The distribution of Cyclone Idai's water impacts in Beira, Mozambique

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Received 28 August 2023
Revised 27 October 2023
14 November 2023
Accepted 15 November 2023

Abstract

Purpose – Climate hazards in the form of cyclones are projected to become more intense under the pressures of future climate change. These changes represent a growing hazard to low lying coastal cities like Beira, Mozambique. In 2019, Beira experienced the devastating impact of Cyclone Idai. One of the many impacts resulting from this Cyclone was disrupted drinking water access. This investigation explores the distribution of Cyclone Idai's impact on drinking water access via an environmental justice lens, exploring how preexisting water access characteristics may have predisposed households to the impacts of Cyclone Idai in Beria.

Design/methodology/approach – Relying on household survey data collected in Beira, the investigation applied a decision tree algorithm to investigate how drinking water disruption was distributed across the household survey sample using these preexisting vulnerabilities.

Findings – The investigation found that households that mainly relied upon piped water sources and experienced inconsistent access to water in the year prior to Cyclone Idai were more likely to experience disrupted drinking water access immediately after Cyclone Idai. The results indicate that residents in formal areas of Beira, largely reliant upon piped water supply, experienced higher rates of disrupted drinking water access following Cyclone Idai.

Originality/value – These findings question a commonly held assumption that informal areas are more vulnerable to climate hazards, like cyclones, than formal areas of a city. The findings support the inclusion of informal settlements in the design of climate change adaptation strategies.

Keywords Vulnerability, Climate hazards, Climate justice, Drinking water, Cities, Cyclone Idai

Paper type Research paper

1. Introduction

1.1 Theoretical background

When Cyclone Idai made landfall in Beira in March 2019, the cyclone brought wind speeds in excess of 180 km/hr (Yu *et al.*, 2019) and devastating floods (Phiri *et al.*, 2021). The observed storm surges were recorded at 3.5–4 meters, while the flood waters rose above 10 meters. As a result of the floods, it has been estimated that up to 90% of Beira was damaged or destroyed (International Committee of the Red Cross ICRC, 2019). Many households were affected by the

The authors wish to acknowledge the support of the Social Sciences and Humanities Research Council of Canada (SSHRC) in funding this project. The authors would also like to thank the research team from Eduardo Mondlane University and CEDECA for their assistance in collecting the data used in this investigation.

Funding: This work was funded by the Social Sciences and Humanities Research Council (No. 430-2020-00635).

Disaster Prevention and Management: An International Journal
Vol. 33 No. 6, 2024
pp. 1-15
Emerald Publishing Limited
0965-3562
DOI 10.1108/DPM-08-2023-0211

cyclone and had their fresh water supply interrupted. These kinds of disastrous climate events are likely to become more intense under the pressures of future climate changes (IPCC, 2021). These impacts will be especially pronounced in low lying coastal cities which are critically exposed to cyclones and their associated storm surges (Le, 2020; Leal Filho *et al.*, 2019). Hazards catalyzed by climate change can create a cascade of impacts across urban systems, undermining development progress and denigrating the health and economic well-being of residents (Lawrence *et al.*, 2020). Climate change has and will pose a "global systemic risk to society" (OECD, 2012, p. 72). It does so primarily by expanding the risks associated with extreme climate events (Uitto and Shaw, 2016) and compounding the factors that "increase severity and frequency of triggering events" (Greve, 2016, p. 13).

The IPCC's Climate Change 2022 report demonstrated that water-related hazards have increased in occurrence and have carried a high level of severity as flooding contributed to 31% of disaster-related economic loss while drought made up 34% of disaster-related death between 1970 and 2019 (WMO, 2021, as cited in IPCC, 2022). Extreme precipitation events have also caused water-related disease outbreaks, commonly due to compromised sanitation and hygiene services (IPCC, 2022). The IPCC reports that this increasingly turbulent precipitation and weather will affect urban reservoirs as well, negatively impacting water services which will particularly be felt in the global south (IPCC, 2022). Water-related hazards also carry implications for food as production faces highly unstable conditions and extreme weather events decrease accessibility to goods through price volatility and infrastructural damage (IPCC, 2022). These effects are often disproportionately felt in informal settlements, low-income groups and marginalized populations (IPCC, 2022), highlighting a potential environmental injustice in the distribution of impacts by water-related hazards.

An environmental justice lens can be a helpful starting point for investigating the distribution of vulnerabilities and hazards associated with disasters in cities (Schlosberg and Collins, 2014; Taylor, 2000). This lens provides insight into the ways in which existing structural injustices and inequalities can position marginalized groups as vulnerable within cities (Anguelovski and Roberts, 2011). In its earliest conceptualization, environmental justice was a movement that highlighted the extent to which hazards and assets were inequitably distributed across a society (Taylor, 2000). From these early days, environmental justice has evolved into new thematic areas with a focus on climate disasters in cities with a global perspective (Bullard, 2007; Bullard *et al.*, 2011; Bullard and Wright, 2009; Carmin and Agyeman, 2011). The distribution of Hurricane Katrina's impacts across New Orleans in 2005 became a watershed moment for the movement. Research following the disaster noted the inequitability with which the hurricane's impacts were distributed, relegating marginalized groups to more severe impacts. The entire event was then framed according to constructed social injustices rather than simply the outcome of inequity (Schlosberg and Collins, 2014). Events like Hurricane Katrina catalyzed the climate justice movement, recognizing how multidimensional inequity could exacerbate climate change impacts (Anguelovski and Roberts, 2011). These movements toward climate justice have opened research gaps in the intersectionalities that seem to define the compounded impacts of climate change (Saraswat and Kumar, 2016) and the need for further data on outcome inequalities, particularly among coastal cities in the Global South.

Climate justice is a way of understanding how people are "differently, unevenly, and disproportionately" impacted by climate change, and how identified injustices can be addressed "in fair and equitable ways" (Sultana, 2021, p. 118). Signaling the reality of inequity within the ongoing crisis, the populations most impacted by climate change effects are often also contributing the least to the causation of climate change (Harlan *et al.*, 2015). On the ground level, these inequities are most pronounced in the increasing lack of access to basic goods, services and political empowerment in cities of the global south (Reikien *et al.*, 2017). Klinskly and Mavrogianni (2020) provide an overview of the conceptual themes of distributive justice, procedural justice and recognition justice as they pertain to environmental justice within cities.

Distributive justice defines the division of assets and hazards across stakeholders. Procedural justice defines the extent to which decisions are made in a transparent, fair and inclusive manner. Finally, recognition justice defines the extent to which individuals or groups are made visible or invisible as stakeholders in any key decision-making process or policy.

As risk steadily increases regarding climate change impacts, there is a clear need to formulate and implement climate mitigation and adaptation strategies to sustain urban livelihoods. That said, Amorim-Maia *et al.* recognize the failings of these strategies as many of them tend to take "exclusionary, inequitable, and technocratic approaches" (np) that come up short in addressing inequities, further exacerbating the impacts and vulnerabilities of these marginalized groups (Amorim-Maia *et al.*, 2022). Although no single solution exists for this issue, climate justice discourse points toward the need of policymakers to better understand the evolving human vulnerabilities that underpin environmental injustice among impacted communities via community-based approaches (Harlan *et al.*, 2015; Coutinho *et al.*, 2020; Amorim-Maia *et al.*, 2022).

Disaster risk reduction can provide helpful conceptual anchors for theorizing and investigating human vulnerability (Birkmann, 2006). Across the various theoretical frameworks in this field, disasters are conceptualized broadly as the impact of hazards on vulnerable populations. Vulnerabilities, then, can be understood as those characteristics of a community that increase the probability of a disaster (the impact of a hazard) (Cutter *et al.*, 2003). In other words, the distribution of community vulnerabilities can provide an insight into the distribution of disaster impacts within a community. In its most broad iteration, vulnerability refers to the capacity of society to deal with hazard (IPCC, 2012). Seen through a more focused lens, UNDEP defines vulnerability as "a human condition or process resulting from physical, social, economic and environmental factors, which determine the likelihood and scale of damage from the impact of a given hazard" (United Nations Development Programme UNDP, 2004). Within this context, the pressure and release model in disaster risk reduction clarifies that disasters occur when a vulnerable community is impacted by a hazard (Birkmann, 2006).

More recent research has taken on a broader outlook, one that integrates much of the previous research, when discussing the variable dimensions of disaster risk. Birkmann's (Birkmann, 2014) work demonstrates that those key dimensions of disaster risks concern the vulnerability of society, infrastructure, economy, environment and governance systems. Further work by Barredo *et al.* (2012), Perez *et al.* (2015), López-Martínez *et al.* (2017) coalesces around this framework and identifies vulnerability as a key aspect of disaster risk. In this way, disaster risk has come to be understood as a result of the interaction between a hazard event and the vulnerability of the system exposed (Liverman, 1990; Dow, 1992; Smith, 1992; Cutter, 1993; Bohle *et al.*, 1994; Birkmann, 2006).

The contextual vulnerabilities of exposed systems (which could include communities, cities or countries) may help to explain why the impacts of climate change are inequitably distributed. Previous analyses by Füssel (2010) demonstrate that the limited capacity of poor nations to respond to climate hazards may explain their heightened vulnerability to climate hazards despite their limited contribution to climate change. This line of thinking can also help to explain how preexisting vulnerabilities, like poor drainage in informal settlements, can relegate severe impacts of climate disasters to marginalized communities. Structural inequalities expressed via inequitable access to infrastructure, can predispose informal settlements for more severe climate outcomes (Williams *et al.*, 2019). This situation is exemplified among urban informal settlements in Sub-Saharan Africa where limited access to clean water can create the necessary preconditions for climate disasters (Zerbo *et al.*, 2020). This investigation will assess these assertions via a case study of Cyclone Idai's impacts in Beira, Mozambique.

1.2 Case study description

The city of Beira is a coastal town in Mozambique with a surface of 633 km^2 and an altitude of 14 m above sea level, and in its eastern area lies de Channel of Mozambique (MINED, 1986; dos

Muchangos, 1999; Maloa, 2016). Its geographic location is marked by the confinement of the west and north by the district of Dondo in the eastern part of the Mozambique Channel and the south the District of Búzi (see map). The city is located at the mouth of two rivers, Púngoè and Búzi, both end in the channel. Dos Muchangos (1999) and Maloa (2016) point out that the city was built in a swamp area closer to the mouth of the Púnguè River. Regarding climate Beira, the average rainfall is around 1400 mm (dos Muchangos, 1999). Beira, like all coastal areas of Mozambique, the city is prone to climate disasters and under permanent threats due to either cyclones or floods coming from the hinterland (Tevera and Raimundo, 2021; República de Moçambique, 2017, 2012; INGC, FEWS-NET MIND; UEM, 2011; van Berchum *et al.*, 2020). INGC, FEWS-NET MIND; UEM (2011) point out that the trajectories of cyclones in Mozambique are mostly in Angoche (northern region) and the provinces of Inhambane (southern part) and Zambezia and Sofala where Beira is located (central area) of Mozambique. The city of Beira is classified as "B" city based on the Government of Mozambique cities classification (Pililão, 1989). Figure 1, prepared by Maloa (2016), indicates the 11 wards that comprise the city.

The city also faces the challenge of managing limited financial resources to facilitate institutional coordination when responding to cyclone impacts on the city's water infrastructure (Sietz *et al.*, 2011). According to the Mozambique Cyclone Idai Post-Disaster Needs Assessment (PDNA), the Beira/Dondo water supply system was totally disrupted for a total of 10 days following Cyclone Idai's landfall (Post-Cyclone Idai Cabinet for Reconstruction PCICR, 2019). This disruption affected roughly 340,000 people and meant that some households were forced to buy bottled water or get water from water trucks at prices that far exceeded the pre-Cyclone market values.

The city has experienced growing informal areas with high population density at a lower topography and thus exposed to flooding hazards (Araujo, 2003; Anjo, 2009; Shannon *et al.*, 2018). These areas were vulnerable to severe Cyclone idai impacts, as reported by Tevera and Raimundo (2021) and Mandamule (2020). Many informal settlements in the city are characterized by low-quality housing with limited access to infrastructure (Anderson and Silva, 2020). Even among households with access to piped water, Victor *et al.* (2022) identified

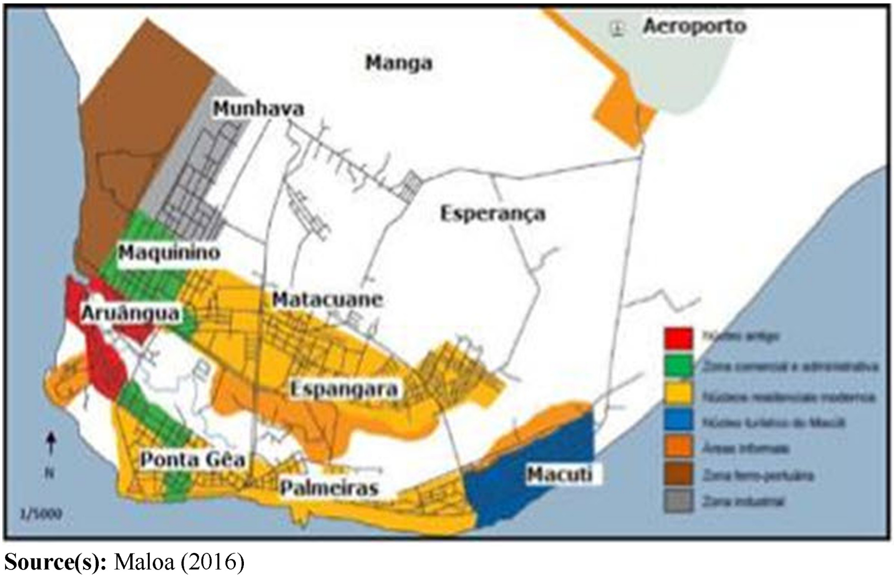


Figure 1.
Map of Beira wards

Source(s): Maloa (2016)

significant heterogeneity in the accessibility of water services within the city, indicating that location can be a significant barrier to water access. Previous research completed by Williamson *et al.* (2023) indicated that Cyclone Idai's compounding impacts contributed to inequality in the city of Beira. This investigation explores the distribution of Cyclone Idai's impacts on drinking water access according to formal/informal divides in infrastructure as well as the consistency of access to clean water in the year prior to Cyclone Idai.

2. Methods

2.1 Research objectives

RO1. Define disrupted household drinking water access following Cyclone Idai in Beira.

RO2. Evaluate the association between disruption in drinking water access following Cyclone Idai and formality of dwelling types and infrastructure access.

RO3. Categorize household drinking water access disruption rates following Cyclone Idai according to the consistency and type of household water sources.

2.2 Sample

This investigation relies on a household survey of Beira households that experienced the impact of Cyclone Idai in 2019 via a collaboration of researchers from the University of Waterloo (UW), Eduardo Mondlane University (EMU) and the University of Licungo (UL). The household survey was conducted in the Fall of 2021 and relied upon GIS-supported random sampling. The investigators created a sampling frame of the buildings in Beira using OpenStreetMaps (OSM). The buildings within Beira had been previously mapped by a research team on OSM (Wagenaar *et al.*, 2018). This building map layer was then extracted on September 7, 2021, to create a list frame of buildings in the city. The 139,027 points listed in this map (each point indicating an identified building in the city along with coordinates) were then exported into SPSS where a random sample of 1,000 buildings was selected (along with GPS coordinates for each building) using simple random sampling without replacement. A survey enumerator team (led by graduate students from Eduardo Mondlane University with support from researchers at the University of Licungo) then navigated to each of the randomly sampled buildings to confirm that the buildings were, in fact, residential before carrying out the survey. Of the 1,000 randomly selected residential buildings in the city of Beira, 975 households agreed to participate in the survey when approached by the survey enumerators.

The survey was administered by graduate students from EMU with support from researchers at UL. The enumerators first established whether the respondent household had experienced the impact of Cyclone Idai in March 2019 (had been present in Beira during the storm's impact). Once this impact was confirmed, the survey was administered to an adult who could respond on behalf of the remainder of the household. Informed consent was provided by respondents to this household survey, which received ethics clearance from the Research Ethics Board at the University of Waterloo (#43049). Appropriate approvals were received from the City of Beira for the implementation of this survey in the city.

The survey instrument used in this investigation relied upon scales meant to measure the impact of Cyclone Idai. The survey instrument was derived from scales measuring disaster impact developed by the United Nations Sustainable Development Group (UNSDG, 2019) and included measures of well-being derived from the Lived Poverty Index (Afrobarometer, 2013). These scales were selected as established people-centered metrics of human well-being to inform policy (UNSDG, 2019; Afrobarometer, 2013). Using this survey instrument, this investigation draws a variable measuring the extent to which households experienced disrupted access to drinking water immediately after cyclone Idai. The analysis also draws variables determining whether the households had maintained consistent or inconsistent access to water in the year prior to Cyclone Idai. This consistency of water access is derived from Afrobarometer's Lived Poverty Index and was administered via the following survey question: "In the year before Cyclone Idai (March 15, 2018 to March 15, 2019), how often, if ever, have you or your household gone without enough clean water for home use?" When responding to this question, respondents were asked to rank the frequency with which their household had experienced inconsistent access to water. These ranked responses included: Never, Just Once or Twice, Several Times, Many Times, and Always. To provide a more objective measure of access over the year prior to Cyclone Idai, this investigation binned these responses into a binary variable representing either Consistent Access ("Never") or Inconsistent Access (the respondent chose either "Just Once or Twice", "Several Times", "Many Times", or "Always").

In the administration of the survey, respondents were also asked to confirm whether their access to drinking water was disrupted immediately following Cyclone Idai. If the respondents answered in the affirmative, a set of follow up questions were administered. These questions clarified the reasons for the disrupted water access and whether household access to drinking water was still disrupted at the time of the survey (noting that the survey was administered two years following the Cyclone Idai event). The survey instrument also included questions about the main source of water that was accessed by the respondent households before Cyclone Idai. Finally, the survey instrument also administered a question on the type of dwelling that the respondent households resided in prior to Cyclone Idai (based on the respondent's report). These dwelling types were paired with measures of formality (dwellings in an informal area or formal area).

2.3 Analysis

To achieve *Research Objective 1,* in this study, this investigation provides frequency distributions of drinking water disruption, and the reasons for that disruption, among the surveyed households following Cyclone Idai. To achieve *Research Objective 2*, the investigation also uses cross-tabulations to describe the extent to which access to basic goods and services in the year prior to Cyclone Idai was associated with changes in the odds of drinking water disruption following Cyclone Idai. Finally, to understand the distribution of drinking water access disruption following Cyclone Idai per *Research Objective 3*, the investigation relied on a CHAID decision tree algorithm to determine the distribution of drinking water disruption based on pre-existing access to basic goods and services in Beria.

CHAID (Chi-Square Automatic Interaction Detection) Trees classify a categorical target variable (like drinking water disruption) amongst a set of categorical predictor variables (like water sources and the consistency of water access). The algorithm creates splits among the predictor categorical variables according to the categories of the target categorical variable. These splits are created based on Chi-Square values when the predictor variables are cross tabulated with the target variable. This splitting process is repeated amongst the subsamples that are created at each split in the decision tree. The algorithm stops this process when there are less than 100 households in the subsample parent node or less than 50 households in the subsample child node. The tree-growing algorithm also stops at three levels in order to avoid overfitting the model. Any surveyed households with missing values for any of the included variables are excluded from the CHAID tree analysis in order to support interpretation of the categories produced by each split in the decision tree. This use of CHAID tree analysis has been effectively used to understand the distribution of food security across the gender and employment of household heads in Maputo, Mozambique (McCordic *et al.*, 2021).

2.4 Limitations

All household survey data are limited to the accurate recall and honest report of the survey respondents on behalf of the entire household. To bolster the accuracy of recall in this study, all enumerators received formal training on survey administration techniques at the start of fieldwork. While the survey sampling strategy made great strides in establishing a simple random sample of the population, further research would be welcomed to replicate the survey findings. As an observational study, any associations identified in this investigation should not be interpreted as causal.

3. Results

3.1 Define disrupted household drinking water access following Cyclone Idai in Beira

Among the household survey sample, over 75% of the respondents indicated that their household had experienced disrupted access to drinking water immediately following Cyclone Idai (Table 1). Given the extensive flooding that was associated with the disaster, this extensive disruption was to be expected following the event.

Among the reasons provided for the disrupted access to water, most of the surveyed households indicated that the disrupted access was either the result of destroyed water sources or water access infrastructure (75% of surveyed households) (Table 2); 14% of the surveyed households indicated that this disrupted access was the result of either insufficient funds or geographically inaccessible water sources.

At the time of the survey in 2021, 18% of those households that experienced disruption in their drinking water access immediately following the Cyclone Idai event still experienced disrupted access to their usual drinking water source (Table 3). This finding indicates the

Table 1. Percentage of households that experienced disrupted drinking water access immediately after Cyclone Idai

Disrupted drinking water access*	n	%
Yes	744	76.9
No	224	23.1
Total	*968*	*100*

Note(s): *Survey Question: Was this household's access to this drinking water source disrupted immediately after Cyclone Idai (after March 15, 2019)?
Source(s): Table by authors

Table 2. Main reason for disrupted drinking water access following Cyclone Idai as identified by survey respondents

Reason for disrupted drinking water access*	n	%
Insufficient funds	71	9.7
Geographically inaccessible water source	32	4.4
Destroyed water source infrastructure	370	50.4
Destroyed water access infrastructure	178	24.3
Other	83	11.3
Total	*734*	*100*

Note(s): *Survey Question: What was the main reason for the disruption of this household's access to this drinking water source?
Source(s): Table by authors

Table 3. Rate of continued drinking water disruption among impacted households from Cyclone Idai to 2021

Drinking water source disruption in 2021*	n	%
Yes	139	18.7
No	605	81.3
Total	*744*	*100*

Note(s): *Survey Question: Is this household's access to this drinking water source still disrupted?
Source(s): Table by authors

long-term impacts in drinking water access that were experienced by households impacted by the Cyclone Idai disaster.

3.2 Evaluate the association between disruption in drinking water access following Cyclone Idai and formality of dwelling types and infrastructure access

The distribution of disrupted drinking water access was split among formal and informal divides, however, not according to the pattern that might be expected. In the survey, household respondents categorized their households according to type and the formality of area (Table 4). Among the surveyed households claiming to reside in a house within a formal area or apartments in a formal area 81.3 and 91.3%, respectively, experienced disrupted drinking water access immediately after Cyclone Idai. That said, houses in informal areas and shacks in informal areas experienced disrupted drinking water access at a rate of 70.4 and 55.6% respectively.

When disrupted drinking water access was distributed according to the reported main source of drinking water for respondent households, there are significant differences in the experience of drinking water disruption following Cyclone Idai depending on the source of drinking water (Table 5); 83% of the surveyed households that relied on piped water access prior to Cyclone Idai experienced disrupted drinking water access. Comparatively, among the surveyed households that relied upon tube wells, boreholes or dug wells, 55.4% experienced

Dwelling type		Access	DDWA	*Total*
House in a formal area	n	110	478	*588*
	%	18.7%	81.3%	*100%*
Apartment in formal area	n	2	21	*23*
	%	8.7%	91.3%	*100%*
House in informal area	n	84	200	*284*
	%	29.6%	70.4%	*100%*
Shack in informal area	n	24	30	*54*
	%	44.4%	55.6%	*100%*
Other	n	3	7	*10*
	%	30.0%	70.0%	*100%*
Total	n	*223*	*736*	*959*
	%	*23.3%*	*76.7%*	*100%*

Source(s): Table by authors

Table 4.
Disrupted drinking water access (DDWA) post-Cyclone Idai by dwelling type before Cyclone Idai

Main source of drinking water		Access	DDWA	*Total*
Piped water	n	125	611	*736*
	%	17.0%	83.0%	*100%*
Tube-well, borehole, dug well	n	95	118	*213*
	%	44.6%	55.4%	*100%*
Water from a spring	n	1	0	*1*
	%	100.0%	0.0%	*100%*
Surface water	n	0	1	*1*
	%	0.0%	100.0%	*100%*
Other	n	3	13	*16*
	%	18.8%	81.3%	*100%*
Total	*n*	*224*	*743*	*967*
	%	*23.2%*	*76.8%*	*100%*

Source(s): Table by authors

Table 5.
Disrupted drinking water access (DDWA) post-Cyclone Idai by main source of drinking water before Cyclone Idai

disrupted drinking water access following Cyclone Idai. Given the infrastructure works required for, and centralized administration involved in, the distribution of piped water, this distinction can be classified according to formal and informal sources of water. In this case, however, households reliant upon formal water sources (piped water) were more likely to experience disrupted drinking water access following Cyclone Idai.

When the main source of drinking water for respondent households was distributed according to the formality and type of dwelling that respondent households resided in prior to Cyclone Idai, an association between these two variables emerges (Table 6). Households residing in houses and apartments in formal areas commonly sourced their drinking water from piped water (81.4 and 90.9% respectively). That said, households residing in houses and shacks in informal areas were not as likely to source their drinking water from piped water (70.9% and 46.3% respectively). Instead, these households identified tube-wells, boreholes or dug wells as main sources of drinking; 27.4% of sampled households residing in houses in informal areas primarily relied on these sources of drinking water while 53.7% of households residing in shacks in informal areas primarily relied on these sources of drinking water.

In addition to the main source of drinking water that households relied upon, the consistency of household access to clean water in the year prior to Cyclone Idai was also associated with observed rates of disrupted drinking water access following Cyclone Idai (Table 7). Perhaps as expected, households that had inconsistent access to clean water and sanitation in the year before Cyclone Idai demonstrated an increased odds of experiencing drinking water disruption immediately following Cyclone Idai.

3.3 Categorize household drinking water access disruption rates following Cyclone Idai according to the consistency and type of household water sources

To establish how disruption in drinking water access was distributed among the sampled households according to the consistency of household access to water and the main source

Main source of drinking water		House in formal area	Apartment in formal area	House in informal area	Shack in informal area	Other
Piped water	n	482	20	202	25	5
	%	81.4%	90.9%	70.9%	46.3%	45.5%
Tube-well, borehole, dug well	n	97	2	78	29	6
	%	16.4%	9.1%	27.4%	53.7%	54.5%
Water from a spring	n	0	0	1	0	0
	%	0.0%	0.0%	0.4%	0.0%	0.0%
Surface water	n	1	0	0	0	0
	%	0.2%	0.0%	0.0%	0.0%	0.0%
Other	n	12	0	4	0	0
	%	2.0%	0.0%	1.4%	0.0%	0.0%
Total	*n*	*592*	*22*	*285*	*54*	*11*
	%	*100%*	*100%*	*100%*	*100%*	*100%*

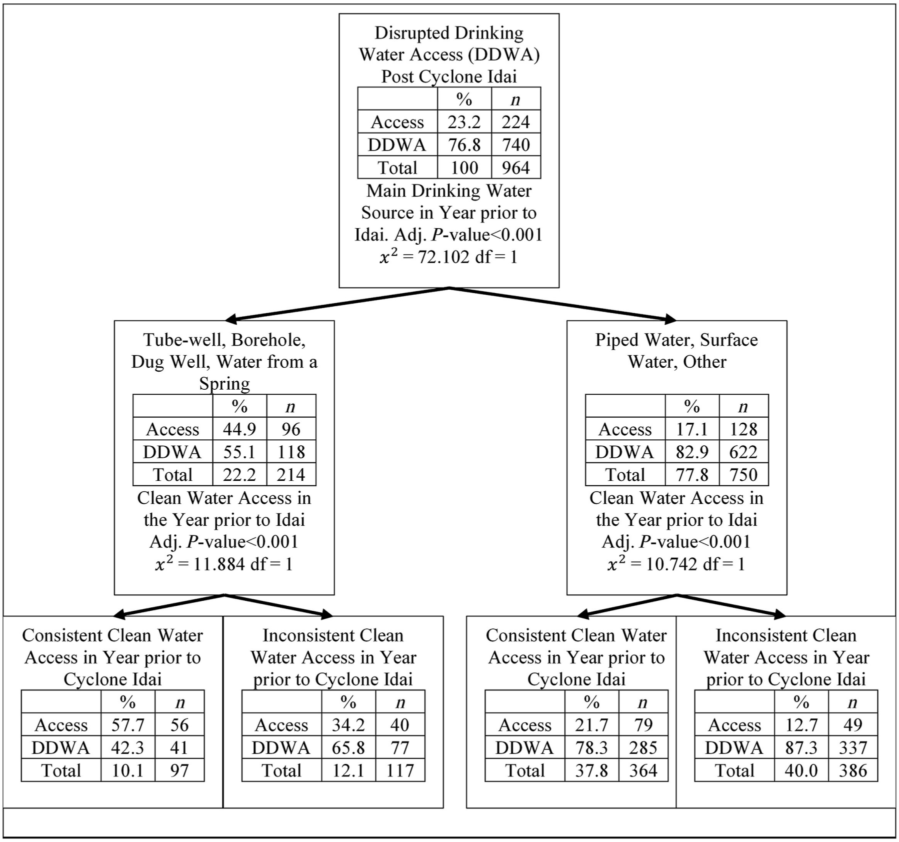
Source(s): Table by authors

Table 6. Main source of drinking water by dwelling type before Cyclone Idai

Resources access in the year prior to Cyclone Idai	Consistency of access	Access n	Access %	DDWA n	DDWA %	*Total n*	*Total %*
Enough clean water for home use	Consistent	135	29.2	327	70.8	462	100
	Inconsistent	89	17.7	414	82.3	503	100

Table 7. Cross-tabulation of disrupted drinking water access post-Cyclone Idai by resource access consistency in the year prior to Cyclone Idai

of drinking water relied upon in the year prior to Cyclone Idai, this investigation relied upon decision tree analysis (Figure 2). In this case, the first split in the decision tree was determined using the main drinking water source in the year prior to Cyclone Idai. The subsets of households created by this split created an interesting pattern in the distribution of drinking water access. Among the households that relied upon water access via tube wells, boreholes, dug wells or water from streams, the rate of disrupted drinking water access was at 55.1%. That said, among the households that relied upon piped water, surface water or other sources, the rate of disrupted drinking water access was at 82.9% of the surveyed households. Among the subsets created by this spit, the survey sample was classified according to the consistency of access to clean water in the year prior to Cyclone Idai. In both subsets, households that experienced inconsistent access to water from their respective water source in the year prior to Cyclone Idai also experienced greater rates of disrupted drinking water access following Cyclone Idai. The decision tree identified that households that had consistent clean water access to tube wells, boreholes, dug wells or springs experienced the lowest rates of disrupted drinking water access (42.3%). That said, households that experienced inconsistent access to piped water, surface water or other sources in the year prior to Cyclone Idai experienced the highest rates of disrupted drinking water access following Cyclone Idai (87.3%).



Source(s): Figure by author

Figure 2.
CHAID decision tree of disrupted drinking water access post-Cyclone Idai

4. Discussion and conclusions

This analysis indicated that, immediately following Cyclone Idai, respondent households residing in more formal areas of Beira and relying upon more formal water sources (liked piped water) experienced a higher rate of disrupted drinking water access when compared to households living in more informal areas and relying upon more informal water sources. According to the decision tree analysis, respondent households most likely to have experienced drinking water disruption in the city had inconsistent access to piped water, surface water or other sources (although less than 20 households indicated surface water or other sources of water as their main source out of the survey of 975 households). These results may suggest a broader distinction among households across formal/informal divides. While the consistency of access was a key characteristic of vulnerability or resilience, reliance upon more formal water infrastructure was associated with a greater risk of disrupted drinking water access following Cyclone idai.

Given the extensive water infrastructure disruptions observed following Cyclone Idai (Post-Cyclone Idai Cabinet for Reconstruction PCICR, 2019), forcing households to rely on bottled water rather than piped water supply, this finding demonstrates the potential fragility of formal water services when compared to the adaptive flexibility of decentralized informal water sources. Given ongoing investigations into the distribution of vulnerability across formal/informal divides, future research should consider how informality may also provide adaptive resilience. Similar research into the impacts of Cyclone Idai in Beira have exposed inequalities in vulnerabilities and coping. Williamson *et al.* (2023) identified that households in Beira that lost access to one resource were much more likely to lose access to additional resources following Cyclone Idai (indicating a compounding of vulnerability). McCordic *et al.* (2022) documented that severely food insecure households still engaged in a diversity of adaptive coping strategies following Cyclone Idai. This case study builds on that literature by identifying the comparative resilience of informal settlements following this disaster. This case study also highlights the need for a practice of procedural justice that recognizes the potential contributions of informal settlements toward discussions of resilience-building. By challenging the historical exclusivity of decision-making within Beira, the incorporation of informal settlement's successes may help to increase the adaptability of Beira as a whole. This imperative has been reiterated by Carvalho and Boanada-Fuchs (2019) in their call for more community-centered discussions on housing development within Beira. Furthermore, as demonstrated in the findings from this research, there may be previously unknown adaptation strategies practiced by historically marginalized groups in informal urban settlements, which could enhance urban resilience under the strain of climate disaster impacts.

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