


## Article

# Urban Climate Justice, Human Health, and Citizen Science in Nairobi's Informal Settlements

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**Abstract:** Urban informal settlements or slums are among the most vulnerable places to climate-change-related health risks. Yet, little data exist documenting environmental and human health vulnerabilities in slums or how to move research to action. Citizen science, where residents co-define research objectives with professionals, collect and analyze data, and help translate findings into ameliorative actions, can help fill data gaps and contribute to more locally relevant climate justice interventions. This paper highlights a citizen-science, climate justice planning process in the Mukuru informal settlement of Nairobi, Kenya. We describe how residents, non-governmental organizations and academics partnered to co-create data-gathering processes and generated evidence to inform an integrated, climate justice strategy called the Mukuru Special Planning Area, Integrated Development Plan. The citizen science processes revealed that <1% of residents had access to a private in-home toilet, and 37% lacked regular access to safe and affordable drinking water. We found that 42% of households were subject to regular flooding, 39% reported fair or poor health, and 40% reported a child in the household was stunted. These and other data were used in a community planning process where thousands of residents co-designed improvement and climate change adaptation strategies, such as flood mitigation, formalizing roads and pathways with drainage, and a water and sanitation infrastructure plan for all. We describe the participatory processes used by citizen scientists to generate data and move evidence into immediate actions to protect human health and a draft a long-range, climate justice strategy. The processes used to create the Mukuru Special Planning Area redevelopment plan suggest that participatory, citizen-led urban science can inform local efforts for health equity and global goals of climate justice.

**Keywords:** climate change; informal settlements; citizen science; public health; Nairobi



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## 1. Introduction

### 1.1. Informal Settlements and Climate Justice

Urban informal settlements, or slums, are amongst the most vulnerable places to climate-change-related disasters and health risks. Informal settlements are self-planned and constructed communities. The UN defines and measures 'slum populations' based on indicators of housing conditions and provision for water and sanitation, whereas 'informal settlements' are areas outside of official land registration, building codes, and/or planning legislation [1]. Definitions of urban 'slum' or informal communities remain problematic and pejorative, which often gives rise to unclear or limited evidence about the environmental and health risks they face [2]. It can also be difficult to conduct scientific assessments in urban informal settlements and with residents, since they may have good reason to not trust outside researchers, may have been exploited by professionals in the past, and they may be physically and socially hard to access groups and areas [3]. Furthermore, the local knowledge and expertise residents often hold about how to survive under extremely harsh

and vulnerable conditions is too frequently ignored in city and national climate adaptation planning [4]. The 2022 Intergovernmental Panel on Climate Change, 6th Assessment, Chapter 6, made note of the detriments of ignoring local knowledge for both climate science and adaptation planning, emphasizing that including the knowledge of those living in urban informal settlements is crucial for achieving climate justice [5]. In this paper, we review how slum dwellers in Nairobi, Kenya, acted as ‘street scientists’ to help diagnose the environmental health risks they faced, co-created solutions using these data, and integrated these proposed interventions into a broader climate justice and slum upgrading plan [6].

In Nairobi, Kenya, approximately 60–70% of the total population lives in informal settlements, making understanding the risks facing these areas and the populations living there a critical social justice, urban science, and climate adaptation issue [7]. In this paper, we focus on one of these settlements, Mukuru, and the climate-change-related environmental health vulnerabilities it faces. We suggest that Mukuru and similar urban informal settlements experience everyday overlooked environmental, human health, and social inequities that are contributing to climate injustice [8,9]. We highlight how a participatory, citizen science in-the-streets, action research process that involved Mukuru residents, non-governmental organizations, and academic partners contributed to new scientific understandings of health risks and offered evidence for urgent action that formed a unique climate justice adaptation plan for Mukuru called the Special Planning Area Integrated Development Plan [10]. The process was organized by the non-governmental organizations Muungano wa Wanivijiji—the federation of the urban poor in Kenya—along with their sister NGOs, Akiba Mashinani Trust (AMT) and Shack Dwellers International—Kenya.

Climate justice is both a social equity concept and practical process for action-research [11]. First, climate justice acknowledges that there is a global to local ‘climate gap’, or the notion that the impacts of an altered climate are disproportionately affecting groups that were not responsible for a majority of the polluting emissions or damages to ecosystems, but these same groups are especially vulnerable to the effects of a changing climate [12]. Urban climate injustice is, in part, about disproportionate burdens from new environmental, social, and human health risks but also about how existing vulnerabilities, from exposure to urban air pollution, to frequent flooding, to insecure housing, to precarious employment, are being made worse by a rapidly changing climate [13]. Urban climate justice includes calls for changing both the processes and outcomes of science and policy, such as ensuring previously ignored groups and places are included and that human rights concerns are given more weight in decision making than abstracted models of decontextualized, one-size-fits-all risk assessments [14]. Urban climate justice is also about the ways already vulnerable populations, such as indigenous peoples, women and youth, racial and ethnic minorities, and the landless urban poor, can engage in and make important contributions to mitigation and adaptation science policies [15].

Urban climate justice places renewed emphases on the embodiment of ‘everyday risks’ and how climate-change-induced vulnerabilities, such as heat/cold events, flooding, drought, food insecurity, and displacement, will exacerbate disease and death not just for the poor but for all groups [16]. In other words, urban climate justice for informal settlements means combining processes that meaningfully engage the most vulnerable groups and places in assessments and decision making with ensuring these same groups benefit from interventions and that actions also address the entire metropolitan region [17]. One implication of urban climate justice is that science policy will need to prioritize reducing poverty, disrupting colonial models of land and resource control, addressing the traumas from multi-generational environmental health vulnerabilities and/or redistributing resources as a form of ‘climate reparations’ [18]. In this paper, we explore how residents in one informal settlement partnered with NGOs and others to initially guarantee access to high quality basic services but expanded their partnership to gather new evidence and co-create an innovative climate justice plan [19].

### 1.2. Pursuing Climate Justice in Nairobi, Kenya

Mukuru is one of Nairobi's largest informal areas located 7km from the city's central business district and adjacent to the Makadara industrial zone. As we describe below, Mukuru was designated a Special Planning Area (SPA) in 2017 by the Nairobi City County Government, in large part due to citizen-science-gathered evidence showing its dangerous environmental conditions, entrenched poverty, resulting disease and health issues, and its susceptibility to climate-change-induced risks [20]. Under Kenya's Physical and Land Use Planning Act, a SPA may be declared by a County Government when (a) the area has unique development, natural resources, environmental potential, or challenges; (b) the area has been identified as suitable for intensive and specialized development activity; (c) the development of that area might have significant effect beyond that area's immediate locality; (d) the development of that area raises significant urban design and environmental challenges; or (e) the declaration is meant to guide the implementation of strategic national projects [21]. The processes used in Mukuru act as an important case for delivering urban climate justice under Kenya's National Climate Change Action Plan, 2018–2020, which included objectives such as reducing "risks to communities and infrastructure resulting from climate related disasters such as droughts and floods" and mainstreaming "climate change adaptation into the health sector and increase the resilience of human settlements," particularly slums [22]. In addition, Kenya's National Climate Adaptation Plan 2015–2030 calls for "conducting climate risk and vulnerability assessments of the informal sector" and enhancing "the adaptive capacity of the urban poor" [23]. Thus, we suggest that unpacking the processes used for the Mukuru SPA can help urban scientists and decision makers understand how to pursue urban climate justice in informal settlements [24].

In the sections that follow, we first describe the specific health and social vulnerabilities urban informal settlements face from climate change. Next, we describe the interdisciplinary, participatory action-research processes used in Mukuru. We describe methods of data gathering, interpretation and planning, all important aspects of justice-oriented "street science" [25]. Third, we offer some outcomes of the collaborative 'street science' processes, highlighting in these findings the overlap of environmental and social vulnerabilities with human health risks. Fourth, we briefly describe how the findings were used to generate upgrading and climate justice interventions and which interventions have been taken up, to date, by the Nairobi Metropolitan Services, the agency charged with community development. We suggest that both the democratic processes behind the scientific data and the resulting high quality of the findings combined to pressure the NMS into action. Finally, we reflect on these processes for urban climate justice science more generally, particularly as it pertains to eliminating vulnerabilities for those living in informal settlements.

### 1.3. Urban Climate Injustice and Informal Settlements

Urban environmental health issues related to climate change vulnerability are increasingly recognized as a crucial part of global health and climate justice [26]. As mentioned above, urban climate injustice is the recognition that there are risks from climate change, such as floods, heat events, droughts, and food shortages, that disproportionately impact already vulnerable populations and places, especially informal settlements [27]. Research has highlighted the specific climate-change-induced events that can exacerbate existing vulnerabilities, particularly those burdening the health and well-being of slum dwellers.

Heat events pose a major climate injustice for those living in urban informal settlements. Increased temperatures, particularly in East Africa, are expected to increase the presence of mosquito-vector-transmitted diseases such as malaria and dengue fever [28]. Warming global temperatures and related changes in weather patterns are suspected of increasing the spread and exposure to the *Aedes aegypti* mosquito in East Africa and Aedes-transmitted viruses, including dengue and yellow fever, chikungunya, Zika, West Nile, and Japanese encephalitis [29].

Heat events in urban informal settlements can combine with short-lived climate pollutants, such as black carbon (BC), and contribute to increased incidence of heart

attacks, asthma, and other cardiopulmonary diseases [30]. For example, recent studies found households in Nairobi's slums experienced elevated levels of particulate matter air pollution and that respiratory disease is a leading cause of morbidity and mortality for these same slum dwellers [31,32]. An increase in asthma has been correlated with local air pollution for residents of urban informal settlements [33].

Food insecurity is another climate injustice for urban slum dwellers. High food prices, lack of access to nutritionally rich foods, reliance on street food vending, and a lack of basic health and hygiene facilities are all contributing to nutrition deficits and food insecurity in urban slums [34]. The urban poor often pay higher costs for the same basic food staples than their middle- and upper-class neighbors, and typically expend 60% or more of their income on food [35]. When climate-induced events, such as droughts, alter food production and distribution, the urban poor can be disproportionately impacted.

Urban climate justice also emphasizes the gendered dimensions of risk and vulnerability [36]. Women and girls face existing burdens in urban slums since they are often responsible for water collection, caring for the sick, and cooking. Unsafe toilets can expose women to infections and sexual violence. Local pollution, particularly air pollution from cooking, may disproportionately impact women's respiratory health. Chronic infections and exposure to pollution can compromise the immune systems of women. A lack of primary health care and medication, along with the high costs of care, can make women living in informal settlements avoid care, which can contribute to more severe diseases over time. As primary caregivers, women are frequently forced to forgo education or skip meals to take care of children. These and other factors suggest that climate justice means ensuring women slum dwellers are made less vulnerable and interventions help them heal from existing burdens [37].

Localized flooding is another urban climate justice issue. Floods from increased frequency and severity of rain events, combined with slum populations being forced to live in flood-prone areas, can cause substantial physical damage to urban slum structures and displace residents. Flooding in urban slums can cause bacteria and toxic materials to contaminate water supplies, elevating the risk of water-borne, respiratory, and skin diseases [38]. Some urban health risks already associated with flooding in informal settlements include cholera, cryptosporidiosis, typhoid fever, diarrheal diseases, and leptospirosis [39]. The lack of solid waste collection in most urban slums results in street or surface drains being blocked, increasing the likelihood and severity of flooding. Flooding can also create breeding sites for mosquitoes that carry vector diseases such as dengue.

The adverse mental health impacts of experiencing multiple climate-change-related environmental risks, such as flooding, displacement, and related adverse health impacts, is an under-acknowledged injustice in urban informal settlements [40,41]. Repeated traumatic events contribute to anxiety, loss of sleep, and can act as a form of chronic or toxic stress. This toxic stress is known to adversely impact brain development, weaken the immune system, contribute to chronic illnesses such as heart disease and diabetes, and is a leading cause of pre-mature mortality for the urban poor [42,43].

Droughts can disproportionately impact the health of those dependent on intermittent access to clean water and electricity, especially where hydropower is a key energy source. Lack of access to clean water can increase the likelihood of water-borne diseases for the urban poor since they may be forced to use contaminated water. Drought can increase the cost of food for the urban poor, leading to skipping meals, reducing food/nutrition intake, and, in some cases, can lead to women slum dwellers being forced into sex work to feed their children or themselves [44]. Economic inequities are intricately linked to inequitable environmental conditions, as the urban poor typically spend about 10 times more of their income on water than the wealthy in the same city [45].

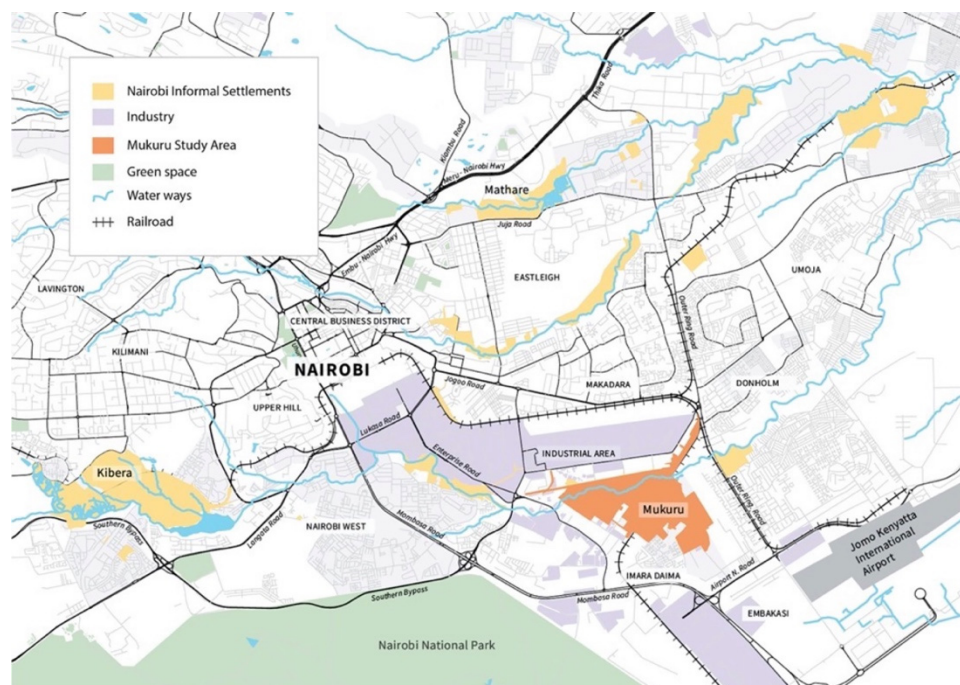
#### *1.4. Street Scientists and Climate Justice*

Community-based, participatory action research has been shown to be an important method for ensuring local residents can act as 'citizen scientists' and shape the research

that often underwrites public policy, especially those around health and environmental justice [46,47]. When urban citizen scientists have unique access to knowledge about how inequitable environmental exposures interact with economic, social, and racial/ethnic discrimination, we call this ‘street science’ [25]. In street science, the poor are not passive volunteers responding to the agendas of professional researchers, but rather, they define what information should be collected and use evidence to build power for influencing actions and policies to address the root causes of urban inequities. Some scholars have recently noted that ensuring disparate forms of expertise and citizen involvement in climate urbanism can avoid overly technocratic, colonial models of science policy often imposed on the poor, and instead promote greater justice in climate change planning [48,49]. Others have argued that citizen science processes can help uncover ignored data about climate risks, mitigation and adaptation strategies [50]. In the next section, we define the ‘street science’ methods used in Mukuru to understand health inequities and promote greater climate justice.

## 2. Methods: Pursing Climate Justice in the Mukuru Informal Settlement

The Mukuru informal settlement is comprised of three communities, Mukuru Kwa Njenga, Mukuru Kwa Reuben, and Viwandani, and thirty-one villages or neighborhoods. The community is in the Eastern industrial belt of Nairobi, bisected west–east by the Ngong River (Figure 1). The name Mukuru means “dump site” in Kiswahili, reflecting the history of waste dumping that persisted. Like many informal settlements in Nairobi, Mukuru’s built environment is characterized by a series of densely constructed 3 m × 3 m informal structures made of corrugated sheet metal and wood. The area is served by a network of unpaved roads, pathways, and informally constructed bridges that cross the Ngong River. A railway runs through the settlement along the border of Kwa Njenga and Kwa Reuben and acts as a common area for the dumping of solid, human, and industrial waste [51].



**Figure 1.** Map of Nairobi and the location of the Mukuru Informal Settlement.

### *Collaborative Research Methods*

The data presented here are the result of a partnership between community residents that are members of the Muungano Alliance; academic researchers from the University of California, Berkeley, the University of Nairobi, and Strathmore Universities; the Stockholm

Environment Institute; and Innovative Canadians for Change. Co-authors of this article were leaders in codesigning participatory research methods and the community planning processes. A mixed set of methods were employed over four and a half years (2015–2019) to document existing climate injustices and climate change risks. Not every process that was used during this time to understand climate and health risks are reported here, since some have been reported elsewhere [52,53]. Instead, we focus on a selected set of methods used to gather new data, interpret findings, and generate proposals for action.

First, a household enumeration was co-designed by the research teams and administered by resident teams that are part of the Muungano Alliance in 2017. The enumeration utilized surveyor training, question design, and data collection methods previous used by Shack Dwellers International and recommended by the Global Health Research Unit on Improving Health in Slums [54–56]. The enumeration collected data on household level living conditions including descriptive data on access to, quality of, and costs of sanitation, water, energy, education, and housing. The survey also asked about head-of household employment status, monthly cost for food, and other monthly household expenditures. The sampling frame included a random selection of 30 households in each of the 30 villages of Mukuru and reached 854 households representing 2682 community members.

Second, a health survey was co-designed and was administered in 2018 by community-based researchers and community health volunteers. This survey sampled 368 households, with at least 10 randomly selected households in each village. This survey asked about specific health symptoms experienced within the last 6 months, as well as about any household members with diagnosed diseases or disabilities within the same time period. The survey also asked about environmental health risks, or what living conditions community residents' thought might be contributing to adult and/or childhood illness. Finally, the survey asked respondents about barriers for accessing healthcare for adults and children, including location, costs, transportation, and other factors.

Third, spatial data were gathered by 'citizen scientists' who were trained by the Muungano Alliance to physically map assets and hazards in the community. Using satellite images on GPS tablets, resident teams walked the entire settlement from 2017 to 2019 to map the locations of all structures and facilities, including toilets, water points, dump sites, frequently flooded areas, and industrial activities. Citizen scientists also journaled their observations about air pollution, waste dumping, flooding locations, and other environmental risks, for which there were no previous data but were of concern to residents. The resulting maps were turned into geographic information systems (GIS) layers and shared in a community planning process. Qualitative data from citizen science journals and observations made by resident researchers were gathered in Swahili, and quotes were selected during participatory community workshops where both maps and descriptive data were shared by Muungano community leaders and research partners.

Fourth, specific environmental health data were gathered by citizen scientists based on perceived risks expressed by Mukuru women who organized to demand safer toilets and flooding mitigation after a series of cholera outbreaks in Mukuru [57]. One result was a plan to gather data on soil pollutants. Again, the Muungano Alliance organized workshops with residents and stakeholders to design a sampling plan. The plan created a 1000 m × 1000 m grid that was superimposed over Mukuru, and 30 separate grid cells were randomly selected. Three locations within each grid cell were selected based on ability to penetrate to subsoil and local knowledge about locations prone to frequent flooding, those in close proximity to industry, and near dumpsites. Community scientists used hand augers to collect 200 soil samples, with at least two samples taken at each location. At each sampling site, soil was collected at two depths: 0–20 cm for topsoil and 20–50 cm for subsoil.

Ten control samples were collected in other slums, including Dandora (the city's waste dump), Kibera, Mathare, and Korogocho. Samples were dried at a lab. Fourier transform mid-infrared spectroscopy was used to analyze the samples using Bruker Tensor 27 FTIR spectrometer. Samples were analyzed using mass spectroscopy to determine quantitative

values of heavy metals including: Arsenic, Cadmium, Chromium, Cobalt, Molybdenum, Nickel, and Lead. A Bruker Tracer 5i portable x-ray fluorescence (pXRF) instrument with Rhodium tube was used to collect total elemental concentrations data for Zinc.

Finally, a series of community focus group discussions (FGD) were held each month from August 2017 to June 2020 and facilitated by the Muungano Alliance. The Muungano Alliance was already established in Mukuru before the research began, and they organized residents through their over 400 village-level micro-savings groups that had hundreds of active members [51]. The Muungano Alliance built upon this network to ensure wider community participation by recruiting one representative from groups of 10 households, eventually designing a process that involved over 5000 residents. The co-authors of this article helped design and implement the participatory processes, as well as facilitated over 36 meetings. Resident representatives participated in public meetings in their geographic cluster, and separate meetings were held to discuss research and propose actions around five sectors: housing, commerce, and infrastructure; water, sanitation, and energy; environment and natural resources; education, youth affairs, and culture; and health services. All meeting minutes and decisions were posted on the Muungano Alliance web site (<https://www.muungano.net/mukuru-spa>, accessed on 23 February 2022). A 'synthesis' working group, comprising residents, NGOs, the Nairobi County Government, and university researchers reviewed the final reports generated from each sector noted above and used thematic mapping analyses to identify, summarize, and report key findings and recommendations [58].

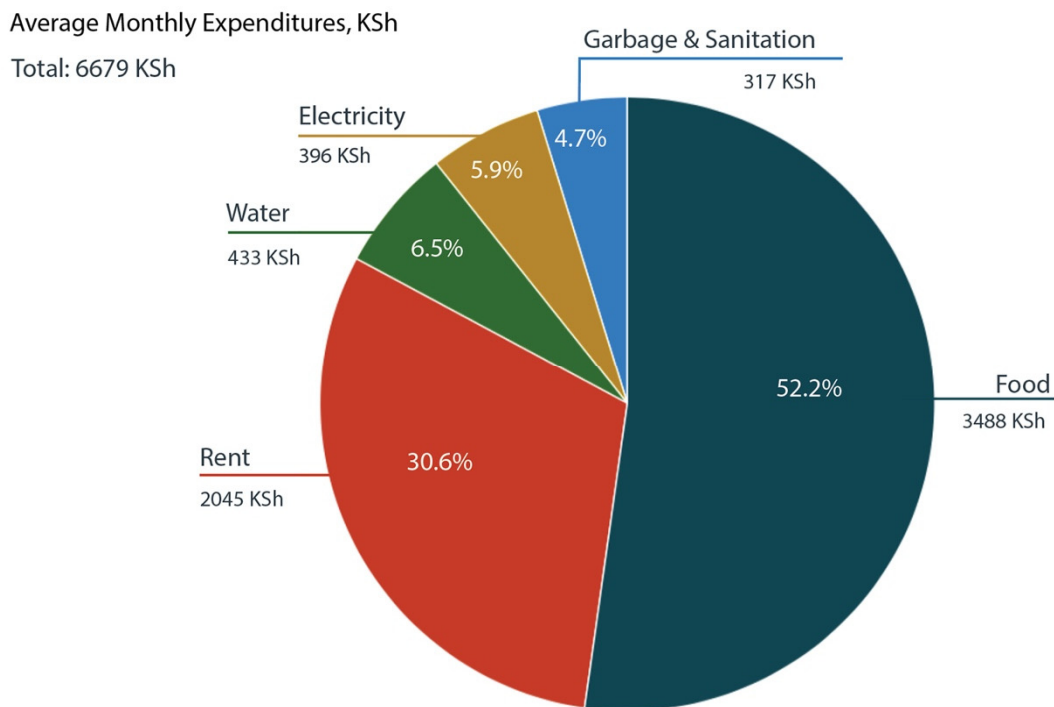
### 3. Findings: Existing Environmental Injustices in Mukuru

The Mukuru household enumeration estimated that there were 100,561 households, 300,000 people, on over 689 acres of land, or about 111,000 people per km<sup>2</sup>, while Nairobi has an average population density of about 600 people/ km<sup>2</sup>. The mean age in Mukuru is 27 years old and the settlement is about 60% male and 40% female. We found a median monthly income of KSh 12,000 (roughly USD 120). About 95% of residents are tenants who rent rooms in single or double-story shacks, typically built of mud and/or galvanized iron sheets. Mukuru's 182 unregulated informal schools serve over 42,000 children and youth.

The largest household monthly expenditure was food, which was over 50%, followed by rent and utilities (Figure 2). We found that 12% of respondents in Mukuru stated they lacked food on most days, 36% of respondents reported purchasing food from the neighborhood kiosk, and 73% stated that they purchase foodstuff for home consumption on a daily basis rather than weekly. We also found that 24% of households reported skipping meals or eating less due to lack of resources.

#### 3.1. Health Vulnerabilities

The high burden of food expenditures may explain our finding that over 40% of households reported that they had a child under 5 years old that was clinically diagnosed as having stunted growth and/or being severely underweight. This compares to about 26% in other slums of Nairobi [59]. We found that 10% of children ages 0–4 experienced diarrhea in the last 6 months compared to only 4% of individuals 5 years or older. Of our respondents, 42.7% of households report that their family visited a health facility more than once in the last 6 months, and 26.9% of households report that their family visited a health facility 3 or more times in the last 6 months. The most common reported symptoms and reasons for visits to a health facility in the last 6 months were cough, chest problems, diarrhea, fever, and headache. We found that 39% of households reported that their family is in poor or fair health and that 44.6% of households report that health issues have impacted a family member in the last 6 months.



**Figure 2.** Average Monthly Expenditures for Household in Mukuru, Nairobi (Kenyan Shillings—KSh).

### 3.2. Water and Sanitation Vulnerabilities

Households in Mukuru lack access to basic life-supporting services including adequate water and sanitation. We found that there was a total of 4469 working toilets and 1311 working water taps in all of Mukuru. Less than one percent of households had access to a private in-home toilet, and up to 547 households shared one public toilet, but the average was 22 households sharing one public toilet (about 67 people/toilet). Households paid on average KSh 218 per month for toilet use fees. Fifty percent of households in Mukuru reported using a communal pit latrine toilet that is not connected to a sewer or available at night, forcing residents to resort to defecating in a bucket or to open defecation (also known as a ‘flying toilet’). Of our respondents, 82% relied on shared yard-latrines, and only 52% lived within 50 m of a toilet facility.

We found that 37% of households lacked regular access to piped water, and only 1% of households had a private in-home functioning water source. Over 12% of respondents stated that they lacked enough water on ‘most days.’ Almost all water points in the settlement are yard-shared (Figure 3), with distances between water points ranging between 25 and 300 m. Residents reported spending an average of 55 min per trip to fetch potable water, including time spent walking or waiting in a queue. A resident of Mukuru pays KSh 240 per cubic meter of water; in comparison, those living in the formal areas of Nairobi served by the Nairobi Water and Sewer Company pay, on average, KSh 55 per cubic meter. Households reported consuming an average of 1.8 cubic meters of water per month, or 55% less than the international recommendation for health and hygiene, making them water insecure.





**Figure 3.** Typical Yard-shared water point in Mukuru, Nairobi.

### 3.3. Flooding Risks

The community field survey found 1151 industrial sites in the area surrounding Mukuru, 718 of which have identifiable toxic production processes. Resident citizen scientists regularly observed an oily-liquid surface pollution in the dirty streets of Mukuru. We identified at least 10 different small waste burning sites and effluent coming from the Usafi Waste Disposal Plant, which burns medical waste, in Mukuru.

Mukuru is mostly low-lying and flat, with an average elevation of 1623 m, 39 m lower than the average elevation in Nairobi. Mukuru is also situated on clay soil, which is mainly comprised of montmorillonite, that absorbs water until saturated and expands when wet. This same clay shrinks in the dry months, causing floors to crack, walls and buildings to tilt, and potholes to form on roads. Twenty-seven percent of all households responding to our survey reported experiencing flooding in their homes at least once in the last six months. However, the frequency of flooding varied by settlement, with 34% of households reporting flooding in the past six months in Mukuru Kwa Reuben, compared to 21% in Viwandani. Forty-two percent of respondents noted that flooding had impacted their health in the last year. Residents noted that frequent flooding displaces and disrupted their livelihoods, access to healthcare, schools, jobs, clean water, food, roads, infrastructure, and increased psychological trauma (Figure 4).

Using household responses about experiences with frequent flooding, elevation maps, media reports of floods, and our citizen-science cartographers—residents that walked the community and used interviews and visual clues to estimate the flood-prone areas of Mukuru—we generated a map of the Mukuru flood zone (Figure 5). For example, our community-researchers noted that the Mukuru Kwa Reuben villages of Gatope, Mombasa, and Feed the Children regularly flooded and experienced a cholera outbreak in 2018. They also documented the extent of the waterline when the Hazina/Kaiyaba bridge west of Mukuru Kwa Reuben and Viwandani in Mukuru Kaiyaba was submerged and impassable due to flooding. Using our data of the locations of all structures in Mukuru, we estimated that 7490 structures, including 1355 existing toilets and 8491 m of existing roads, are at risk of being adversely impacted during a major flooding event in Mukuru. We estimated that a

flood event in our zone of impact would displace at least 22,500 people and over 1500 local businesses/street vendors.



Figure 4. Flooded Street in Mukuru, Nairobi.



Figure 5. Estimated Mukuru Flood Zone and Impacted Structures.

### 3.4. Soil Contamination Risks

The Mukuru settlements are built almost entirely on landfill, in an area containing black clay with high levels of montmorillonite. Our soil sampling data found the presence of Arsenic (As), Lead (Pb), Nickel (NI), Cadmium (Cd), and Zinc (Zn), all of which can be a serious health risk if humans are exposed at elevated levels. It is important to note that Kenya does not currently have its own guidelines for background or safe levels of concentrations of heavy metals in soils. Typical sources of Pb and Cd in urban soils are from lead-based paints and vehicle and electronics batteries (i.e., Ni/Cd batteries). Our citizen scientists noted that there were at least four informal used lead-acid battery (ULAB) and electronic waste recycling operations happening throughout Mukuru. They observed that Mukuru ULAB recyclers tended to break up used batteries, removing lead plates, and using open burn pits to melt down the materials, all releasing lead-containing fumes, dust, and uncaptured waste into the surrounding soils.

Nickel (Ni) also comes from electronic batteries, metal plating industries, and trash incinerators. Nickel generally enters into the soil and is ingested through dust or when it mixes into surface water, which can be ingested or absorbed through dermal (skin) contact. The elevated levels of Zn are likely from the burning of waste, vehicle tire debris, and open sewage being discharged into the community. Since Kenya does not have soil contamination guidelines or regulations, we selected the Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health residential soil concentrations guidelines as a reference point to compare to the concentrations found in Mukuru's soils (Table 1).

**Table 1.** Mukuru Soil Concentrations of Metals in (mg/kg dry weight ).

Value	Arsenic (As)	Cadmium (Cd)	Lead (Pb)	Nickel (Ni)	Zinc (Zn)
Minimum	4.58	1.23	21.38	0.51	230.81
Median	8.59	2.28	31.01	1.47	520.36
Mean	8.54	2.91	43.16	1.56	752.04
Maximum	18.41	22.73	289.46	3.73	4979.67
Recommended safe/remediation level (CCME 2019)	12	10	140	45	250

We also compared our findings from the three settlements of Mukuru Kwa Jenga, Kwa Reuben, and Viwandani to our control samples taken in Dandora (the city's waste dump) and the slums of Kibera, Mathare, and Korogocho (Table 2). For almost all metals, Mukuru's soil concentrations are lower than the other sites, except for Kibera, and for the pollutant Arsenic. While some urban Arsenic in soils is likely naturally occurring, the concentrations we found are likely due to waste burning, industries that manufacture arsenic-containing pesticides, process metal adhesives, and manufacture glass, textiles, and/or paper. Arsenic found in our soil samples also likely leached from arsenic-treated rail-road wood ties.

**Table 2.** Mukuru and Control Sites: Mean Soil Concentrations, Select Metals (mg/kg).

Site	Arsenic	Cadmium	Lead	Nickel	Zinc
Dandora	5.96	12.41	112.48	2.60	2778.42
Kibera	8.65	3.30	47.40	1.70	386.98
Korogocho	7.99	4.47	96.07	2.36	1611.12
Mathare	7.46	3.19	73.52	1.98	920.63
Mukuru-Kwa Njenga	9.02	2.14	33.42	1.35	561.63
Mukuru-Kwa Reuben	8.04	2.84	39.19	1.50	711.02
Mukuru-Viwandani	8.73	3.53	53.72	1.80	926.56

The results of these analyses were synthesized into the Mukuru Rapid Health Impact Assessment (HIA) Report [60]. The health assessment report aimed to combine multiple hazards into an ‘environmental injustice’ profile for Mukuru. The Health Impact Assessment report was shared with residents and acted as a starting point for the community planning processes that explored ways to reduce hazards and make the community more healthy and climate resilient.

#### 4. From Community Science to a Climate Justice Plan

While many citizen science processes stop at data gathering, the Muungano Alliance was committed to using evidence for action. The Muungano Alliance organized ‘baraza ndogo’ (public meetings) with community members and created special forums for women and youth to participate in planning for improvements [52]. Thousands of residents and hundreds of planning meetings were held where data were shared by resident leaders (Figure 6). Youth were also hired by the Muungano Alliance to make films about the health and climate risks in the community, which was a way to share complex science in a more understandable way to a broad audience [61].



**Figure 6.** Resident and Youth Field Researchers (**left**), a household survey (**top right**), and a community planning meeting interpreting citizen science and generating climate justice solutions (**bottom right**).

During this science-to-action planning phase, the research team generated data graphics that communicated findings to community residents and highlighted potential associations between existing environmental risks and health outcomes. For example, the links between climate change induced weather events, combined with other local factors such as lack of sanitation, clay soils, and roads without drainage, were linked to flooding and related health impacts (Figure 7). Another ‘pathway diagram’ explained potential connections between lack of sanitation and health outcomes in both Swahili and English (Figure 8). These graphics were used to ensure all community residents could participate in the climate justice planning for solutions processes [60].

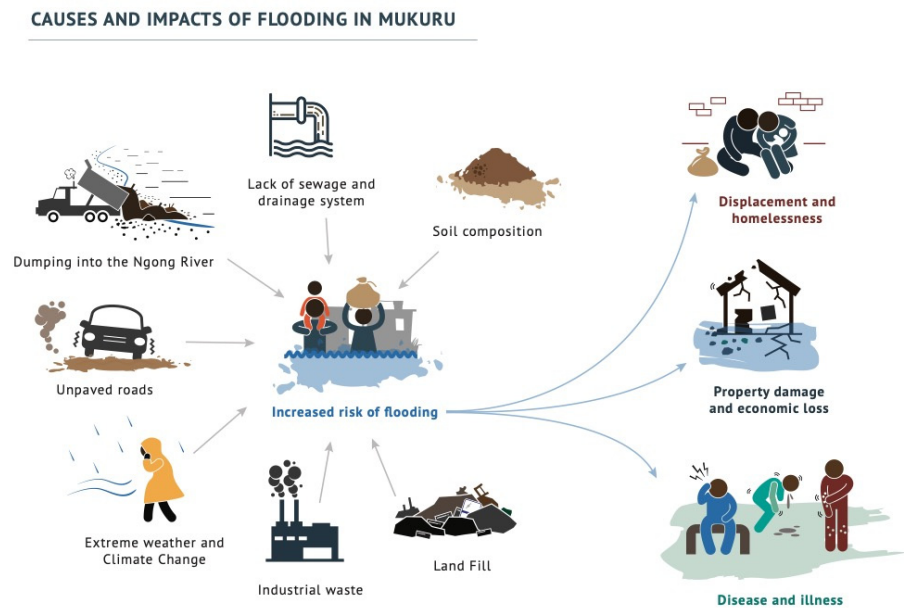


Figure 7. Community Graphic Used for Planning Climate Justice in Mukuru.

## M IPANGO YA JUMUIA NA KUHARA COMMUNITY PLANNING & DIARRHEA

Kuboresha ubora wa maji kwa njia ya uwekezaji na mipango  
inaweza kusaaidia kuzuia kuharisha

*Improving water quality through investment and planning can  
help prevent diarrhea*

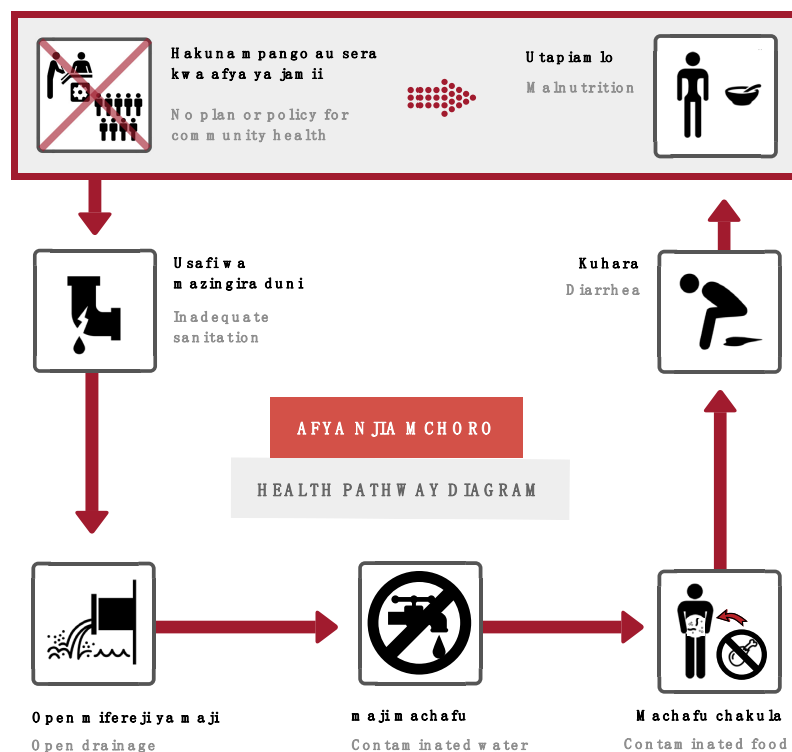


Figure 8. Community Planning Graphic Used to Prevent Diarrheal Diseases.

The community planning process prioritized mobility, safety, and climate resilience, so a focus on improving roads and pedestrian paths became a key discussion item. The housing and infrastructure planning team worked with the land and water and sanitation teams to co-design new roadway standards for the informal settlement. Their challenge was that Kenyan planning standards only included roadway widths that reflected a greenfield or suburban-sized road, which were deemed inappropriate for high density informal settlements. During planning sessions in Mukuru, residents noted that if existing Kenyan road engineering standards were applied to Mukuru, thousands of households, businesses, schools, and other facilities would be displaced, and these same roads rarely included sidewalks wide enough for the street vending that was common in the community. The Muungano Alliance and partners facilitated community dialogues that used design charettes, where different examples of roadway widths, pedestrian and cycle paths, transit stops, and runoff management (i.e., catch-basins, bioswales, etc.) were debated. A consensus emerged that a typology of roadway improvements should be offered based on climate justice principles, such as reducing local air pollution, flood protection, prioritizing pedestrian safety, and ensuring street vending, including food stalls. The results were new mobility proposals for climate justice, health and safety, along with new river crossings that stabilized a riparian zone along the river to prevent flooding. The proposals aimed to combine ecologic and engineering strategies to promote climate justice.

#### *Pilot Projects for Climate Justice*

A central tenet of urban climate justice is to act now, even in the face of scientific uncertainty, especially since communities of the poor and socially marginalized groups are already suffering [27]. Thus, the Mukuru planning process also included recommendations to address urgent water and sanitation issues before the entire integrated plan was adopted. Thus, resident citizen-scientists used their data on toilet access, quality, and safety to propose a pilot project for a low-cost, condominial, sometimes called simplified, sewer system. The residents worked with engineers from the Nairobi Water and Sanitation Company to co-design the system in one village to serve over 3000 households. The project was called the Mosque Road Pilot Sanitation Project, and the municipal utility agreed to connect the community-reticulation scheme to the trunk sewer, which would treat waste off-site. In order to ensure residents could access water for the newly proposed sewer, the community demanded new boreholes be drilled and connected to water kiosks throughout the community. The citizen science mapping and data acted as the basis for where to optimally locate water points to serve as many people as possible and what the capacity of the sewer system would need to be to allow for in-home, pour-flush toilets—the desired toilet of most residents.

In negotiations with the water and sewer utility, the Muungano Alliance agreed to sensitize residents about how to best manage the new infrastructure and that residents themselves would be paid to maintain the system, such as cleaning any clogged drains and pipes. The utility, in turn, agreed to provide 24/7 clean water, that no resident would be denied water or a safe toilet due to cost, and that lighting and security would be provided for any shared, public toilets.

By February 2022, the Nairobi Metropolitan Services (NMS) was implementing key aspects of the Mukuru community's upgrade proposals. The sewer mains serving the area were completed and residents were being paid to install and maintain the 'last mile' connections into their households and schools [62]. A new National Hygiene program hired over 10,000 youth from the slums to help clean-up Mukuru, plant trees, and secure the riverbank to help prevent flooding [63,64]. The NMS also budgeted to build over 13,000 units of social housing, new clinics, and hospitals, and the NMS director stated in 2021 that "by March 2022, no slum will be without roads, sewer lines and water" [65]. At the time of this writing, that promise had not been fulfilled, but the citizen science data and community planning around the Mukuru SPA had helped deliver: over 42 km of improved, tarmacked roads with drainage; 16 bore holes for clean water; 3 new hospitals [66]; and a

river-riparian clean-up, along with tree planting. However, more recently a major highway project has resulted in the police-enforced displacement of thousands of Mukuru residents, so the guarantee of climate justice for all was in jeopardy [67].

## 5. Discussion and Conclusions

The environmental health injustices measured by Mukuru street scientists were unknown and largely ignored prior to the processes described here. This paper has suggested that not only are the urban poor capable of engaging in complex data collection to document the climate risks they face, but these same residents are also able to generate upgrading interventions that can lead to an integrated climate justice strategy. The Mukuru researchers and NGO partners organized a complex, multi-year participatory data collection and planning process that might act as a model for similarly situated urban communities. The Mukuru SPA process also revealed how research can lead to tangible, health-promoting actions, such as improved roads and a sewer system, that will benefit local residents and the entire city [68,69]. The Mukuru citizen science processes also suggest that those living in informal settlements have unique and valuable expertise that must be integrated into adaptation planning in order to achieve climate justice [70,71].

The coproduction of knowledge and redevelopment plans in Mukuru are unique among slum upgrading programs within Kenya. For example, a review of the Kenyan Slum Upgrading Program by researchers at Daystar University found that resident engagement was largely a consultative process and 68% of participants felt their voice was not being heard by government planners [72]. Another slum upgrading program sponsored by the World Bank, called the Kenya Informal Settlements Improvement Program, has been implemented largely by the Ministry of Housing and an evaluation report revealed that the Settlement Executive Committees, charged with organizing residents, have struggled to build trust and meaningfully involve residents in decision making [73].

The Mukuru process has not been without its challenges. First, the processes summarized here took over six years from inception to plan creation. Other communities with similar challenges and needs may not be able to sustain this type of work over multiple years. Second, maintaining resident and NGO engagement over the long time period was also a challenge since some participants left, resulting in a loss of continuity and institutional memory. Much of the work of the Muungano Alliance was maintaining and nurturing these partnerships, including those with the Nairobi County Government.

Keeping the participatory process together, both the citizen science and planning, was enabled by linking the different sector issues to human health. According to Muungano Alliance organizers, residents were most concerned with the health and well-being of their families, so connecting issues of social exclusion, poverty, lack of mobility and services, as well as other issues to the social determinants of health in Mukuru was a key strategy used during the process. This process also valued narratives and lived experiences along-side the quantitative data, while helping keep many partners that might have been discouraged from participating in a highly technocratic science and planning process, such as youth, engaged and returning to meetings. As noted above, youth had insights about exposures and risks unknown by adults and could communicate findings to previously under-engaged audiences. The youth used art, culture, music, and other creative means to gather data, communicate findings, and propose solutions that would work for them—the future of the community.

Another challenge of this process was the lack of financial resources. The Canadian International Development Research Centre provided much of the initial funding for the project. However, these grants ended and the Muungano Alliance was forced to raise additional funds and ask partners to contribute time and resources *pro bono* in order to complete the project. The lack of financial investment in processes such as these, by local and global funders, underscores another injustice, namely, that most professionals are paid while community experts struggle to maintain their livelihoods when trying to improve their own communities [74].

Finally, the Mukuru SPA was purposefully focused on one, large informal settlement, but of course, climate change is impacting the entire city and region of Nairobi. Ideally, the Mukuru Plan will be integrated into a more broad, regional climate-change-adaptation strategy. Scaling-up is always a challenge in urban health, since exposures and solutions can be very localized. However, the Mukuru SPA revealed that integrating local knowledge into climate justice planning should take precedent and not be superseded by national or global concerns. The insights from the Mukuru process are already being recognized as a model for future efforts in Kenya and across urban Africa [75].

Urban climate justice demands that the least well-off populations and most vulnerable communities are receiving the social, economic, and health benefits of city life. As this study has shown, this demands attention to multiple, existing injustices, and on-going participatory planning and action processes. Community scientists are instrumental actors in the search for climate justice and should never be ignored in research or policy making. While the ultimate outcomes for Mukuru residents remain uncertain, the processes used to date suggest that slum dwellers and partner organizations can collaborate to co-produce new science and policy for urban climate justice.

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