9*	*0,5*	*0,9*	*0,7*	*0,8*
Aug 2016	*0,5*	*0,1*	*0,9*	*0,8*	*0,7*	*1,1*	*0,9*	*0,5*	*0,9*	*0,7*	*0,8*
Sep 2016**	0,6	0,3	0,8	1,1	0,8	1,1	0,3	0,4	1,3	0,6	0,8
Oct 2016*	*0,6*	*0,3*	*0,8*	*1,1*	*0,8*	*1,1*	*0,3*	*0,4*	*1,3*	*0,6*	*0,8*

* Observation values (LIRAa index) available
** Replaced by the observation value of October 2016 (16^{th} to 22^{nd})

Appendix 2: Comprehensive literature review

A2.1 Comprehensive literature review – the quantitative analysis framework

FACTORS ASSOCIATED WITH THE NATURAL ENVIRONMENT	Sources	Quantity	KEYWORDS TAKEN FROM THE LITERATURE
environment/environmental factors	1, 2, 4, 10, 13, 15, 16, 17, 19, 20, 21, 23, 24, 26, 28, 29, 30, 33, 34, 35, 36, 37, 39, 41, 43, 44, 46, 47, 52, 53, 58,	**33 (43)**	natural, urbanized, deforestation, vegetation, microclimate, human habitat, daylight/sunlight, wind, urban/suburban/slum, pollution of rivers/ditches, elevation
urban environment/ urban setting	1, 4, 11, 13, 17, 18, 23, 27, 32, 34, 35, 39, 41, 43, 46, 51, 56, 63, 65	**19**	
human habitat	5, 6, 10, 13, 15, 29, 39, 41, 53, 58, 64	**11**	residents community, proximity to human host
climate/climatic factors	1, 2, 3, 6, 10, 13, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 31, 32, 35, 36, 37, 39, 41, 42, 43, 44, 46,	**43 (56)**	weather, rainfall, temperature, humidity, air temperature, water temperature
meteorological factors	3, 4, 6, 7, 8, 9, 10, 12, 13, 14, 15, 16, 17, 18, 21, 22, 24, 25, 26, 27, 28, 30, 32, 34, 36, 37, 38, 39, 41, 42, 43, 44,	**43**	climate variety, climate effects, climate zones, tropics, subtropics (tropical megalopolis), El Nino/ENSO
seasonality	6, 12, 13, 17, 22, 24, 25, 28, 31, 34, 36, 38, 41, 42, 43, 44, 46, 49, 54, 55, 58,	**24**	heavy rain/drought, flooding, summer/winter, hot/dry, warm/humid
climate change	3, 14, 18, 24, 27, 28, 32, 34, 35, 38, 41, 42, 46, 54, 56, 59, 60, 61, 63	**19**	globale warming, extreme events
extreme weather events	4, 8, 17, 28, 34, 37, 38, 56, 59, 60, 63	**11**	flooding, drought, heavy rainfall, heat island effect/heat
FACTORS ASSOCIATED WITH THE VECTOR ECOLOGY			
vector population (characteristics)	1, 14, 15, 23, 28, 29, 30, 41, 42, 46, 53, 63	**12 (44)**	domestic: Aedes aegypti; rural: Aedes albopictus, capable, susceptible, mosquito immunity
vector abundance	4, 5, 7, 12, 22, 23, 24, 27, 33, 38, 39, 41, 44, 45, 50, 51, 52, 56, 58	**19**	spatial diversity, distribution, movement, density, hot spots, household cluster
vector behavior	4, 5, 7, 10, 14, 15, 16, 20, 21, 23, 26, 34, 37, 39, 41, 42, 44, 53, 63	**19**	anthropophilic, domestication, adaption to human habitat, feeding on human host, flight distance 10 - 30m, biting rate/activity
breeding sites	1, 4, 8, 10, 11, 13, 16, 18, 21, 29, 30, 34, 38, 40, 43, 53, 59, 63	**18**	artificial, created by rainfall, natural breeding sites, within human habitat
vector dynamics/development	3, 6, 14, 27, 28, 30, 43	**7**	water dependent, adaption to environment, EIP, gonothropic cycle, infestation rate, mosquito genetics, mortality
vector competition	4, 13, 20, 26, 44, 58	**6**	urban vs. rural, ecological interaction, co-existence of mosquitoe species, predation, parasitism, biotic factors
FACTORS ASSOCIATED WITH MBD/PATHOGEN EPIDEMIOLOGY			
virus properties/circulation	5, 7, 17, 23, 24, 25, 28, 34, 35, 46, 53,	**13 (22)**	introduction, transmission to human host, co-circulation of akin
transmission dynamics	1, 7, 15, 21, 30, 32, 45	**7**	urban, mosquito bite, household transmission
virus development	5, 30, 37, 44, 58, 65	**6**	adaption to mosquito, houselhold cluster, incubation period
vector-pathogen-host-interaction	4, 16, 24, 28, 29, 33, 39, 41, 59	**9 (9)**	vector-host-contact, ecological interaction, vector-pathogen environment, vector-host-relationship
MBD control measures		**24**	
vector control	1, 6, 7, 8, 11, 21, 23, 36, 43, 44, 45, 46, 48, 56, 59, 60, 63	**17**	Insecticides, larvicides, resistance, ineffective measures/paucity of control, community action
transmission control	6, 16, 31, 34, 35, 36, 41, 50, 52, 53, 59,	**12**	No vaccine/treatment, surveillance, early warning system/early
public health measures	57	**1**	
FACTORS ASSOCIATED WITH HOST ECOLOGY			
host population (characteristics)	6, 15, 16, 22, 23, 26, 28, 30, 34, 37, 53,	**12 (40)**	human, susceptible, infected, exposed, recovered, vulnerability
population density	18, 21, 22, 23, 24, 28, 30, 37, 39, 41, 46, 47, 54, 56, 61, 64, 65	**17**	
human behavior	10, 22, 23, 24, 25, 26, 27, 29, 32, 34, 35, 38, 40, 43, 44, 49, 55, 57, 58, 59,	**22**	water storage, knowledge/awareness, protective measures, public health action, health education, health literacy,
immunity	3, 16, 17, 23, 24, 25, 37, 42, 44, 46, 51	**11**	Immunity, herd immunity
FACTORS ASSOCIATED WITH THE LOCAL AMBIENCE			
socio-economic conditions	15, 16, 22, 23, 24, 26, 29, 30, 32, 33, 34, 36, 39, 41, 42, 46, 48, 52, 53, 56,	**25 (29)**	demographics (age, gender, heterogeneity), social context, poverty, lifestyle, resource-poor, religon/ethnicity, culture
living/housing conditions	7, 18, 22, 24, 26, 30, 32, 36, 39, 46, 52, 59, 63, 64, 65	**15**	social status, residents per household, material, connectivity, protective measures (window screens, air condition,
Infrastructure	7, 11, 15, 16, 17, 18, 23, 24, 29, 32, 35, 36, 39, 41, 43, 45, 48, 51, 52, 55, 57, 58, 59, 62, 63, 64	**26 (27)**	public/basic services, waste management/garbage collection, water supply/sewage system, access to clean water, public events, sanitation, health care services, public transport,
community characteristics	18, 23, 29, 33, 36, 58, 65	**7**	community dynamics, housing density/overcrowding, communicty structure/social structure/connectivity, cultural complexity,
political/historical/economic factors	36, 44, 58	**3 (4)**	policy making, political issues, war/famine, lack of political will
technology/industry	58	**1**	
FACTORS ASSOCIATED WITH THE GLOBAL AMBIENCE			
globalization	2, 32, 34, 58, 63, 65	**6**	global connectivity, demographic and social pattern
population growth	5, 16, 18, 36, 40, 43, 44, 56, 59, 63, 65	**11**	migration, overcrowded cities, megacities, demographic change
urbanization	1, 16, 17, 18, 21, 27, 28, 29, 32, 34, 35, 36, 42, 52, 56, 58, 59, 61, 63, 64, 65	**21**	urban development, rural-to-urban movement
(global) human movement	5, 16, 17, 18, 27, 33, 51, 52, 59	**9 (17)**	migration, unstructured, human mobility
global travel/trade	1, 17, 18, 26, 32, 46, 50, 56, 58, 59, 63	**11**	affected regions, global connectivity
technology/industry	58	**1**	global connectivity

A2.2: Mosquito-borne disease ecology and epidemiological system

Basic plans following the graphic frameworks by Tabachnick (2013), Ellis and Wilcox (2009), and Caprara et al. (2015):

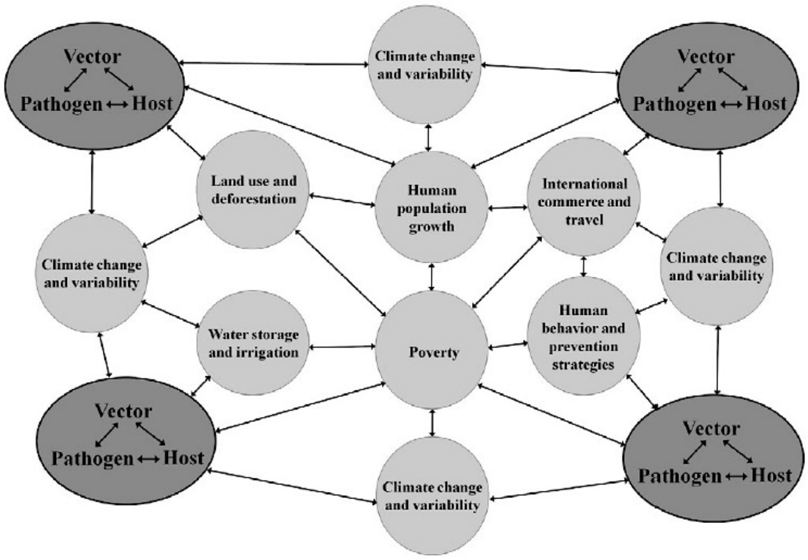


Figure A3: MBD ecology following Tabachnick (2013, fig. 1, p. 947): *The vector-borne disease episystem illustrating interactions between selected environmental factors with effects on the vector-pathogen-host epidemiologic cycle [modified from Sutherst [Sutherst, 2004])*

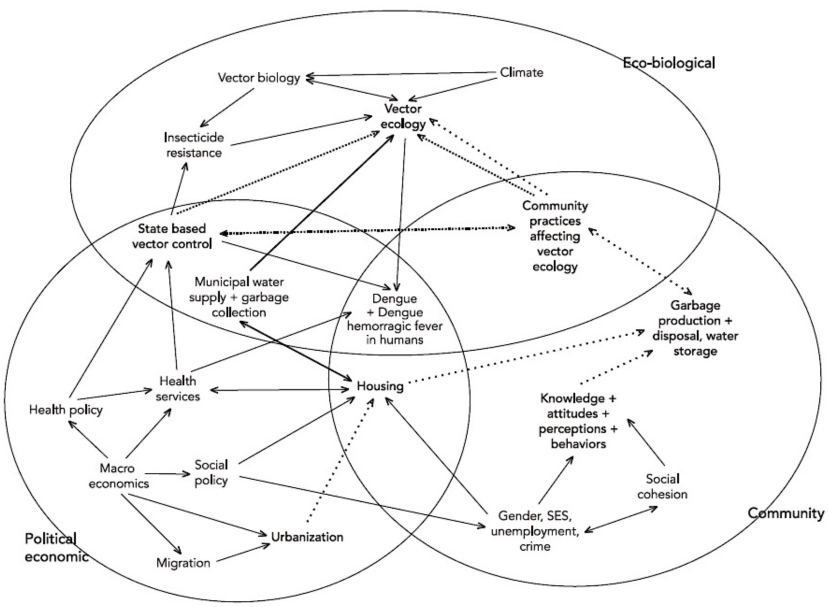
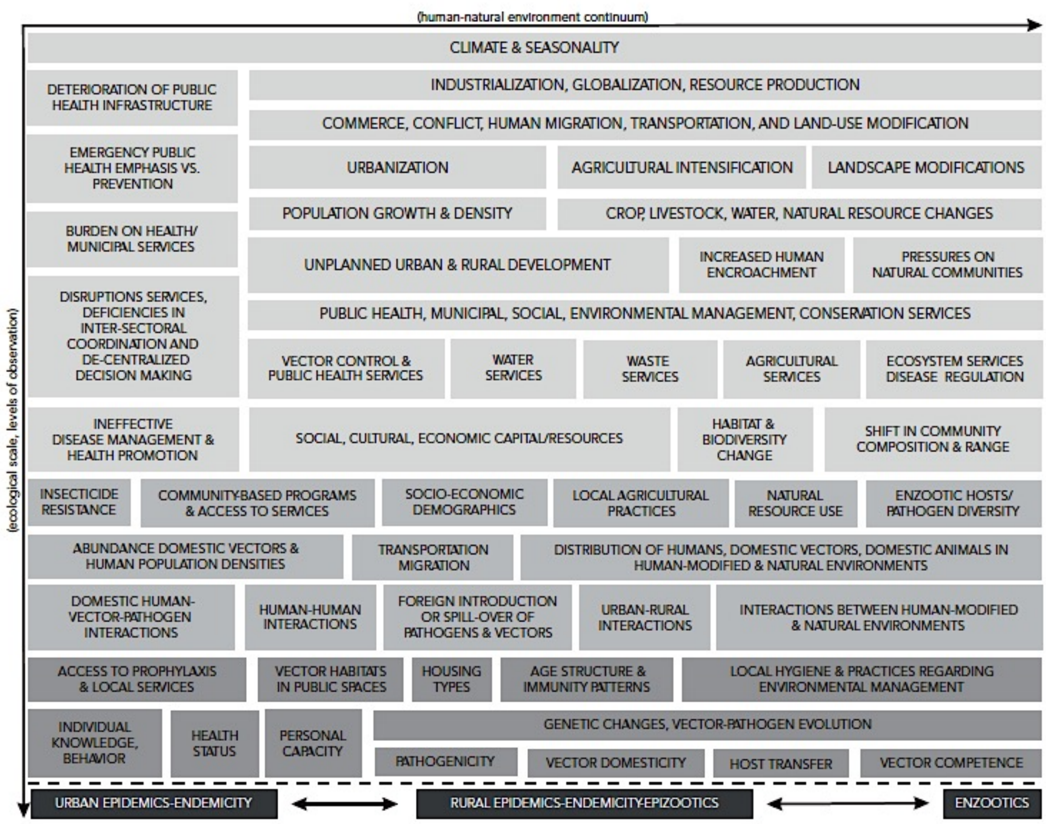


Figure A2: MBD ecology following Caprara et al. (2015, fig. 1, p. 126): *Ecological determinants affecting dengue fever incidence in Fortaleza, Ceará State, Brazil*



Note: from left to right: a continuum of factors/drivers spanning from human to natural environments. From top to bottom: factors/drivers oriented according to ecological scale and/or level of observation.

Figure A4: MBD ecology following Ellis and Wilcox (2009, fig. 2, p. 159): *Spectrum of ecological interactions associated with vector-borne disease transmission*

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Appendix 3: Rio de Janeiro city

Spatial description of Rio de Janeiro – overview about APs and districts

AP 1.0	AP 2.1	AP 2.2	AP 3.1	AP 3.2	AP 3.3	AP 4.0	AP 5.1	AP 5.2	AP 5.3
Benfica	Botafogo	Alto da Boa Vista	Bonsucesso	Abolição	Acari	Barra da Tijuca	Bangu	Barra de Guaratiba	Paciência
Caju	Catete	Andaraí	Brás de Pina	Agua Santa	Anchieta	Camorim	Campo dos Anfonsos	Campo Grande	Santa Cruz
Catumbi	Copacabana	Grajaú	Complexo do Alemão	Cachambi	Barros Filho	Cidade de Deus	Deodoro	Cosmos	Sepetiba
Centro	Cosme Velho	Maracanã	Cordovil	Del Castilho	Bento Ribeiro	Grumarí	Jardim Sulacap	Guaratiba	
Cidade Nova	Flamengo	Praça da Bandeira	Ilha do Governador:	Encantado	Campinho	Itanhangá	Magalhães Bastos	Inhoaíba	
Estácio	Gávea	Tijuca	*Bancários*	Engenho da Rainha	Cascadura	Jacarepaguá:	Padre Miguel	Santíssimo	
Gamboa	Glória	Vila Isabel	*Cacuia*	Engenho de Dentro	Cavalcanti	*Anil*	Gericinó	Senador Vasconcelos	
Mangueira	Humaitá		*Cidade Universitária*	Engenho Novo	Coelho Neto	*Curicica*	Realengo	Pedra de Guaratiba	
Paquetá	Ipanema		*Cocotá*	Higienópolis	Colégio	*Freguesia*	Senador Camará		
Rio Comprido	Jardim Botânico		*Freguesia*	Inhaúma	Costa Barros	*Gardênia Azul*	Vila Militar		
Santa Teresa	Lagoa		*Galeão*	Jacaré	Engenheiro Leal	*Jacarepaguá*			
Santo Cristo	Laranjeiras		*Jardim Carioca*	Jacarezinho	Guadalupe	*Pechincha*			
São Cristóvão	Leblon		*Jardim Guanabara*	Lins de Vasconcelos	Honório Gurgel	*Praça Seca*			
Saúde	Leme		*Moneró*	Maria da Graça	Irajá	*Tanque*			
Vasco da Gama	Rocinha		*Pitangueiras*	Méier	Madureira	*Taquara*			
	São Conrado		*Portuguesa*	Piedade	Marechal Hermes	*Vila Valqueire*			
	Urca		*Praia da Bandeira*	Pilares	Oswaldo Cruz	Joá			
	Vidigal		*Ribeira*	Riachuelo	Parque Anchieta	Recreio dos Bandeirantes			
	Lapa		*Tauá*	Rocha	Parque Columbia	Vargem Grande			
			Zumbi	Sampaio	Pavuna	Vargem Pequena			
			Jardim América	São Francisco Xavier	Quintino Bocaiuva				
			Manguinhos	Todos os Santos	Ricardo de Albuquerque				
			Maré	Tomás Coelho	Rocha Miranda				
			Olaria		Turiaçu				
			Parada de Lucas		Vaz Lobo				
			Penha Circular		Vicente de Carvalho				
			Penha		Vila da Penha				
			Ramos		Vila Kosmos				
			Vigário Geral		Vista Alegre				
15	**19**	**7**	**28**	**23**	**29**	**19**	**10**	**8**	**3**

Figure A4: Spatial description of Rio de Janeiro following the 161 districts
(Source map: http://portalgeo.rio.rj.gov.br/bairroscariocas/index_bairro.htm)

Appendix 4: MBD dynamics in Rio de Janeiro

Spatio-temporal development of ZIKV, DENV and CHIKV in 2015/2016

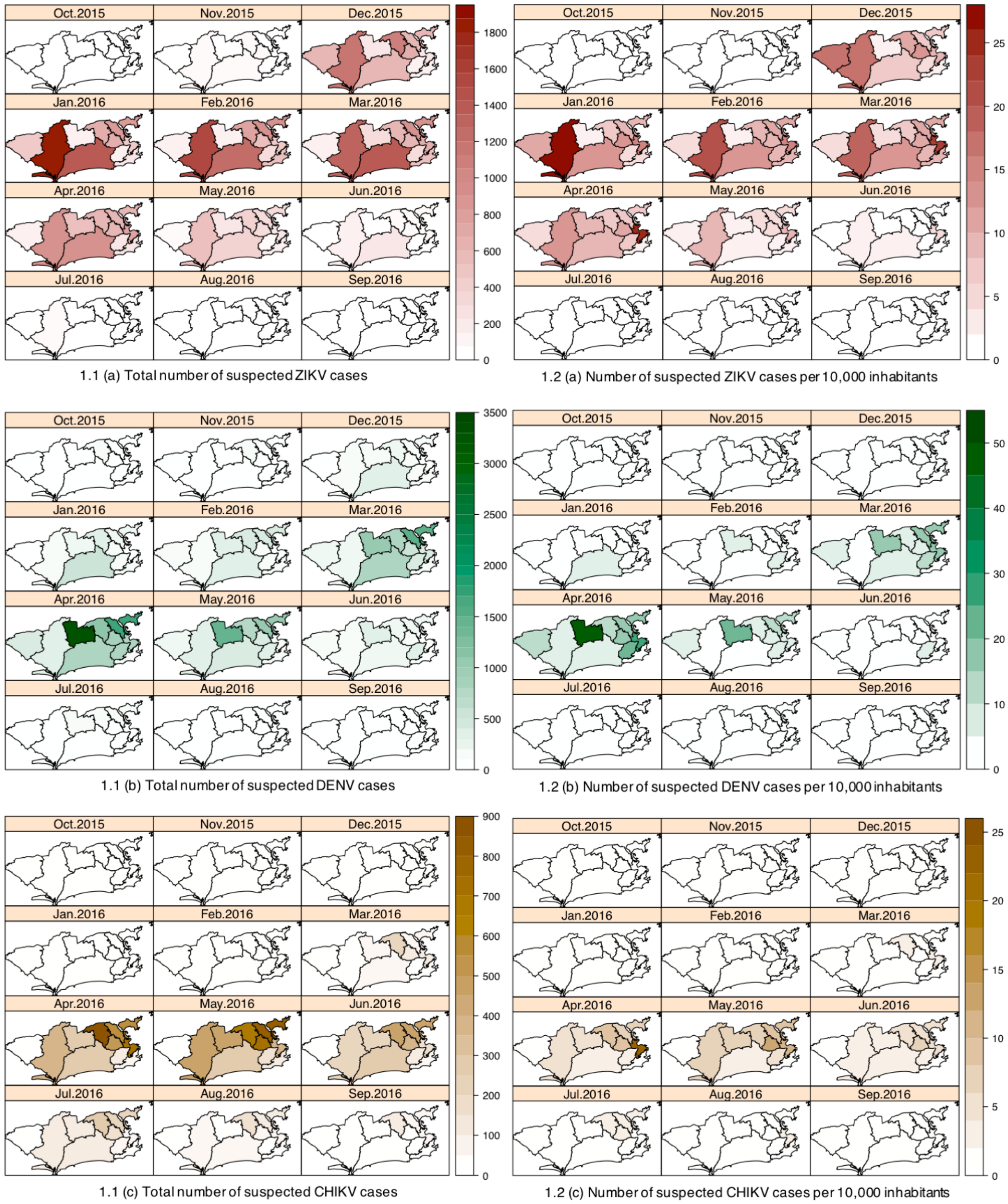

Figure A5: Spatio-temporal perspective – the development of ZIKV, DENV, and CHIKV in Rio de Janeiro 2015/2016 following the total number of suspected cases (1.1a-c) and number of suspected cases per 10,000 inhabitants (1.2a-c)

Appendix 5: Media Coverage and Public Interest 2015 to 2017

Table A3: An overview about the most important Zika virus news considering Rio/Brazil 2015-2017 taken from scientific news, public health authorities and newspaper agencies

Zika virus news* concerning Rio de Janeiro/Brazil 2015 - 2017		
Date	**News/Information**	**Source****
2015 03/25	**An unknown acute viral illness occurred for the first time in Bahia state of Brazil presenting rash, pruritus, and in some cases fever and pain**	ProMed: International Society for Infectious Diseases
2015 03/29	Brazil notifies WHO of an illness characterized by skin rash in northeastern states (ZiKV was not suspected at this stage, no tests were carried out)	WHO
2015 05/07	Brazil's National Reference Laboratory confirms ZIKV is circulating in the country; the Organization recommends that countries establish and maintain ZIKV infection detection, clinical management and community engagement strategies to reduce transmission of the virus	WHO
2015 06/09	**"On 30 May 2015, the health authorities of the State of Rio de Janeiro have reported the first case"**	ProMed: PRO/PORT
2015 07/17	Brazil reports neurological disorders associated with a history of infection, primarily from the north-eastern state of Bahia	WHO
2015 10/30	Brazil reports an unusual increase in the number of cases of microcephaly among newborns	WHO
2015 11/11	**Brazil declares the National Public Health Emergency as cases of suspected microcephaly continue to increase**	WHO
2015 12/01	WHO/PAHO issue an alert on the association of ZIKV infection with neurological syndrome and congenital malformations in the Americas	WHO
2016 01/28	WHO convenes an International Health Regulations Emergency Committee on ZIKV and observed increase in neurological disorders/neonatal malformations	WHO
2016 02/01	**WHO director general, Margaret Chan called Zika an "extraordinary event" that needed a coordinated response. 'I am now declaring that the recent cluster of microcephaly and other neurological abnormalities reported in Latin America following a similar cluster in French Polynesia in 2014 constitutes a public health emergency of international concern.**	BBC News
2016 02/05	Brazil's Carnival starts today: Revelers don't seem to be worried about Zika, but epidemiologists have called the festival an "explosive cocktail	AP News
2016 02/17	"Zika isn't the only mosquito-borne virus we should be worried about."	STAT News
2016 02/24	Brazil's microcephaly case count has been revised upward, and its health service is struggling to cope	Reuters
2016 02/28	CDC tells pregnant women: Don't go to the Summer Olympics in Brazil	STAT News
2016 03/05	**The Zika virus has spread to 22 out of the 27 Brazilian states, said the Ministry of Health, today, in his most recent report on the epidemic**	Science Daily
2016 03/22	**WHO expert meetings have identified gaps in knowledge about ZIKV, potentially related complications, effective interventions, and areas of needed research/technologies**	WHO
2016 03/29	Brazil should address ZIKV as an STD outbreak, researchers say	The Guardian
2016 04/01	There's now scientific consensus that Zika is linked to microcephaly and Guillain-Barre Syndrome (WHO)	STAT News
2016 04/26	The country's populous southeast, which includes Olympic city Rio de Janeiro, registered the most diagnoses of any region, with 35,505 likely cases.	Reuters
2016 05/13	WHO released guidelines for athletes and visitors planning to attend the Summer Games in Rio: Olympics would not be delayed or postponed	New York Times

2016 06/10	**Brazil recorded a reduction of 87% of the notifications of cases of Zika. The peak incidence of notifications was recorded in the third week of February, with 16,059 cases.**	Ministry of Health of Brazil
2016 06/30	WHO has launched a global Strategic Response Framework and Joint Operations Plan to guide the international response to the spread of ZIKV and complications associated with it	WHO
2016 08/18	The fight against Zika can't wait for a vaccine	The Harvard Business Review
2016 09/01	**According to the International Health Regulations Emergency Committee's the International Public Health Emergency is continued**	WHO
2016 09/22	Brazil will begin testing a vaccine against the mosquito-borne ZIKV in humans	The Rakyat Post
2016 10/25	WHO launches the ZIKV Research Agenda	WHO
2016 11/18	**WHO declared that Zika was no longer a global health emergency and should be considered a dangerous mosquito-borne virus**	WHO
2016 03/16	The first 11 weeks of 2017 showed a decline of 94% in the number of confirmed cases of dengue; those of chikungunya fell 79% and of Zika, 88%	Globo
2016 05/12	**Brazil declared an end to national emergency status for ZIKV in Brazil**	BBC News

* Most relevant news reports chosen by the author

Table A4: Quantitative analysis of online media reports and Google Trend analysis (search queries "Zika", "Dengue", "Chikungunya") for Rio de Janeiro state, March 2015 to May 2017

Month	News Reports	*Zika*	*Dengue*	*Chikungunya*	Month	News Reports	*Zika*	*Dengue*	*Chikungunya*
Mar 15	3	1	30	5.8	**Mai 16**	28	22.8	21.4	54.0
Apr 15	1	1	38.2	9.2	**Jun 16**	25	10.8	11.0	23.0
May 15	2	11.2	36.2	10.8	**Jul 16**	22	7.6	7.0	13.8
Jun 15	7	10.75	17.5	5.5	**Aug 16**	10	7.0	5.2	8.0
Jul 15	4	8.25	9.2	4.0	**Sep 16**	21	4.2	5.2	5.5
Aug 15	4	6.2	8.2	2.8	Okt 16	10	3.8	6.2	6.2
Sep 15	3	3.75	8.0	1.2	Nov 16	7	4.8	7.5	8.2
Oct 15	3	3.25	8.2	2.0	Dez 16	4	4.3	6.8	7.8
Nov 15	8	14.4	14.4	6.0	Jan 17	5	4.4	10.6	13.2
Dez 15	4	51.75	31.8	18.0	Feb 17	5	5.8	18.8	13.5
Jan 16	4	53.8	33.0	19.8	Mär 17	6	5.3	15.2	11.0
Feb 16	54	88.5	81.5	52.2	Apr 17	2	4.2	11.4	9.4
Mär 16	54	56.75	61.2	58.5	May 17	2	3.0	7.0	10.0
Apr 16	32	51.5	49.5	91.2	***Total***	*330*	$\bar{x}$=16.7	$\bar{x}$=20.8	$\bar{x}$=17.4
Google "Zika"	**Top 5 Google queries related to "Zika" search term (related proportion):** zika sintomas* (100), sintomas* (100), virus zika (85), sintomas* da zika (65), zika dengue (40) (sintomas [BP] = symptoms)								
Google "Dengue"	**Top 5 Google queries related to "Dengue" search term (related proportion):** sintomas* dengue (100), sintomas* (100), mosquito dengue (75), mosquito (75), mosquito da dengue (65) (sintomas [BP] = symptoms)								
Google "Chikungunya"	**Top 5 Google queries related to "Zika" search term (related proportion):** chikungunya sintomas* (100), zika (100), dengue chikungunya (80), dengue (75), dengue zika chikungunya (55) (sintomas [BP] = symptoms)								

Appendix 6: Results of the Qualitative Content Analysis

Table A5: Results of the Quantitative Content Analysis – An overview about the identified influencing factors from a medical, environmental, entomological, anthropogenic and governmental perspective

Focus: Pathogen and Disease		
Risk/Promoting Factors	**Association/Complication**	**Public Health Challenge**
"New viruses occurring in Rio de Janeiro, Brazil"	…affects a highly susceptible host population	No (herd) immunity Rapid/explosive spread with many cases and severe complications within a short duration
	…meets an unprepared health care system	
	Lack of (evidence-based) knowledge High level of uncertainty Only small and sporadic outbreaks in the past (Asia, Africa, Pacific Islands, Oceania)	Underestimation of health burden, challenge for health system/public health care due to a high number of infected cases and development of severe health complications
		Need for research/immediate response
	ZIKV: not only vector-to-human transmission, but human-to-human (body fluids/placenta)	Infected cases besides seasonal occurrence of MBD due to human-human transmission (especially sexual contact + pregnancy)
„Co-circulation of three arboviruses of major public health concern"	Overlapping distribution	Hard to differentiate between ZIKV, DENV, CHIKV following the clinical picture Severe health consequences? Economic and structural challenge for Brazil's health care system
	Interaction? (DENV ⇔ ZIKV)	
	Akin clinical picture	
	Lack of basic health care supply	
"Vulnerable groups"	*"Everybody can become bitten by infected mosquitoes"*	Areas with high probability of vector-host contact: high vector and host density
	ZIKV: Infants and pregnant women	ZIKV transmission during pregnancy, risk of congenital complications among newborns
	Arboviruses: Infants, children and elderly; people with co-morbidities, chronic diseases	Vulnerable immune system Co-infection may lead to severe complaints
"**Lack of diagnostic and laboratory resources"** **"Unimproved tools"**	Risk of misdiagnosis/case confusion	Inadequate clinical surveillance (often only based on suspected cases) Inadequate case management
	High probability of undetected cases and ineffective case management	
"Mild clinical picture or asymptomatic development"	Unnoticed arbovirus infection/circulation	Source for further spread of the virus from human-vector-human/ human-human
	Risk of misdiagnosis (due to atypical and thus misleading clinical picture)	
	Neglected infectious disease (ZIKV, CHIKV)	Underestimation of health/economic burden
		Inadequate outbreak management and risk communication
"Missing antiviral treatment and effective vaccine" ***(current DENV vaccine considered as ineffective)***	Inadequate case management	Risk of severe health consequences and co-infections Challenges in case detection, control and the prevention of transmission
	Patients do not seek for medical help since there is no effective treatment available	
	Lack of medical tools for transmission prevention and control	Improper medical protection; challenge of case control/transmission prevention

Focus: Weather, Climate and Environment		
Risk Factor	**Association/Complication**	**Challenge**
„Tropical climate“	Warm and humid conditions	Suitable habitat for vector/MBD epidemics
“Rainfall” ***(essential for mosquito breeding habitat)***	Prolonged rainfall/ heavy rainfall	Accumulation of water/ Increasing breeding sites
	Scarcity/dry period	(Uncovered) water storage
“Temperature” ***(influences development)***	Elevated temperature/ warm conditions	Accelerated development of mosquito and virus
“Temperature and rain: hard to disentangle”	Warm temperature and increased rainfall creating a high level of humidity	More mosquitoes within a short period of time and high biting activity
Spring and summer season	Hot and humid (high season, epidemiological peak expected in April/May)	High density of mosquitoes
		Seasonal re-emergence/rapid MBD development
“Extreme weather patterns”	Heat waves	Indoor activity of mosquito
	Intense precipitation	Water accumulation/increasing breeding habitat
	Scarcity of rainfall	Increased water storage/artificial breeding sites
“Environmental relief”	Complex topography (hills, lowlands, rivers, lagoons and bays)	Physical accumulation of water Influencing occurrence of weather phenomena
	Dense urbanization Urban environment with a high population density Megacity Rio de Janeiro	High population density, high neighborhood connectivity, high social diversity Lack of infrastructure and basic supply
		Favorable habitat for domestic mosquito species
		Increased vector-host contact
		Faster virus spread

Focus: Vector Ecology and Entomological Perspective		
Risk Factor	**Association/Complication**	**Challenge**
“High mosquito abundance and density”	Domestic vector in human habitat: increased vector-host contact	Rapid spread of MBD
		Inadequate/ineffective vector control
“*Aedes aegypti* behavior and ecology”	Sip feeder: multiple bites from different human hosts	Faster spread of mosquito-transmitted pathogens within vector-host cycle
	Opportunistic egg laying: can lay eggs in almost all breeding sites with accumulated (still) water	High probability of successful reproduction and survival of mosquito offspring: hard to control for vector and potential breeding sites especially during favorable climatic season/weather patterns
	Reproductive guaranty: different numbers of eggs from the same batch in different breeding sites	
“Adaptation of *Aedes aegypti*”	Vector domestication Urban activity	Primary blood source: human beings
		Lifecycle dependent to human habitat/ can completely shift indoors
		Breeding sites close to host (roof gutters, plants, pots, drains, garbage, tanks, …)
	Insecticides resistance	Ineffective vector control
Mosquito “hot spots”	High density of *Aedes aegypti* and (artificial) breeding sites (standing water, water storage, drains, garbage, ornamental plants, …)	Uncontrolled distribution and development of mosquitoes High probability of vector-host contact
	High population and household density	

Focus: Anthropogenic Factors, Socio-Economic Conditions and Governmental Action		
Risk Factor	**Quality/Complication**	**Challenge**
(A) Individuals, Communities, and Population		
“High population density”	Densely populated areas with high vector density and human-human contact	High probability of mosquito “hot spots” and vector-host contact/mosquito bites
“Demographic conditions”	At risk: Infants/children and elderly due to a more vulnerable immune system	Higher risk to become severely affected by MBD
“Poor socio-economic conditions”	Low/lack of education	Obstacles to understand health information and public health guidelines
	Social inequalities/poverty Low income/financial resources	Associated with: poor living/housing conditions, lack of basic resources, poor(er) health outcomes
“Poor housing and living conditions”	High density of vector/ increased vector-host contact	Rapid spread of MBD Inadequate/ineffective vector control
“Anthropogenic breeding places”	Uncovered water storage (tanks, containers, drains) Household items that can accumulate water (pots, vases, ornamental plants) Domestic garbage (inadequate domestic waste management) that can accumulate water	Breeding water for Aedes aegypti close to human host Uncontrolled mosquito reproduction and development inside housings and private backyards Mechanical vector control dependent to individual and community action
“Low risk perception/ Lack awareness regarding MBD and vector control”	Underestimation/Non-recognition of an ongoing health threat Lack of vector control Ineffective application of protective measures (repellents, nets, clothing)	Lack of public empowerment to take self-responsible action (protect against MBD) High probability of vector-host contact/transmission High risk of unnoticed infected cases
“Inconsistent application of protective measures/ public health action”	Repellents need to be applied frequently (every 3-4 hours, even at night); high prices esp. during season Uncomfortable to wear long-sleeved clothes during summer season Inadequate performance of vector/ breeding sites control and (domestic) garbage collection within communities Campaigns not well-performed during the whole year (focus: before season)	Ineffective implementation of individual protective measures as well as public health campaigns Lack of effective alternatives (esp. repellents) Lack of awareness regarding ongoing MBD diseases and the risk of severe consequences
“Lack of trust in authorities/ government”	Mistrust/Resignation/Protests among the population/communities	Population does not believe in distributed information by authorities/government Misleading media attention/media spotlight
	Political corruption	Lack of access to private households/ communities (e.g. for vector control) Political riots, higher rates of crime

(B) Municipal Level and Governmental Perspective		
"Lack of basic supply"	Inadequate collection of domestic and public waste: accumulation of water in garbage items	Potential breeding sites for *Aedes aegypti* close to human housings
	Lack of basic water supply and distribution of piped (cleaned) water	Water storage, risk of water-borne diseases/ co-infections
	Lack of basic sanitation/ inadequate drainage	Potential breeding sites for mosquitoes/ lack of hygiene
"Lack of governmental resources/control"	Lack of financial resources	No funding for public health action on a community, municipal and state level
	Lack of human resources	Inadequate public health actions/vector control
	Weak educational sector	Lack of basic education
	Social inequalities/poverty	
"Specific challenge: governmental control in Favelas"	Lack of control and governmental support	Access to communities
	Crime and conflicts/gang fights	Obstacles in supply of basic resources (health care, educational facilities, garbage collection, …)
(C) Global Perspective		
"Mass gathering events" (Olympic Games/ Carnival 2016)	High density of local and foreign population	Rapid spread of MBD
	Close human contact (especially Carnival)	Higher risk of sexual transmission (ZIKV)
		Low risk perception/awareness regarding MBD
Urbanization/ Population Growth	Increased population density/ urbanized environment	Favorable habitat for domestic vector species
Globalization	Increased (international) trade and travel promote the global spread of vector and pathogens to areas with suitable habitat	Global risk of MBD epidemics and autochthonous transmission of MBD
(D) Vulnerable "Hot Spot": Favelas		
Population density	Highly/densely populated areas	Increased human-to-human contact
	High household size/density	
	Poor housing and living conditions	
Lack in basic supply	Lack of basic sanitation, water supply and garbage collection	Storage/accumulation of water and improper sanitation creates artificial breeding sites
	Lack of access to educational and health care services	
Community characteristics	Associated with a poorer socio-economic conditions/poverty	Hard to get access to residents and their houses
	Associated with a higher level of crime + violence; lack of governmental control	

Appendix 7: Findings of the SIFA concept (tool 6, 7, 8, 10, and 11)

A7.1 Barriers and enabling factors (Tool 6)

Original Focus: *Use this tool to capture and record the factors that might positively or negatively impact on each audience segment's behaviour in relation to uptake of measles vaccination.* (ECDC 2014, p. 46)

Modification: *Use this tool to capture and record factors that might positively or negatively impact on MBD outbreak management strategies considering vector and virus development.*

	Barriers to MBD outbreak management	**Enabling factors for MBD outbreak management**
Social and Cultural	• social and cultural disparities mainly shape public health activities' outcome (rich vs. poor, white ethnicity vs. colored ethnicity, southern zone vs. northern zone) • hard-to-reach communities are living in *Favelas* → impeded access due to a higher level of crime and violence • lacking financial resources limit application of protective measures (e.g. expensive repellents, air conditions, screened windows/doors) • lacking community action/ empowerment and involvement, especially when it comes to vector control • access to private households/ backyards often refused due to privacy • other health risks are perceived more important (e.g. water-borne disease, associated with crime, violence, poverty) → *MBD usually mild/benign and there is no specific treatment, anyway*	• Brazilian culture: open minded, culturally diverse, even among communities → consider cultural differences and community solidarity for intervention planning • major Brazilian religion: Catholic (Central Intelligence Agency, 2017) → involve ecclesiastical institutions for risk communication • importance of music and art → potential communication channel for risk communication and health information • strong cohesion relations, especially by the extended family ((The Hofstede Centre, n.d.) → opportunity to multiply health messages

Environ-mental	• increase in warming trend • increasing occurrence of extreme weather events • need for climate change adaptation (especially flooding during torrential rainfall and adequate water storage during dry periods)	• MBD outbreak predictions following seasonal weather patterns → focus on the increasing epidemiological trend, not on the peak • consider restricting factors for biological vector control (e.g. heat, flooding, altitude)
Financial and Political	• Rio de Janeiro financial crisis → lacking governmental support • high prices for effective repellents • expensive entomological and clinical diagnostics (RT-PCR) • need for financial and human resources for effective and sustainable vector control	• strengthen national and international collaboration and open science → less dependent to local resources • develop policy guidelines to promote community approaches and convince the population
Others	• gap in knowledge, high level of uncertainty (especially ZIKV): mosquito-borne diseases → neglected tropical diseases • missing antiviral treatment and effective vaccine → transmission control and case management based on the application of protective measures, vector control and health education • lacking health care capacities	• strengthening ecological research to better understand transmission dynamics and vector development • predictive modelling in research

A7.2 Competition analysis map (Tool 7)

Original focus: *List all the competing forces that may stop your target audience undertaking the behaviour you want them to.* (ECDC 2014, p. 47)

Modification: *List all the competing forces that may stop to realize effective MBD outbreak response within the study area Rio de Janeiro city.*

Existing outbreak management competition

- three co-circulating arboviruses of major public-health concern
- health burden of other infectious diseases (e.g. food or water-borne diseases)
- health system emergency in December 2015 (Viga Gaier, 2015)
- lack of financial and human resources for effective vector control/MBD outbreak response
- high abundance/density of *Aedes aegypti*; highly susceptible population for ZIKV, CHIKV
- ineffective vector control; lacking antiviral treatment and vaccine
- ZIKV: not only a MBD disease, human-to-human transmission routes identified

Other factors of influence linked to the study area and outbreak scenario

- social disparities and inequality
- MBD and *Aedes aegypti* hot spots in *Favelas* (lacking access, hard-to-reach communities)
- lack of governmental control and increasing public mistrust
- increasing crime and violence, lack of public safety due to Rio de Janeiro's political crisis

Environmental competition

- occurrence of weather extremes in temperature and rainfall
- increasing trend in urbanization and population growth
- growing distribution of unstructured and impoverished settlements like *Favelas*

Other promotions

- lacking MBD outbreak management and vector control strategies → need for innovative approaches and cost-effective alternatives

Other competitors

- Roman catholic church's position on abortion and (contraceptive) birth control regarding ZIKV/restriction on abortion: "Catholic leaders say Zika doesn`t change ban on contraception" (Goodstein, 2016)

A7.3 Key data summary (Tool 8)

Original focus: *This tool will help you summarise all key data available from existing research and information systems about the challenge or problem. It can also help you identify potential missing data sets that you might need to acquire.* (ECDC 2014, p. 48)

Modification: *This tool will help to summarize all key data available from existing research and information systems associated with the occurrence of MBD epidemics within the metropolitan setting Rio de Janeiro. It can also help to identify potential missing data sets that might need to be acquired.*

Data type	Source (cf. methods)	Potential evaluation metric
Key findings of an integrative literature review (ecology of vector development and transmission dynamics) *(qualitative and quantitative data)*	Clinical/experimental studies, review articles, case studies academic commentaries, technical public health reports, science news articles that meet the inclusion criteria	Identified influencing factors, recommendations for research and fields of action, potential solution approaches relevant for metropolitan settings located in tropical climate like Rio de Janeiro
Distribution of arbovirus infected cases based on the monthly notification of suspected cases *(quantitative data)*	Clinical surveillance ZIKV, DENV, and CHIKV notification	Number of suspected cases (ICD -10) reported per month including spatial allocation *Note: laboratory confirmed cases would enhance evaluation*
Vector abundance and density within the study area *(quantitative data)*	LIRAa: *Aedes aegypti* infestation rapid survey, Predominant breeding sites of *Aedes aegypti*	Proportion of larvae infestation within the investigated setting, classification of the level of alert *Note: for Rio de Janeiro, only an incomplete report is provided*
Environmental profile of the study area *(quantitative data)*	Geological sources, population estimations and census data provided online, Google maps	Population size (total number), population density (inhabitants/ km^2), area (km^2), level of urbanization (map), altitude (m above sea level), natural water area (quantities, km^2), coastline (km)

Climatic profile of the study area (temperature and precipitation) *(quantitative data)*	Satellite data derived from the day and night surface temperature and precipitation (spatially), information from a meteorological station in AP 1.0 (temporally)	Spatio-temporal development of minimum temperature, maximum temperature and rainfall; temporal development of extreme weather phenomena considering temperature and rainfall
Social and infrastructural profile of the study area *(quantitative data)*	Information derived from the 2010 census, 2015/2016 estimations, and 2016 geological maps/investigations	Proportion of age groups (years), sex, ethnicity; level of income (R$), portion of analphabets; quantities of housing type, water supply, sanitation, garbage collection; quantities and allocation of health care units and educational facilities; allocation of *Favelas*
Proxy: public interest and media coverage *(quantitative and qualitative data)*	International news coverage, research findings, and public declarations/alerts; Google search trend for the queries *Zika*, *Dengue*, *Chikungunya*	Number of reports relevant for Brazil from March 2015 to May 2017 Relative application frequency for each query in Rio de Janeiro state from March 2015 to May 2017 + related queries Identified influencing factors, recommendations for research and fields of action, potential solution approaches
Key qualitative findings based on the achievements, challenges and lessons learned during the Zika outbreak scenario in Rio de Janeiro 2015/2016 *(qualitative data)*	10 expert narratives from the field of medical sciences, entomology, public health, environmental sciences 5 field observations Complementary materials related to the field of vector control and MBD outbreak management	Qualitative framework presenting identified influencing factors, recommendations for research and fields of action, as well as potential solution approaches based on the experiences gained during the field work and knowledge of interdisciplinary research and field work

Identified missing input

Adequate, consistent and laboratory confirmed clinical and entomological surveillance	*Suggestions:* *Health authorities, research institutions*	*Number of monthly confirmed case notifications including spatial allocation* *Monthly report of LIRAa index/entomological index*
Statistical analysis of the level of impact for each influencing variable	*Suggestions:* *Correlation analysis/ regression analysis*	*Degree of relationship* *Degree of interaction*
Profound cultural, political and historical background of the study area	*Suggestions:* *Ethnographies, case studies, literature review, population survey*	*Qualitative description of potential influences, quantitative evaluation of identified influencing factors*

A7.4 Other assets map (Tool 10)

Original focus: *Make the most comprehensive list and estimates possible of all contributions from other sources to the programme. This mapping will assist with cost benefit, return on investment and value for money analysis.* (ECDC 2014, p. 50)

Modification: *Make the most comprehensive list and estimates possible of all contributions from other sources to enhance and assist effective MBD outbreak management and response. (Assets may include: social networks, community, environmental, stakeholder and health service assets)*

Community assets
Social and community cohesion – cultural background – religious beliefs and ecclesiastical institutions – music and art – benefits of community properties – strong collaboration between public health sector and communities

Public sector assets
Health information placed in public locations and transport, especially in centered areas – state-based health advice via public, digital and social media – mass gathering events for health advice and awareness rising – involvement of celebrities, actors, musicians, artists – strong collaboration between public health sector and public sector

Commercial sector/Communication channel assets

Health advice and health education via public, digital and social media – promotion of protective measures and individually applied vector control strategies (e.g. control for breeding sites) – identification of favorite/popular communication channels – include health care workers of various professions to communicate risks and health advice – support promotional offer for protective measures (especially repellents and nets for windows and doors)

NGO/Charity sector assets

Additional funding – provision of financial and human resources – national and international collaboration with local institutions to make them less dependent to the setting's limitations – support for community action and development of risk communication guidelines/health information

Staff skills assets

Education of health care works – improvement of diagnostics/application of diagnostic tools – development of risk communication guidelines for clinicians – guidelines for adequate case management and diagnosis based on the clinical picture of arbovirus infection

Financial assets

Funding/financial resources for diagnostics, clinical and entomological surveillance, laboratory research and field investigations, development of treatment and vaccine, development and application of vector control strategies, medical equipment and human resources, ...

Information assets

Development of targeted risk communication and health information materials for clinicians, patients and the public considering the different characteristics of vulnerable groups and communities – involvement of official and informal information sources to provide trustworthy information – involvement of communication and behavioral sciences

Political and management support assets

To strengthen governmental support and control, especially in unstructured settlements – development of health policies to implement effective vector control strategies on a community level – strong collaboration between public health sector and governmental institution – support of open science community and real-time communication/information exchange

A7.5 Partner/stakeholder contributions record tool (Tool 11)

Original focus: *Detail how all priority partners will contribute to the programme and how this contribution will be evaluated by you and them. This plan will assist with the targeting of efforts to engage key partner organisations.* (ECDC 2014, p. 51)

Modification: *Detail how multidisciplinary partners may contribute to an effective MBD outbreak management and rapid response and how this contribution will be evaluated. This plan will assist with the targeting of efforts to engage key partner organizations.*

Partner (field of action)	Aim of relationship (focus)	How evaluated (ideas)
Collaborating laboratories (nationally and internationally)	To improve case diagnostic and early case detection To conduct a real-time clinical and entomological surveillance	Consistent surveillance of vector and human host Early case detection
Environmental and climate sciences	To develop reliable predictive models for future MBD epidemic trends following the occurrence of weather patterns and seasonal climate conditions To implement mechanical and chemical vector control strategies during less suitable environmental conditions To implement biological vector control strategies (release of modified mosquitoes) in highly suitable environment	Improved outbreak response at an early stage Effective vector control, lower density of *Aedes aegypti* Increasing modified vector population (however, consider vector competition)
Involvement of social sciences and qualitative inquiries	To strengthen behavioral and cultural investigations inside Rio de Janeiro's communities to develop more targeted public health strategies and health information	Efficiency of public health interventions aiming a change in behavior regarding vector control and the application of protective measures

Ethnographic research approaches/in-depth case studies inside *Favelas*	To address the needs, risks, resources and opportunities within Rio de Janeiro's most vulnerable settings	Improvement in health outcomes, decrease in MBD infections and vector density
Community representatives	To address the needs, risks, resources and opportunities according to Rio de Janeiro's community characteristics	Improvement in health outcomes, decrease in MBD infections and vector density
Educational sector	Distribution of health information, public health education	Increase in level of awareness and basic knowledge about Aedes aegypti and arboviruses
Biotechnological and pharmaceutical industry	Development of treatment, vaccine, cost-effective repellents and innovative insecticides	Less notifications of severe health consequences, development of herd immunity Alternative protective measures, higher uptake rate
Governmental institutions	To develop policy guidelines to strengthen public health action on a community level	Increase in participation and efficiency of public health programs on a community level
Media and Communication Sciences	To identify favorite communication channels, widely used information soucres and the preferred type of information To identify the media spotlight and trends in public interest during MBD epidemics	Targeted risk communication, widely used health information, increased public awareness during epidemics
Multi-sectorial and multidisciplinary funding partners	To improve diagnostics, adequate clinical and entomological surveillance, case management and to strengthen research and field work	Increase in financial and human resources Improved MBD and vector surveillance, case management and outbreak response

Appendix 8: Qualitative field research – Collection of materials

A8.1 Conversation guideline (1/3) – supportive materials

Introduction

To learn more about co-circulating arbor-viruses here in Brazil, we are interested in the different approaches to face the burden of neglected mosquito-borne diseases.

Can you give us a short insight of your field of work? What exactly are your responsibilities, just a few sentences?

Zika outbreak 2015/16 (narrative)

Although the Zika virus is present for more than 60 years, the latest outbreaks in the Americas appears as a new challenge. Right after the WHO declared Zika as a Public Health Emergency of International Concern in February 16, people started to worry about – also in Germany! And still there are a lot of open questions... This was the very first time we came in touch with the issue of tropical vector-borne diseases and health sciences and decided to learn more about it.

We can imagen that you have your own professional view about the Zika outbreak. Can you tell us about your experiences and perceptions just from the first time you got in contact with Zika?

Cave: What do you think was new about this outbreak?

Cave: Which influencing factors do you see in relation to the outbreak?

Cave: In our project we are focusing on the city Rio de Janeiro.
What do you think went successfully facing the Zika outbreak? (Outbreak management, case control, mosquito control, risk communication, research, ...)

Cave: Where did you perceive challenges?
Which questions concerning Zika were easy to answer? Which questions are still open?

Cave: From your professional perspective, with whom did or do you collaborate?

Cave: If you would have the chance to set up your own Zika/Arbor-viruses outbreak management team, which professionals or disciplines would you choose?

A8.1 Conversation guideline (2/3) – supportive materials

Some question to you as an expert of your field: Mosquito/ Aedes aegypti

A German Magazine (Spiegel, 2016/30) describes the mosquito as "The most dangerous animal on planet earth"- what do you think?

What are your suggestions to control the vector Aedes aegypti in Rio?

In general, is every person at the same risk of mosquito-borne diseases?
(Vulnerability-burden of MBD: biggest for poorest?)

In how far do you think can climate conditions – like temperature, rainfall, humidity – be seen as important influencing factors? As we found out Aedes aegypti can completely adapt to the human habitat and shift its complete lifecycle indoors – in how far is it still climate vulnerable?
(Cave: Tropical mosquito-borne diseases not tropical anymore?)

What do you think is the most important experience taken from your research field about mosquito-borne diseases you want to share with us? (Just take some minutes to think about it..)

Last but not least: How do you protect yourself against mosquito-borne diseases?

Some question to you as an expert of your field: Virus/Disease

Why is it so difficult to differentiate between Zika, dengue and chikungunya?

What is the best strategy to control the cases infected by Zika, dengue and chikungunya?

What is the most dangerous virus of these three arborviruses and why?

What do you think are important influencing factors that can increase the peak and spread of an outbreak like Zika?

What do you think is the most important experience taken from your research field about mosquito-borne diseases you want to share with us? (Just take some minutes to think about it..)

Last but not least: How do you protect yourself against mosquito-borne diseases?

A8.1 Conversation guideline (3/3) – supportive materials

Some question to you as an expert of your field: Climate Change/Environmental Sciences

Which relationships do you see between climate conditions and mosquito-borne diseases in general?

What changes in climate and environment did you perceive during the past (ten) years in Rio, which could have contributed to the Zika outbreak?

In how far is climate research used to control mosquito-borne diseases? How could your findings help to prevent outbreaks?

We observed that patients often do not show up at physician's appointments when it is raining, which can cause challenges, for example in Zika case control. Can you think of other challenges which can come up with the interplay of human behavior, climate conditions and mosquito-borne diseases? *(housing and living conditions, population movement, water storage, …)*

What do you think is the most important experience taken from your research field about mosquito-borne diseases you want to share with us? (Just take some minutes to think about it..)

Last but not least: How do you protect yourself against mosquito-borne diseases?

Some question to you as an expert of your field: population health interventions

Within your project: what are you doing to fight mosquito-borne diseases in detail? With whom are you collaborating?

Where do you get your information from to plan your intervention?

Why is your work so important, especially for the communities?

Where do you perceive challenges? *(short-term, long-term)*

What do you think is the most important experience taken from your work about mosquito-borne diseases you want to share with us? (Just take some minutes to think about it..)

Last but not least: How do you protect yourself against mosquito-borne diseases?

A8.2 Information and Consent of participation (1/8) – electronically supplemented

Neglected Vector-Borne Diseases, Climate Change and Health: A Case Study about the recent Zika Outbreak in Rio de Janeiro/Brazil declared as a Public Health Emergency of International Concern in 2016

Introduction:

Factors such as humidity, temperature and precipitation patterns influenced by climate change are known to favor the spread of vector-borne diseases, by having direct and indirect impacts on the survival and distribution of pathogens and their vectors. One of them is the mosquito Aedes aegypti which carries the three arbor-viruses Zika, chikungunya, and dengue, and whose spread in Brazil poses a serious challenge to the country's health system. Although the Zika virus was first identified in 1947 in Uganda and is hence present for more than 60 years, the latest Zika outbreaks in the Americas appear to be something new, causing severe congenital and neurological complications. According to WHO, 73 countries and territories have reported mosquito-borne Zika virus transmission since 2007. In order to improve vector and disease control it is important to better understand the complex relationship between climate as well as environmental conditions and mosquito-borne diseases.

Objectives/Methods:

This descriptive study aims to investigate the interface between epidemiological aspects of mosquito-borne diseases and climate conditions in the city of Rio de Janeiro, Brazil, discussing the influence of socio-economic and environmental determinants. Based on a mixed-methods approach, it focuses on

- the review of relevant literature analyzing both past and current research efforts related to the Zika virus, taking relevant influencing factors and health impacts of other mosquito-borne diseases into account
- the connection between three main meteorological variables (temperature, humidity and precipitation), the cases infected by Zika, dengue (and chikungunya) as well as the distribution of their common vector Aedes aegytpti (Building Infestation Index for Aedes aegypti), displayed over the past years (quantitative analysis)
- the conduction of conversations, material screening and observations focusing on experts from different fields of research (Fiocruz), who were involved during the Zika outbreak in Rio de Janeiro, Brazil (qualitative approach)

Expected Results/Discussion:

This study allows a better understanding of the mechanics and challenges of tropical vector-borne diseases, their health impacts and relation to climate change in Brazil. It also investigates the occurrence of extreme weather events caused by climate change and outlines some challenges and measures which may be addressed to cope with the spread of vector-borne diseases in the Americas. The findings also provide useful multidisciplinary insight from the perspectives of clinical research, entomology, climate and environmental sciences as well as socio-economic and human behavior determinants, highlighting the lessons learned for effective outbreak management of mosquito-borne diseases such as Zika for the future.

Project Team: Juliane Boenecke, Hannah Spielmann (HAW Hamburg) **Supervisor: Prof. Dr. Walter Leal (HAW Hamburg)**

A8.2 Information and Consent of participation (2/8) – electronically supplemented

INFORMATION SHEET: CLIMATE CHANGE AND HEALTH
Neglected Vector-Borne Diseases, Climate Change and Health – A Case Study about the recent Zika Outbreak in Rio de Janeiro/Brazil declared as a Public Health Emergency of International Concern in 2016

Introduction

Hannah/Juliane and I, master students from the University of Applied Sciences in Hamburg, Germany, are conducting a retrospective study in regard to the recent Zika outbreak in Brazil and the challenges caused by co-circulating viruses like dengue and chikungunya, focusing their incidents in Rio de Janeiro. Therefore we are interested in learning about your experiences and work at the Oswaldo Cruz Foundation in Rio de Janeiro, Brazil - especially during the outbreak - taking the health impacts of mosquito-borne diseases into account. We also want to consider environmental, social and climate conditions in Brazil. The results will be presented in a scientific paper and will also be used for our master theses on neglected vector-borne diseases, climate change and health in the field of Health Sciences/Public Health.

Why is this study conducted?

We would like to know more about the three vector-borne diseases Zika, chikungunya and dengue, their health impacts and occurred challenges focusing Rio de Janeiro, Brazil, during the past 10 years. To do this we are collecting data about the epidemiology of Zika, dengue, and chikungunya, climate conditions, as well as the main vector Aedes aegypti. Additionally, we are talking to selected experts about their specific field of work in relation to mosquito-borne diseases, their tasks, responsibilities and their experiences regarding Zika, dengue and chikungunya. This information will help us to understand your professional view, to learn about multidisciplinary perspectives of research – considering the vector, the virus, and the environment – and thus to get an in-depth picture of which lessons could be learned and how much effort is needed to investigate the latest Zika outbreak and its challenges.

What will happen today if I take part in this study?

Today, we would like to ask you some questions about your professional perspective and the outbreak management of mosquito-borne diseases in Rio de Janeiro, Brazil. We will take notes of the conversation and a recording will also be made using an audio tape/mobile phone, if permitted. After we ask these questions today we would like to revert to you in case of additional queries. All information gathered will be treated as confidentially by the project team, and records of the conversations will be kept securely. No personal identification information such as names will be used in any reports arising out of this research if not permitted.

How long will the study last?

Today, our conversation will last approximately 60 minutes. The total duration of the study project will end at the end of our summer semester in August 2017.

Can I stop being in the study?

You can decide to decline any question, to end the discussion, and to stop participating at any time. We will not ask you to share personal beliefs, practices or stories and you do not have to share any knowledge, if you are not comfortable sharing. Just tell one of the project team right away if you wish to stop the conversation or upcoming queries.

A8.2 Information and Consent of participation (3/8) – electronically supplemented

What risks can I expect from being in the study?

Participation in any research study may involve a loss of privacy. Information you provide about your experiences will be recorded, but your name will not be used in any reports of the information provided. No quotes or other results arising from your participation in this study will be included in any reports, even anonymously, without your agreement. The information obtained from these conversations will only be used by the project researchers. We will do our best to make sure that the personal information gathered for this survey is kept private.

Are there benefits to take part in the study?

There will be no direct benefit to you from participating in this study. However, the information that you provide will help researchers, nationally and internationally, to understand how to face the outbreak and spread of mosquito-borne diseases like Zika, especially in times of uncertainty and emergency. Furthermore this case study can strengthen international collaboration and could be considered as an example taken from real life presenting the successes and lessons learned during the Zika outbreak in 2015/2016 in Rio de Janeiro.

What are my rights if I take part in this study?

Taking part in this study is your choice. You may choose either to take part or not to take part in the conversation. If you decide not to take part in this study, there will be no consequence or disadvantage for you.

What are the costs of taking part in this study? Will I be paid for taking part in this study?

There are no costs to you for taking part in this study. You will not be paid for taking part in this study.

Who can answer my questions about the study?

You can talk to the researchers or our supervisor Prof. Dr. Walter Leal about any questions or concerns you have about this study. Contact me or my fellow student via e-Mail. If you have any questions, comments or concerns about taking part in this study, first talk to the project team. If for any reason you do not wish to do this, or you still have concerns about doing so, you may contact Prof. Dr. Walter Leal.

Giving consent to participate in the study

You may keep this information sheet if you wish. Participation in this conversation is voluntary. You have the right to decline to participate in the study, or to withdraw from it at any point without consequences. If you do not wish to participate in the study you should inform the researchers now (or at any time of the discussion). If you do not agree to quotes or other results arising from your participation in the study being included, even anonymously, in any reports about the study, please tell the researcher now.

A8.2 Information and Consent of participation (4/8) – electronically supplemented

Consent for participation in a research conversation

"Neglected Vector-Borne Diseases, Climate Change and Health – A Case Study about the recent Zika Outbreak in Rio de Janeiro/Brazil declared as a Public Health Emergency of International Concern in 2016"

This informed consent form is for experts of the Oswaldo Cruz Foundation in Rio de Janeiro, Brazil, who we are inviting to participate in the following research project:

Purpose of the research:	Neglected Vector-Borne Diseases, Climate Change and Health – A Case Study about the recent Zika Outbreak in Rio de Janeiro/Brazil declared as a Public Health Emergency of International Concern in 2016
Organization/Supervision:	Hamburg University of Applied Sciences Prof. Dr. Walter Leal
Persons responsible for design and conduction of the conversation:	Juliane Bönecke Hannah Spielmann

I agree to participate in a research project conducted by presented researchers (persons responsible) from the Hamburg University of Applied Sciences (HAW) in Germany, supervised by Prof. Dr. Walter Leal (HAW Hamburg). I understand that the project is designed to gather information about mosquito-borne diseases in Rio de Janeiro, Brazil, focusing the recent Zika outbreak in 2015/16 as an example of neglected vector-borne diseases, climate change and health. I will be one of approximately fifteen people being invited for this research. The purpose of this document is to specify the terms of my participation in the project.

1. I have been given sufficient information about this research project. The purpose of my participation as a participant in this project has been explained to me and is clear.
2. My participation as an expert in this project is voluntary. There is no explicit or implicit pressure whatsoever to participate.
3. Participation involves being surveyed by researchers from the Hamburg University of Applied Sciences (HAW). The conversation will last approximately 60 minutes. I allow the researcher(s) to take written notes during the discussion. I also may allow the recording (by audio tape/mobile phone) of the conversation. It is clear to me that in case I do not want the conversation to be taped I am at any point of time fully entitled to remove from participation.
4. I have the right to not answer any of the questions. If I feel uncomfortable in any way during the discussion, I have the right to decline to answer any question or to end the conversation.
5. I have been given the explicit guarantee that, if I wish so, the researchers will not identify me by name or function in any reports using information obtained from this research, and that my privacy as a participant in this study will remain secure. In all cases subsequent uses of records and data will be subject to standard data use policies of the Hamburg University of Applied Sciences which protect the anonymity of individuals and institutions.

A8.2 Information and Consent of participation (5/8) – electronically supplemented

6. I have been given the guarantee that this research project has been approved by the presented supervisor Prof. Dr. Walter Leal, who may be contacted in case of research problems or any other question regarding the study project.
7. I have read and understood the points and statements of this form. I have had all my questions answered to my satisfaction, and I voluntarily agree to participate in this research project.
8. I have been given a copy of this consent form co-signed by the researchers.

______________________	______________________
Participant's Signature	Date of Signature
______________________	______________________
1st Researcher's Signature	Date of Signature
______________________	______________________
2nd Researcher's Signature	Date of Signature

For further information, please contact:

Juliane Bönecke (HAW Hamburg) e-Mail: [redacted]
Hannah Spielmann (HAW Hamburg) e-Mail:
Prof. Dr. Walter Leal (HAW Hamburg) e-Mail:

A8.2 Information and Consent of participation (6/8) – electronically supplemented

TERMO DE CONSENTIMENTO LIVRE E ESCLARECIDO (TCLE)

ICICT
Instituto de Comunicação e Informação Científica e Tecnológica em Saúde

Ministério da Saúde
FIOCRUZ
Fundação Oswaldo Cruz

Prezado participante,

Você está sendo convidado(a) a participar da pesquisa: ***"Climate Change and Health. Neglected Vector-Borne Diseases, Climate Change and Health – A Case Study about the recent Zika Outbreak in Rio de Janeiro/Brazil declared as a Public Health Emergency of International Concern in 2016" (Mudanças climáticas e saúde: Doenças vetoriais negligenciadas, mudanças climáticas e saúde – Estudo de caso sobre a epidemia de Zika no Rio de Janeiro declarada uma Emergência Sanitária).*** Esta pesquisa está sendo desenvolvida por um grupo de pesquisadores coordenado pelo Prof. Christovam Barcellos, pesquisador e coordenador do Laboratório de Informação em Saúde do Instituto de Comunicação e Informação Científica e Tecnológica em Saúde da Fundação Oswaldo Cruz (LIS/ICICT/Fiocruz).

O objetivo do estudo é investigar a relação entre os aspectos epidemiológicos das doenças transmitidas por mosquitos e as condições climáticas na cidade do Rio de Janeiro, sob a influência dos determinantes socioeconômicos e ambientais. Outros objetivos são i) conhecer com profundidade as três doenças transmitidas pelo mosquito *Aedes* (Zika, chikungunya e dengue), seus impactos sobre a saúde e seus desafios no Rio de Janeiro nos últimos 10 anos; ii) coletar dados sobre a epidemiologia do Zika, dengue e chikungunya, condições climáticas, bem como o principal vetor *Aedes aegypti*; iii) aprender com especialistas selecionados sobre seus campos específico de trabalho em relação às doenças transmitidas por mosquitos *Aedes*, suas tarefas, suas percepções e experiências individuais, bem como sua atitude pessoal em relação a Zika, dengue e chikungunya; iv) entender o seu ponto de vista pessoal destes especialistas, aprender sobre as perspectivas multidisciplinares da pesquisa - considerando o vetor, o vírus e o ambiente – para obter uma visão detalhada de quais lições poderiam ser aprendidas e quanto esforço é necessário para investigar o último surto de Zika e seus desafios.

A metodologia deste pesquisa está focando em:

i) A revisão da literatura pertinente que analisa os esforços de pesquisa passados e atuais relacionados com o vírus Zika, tendo em conta os fatores de influência relevantes e os impactos para a saúde de outras doenças transmitidas por mosquitos;
ii) A análise quantitativa da relação entre três variáveis meteorológicas principais (temperatura média, umidade e precipitação), os casos de Zika, dengue e chikungunya, bem como a distribuição de seu vetor comum Aedes aegytpti (Índice de Infestação Predial) nos últimos dez anos (análise quantitativa);
iii) A realização de entrevistas abertas com especialistas e pesquisadores de diferentes áreas de pesquisa da Fiocruz, que estiveram envolvidas na investigação do surto de Zika no Rio de Janeiro, Brasil.

Este convite se deve a sua estreita relação com os objetivos e propósitos de nosso projeto. No entanto, por ser sua participação voluntária, você tem plena autonomia para decidir se quer ou não participar do mesmo, bem como, desistir da sua participação a qualquer momento – o que não resultará, de forma alguma, em qualquer constrangimento ou penalização. Esclarecemos, contudo, que sua participação será de grande importância para o alcance dos objetivos a que nos propomos.

A8.2 Information and Consent of participation (7/8) – electronically supplemented

▫

São compromissos assumidos pela equipe de pesquisadores, a garantia de confidencialidade e privacidade das informações por você prestadas. Qualquer dado que possa identificá-lo será omitido na divulgação dos resultados da pesquisa. O material registrado será armazenado em local que garanta esta confidencialidade. Em caso de necessidade, você será identificado(a) apenas pela sigla do seu nome, idade, sexo.
A qualquer momento, durante ou após a pesquisa, você poderá solicitar do pesquisador que o entrevistou ou ao coordenador deste projeto, informações sobre sua participação e/ou sobre a pesquisa, o que através dos meios de contato explicitados neste Termo.
A sua participação consistirá em responder perguntas de um roteiro de uma entrevista à pesquisadores do projeto, que poderá será gravada, se você autorizar. O tempo de duração da entrevista é de aproximadamente uma hora. É importante lembrar que as entrevistas serão transcritas e armazenadas, em arquivos digitais, mas somente terão acesso às mesmas os pesquisadores e o coordenador da pesquisa. Ao final da pesquisa, todo material será mantido em arquivo por pelo menos 5 anos, conforme Resolução 466/12 e orientações do CEP/EPSJV, ao qual o ICICT está vinculado.

Sua participação neste projeto de pesquisa tem relação direta com os objetivos i, ii e iv acima descritos. Os resultados deste estudo serão divulgados apresentações, oficinas de trabalho, e outras atividades que reúnam pesquisadores e entrevistados, programadas e divulgadas com a devida antecedências de modo a garantir a sua presença. Os nomes dos participantes da pesquisa não serão divulgados nestas apresentações.

Este termo está redigido em duas vias, que deverão ser assinadas pelo pesquisador responsável pelo projeto, e por você, que receberá, no momento da entrevista, uma cópia deste Termos de Consentimento Livre e Esclarecido (TCLE).

[redacted]

A8.2 Information and Consent of participation (8/8) – electronically supplemented

Em caso de dúvida quanto à condução ética do estudo, entrar em contato com o Comitê de Ética em Pesquisa da EPSJV\Fiocruz. Os Comitês de Ética em Pesquisa são instâncias da Fiocruz que tem como objetivo defender os interesses dos participantes da pesquisa em sua integridade e dignidade e contribuir no desenvolvimento das pesquisas em saúde dentro de padrões éticos estabelecidos pela resolução Resolução 466/12 do Conselho Nacional de Saúde. O CEP tem o papel de avaliar e monitorar o andamento do projeto de modo que a pesquisa respeite os princípios éticos de proteção aos direitos humanos, da dignidade, da autonomia, da não maleficência, da confidencialidade e da privacidade.

Contato com o Comitê de Ética em Pesquisa da EPSJV/Fiocruz:
Avenida Brasil, 4365 – Manguinhos – Escola Politécnica de Saúde Joaquim Venâncio, sala 316
Tel.: (21) 3865-9710
email: cep@epsjv.fiocruz.br

Marcar se autorizado:

(__) Autorizo a gravação da minha entrevista para a pesquisa:

(__) Declaro que entendi os objetivos e condições de minha participação na pesquisa e concordo em participar.

_______________, ____ de _____________ de 2016

____
(Assinatura do participante da pesquisa)

A8.3 Summary and observation minute (1/4) – electronically supplemented

SUMMARY OF THE CONVERSATION

1. How would you describe the atmosphere and context of the discussion?

2. What were the main points made by the respondent during this conversation?

3. What new information did you gain through this discussion (compared to previous conversations)?

4. Was there anything surprising to you personally? Or that made you think differently?

5. What messages did you take from this discussion for intervention design?

6. Were there any problems with the guideline (e.g. wording, order of topics, missing topics) you experienced in this conversation?

A8.3 Summary and observation minute (2/4) – electronically supplemented

OBSERVATION MINUTE I CONVERSATION

Observer: ______________________________

Interrogator(s): ______________________________

Date of conversation: ______________

Beginning: ______________ End: ______________

Location: ______________________________

Participant: ______________________________

Meeting place description: *detail and description, e.g. size and accessibility, and how this could affect the discussion; interruptions during the discussion*

Participants: *how many of those invited participated, description of demographics if not formally collected*

A8.3 Summary and observation minute (3/4) – electronically supplemented

Seating diagram:

Group dynamics: *general description – level of participation, dominant and passive participants, interest level, boredom, anxiety – and how these relate to the different topics discussed*

Impressions and observations:

A8.3 Summary and observation minute (4/4) – electronically supplemented

Running notes: ***detailed notes following the discussion, as near verbatim as possible, including identification of all contributors***

A8.4 Field observation minute – electronically supplemented

Observation Protocol

Date:

Project: Neglected Diseases: Climate Change, Vector-Borne Diseases and their Health Impacts

Observer: *(Researcher)*

Place: *(Location)*

Time: *(Duration)*

Focus: *(Observation foci during the field research/participating observation)*

Category (cf. Focus)	**Descriptive Notes**	**Reflective Notes**
...	...	...

Others: ...