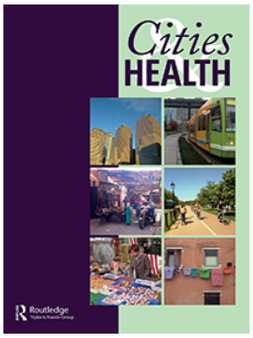

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Integrating city resilience and mosquito-borne diseases – a multi-site case study from the Resilient Cities Network

Beatrice R Egid[a], Marcela Herrera Jaramillo[b], Thomas C Lindsay[c], Clara Isabel Lopez Villegas[b], Krishna Mohan[d], Kim Ozano[e], Raul Alberto Rojo Ospina[f], Carlos Alberto Sarria Ocampo[g], Bindu Taylor-Brewer[h], Carlos Andrés Villarreal Restrepo[b], Lina Liakou[i] and Anne L Wilson[a,j]

[a]Department of Vector Biology, Liverpool School of Tropical Medicine, UK; [b]ACI Medellín, Medellín, Colombia; [c]Accelerating Change Together, UK; [d]Chennai Resilience Centre, Chennai, India; [e]Department of International Public Health, Liverpool School of Tropical Medicine, UK; [f]Secretary of Health, Medellín, Colombia; [g]Administrative Planning Department, Medellín, Colombia; [h]Paynesville City Corporation, Paynesville, Liberia; [i]Resilient Cities Network, the Netherlands; [j]Department of Biosciences, Durham University, Durham, UK

ABSTRACT

Urbanisation is increasing the risk of mosquito-borne diseases such as dengue and malaria in cities, with resulting impacts on health and development. At the same time, cities worldwide are building and investing in urban resilience. It is not known to what extent and how cities are considering mosquito-borne diseases in their resilience strategies. This research uses a multi-site case study methodology, focused on Resilient Cities Network member cities Chennai (India), Paynesville (Liberia) and Medellín (Colombia), to understand the intersection between mosquito-borne diseases and city resilience. Data collection involved in-depth interviews with resilience representatives of each city and document review to explore perceptions of mosquito-borne diseases, their prioritisation in resilience planning and what resilience activities are implemented and how. Analysis showed that while mosquito-borne diseases are not considered explicitly as a resilience challenge, many resilience activities implemented by cities have co-benefits for mosquito-borne disease control or could be enhanced to realise this potential. For Resilient Cities Network member cities looking to integrate mosquito-borne disease control into their resilience approach, we recommend increasing awareness of interlinkages between city resilience and mosquito-borne diseases, leveraging multi-sectoral collaborations with co-benefits for mosquito-borne disease control, and engaging communities in urban planning and mosquito-borne diseases control efforts.

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Mosquito-borne disease; vector-borne disease; city resilience; urban health; solid waste management

Introduction

Outbreaks of mosquito-borne diseases such as dengue, Zika and chikungunya, transmitted by species of the *Aedes* mosquito, are becoming increasingly common in cities (World Health Organization 2020) and are a major burden on health and development worldwide. There are an estimated 390 million dengue infections globally per year (Bhatt *et al.* 2013) with the annual global cost of dengue at approximately $8.9 billion in 2013 (Shepard *et al.* 2016). Rapid urbanisation and greater interconnectedness through travel and trade are the major drivers of the increase in mosquito-borne diseases in recent decades. Today 55% of the world's population lives in urban areas and this is expected to reach 68% by 2050, with 90% of the increase taking place in Asia and Africa (United Nations 2018). Overcrowding, poor-quality housing, poor drainage and lack of basic services and infrastructure, such as safe and accessible drinking water, sanitation, waste collection and healthcare, combine to create favourable conditions for mosquito-borne disease transmission. In particular, the *Aedes aegypti* mosquito has adapted to live in water storage containers, discarded tyres, and rubbish which abound in some urban environments. Recently, an urban malaria mosquito (*Anopheles stephensi*) typically found in South Asia and the Arabian Peninsula has invaded the Horn of Africa, increasing the risk of malaria in towns and cities there (Sinka *et al.* 2020). While vector control tools such as insecticide-treated nets or spraying of insecticides are commonly used to control mosquito-borne diseases, challenges such as development of insecticide resistance in mosquitoes, insufficient funding for vector control (Haakenstad *et al.* 2019), and difficulty achieving high coverage of interventions threatens to undermine the progress that has been made in reducing disease transmission (Ranson and Lissenden 2016). As such, there is an increasing focus on non-insecticide based interventions for vector control and involvement of the non-health sector, including social, economic and environmental interventions for disease control, such as improving solid waste management and housing, and drainage of standing water (World Health

CONTACT Beatrice R Egid beatrice.egid@lstmed.ac.uk Department of Vector Biology, Liverpool School of Tropical Medicine, UK

Organization 2017, Sim *et al.* 2020, Wilson *et al.* 2020).

At the same time as urbanisation is increasing the risk of mosquito-borne diseases, many cities worldwide are building and investing in city resilience. City resilience is defined as 'the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience' (Arup and Rockefeller Foundation 2015). Typically, chronic stresses are factors that pressure a city on a daily or reoccurring basis, such as high unemployment and recurrent flooding, while examples of acute shocks include earthquakes and terrorist attacks. Endemic mosquito-borne diseases can be considered a chronic stress affecting cities, while outbreaks of known and emerging mosquito-borne diseases are major shocks. However, the extent to which mosquito-borne diseases are considered in resilience planning and implementation is not known. While there may be mutual benefits of city resilience on mosquito-borne disease management, these links need to be explicitly made, and city resilience strategies could also have unintended consequences on mosquito-borne diseases. For example, while provision of basic services (e.g. solid waste management and reliable piped water) could help to reduce mosquito-borne diseases, providing and enhancing man-made and natural assets such as city parks could increase vector habitats. Importantly, multi-sectoral collaboration – defined as 'multiple sectors and stakeholders intentionally coming together and collaborating in a managed process to achieve shared outcomes' (Kuruvilla *et al.* 2018) - is a prerequisite for both city resilience and health, including mosquito-borne disease control (Gimenez *et al.* 2016, World Health Organization 2017, Rasanathan *et al.* 2017, Therrien *et al.* 2017, Zhong and Fouque 2020, Rasanathan, 2021). Engagement of different stakeholders, including communities, during planning and implementation of resilience actions and mosquito-borne disease control programmes is one way to achieve this.

We use a case study methodology to explore the links between mosquito-borne diseases and city resilience in three cities, Chennai (India), Paynesville (Liberia) and Medellín (Colombia). These cities are members of the Resilient Cities Network (*R*-Cities), a network of 96 cities worldwide which aim to strengthen city resilience (Resilient Cities Network 2022) - approximately 45 R-Cities member cities are located in areas suitable for mosquito-borne diseases (Figure 1). Using document review and in-depth interviews to understand the context and the perspectives of resilience representatives, we draw out key findings and highlight recommendations for R-Cities member cities at risk of mosquito-borne diseases. While the research aims to support both city resilience and effective control of mosquito-borne diseases in R-Cities, the findings will be of relevance to cities suffering from mosquito-borne diseases worldwide.

Methods

Study design

A multi-site case study methodology was used to understand the intersection between mosquito-borne diseases and city resilience in the context of the *R*-

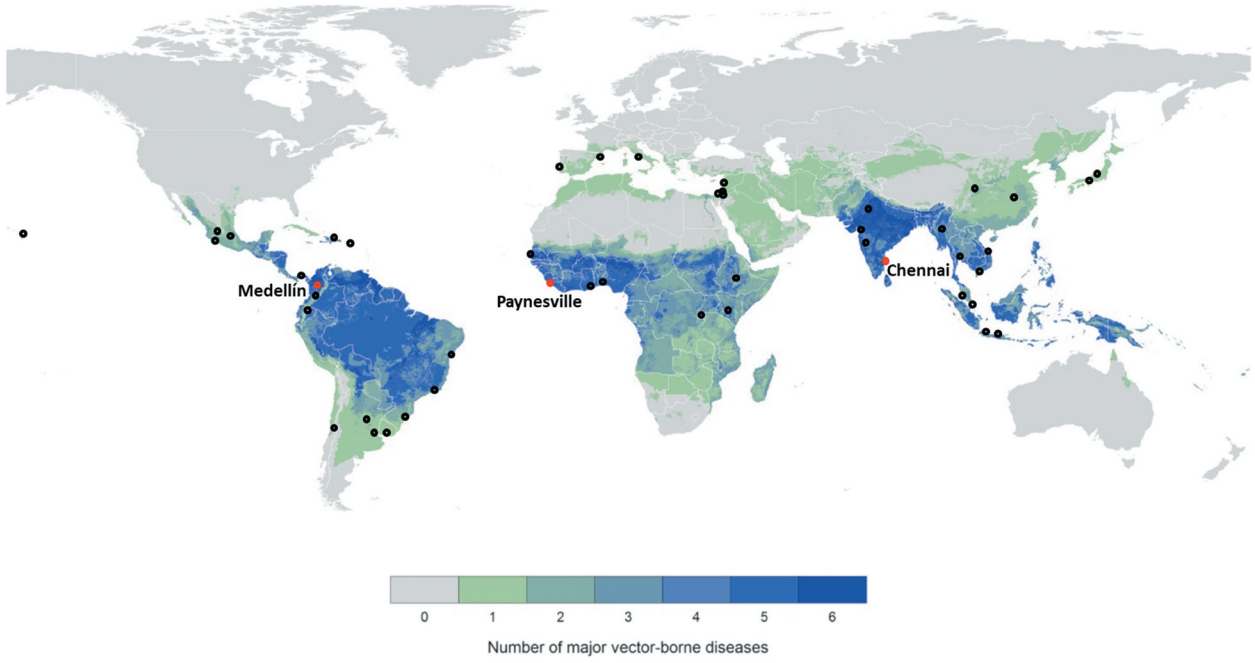

Figure 1. Resilient Cities Network member cities located in areas of vector-borne disease risk. Adapted from Golding *et al.* 2015. Case cities are highlighted in red.

Cities. A 'case' here refers to a particular *R*-Cities member city. Within cases, there was a focus on understanding the views of Chief Resilience Officers (CROs), individuals who have been appointed by cities to lead city resilience activities by working across government departments (including health) and with non-governmental actors.

Setting and Participants

Three cities were used as cases in the study: Chennai, Paynesville and Medellín. Cities were purposively selected based on geographic spread, likely willingness to participate, and varied mosquito-borne disease challenges. Recruitment for the interviews took place by email, whereby the *R*-Cities Global Director for Engagement and Knowledge (LL) contacted *R*-Cities Regional Directors for Africa, Asia and Latin America and the Caribbean, who then contacted city CROs (nine in total) they identified as experiencing challenges with mosquito-borne diseases. Interested CROs (and/or their representatives) were invited to contact the study leads (BRE and ALW). Cases are described in detail under 'Case summaries'. Study participants included the CROs of Chennai and Paynesville, and the Advisor to the Office of the Director of Administrative Planning in Medellín, who is a key member of the city's resilience team. Participants were all in positions of authority in their respective cities, with extensive knowledge regarding their local context and resilience initiatives. They did not, however, have significant expertise regarding mosquito-borne disease burden, risk factors and control. The Medellín interview was also attended by the Coordinator of the Vector Program of the Secretary of Health in Medellín who is not a core member of the resilience team but has expertise in mosquito-borne diseases.

Data collection

Document review

Documents mapping city resilience strategies and other relevant documents were reviewed to explore the relationship between city resilience and mosquito-borne diseases in the selected *R*-Cities. Documents were identified through literature searches and via interviewees, and included policy documents, academic literature, online resources and news articles (Appendix 1).

In-Depth interviews

A semi-structured interview guide was developed (Appendix 2), with questions based on a conceptual framework for case studies of multi-sectoral collaboration (Figure 2, adapted from (Partnership for Maternal Newborn and Child Health 2018)). The interview guide was adapted prior to each interview to elicit the most relevant information from participants. All interviews were conducted on Zoom. Interviews for Chennai and Paynesville lasted 1 hr 30 mins and were conducted in English. The Medellín interview lasted 2 hours and a translator was present to translate from English to Spanish and vice versa.

Analysis

Thematic analysis (Nowell *et al.* 2017) of interview transcripts and documents was performed using Nvivo 12, employing a mixed inductive and deductive approach. While an initial coding framework was developed based on the conceptual framework for case studies of multi-sectoral collaboration

Figure 2. Framework for case studies on multi-sectoral collaboration for health and sustainable development, adapted from Partnership for Maternal Newborn and Child Health 2018. Context describes the policy/political, environmental, epidemiological, historical, sociocultural, socioeconomic, legal and/or health system.

(Partnership for Maternal Newborn and Child Health 2018), BRE and ALW individually read transcripts and other documents and identified emerging themes which they incorporated into their coding frameworks. BRE and ALW met and discussed parallels and discrepancies between their coding frameworks and developed an integrated final coding framework. This framework contained the following parent nodes; (1) Challenge, context and stakeholders, (2) Planning action, (3) Implementation, (4) Monitoring, accountability and learning, (5) Looking forward. The codes were then applied to all transcript and document data by BRE, and coding was sense-checked by ALW. Data coded under (1), supplemented by other literature identified through searches, was used to construct a case summary of each city. Themes were identified through the charting process, whereby data is summarized by coding category – this stage represents the cross-case analysis. These themes are presented in the Results section.

Results

Case summaries

Chennai

Chennai (population 8.6 million (*Chennai City Population* 2022)) is the fourth most populous urban agglomeration in India and joined the *R*-Cities Network in 2014 as one of the second cohort of cities. Released in 2019, the Resilient Chennai Strategy (Resilient Chennai and Okapi Research & Advisory 2019) includes 86 interventions across five thematic areas; Healthy Urbanisation, Water Systems, Governance Ecosystem, Vulnerable Communities and Civic Engagement. Chennai's current CRO joined in 2017 and has a team of 5 members. The CRO interacts with the Greater Chennai Corporation (GCC), the civic body that governs Chennai.

Chennai's main resilience challenges include natural disasters such as flooding and drought, unplanned urbanisation which encroaches on natural ecosystems, and uncoordinated governance systems. The city experienced severe flooding in 2015, and then extreme drought in 2019. Chennai's water management issues are exacerbated by both climate change and unplanned development, which threatens the traditional *ery* system of waterbodies which ensure availability of water year-round and prevent flooding. Lack of effective solid waste segregation and recycling lead to waste being dumped onto marshland and other ecologically sensitive areas. Rapid urbanisation and uneven economic development have aggravated risks faced by vulnerable communities and around 30% of the population live in informal settlements, mostly alongside water bodies and transportation networks. Resettlement programmes have been problematic and often result in loss of livelihood and reduced access to education and healthcare facilities.

Malaria is endemic in Chennai, transmitted predominantly by *Anopheles stephensi* mosquitoes that lay their eggs in containers such as overhead water tanks (Kumar *et al.* 2014, Thomas *et al.* 2016). In 2021, 585 cases of malaria were reported in Chennai, accounting for 76% of cases in Tamil Nadu state (*Malaria incidence* 2021). Chennai has been part of the National Vector Borne Disease Control Programme – Urban Malaria Scheme since 1973, which focuses on removal of mosquito habitats (Messina *et al.* 2019), larviciding, and legislative measures (Sharma *et al.* 2014). Chennai has long-term, endemic circulation of dengue and epidemic chikungunya transmission (Rodríguez-Barraquer *et al.* 2015, Padmapriya *et al.* 2017). There were 6039 dengue cases and 8 dengue deaths (*Dengue Cases* 2021) and 153 chikungunya cases (*Chikungunya Fever Cases* 2021) reported in Tamil Nadu state in 2021. In response to high dengue cases in 2021, over 3000 personnel were deployed to perform door-to-door checks for *Ae. aegypti* aquatic habitats and carry out insecticide fogging (The Times of India 2021).

Paynesville

Paynesville is a suburban city east of Monrovia, the capital of Liberia, and is a key contributor to Liberia's GDP. It is home to over 500,000 people, having undergone a period of rapid urbanisation at the end of the 14-year civil war in 2003. The CRO of Paynesville reports directly to the mayor of Paynesville City Corporation (PCC) and does not have a specific office or team. The PCC is responsible for municipal-related issues including solid waste management, illegal construction, and zoning. Paynesville's resilience activities focus on advising the mayor and working with existing projects due to extreme resource limitations. Paynesville joined the *R*-Cities Network in 2016 and is developing a Resilience 'Roadmap' rather than a full Resilience Strategy, with a focus on solid waste management, improving economic opportunities, and increasing access to clean water.

Many of Paynesville's resilience challenges stem from a lack of effective basic services. For example, solid waste management is weak, with waste often being dumped, buried or burnt indiscriminately. This can block the flow of water in drainage channels and cause flooding during the rainy season. Solid waste management used to be outsourced to Monrovia but the PCC is now responsible, working alongside local businesses. The city also faces serious difficulties with water management, with poor sewage and drainage systems causing contamination of clean water. The informal settlements that comprise 80% of the city are not connected to the

national piped water supply (Resilient Cities Network 2019) leading to water storage in containers in and around the home, which are potential habitats for *Ae. aegypti* mosquitoes. Heavy rainfall also leads to the creation of aquatic habitats for malaria-transmitting *Anopheles* mosquitoes. Slums are often built on low lying land which can flood easily, a problem which is being exacerbated by climate change.

Liberia has a high burden of mosquito-borne diseases, with malaria and neglected tropical diseases such as lymphatic filariasis and onchocerciasis posing significant risks. Malaria transmission occurs year round and in Greater Monrovia malaria prevalence is 12% (USAID 2021). While there have been no reports of arboviral disease in Liberia to date, presence of the key vector *Ae. aegypti* and circulation of viruses such as dengue and chikungunya in the region suggest that these diseases may be going undiagnosed.

Medellín

Medellín is Colombia's second largest and most inequitable city, with a population of 2.4 million (Medellin 2022). One of the first cities to be included in the *R*-Cities Network in 2014, Medellín's Resilience Strategy was published in 2017 (Medellin Resiliente & Alcaldia de Medellin 2017). The Strategy is currently being updated and harmonized with the city's Development Plan, which supports the notion that holistic human development lies in fundamental rights and serving a range of basic needs. Resilience and urban transformation in Medellín pre-dates the city's involvement in *R*-Cities; these themes were already being considered in the city Development Plan released in 2004. The city's resilience team have a strong capacity for planning, coordination and evaluation of its projects and programmes.

Medellín's main resilience challenges include the deterioration of public safety, severe inequity, threats to management of land and natural resources, and lack of reliable data to inform decision-making processes. While significant progress has been made, the history of extreme violence linked to narcotics trafficking still has an influence on the city, and intolerance and social conflict continue to hinder development.

Dengue is endemic in Medellín with large outbreaks every few years (Ospina *et al.* 2010). Over the last 10 years, annual dengue incidence in Medellín has ranged from 161 to 745 cases per 100,000 inhabitants (Carabali *et al.* 2021) and the city faced an large outbreak in 2016 (Alvis-Guzmán *et al.* 2017). Between 2008 and 2017, 656 cases of Zika were reported in Medellín (Carabali *et al.* 2022), particularly impacting pregnant women and their children (Tirado *et al.* 2020). Colombia is one of the countries most affected by chikungunya in the Americas region, with a recent epidemic peaking in 2015 (Carabali *et al.* 2021); 724 cases of chikungunya were reported in Medellín between 2008 and 2017 (Carabali *et al.* 2022).

Framing the issue

Mosquito-borne diseases were not an explicit priority in the resilience plans or activities of any of the cities. In Chennai and Paynesville this probably reflects the fact that health is not the responsibility of the city. For example, in Chennai, prevention of mosquito-borne diseases and provision of health services is predominantly a state responsibility. Healthcare was also viewed as an overall strength in Chennai and was therefore considered less of a resilience priority.

> . . . we didn't look at health issues as a challenge at all in our resilience strategy because it came out as a strength for Chennai . . . we have some of the top hospital chains here . . . government hospitals [are] . . . very well run . . .
>
> *(CRO, Chennai)*

Nevertheless, CROs discussed resilience activities such as solid waste management, building regulations, and water management which can help to reduce mosquito-borne diseases, even if the links were not fully recognised.

> waste management is a major issue, making sure that still water isn't left unattended to, if it's not required . . . all of these actions, if put in place would have a health-related impact on the community . . . reducing the mortality rate of infants and children and adults as well.
>
> *(CRO, Paynesville)*

While mosquito-borne diseases were not considered explicitly as part of Medellín's resilience strategy, the city's resilience agenda places importance on health. Resilience, and the interconnectedness between the actions of different sectors, was well understood in Medellín, as was outlined in their successive and interlinked development plans.

> I do feel like each department is trying to implement what resilience is trying to achieve, but in different ways . . . that have common goals.
>
> *(Advisor to the Director of Administrative Planning, Medellín)*

Planning action

All cities identified resilience priorities, including those that may have impacts on mosquito-borne diseases, in a consultative way with stakeholders from different sectors to generate an integrated understanding of problems and co-ownership of the resilience strategy. For example, Paynesville's CRO interacted with government agencies in the health sector and non-health sector (e.g. Ministry

of Public Works, Environmental Protection Agency), local hospitals, schools, private stakeholders and communities via workshops and surveys to identify priorities and develop their Resilience Roadmap.

Despite this, maintaining inclusivity in planning is an ongoing challenge for the cities. In Chennai, limited stakeholder participation in planning has hindered representation of the poor and other marginalised groups, particularly residents of informal settlements, who face the greatest burden of resilience challenges relating to urbanisation, water crises, disasters, and city governance. Chennai's Resident Welfare Associations – non-governmental organizations that represent the interest of residents in a specific locality – predominantly act on behalf of the middle class. Furthermore, government consultations with the public are often poorly advertised or held in locations that are hard for many stakeholders to access, and are used for grievance redressal, rather than encouraging active participation in decision-making processes.

> . . . collective and participatory governance has not been sufficiently grounded in institutional structures and processes. It is often limited to aiding select government decision-making processes and is not integrated or mainstreamed as a planning tool. This creates mistrust and makes common citizens disinterested in city development programmes that are in fact meant for them.
>
> *(Resilience Strategy, Chennai)*

Community engagement

Community engagement formed an important part of implementing resilience initiatives across the three cities. In all cities, it was deemed important to work through existing community structures and engage community leaders to encourage community buy-in and effectively implement collaborations. In Chennai, each locality has a Resident Welfare Association that is registered to the GCC, with a president, a secretary, and a committee. Resident Welfare Association sub-committees are responsible for different thematic areas, including roads, water infrastructure and solid waste management. In Medellín, working alongside community structures and social leaders helps the authorities to access communities with security difficulties.

Engagement of communities in solid waste management was a common theme across cities. Although waste segregation is a challenge in Chennai, Resident Welfare Associations in a few locations segregate 100% of their waste due to active participation from residents. In Paynesville, community clean-ups are held on the first Saturday of each month, where at least one member of each household is expected to help clean their local area, for example by sweeping, collecting rubbish, and clearing drainage channels.

Print, visual and audio media, as well as social media (e.g. WhatsApp) were used to engage communities, while Chennai and Medellín also had specific mechanisms for citizens to report concerns. The Namma Chennai app assists residents to report civic issues such as potholes in roads and flooded stormwater drains, and to seek redressal by taking and uploading photographs. However, a civic engagement survey found that only 15% of respondents have or use the Namma Chennai app (Chennai Resilience Centre 2018). In Medellín, a similar system ('*Mercurio*') allows citizens to raise requests, complaints and suggestions. Information on mosquito-borne disease risk and control activities is communicated to citizens by disease experts in partnership with communication experts in Medellín, and the city plans to make greater use of social media to raise awareness and encourage communities to take action.

> [we plan to] make more intensive use of the tools provided by social networks through electronic means, to spread more information about the programme and have the community take more ownership of the development of control actions.
>
> *(Coordinator of the Vector Program, Medellín)*

Despite several successful community-based initiatives, all cities reported instances where a lack of community buy-in hindered implementation of resilience activities or mosquito-borne disease control interventions. The Chennai CRO highlighted residents' resistance to control measures such as covering potential aquatic habitats for mosquitoes around their homes, and strong opposition against attempts to bring in user fees for consumption-based water pricing. Similarly, in Paynesville relatively modest user fees for waste removal are unaffordable and therefore not supported by some residents.

> That's something that we're working on, trying to get the message out that clean communities are healthy communities . . . [but] people do not want to contribute necessarily to the costs of waste management . . . even if it's minimal, like $1 a month.
>
> *(CRO, Paynesville)*

Furthermore, reports of poor attendance at community meetings reflects in part a lack of citizen awareness and trust that they can make a difference in their city. In Chennai, citizens are perceived to view the government as solely responsible for dealing with all issues in the city and as such are quick to 'blame' the government when things go wrong. In Medellín, during periods of low incidence, mosquito-borne diseases are often considered by communities to be low-risk, leading to reduced community interest in disease control. Poor communication between government and citizens was also reported as a contributor to low community engagement.

> The Greater Chennai Corporation is so apprehensive of dealing with citizens that sometimes they do work in the middle of the night. People don't know what's

> happening so by the time you get up in the morning, something's already happened and done with. This is strange, because you should really be having a dialogue with citizens.
>
> *(CRO, Chennai)*

Governance and political support

Lack of continuity in governance posed a major barrier to the implementation and sustainability of resilience initiatives. Chennai's institutional structure was described as 'fragmented', characterised by frequent changes in leadership. For example, the Managing Director position at the Chennai Metropolitan Water Supply and Sewerage Board (CMWSSB) has been held by seven officials since 2011, while Indian Administrative Service (IAS) officials are frequently transferred to different portfolios (Resilient Chennai and Okapi Research & Advisory 2019).

> an IAS officer that comes in to run the water systems . . . can be moved out within a year or two years . . . somebody else comes in and doesn't necessarily build on what the other person has started.*(CRO, Chennai)*

In Chennai and Paynesville, problems with political alignment and coordination between city, state and central government were also reported. In Chennai, the predominance of para-statal agencies and state-level presence in urban decision-making posed limits on empowering local-level governance structures. It was deemed difficult to gain political support for resilience initiatives, and this support was thought to be influenced by the personal preferences of politicians rather than evidence. There was reported to be little coordination or collaboration between Paynesville and other towns and cities in Greater Monrovia. However, Medellín municipal government has political, administrative, and fiscal autonomy guaranteed by the Constitution, reflecting strong governance practices.

> We have not engaged in a lot of coordination activities with the rest of Greater Monrovia . . . Monrovia, because its [the] capital, gets the bulk of whatever project [money] is directed towards Greater Monrovia. So unfortunately, there's not a lot of collaboration to date.
>
> *(CRO, Paynesville)*

> There are no limitations in governance since the competencies are clear, the inter-institutional relations work and are effective between the national, departmental, and municipal levels.
>
> *(Coordinator of the Vector Program, Medellín)*

Financial and human resources

Financial and human resource constraints impacted the ability of cities to carry out resilience activities. This was most stark in Paynesville, where there is extremely limited financial support from the government and almost total reliance on donors to fund basic services and infrastructure development. Paynesville also suffers from weak revenue generation in that many donors deal with the central government and not municipal governments. Paynesville has, however, been able to leverage funding from UN Habitat and the Cities Alliance, who manage funds from the World Bank, the EU, the UK government, and others. A large proportion of the PCC budget is devoted to solid waste management.

> *'We started getting our equipment to be able to pick up waste . . . this is the first time the city is picking up their own waste in the past three years . . . we started with one truck, so now at least we have three trucks and one loader and another two skips'.*
>
> *(CRO, Paynesville)*

Medellín also faces difficulties with insufficient budget allocation and lack of human resources in the Department of Health for the mosquito-borne disease program. The city depends entirely on contractors to perform vector control actions, and limited financial resources have to be injected into control programs when epidemic peaks occur. Issues in the contracting process can result in gaps in vector surveillance and control.

> the personnel capacity in the Secretariat of health is low . . . we depend completely on contractors to perform operative actions . . . when there are interruptions in the contractual process, the city is left without the capacity to respond, running the risk that areas that were under control may present reinfestations of mosquitoes.
>
> *(Coordinator of the Vector Program, Medellín)*

Multi-Sectoral collaboration

Collaboration within and across sectors was a theme in all cities. For example, Paynesville and Medellín both collaborated with environmental health authorities to perform vector control operations, often in a targeted way in response to increased risk.

> [the] Environmental Health Department . . . liaises with the Ministry of Health, [which] has a county health officer . . . if we receive information that a particular community is dealing with an infestation of mosquitoes, we go with our Environmental Health team and they spray for mosquitoes . . . they can even spray chlorine just to clean waste.
>
> *(CRO, Paynesville)*

Both Chennai and Medellín collaborated with the education sector. In some schools in Chennai, children are taught about the environmental impacts of poor solid waste management with the hope that they can influence the behaviour of their families and communities. This builds upon the *Swachh Bharat* programme, initiated by the Government of India to eliminate open defecation and improve solid waste management, in which schools

are an integral partner (Swacch Bharat Mission 2022). In primary and secondary schools in Medellín, the Department of Health has established anti-dengue student committees who are mobilised to search for and eliminate aquatic habitats in their homes and schools. In addition, schools are designated as sentinel sites for mosquito trapping which supports assessment and communication of dengue risk across the city.

> . . . we have the trap network in different educational institutions . . . the people that work with us visit these institutions every week . . . [we] communicate with the institution directors and provide them with the risk information . . . we use these institutions as a reference place for the whole area.
>
> *(Coordinator of the Vector Program, Medellín)*

Chennai and Paynesville reported using public-private partnerships, particularly for solid waste management. Chennai has recently changed to a new provider with a focus on waste segregation, rather than payment by volume, in line with new legislation (Corporation of Chennai 2020). Waste segregation supports Chennai's focus on recycling and composting as resilience actions, the latter supporting urban farming initiatives to combat food insecurity. In Paynesville, the city's limited resources resulted in the engagement of the private sector to strengthen solid waste management.

> this is a one man business or two man business . . . they have mopeds, they've constructed a back for the moped like a pickup truck back . . . they pick up [waste] from house to house and they collect maybe $20 a month, or something like that . . . [it's] a community-based thing that we try as a city to work along with them to ensure that they're able to work.
>
> *(CRO, Paynesville)*

Regulations, byelaws, and enforcement

Cities have enacted regulations and byelaws related to urban development, which may impact mosquito-borne diseases. For example, the GCC have enacted the Solid Waste Management Rules, 2016 through their solid waste management byelaws, which could lead to reduced habitats for *Aedes* mosquitoes through prohibition of littering and legislating that waste is segregated at source (Corporation of Chennai 2020). These rules also imposed a ban on plastic bags, which was extended to a state-wide ban on single use plastics (Plastic Pollution Free Tamil Nadu Campaign 2022). In addition, amendments to the Tamil Nadu District Municipalities Act, 1920 mandate control of nuisance mosquitoes in pools and other containers (*The Tamil Nadu District Municipalities Act 1920*).

However, enforcement of regulations is weak and results in problems such as poorly managed waste disposal, pollution, water body encroachment and groundwater over-extraction in Chennai. There are planning rules which state that new real estate developments should follow state requirements for stormwater drains, sewage drains and open areas to absorb rainfall, but these are not enforced. Similar themes arose in Medellín around revision of existing regulations and problems of enforcement. It was suggested that introducing incentives could increase citizen compliance with regulations.

> Citizens are often indifferent to solid waste in part because they do not pay for it. Introducing positive and negative incentives will be one effective way to induce compliance to proper management such as source segregation at home, work or on the streets.
>
> *(Resilience Strategy, Chennai)*

Discussion

Our analysis shows that while mosquito-borne diseases are not considered explicitly or prioritised as a resilience challenge in the three case cities, cities are already carrying out actions that can be harnessed to integrate mosquito-borne disease control into resilience planning and implementation. The *R*-Cities framing of urban resilience means that CROs and other resilience actors inherently look at cities as systems and understand the need for cross-disciplinary thinking and action, making them extremely well-placed to plan for mosquito-borne disease prevention. Here we discuss the main findings from this analysis and use this to propose four key recommendations for *R*-Cities looking to integrate mosquito-borne disease control into their resilience approach (Box 1).

Despite mosquito-borne diseases such as dengue posing a significant shock to cities throughout the tropics, there is currently little focus on mosquito-borne diseases in City Resilience Strategies. This is despite inclusion of 'minimal human vulnerability' and 'effective safeguards to human health and life' as goals in the Rockefeller Foundation/Arup City Resilience Framework, the framework that guided development of City Resilience Strategies (Arup and Rockefeller Foundation 2015). Our analysis sheds light on potential reasons for this; in some cases, health is seen as a strength and therefore not considered a priority, while in others mosquito-borne diseases are viewed solely as the responsibility of the health system. While resource constraints understandably restrict what *R*-Cities can prioritise as their resilience foci, this restricted view of 'health' reflects siloed-thinking which is sometimes common in urban governance, and points to fragmented institutional structures (Bai *et al.* 2016). Working across sectors in support of health has been long championed in health policy (World Health Organization 2008, WHO and the Government of South Australia 2010, Tang *et al.* 2014), but consideration of health and wellbeing has been slower to filter back into built environment policy.

This is changing, however, for example mosquito-borne diseases are mentioned in the New Urban Agenda (Tang 2017), and in 2020 a UN-Habitat sourcebook for integrating health in urban and territorial planning was launched (UN-Habitat and World Health Organization 2020). Furthermore, initiatives like 'Healthy Cities Healthy People' are advocating for better integration of mosquito-borne diseases and neglected-tropical diseases into urban development, focusing on mayors and local government leaders as the best actors to catalyse multi-sectoral and community-based efforts (Healthy Cities Healthy People 2021). The COVID-19 pandemic has brought health emergency planning to the forefront of urban agendas, with recognition of the key role of cities in national emergency preparedness and planning activities (Sharifi and Khavarian-Garmsir 2020, World Health Organization 2021a, 2021b). To further raise awareness of health (and mosquito-borne diseases specifically) in resilience planning, the *R*-Cities Network could consider appointing a specific lead for health, who could act to bolster the profile of health as part of resilience, identify where mosquito-borne diseases fall thematically into existing activities, and to highlight prioritisation for funding. Furthermore, building capacity of internal and external bodies, already working with cities on complex systems issues such as circular economy, to better understand what their work means for mosquito-borne diseases could help to support cities to integrate these considerations into ongoing projects.

Case cities leveraged multi-sectoral collaborations to different extents, but all recognised the importance of collaboration and intend to build new collaborations to strengthen service provision, improve communication, and exchange knowledge. Collaboration between sectors in Medellín was particularly strong, as demonstrated by the continued investment in relationships with the education, health and private sectors. A new circular economy initiative for solid waste management in Medellín, which will focus on tyre disposal and management of critical waste points and recycling warehouses (*Medellin Towards a Circular Economy* 2017), exemplifies the potential co-benefits between resilience activities and mosquito-borne disease control. Tyres filled with rainwater are a common habitat for *Ae. aegypti* mosquitoes to lay their eggs (Rubio *et al.* 2011, Bennett *et al.* 2019). Studies from elsewhere in Latin America have shown that recycling programmes can contribute to control of *Ae. aegypti*; for example, management of disused tyres in Chapecó, Brazil was shown to have a positive public health impact (Lutinski *et al.* 2018), while in Merida, Mexico, a recycling programme was found to reduce *Ae. aegypti* infestation and had strong community support (Barrera-Pérez *et al.* 2015). Investment in solid waste management can have multiple health benefits in addition to reductions in mosquito-borne diseases, including reducing risk of other infectious diseases, chronic diseases, injury and acute poisoning (Alabaster 2016, Ziraba *et al.* 2016).

However, moving beyond a collaboration model towards a 'systems approach' (Bai *et al.* 2016) to urban research and practice will be critical if the systemic interactions between health and factors such as urban planning, design, sanitation, and environment are to be understood and sustainable health outcomes achieved (Bai *et al.* 2012). The systems approach can help to reveal unrecognized opportunities to maximize co-benefits, identify unintended consequences and guide management of inevitable trade-offs (Bai *et al.* 2016). The approach supports preventative rather than remedial action and highlights the need to think explicitly about suites of linked responses rather than singular 'silver bullets'. This point is also pertinent to control of mosquito-borne diseases, which has been dependent on insecticide-based vector control, often applied as monotherapy, for decades (Wilson *et al.* 2020). Today, there is increasing advocacy for utilising a range of insecticide and non – insecticide-based approaches in a locally tailored manner for more effective and sustainable vector control, a vision which could be integrated with a systems approach to address broader health challenges in cities.

Community engagement was recognised as important for resilience planning and implementation across cities, and there is strong potential here for linking and investigating co-benefits with mosquito-borne disease control. People are more likely to support mosquito-borne disease control policies and adopt preventative measures when they are involved in their development and implementation (Alabaster 2016), and with awareness and understanding, citizens can become empowered to take responsibility for resilience activities. However, they often need support from the other entities to carry out these activities. For example, more Resident Welfare Associations in Chennai could segregate their waste with active participation from residents if they had more technical and political support from the GCC. Engagement with educational establishments was a strength in Medellín and Chennai and could be leveraged further to support mosquito-borne disease control. For example, the Chennai Resilience Strategy includes a specific aim to introduce community service in school curricula. Proposed activities including campaigning for water conservation and street cleaning could have significant potential co-benefits for mosquito-borne disease control. Schools are pivotal in development of civic skills, knowledge and attitudes, and children can be effective agents of behaviour change in their families and communities. Previous studies have shown that school health education programs can be effective in changing knowledge and practices around mosquito-borne diseases (LaBeaud *et al.* 2009, Deepthi *et al.* 2014, Swain *et al.* 2019).

While all cities identified resilience priorities in a consultative way, increasing inclusivity in planning was flagged as a priority issue. The value of citizen participation has been increasingly promoted by governments, academics and donor agencies over recent decades, however there is concern, as highlighted in Chennai, that disadvantaged groups are left out of planning processes (Horn *et al.* 2018). Resilience teams should aim to mainstream participatory planning and provide space for bottom-up, citizen-led approaches to urban planning, to ensure that citizens are playing a key role in shaping resilience initiatives. Particular emphasis should be placed on engaging those living and working in informal settlements who face significant challenges, including a heavier burden of mosquito-borne diseases (Carabali *et al.* 2022). Priority issues that may be raised by informal settlement residents during planning processes, such as unreliable water supply, inadequate solid waste management or inadequate housing in particular areas of a city, if addressed will have mutually beneficial impacts on citizens' quality of life and on mosquito-borne disease risk. Where more traditional mosquito-borne disease interventions are required, for example indoor-residual spraying, involving citizens in decision-making over when, how and by whom this service is provided will help to increase adherence and overall effectiveness (Gunn *et al.* 2018). Furthermore, strengthening the role of civil society can help to hold governments to account during periods of political flux or personnel changes.

BOX 1. Key recommendations for *R*-Cities looking to integrate mosquito-borne disease control into their resilience approach.

1. **Raise awareness of the links between city resilience and mosquito-borne diseases** – provide training and build capacity of CROs, resilience teams and related institutions (e.g. those working on circular economy) regarding mosquito-borne diseases. Consider appointing an *R*-Cities Network health lead to support integration of health (including mosquito-borne diseases) into existing resilience work. Establish links between *R*-Cities Network and other initiatives working on health in urban settings e.g. Healthy Cities Healthy People to share expertise.
2. **Develop multi-sectoral collaborations with co-benefits for mosquito-borne disease control** – identify collaborations which can simultaneously address multiple challenges, for example collaborating with the waste sector through public-private partnerships to reduce mosquito habitats and environmental impact.
3. **Increase inclusivity in urban planning to protect vulnerable groups** – prioritise inclusion of marginalised groups, particularly those living and working in informal settlements. These groups often face the highest burden of mosquito-borne diseases, have the greatest awareness of the impacts of poor urban planning, and have problematic access to services such as water provision and solid waste management.
4. **Engage with communities to implement mosquito-borne disease control/resilience initiatives** – involve citizens in the development of initiatives and encourage them to take responsibility for actions in their communities. Build trust and keep communities informed about activities through regular meetings, social media, links with community health committees/community health workers and through educational establishments. Provide adequate support to ensure sustainability of these initiatives.

The case study approach was used in this study as it enables investigation of a contemporary phenomenon within its real-life context. The strengths of the case study approach include influential contextual factors becoming part of the focus of inquiry, consideration of relationships between actors and agencies, and utility in both generating information *for* policy development and analysing policy development (Yin 2003). However, the approach has sometimes been criticised for lack of scientific rigour and limited potential for generalizability (Crowe *et al.* 2011). As much of the data presented in this study is qualitative – derived from the recollections and opinions of the interviewees – some information may have been misremembered or miscommunicated. Statements have been member-checked and fact-checked to mitigate this as far as possible. Furthermore, some of the CROs expressed concern that they were not specialists on mosquito-borne diseases and seemed unconfident in discussing an unfamiliar subject. While we explained that this diversity of understanding in CROs was one of the points of interest for the research, CRO responses to questions may have been impacted by their perceived lack of expertise. In addition, from a group of nine cities which were invited to participate in the study, Chennai, Paynesville and Medellín self-selected to participate which may have influenced our findings. Finally, in Medellín the CRO was not available to interview and instead we spoke to the Advisor to the Office of the Director of Administrative Planning and the Coordinator of the Vector Program of the Ministry of Health in Medellín. Therefore, we gained a much more detailed understanding of the mosquito-borne disease control programme in Medellín in contrast to the other two cities.

Conclusion

Resilience is a multi-faceted concept and given the complex, dynamic nature of urban settings and limited resources, it is inevitable that *R*-Cities must choose specific aspects of resilience to focus on in their strategies. While mosquito-borne diseases could be considered as just one of the many challenges faced by cities, their control is integrally linked to a range of economic, social and environmental processes which are addressed in resilience planning. Furthermore, many of the resilience activities that cities are already doing

have co-benefits for mosquito-borne disease control or could be enhanced to realise this potential. Linking mosquito-borne diseases and city resilience is therefore likely to be an efficient, cost-effective, and achievable means of reducing mosquito-borne disease burden in cities.

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MHJ, CILV and CAVR are affiliated with ACI Medellín, KM with the Chennai Resilience Centre, RARO with the Secretary of Health, Medellín, CASO with the Administrative Planning Department of Medellín, BTB with the Paynesville City Corporation and LL with the Resilient Cities Network. BRE, TCL, KO and ALW have declared no competing interests exist.

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Notes on contributor

Beatrice R Egid is a PhD student in Global Health at the Liverpool School of Tropical Medicine, who uses mixed-methods approaches in her research to understand vector-borne diseases in urban environments. For this research project, she worked with her PhD supervisor Anne Wilson, an infectious disease epidemiologist, to bring together representatives from the Resilient Cities Network (Krishna Mohan, Bindu Taylor-Brewer, Carlos Alberto Sarria Ocampo, Lina Liakou, Marcela Herrera Jaramillo, Clara Isabel Villegas, Carlos Andrés Villarreal Restrepo), vector control actors (Raul Alberto Rojo Ospina), international public health researchers (Kim Ozano) and urbanists (Thomas C Lindsay).

ORCID

Beatrice R Egid http://orcid.org/0000-0001-8206-8903

Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Ethics

This study received approval from the Research Ethics Committee at LSTM (20-086) in November 2020. Written informed consent was obtained from all interview participants.

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Appendix 1. Documents included in case summaries

City	Policy documents	Academic papers	Online resources/news articles
Chennai	Resilient Chennai and Okapi Research & Advisory. *Resilient Chennai Strategy*. 2019 Resilient Chennai. *Preliminary Resilience Assessment*. 2018. Resilient Chennai, CityWorks, Okapi Research & Advisory. *Discovery Area Report – Civic Engagement*. 2019. Resilient Chennai and Okapi Research & Advisory. *Discovery Area Report – Informal Settlements, Vulnerable and Low Income Groups*. 2019. Resilient Chennai and Okapi Research & Advisory. *Discovery Area Report – Chennai's Water System*. 2019. National Vector Borne Disease Control Programme. *Compendium on entomological surveillance and vector control in India*. 2016.	Thomas, S., *et al*., *Overhead tank is the potential breeding habitat of Anopheles stephensi in an urban transmission setting of Chennai, India*. *Malar. J.,* 2016. **15**(1): p. 274. Kumar, D.S., *et al*., Spatial trend, environmental and socioeconomic factors associated with malaria prevalence in Chennai. Malar. J., 2014. **13**(1): p. 1-9. Padmapriya, P., *et al*., Dengue scenario: Chennai perspective – a six-year study (2009-2014). *Arch. Virol.,* 2017. **162**(1): p. 273-279. Rodríguez-Barraquer, I., *et al*., The Hidden Burden of Dengue and Chikungunya in Chennai, India. *PLoS Negl. Trop. Dis*., 2015. **9**(7): p. e0003906. Sharma, S., *et al*., Urban malaria scheme – past, present and future. *J. Commun. Dis.,* 2014. **46**(2): p. 77-84	*Chennai City Population 2011-2022*. [22/03/2022]; Available from: https://www.census2011.co.in/census/city/463-chennai.html. *Malaria incidence rural and urban areas of Tamil Nadu*. [08/12/2021]; Available from: https://tnhealth.tn.gov.in/tngovin/dph/dphdbmal.php. *Dengue Cases and Deaths in Tamil Nadu* [08/12/2021]; Available from: https://tnhealth.tn.gov.in/tngovin/dph/dphdbdengue.php. *Chikungunya Fever Cases in Tamil Nadu*. [08/12/2021]; Available from: https://tnhealth.tn.gov.in/tngovin/dph/dphdbchicken.php. The Times of India. *Health minister Ma Subramanian inspects dengue control measures as cases rise in Chennai*. 2021 [08/11/2021]; Available from: https://timesofindia.indiatimes.com/city/chennai/health-minister-ma-subramanian-inspects-dengue-control-measures-as-cases-rise-in-chennai/articleshow/86770836.cms. The Times of India. *As malaria, and other mosquito-borne diseases spread, Tamil Nadu feels bite*. 2018 [05/11/2021]. Available from: https://timesofindia.indiatimes.com/city/chennai/as-malaria-and-other-mosquito-bornediseases-spread-tamil-nadu-feels-bite/articleshow/64212710.cms The Hindu. *A year into the plastic ban, Tamil Nadu still struggles to kick the habit*. 2020 [07/11/2021]. Available from: https://www.thehindu.com/news/national/tamil-nadu/plastics-down-but-not-out/article30422345.ece
Paynesville	Resilient Cities Network, *Resilient Cities, Resilient Lives: Learning from the 100RC Network*. 2019. Liberia Ministry of Health National Malaria Control Program. *Malaria Communication Strategy 2016-2020*. 2016. Republic of Liberia Ministry of Health and Social Welfare. *National Health and Social Welfare Policy and Plan 2011-2021*. 2011.		USAID. *Liberia Factsheet PMI*. 2021; Available from: https://www.usaid.gov/sites/default/files/documents/Health_Activity_Fact_Sheet_Presidents_Malaria_Initiative.pdf. Platforms for Dialogue and Peace. *Frameworks for assessing resilience: Liberia Country Note*. 2015. Available from: http://www.interpeace.org/wp-content/uploads/2015/05/2015_05_01_FAR_Excutive_Summary_Liberia.pdf Front Page Africa. *Union of Liberian Associations in the Americas, Paynesville City Corporation launch solid waste management project*. 2022 [20/06/2022]. Available from: https://frontpageafricaonline.com/environment/union-of-liberian-associations-in-the-americas-paynesville-city-corporation-launch-solid-waste-management-project/
Medellín	Medellín Resiliente & Alcaldia de Medellín. *Resilient Medellín: a strategy for our future*. 2017. Alcadia de Medellín. *Proyecto de Acuerdo: Plan de Desarrollo Medellín Futuro 2020-2023*. 2020. Alcadia de Medellín. *Plan de Desarrollo 2016-2019, Medellín cuenta con vos*. 2016.	Ospina, M.C., Diaz, F.J., and Osorio, J.E., *Prolonged co-circulation of two distinct Dengue virus Type 3 lineages in the hyperendemic area of Medellín, Colombia*. Am. J. Trop. Med. Hyg., 2010. **83**(3): p. 672-678. Carabali, M., *et al*., *Assessing the reporting of Dengue, Chikungunya and Zika to the National Surveillance System in Colombia from 2014-2017: A Capture-recapture analysis accounting for misclassification of arboviral diagnostics*. PLoS Negl. Trop. Dis., 2021. **15**(2): p. e0009014. Tirado, V., *et al*., *Women's reluctance for pregnancy: Experiences and perceptions of Zika virus in Medellín, Colombia*. Int. J. Gynaecol. Obstet., 2020. **148**(S2): p. 36-44.	*Medellín, Antioquia population*. [30/04/2022]; Available from: https://www.citypopulation.de/en/colombia/antioquia/medell%C3%ADn/05001000__medell%C3%ADn/. World Bank Blogs. *How is Medellín a model of urban transformation and social resilience?* 2017. Available from: https://blogs.worldbank.org/sustainablecities/how-Medellín-model-urban-transformation-and-social-resilience

Appendix 2. Semi-structured interview guide

Establishing rapport

Can you tell me a bit about your experience as a CRO so far?

(a) How long have you been a CRO here?
(b) How did you come to take up this position?
(c) What do you enjoy about it?
(d) What aspects do you find difficult?

PROGRAMME DESCRIPTION

Confirm anything not clear from document review

CONTEXT, CHALLENGE AND STAKEHOLDERS

Context	Confirm anything not clear from document review
Stakeholders	Confirm anything not clear from document review
Challenge	• What are the main infectious diseases, including VBDs, of concern in your city? • Are there particular problems with VBDs in some areas of the city compared to others? Why is this? • How do you receive information on VBDs? • How do you share information/interact/engage with health/environment/other actors on the topic of VBDs?
FRAMING THE ISSUE AND PLANNING ACTION	
Awareness and prioritisation	• What is the most important shock/stress your city is facing at the moment? How are you managing this? • What is your city's main focus with respect to resilience? • To what extent do you perceive VBDs as an acute shock? • How are VBDs prioritised in comparison to other shocks and stresses? Has this changed in light of COVID-19? If so, how? • How do you think city resilience impacts VBD? What, in your opinion, is the main route by which this happens? • Thinking back to outbreak [disease and year for particular city], how could city resilience have prevented it or led to a better outcome?
Planning action	• What were the methods and rationale for the specific themes outlined in your city resilience plan? How did you come to this consensus? • What sectors were represented during formulation of the city resilience strategy? Were health/VBD actors present?
IMPLEMENTATION	
Implementation	(a) How are city resilience policies implemented and by who? (b) How do you plan/coordinate different sectoral actors in support of city resilience? (c) What strategies/practices have been put in place to support VBD prevention and control? Who is responsible? (d) Are there policies/practices implemented in your city that have had negative impacts on VBDs? Can you give an example? Are there data supporting this? (e) What other resilience activities might be mutually beneficial for VBD control?
Factors affecting collaboration	(a) What role do different sectors (e.g. communities, civil society, private sector) play in support of VBD prevention/control in your city? Can you give me an example? (b) How are policies implemented or not within informal settlements? (c) Thinking about the specific example given above: (d) Did any barriers to collaboration emerge? How were they overcome? (e) Where collaboration was successful, what facilitated this?
Limitations to power	• To what extent does your city have the power/capacity/resources to prevent/control infectious diseases/VBDs within city limits? • How much control do you have over the implementation and integration of VBD management into your city resilience strategy? • What are the limitations to this? • Are there limitations in terms of city vs national governance? • What supports this process in your city?
MONITORING, ACCOUNTABILITY, LEARNING, RESULTS	
Monitoring, results, accountability	• How are you measuring progress in achieving city resilience? Is progress against VBDs one of the indicators? • Are you seeing results of city resilience against VBDs? Can you give an example? • How does accountability work across sectors and levels within the city?
Learning	• What do you see as main challenges to more effective prevention and control of infectious diseases and VBDs? • What do you think could be done differently regarding VDBs in your city? • What do you need to be able to address VBDs and other infectious diseases through city resilience? • How can the VBD community best support your work? • What recommendations would you give for other cities wanting to become more resilient against VBDs?