Master Course in Territorial, Urban, Environmental and Landscape Planning
Curriculum in Planning for the Global Urban Agenda

Master Thesis

Beira-Mozambique, After the Storm.

A GIS-based application of multisource data collection and Tropical Cyclone Idai damage assessment.

Supervisors
Prof. Piero Boccardo, Supervisor
Prof. Marco Santangelo, Co-Supervisor
Prof. Andrea Ajmar, Co-Supervisor

Student
Jessica Comino

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Abstract

On the 14th of March 2019 Tropical Cyclone Idai hit the coast of Beira, in the Southwest Indian Ocean, Mozambique, later being renamed <<Global South strongest hit>>. The damages caused by the event were devastating and contributed to increase pre-existing vulnerabilities of a highly fragile country, characterized by a complex planning system, dynamics of informality and climate vulnerability.

The interdisciplinary master thesis laboratory of Polytechnic of Turin, along with the partnership of the Community of Sant'Egidio has launched a master thesis laboratory aimed at studying the event and presenting future scenarios for the city of Beira. As a young urban planner, with personal interest in hazardous events and emergency mapping, multiple questions started to arise while studying the event and getting to learn about it. Mostly one over the others on how to provide a relatable spatial analysis of the Cyclone's impacts through the multitude of data available spread among the different platforms. For instance, the city of Beira and the Government of Mozambique have long-time cooperated with a conspicuous variety of international stakeholders – United Nations (UN) and United Nations for Training and Research (UNITAR), World Food Programme (WFP), Humanitarian OpenStreetMap Team (HOT), Red Cross, Earth Observation (EO) Browser and Copernicus Emergency Management Service, towards resources management and projects' development.

The presence of the latter is unquestionably fundamental during emergency preparedness and post-disaster assistance. Nevertheless, the multitude of actors

necessarily results in a multitude of different intervention' approaches, hence various platforms for data collection to provide emergency mapping and support.

The aim of this research study is therefore the harmonization of data through the collection and implementation of the several data formats into one comprehensive geodatabase that will be utilized to identify the spatial impacts over the built environment and the infrastructural system of 2019 Cyclone Idai, eventually outlining the importance of a global geodatabase that can foster not only the extraordinary mapping – with the implementation of 2021 Cyclone Eloise data – but can serve as a key tool also in ordinary mapping.

Following an overview of the city of Beira and its unique configurations, the research will later investigate its vulnerability towards tropical cyclones, taking into account studies and analyses that have been developed throughout the years by private agencies and non-governative organizations.

The study will then present the replicability of the methodology adopted that has been put in place to support ordinary and extraordinary mapping in Malawi through the UNICEF's capacity building UP4DREAM project, where also data gathered by drones has been implemented.

The research will eventually reveal some obstacles while collecting data, in relation to the number of data platforms, the quite often lack of cohesion between the data formats, and consequently the reliability of each datum that might have been collected in different time and space periods. Regardless these limitations, the survey will highlight the importance for a comprehensive geodatabase as a mean to enhance ordinary and extraordinary mapping, meanwhile increase global cooperation.

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I would first like to thank Professor Piero Boccardo, for believing in me at first and pushing me to keep learning, exploring further investigating topics and techniques I did not know I could do.

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Contents

Introduction

When dealing with natural hazards and the assessment of these phenomena on land, it is quite common that a multiplicity of actors intervenes in the scene, through both in-situ as well as through remote intervention. The final goal is usually one and shared and conveys the most rapid and efficient support that can be provided to the affected population and their land. For instance, many organizations, depending on their characteristics, their expertise and final object act in different ways, usually, adopting specific methodologies and data, that might have been collected by them or by other reliable agencies. It follows that also the editing and the elaboration of products is per cluster-finalized and made available at the discretion of the organization, or put on request. Especially with global catastrophes, such as the case of Tropical Cyclone Idai[1], due to the outstanding international and/or non-governmental involvement, the multiplicity of data portals and products increase in quantity. One of the main challenges within emergency assessment indeed, lies at the base of the

[1] Tropical Cyclone Idai has been one of the strongest tropical systems ever occurred in the Southern Hemisphere. Its torrential rain and massive winds' strength caused enormous damages, life losses and missing people, particularly in the countries of Mozambique, Zimbabwe and Malawi at the beginning of March 2019. https://reliefweb.int/disaster/tc-2019-000021-moz

potential intervention and consists in the collection of proper and homogenous data that can be gathered, edit and shared for its multiple purposes.

Starting from personal interest in hazardous events and spatial implications of these phenomena over land and human settlements, I have realized how important it is to have the most comprehensive picture of information and data of any kind, in order to develop the best preparedness possible and be able to act, fast and competently in the case of an emergency. Following a first-hand experience in the Fiji Islands after Tropical Cyclone Josie in April 2018 and Tropical Cyclone Savannah in Indonesia during March 2019, I could see the tremendous destruction that these events bring to lands and to people, tearing down homes, living environment, exacerbating the already at stake resources availability of fragile countries, such as the case of Mozambique indeed. It is after these premises that a new personal stimulus to foster these studies started to grow and found the ideal opportunity a year ago, when a call from the Polytechnic of Turin has been addressed over the post-cyclone strategies for the city of Beira in Mozambique, after it got struck by Cyclone Idai in 2019, destroying 90% of the city (IFRC, 18/03/2019). Objective of the interdisciplinary Master Thesis Lab was the assessment of cross-cutting disciplinary issues such as climate change, hydro-geological risk, resilience, resettlement and reconstruction, aimed at tackling potential adaptative solutions for the city of Beira in regard to hazardous events, otherwise consider possible interventions of relocation.

Meanwhile, the world experienced the coming of covid-19, whose implications have directly affected moving and traveling in between countries. As a result, the development of the master thesis lab, whose initial purpose was an on-site visit to collect information and better understand the context, could not occur. Unfortunately, because of further struggles of actual teamwork, individual research was triggered. In this respect, personal questions started to arise about how to better contribute to the case throughout urban planning and geomatics competences, particularly how to combine this amount of data addressing spatial impacts of the cyclone, hence supporting decision-making and potential future strategies.

One of the main issues outlined in the official reports revealed the difficulties and delays that local and international organizations encountered in the emergency assessment and mostly, in the provision of assistance and primary goods. Giving time allotment due to the urgency of the crisis indeed, only major infrastructural bodies have been considered with the road system analyses. As a matter of fact, one of the main World Food Programme (WFP[2]) analyst, that has been to the site right after Idai, reported a restricted and

[2] World Food Programme is the main humanitarian agency involved in the tackling of global emergencies all over the world to provide assistance in case of natural disasters, conflicts or challenges that create inequalities and poverty. https://www.wfp.org/

somehow limited set of data had to be analysed, so to provide immediate information about the accessibility of the affected areas in regard to the infrastructure system. For instance, this exclusive set of data did not consider many secondary or tertiary roads, usually serving rural areas and farther districts. Moreover, scarce communication and lack of homogeneous data led to the elaboration of independent data gathering and elaboration per clusters, causing delays and data inconsistency.

On these accounts, aim of the current research is the collection of multi-sources and various formats – vector[3] and raster[4] – data within one global geodatabase[5], as a mean to better understand spatial impacts of the tropical cyclone over the whole asset of infrastructural asset and the built environment, and further provide an important tool for ordinary assessment of the city's apparatus.

The collection and spatial analysis have been possible thanks to the availability of *open-source* data particularly by global humanitarian organizations, such as the United Nations Institute for Training and Research (UNITAR[6]) and UN Satellite Centre (UNOSAT[7]), the World Food Programme (WFP) and Red Cross[8]. The new geodatabase also includes local data, assembled from local data sources, such as the Mozambican Data Portal[9], whereas most of the vectoral data has been downloaded from the Humanitarian Open Street Map (HOT[10]) and Open Street Map (OSM[11]) platforms. Concerning satellite data[12] on the other hand, main satellite

[3] Vector data can be defined by a combination of points, lines and/or polygons precisely registered with a pair of coordinates that determine its physical position in the space. https://spatialvision.com.au/blog-raster-and-vector-data-in-gis/

[4] Raster data is the representation in grid of specific values, whose attributes may provide important information or define the visual representation of the surface. A digital photography is the largely known example of a raster data, defined by pixels, namely cells with peculiar attributes for colours. https://spatialvision.com.au/blog-raster-and-vector-data-in-gis/

[5] A geodatabase is the primary data system for ArcGIS software. It can be used to store data, define a hierarchy of the data in regard to the data attributes, edit and manage the data.

[6] UNITAR: UNITAR is the official Institute for Training and Research that has been established by the United Nations in 1963 with the aim of providing UN-Member States the expertise and knowledge to stand the diplomatic environment and develop strategies. https://unitar.org/

[7] UNOSAT is the UNITAR branch for elaboration and production of geospatial data, outstandingly recognized for data analysis through satellite imagery aimed at supporting United Nations objectives. https://unitar.org/sustainable-development-goals/united-nations-satellite-centre-UNOSAT/our-portfolio/unosat-mapping

[8] Red Cross is the independent and neutral humanitarian agency that intervenes in case of emergencies, particularly in situations of was and/or armed conflicts. https://www.icrc.org/en

[9] https://mozambique.opendataforafrica.org/

[10] https://www.hotosm.org/

[11] https://www.openstreetmap.org/

[12] Satellite data corresponds to the geographical representations of portions of the globe with cell values, whom attribute can be

imagery engines have been surveyed, for instance Copernicus Open Access Hub[13] and Earth Observation (EO) Browser[14].

Starting from this ground of information and initial considerations, the new geospatial database has been created as a georeferenced storage of multi-sources data using ArcGIS processing program, as well as for the development of the event damage assessment. For the spatial analysis, the methodology adopted follows the IWG Emergency Mapping Guidelines (International Working Group on Satellite-based Emergency Mapping, 2015) consisting of an overlapping of vector data representing the urban asset - mainly composed by the built environment and the infrastructural system - over the satellite images during the year of the event. Subsequently, in accordance with data intersection outcomes, a first classification of the level of damage has been provided, in line with whether the water extent has completely covered the urban asset, more slightly affected it or rather not encountered it.

The study has also been supported by a detailed analysis over the hazardous events that generate in the so-called Mozambican Channel, located forth the coast of Beira and the district of Buzi. Assumptions that emerged from this inquiry mainly evoke a strong connection between environmental conditions necessary for a tropical cyclone to generate and the effects of climate change, which somehow contribute to the increase in Tropical Cyclones genesis. The country of Mozambique has indeed faced several of these phenomena in its history, therefore a specific timeline has been reconstructed, crossing multitemporal studies and elaborations, and then extra data involving the struck of Cyclone Eloise[15] during January 2021 has been added and elaborated.

The geospatial analysis of Eloise has proved the importance of the proposed geodatabase, able not only to assess a single event, though to work as a global storage for multiple events. This methodology could be implemented with commonly georeferenced multi-sources data of other events, so to create a data history that will help achieving a more comprehensive overview of these phenomena' impacts and further enhance preparedness for potential future scenarios.

The methodology could be easily replicated for other countries and different events, and foster cooperation among countries and global organizations. The same procedure has indeed been recreated for the country of Malawi throughout a parallel project – UP4DREAM - financed by the United Nations Children's Fund (UNICEF), additionally including drones'

[13] https://scihub.copernicus.eu/

[14] https://apps.sentinel-hub.com/

[15] Tropical Cyclone Eloise is one of most recent tropical system that made landfall in Mozambique less than two years after Tropical Cyclone Idai. In January 2021 Tropical Cyclone Eloise made more than 1750.000 displaced people and 11 deaths. https://reliefweb.int/disaster/tc-2021-000008-moz

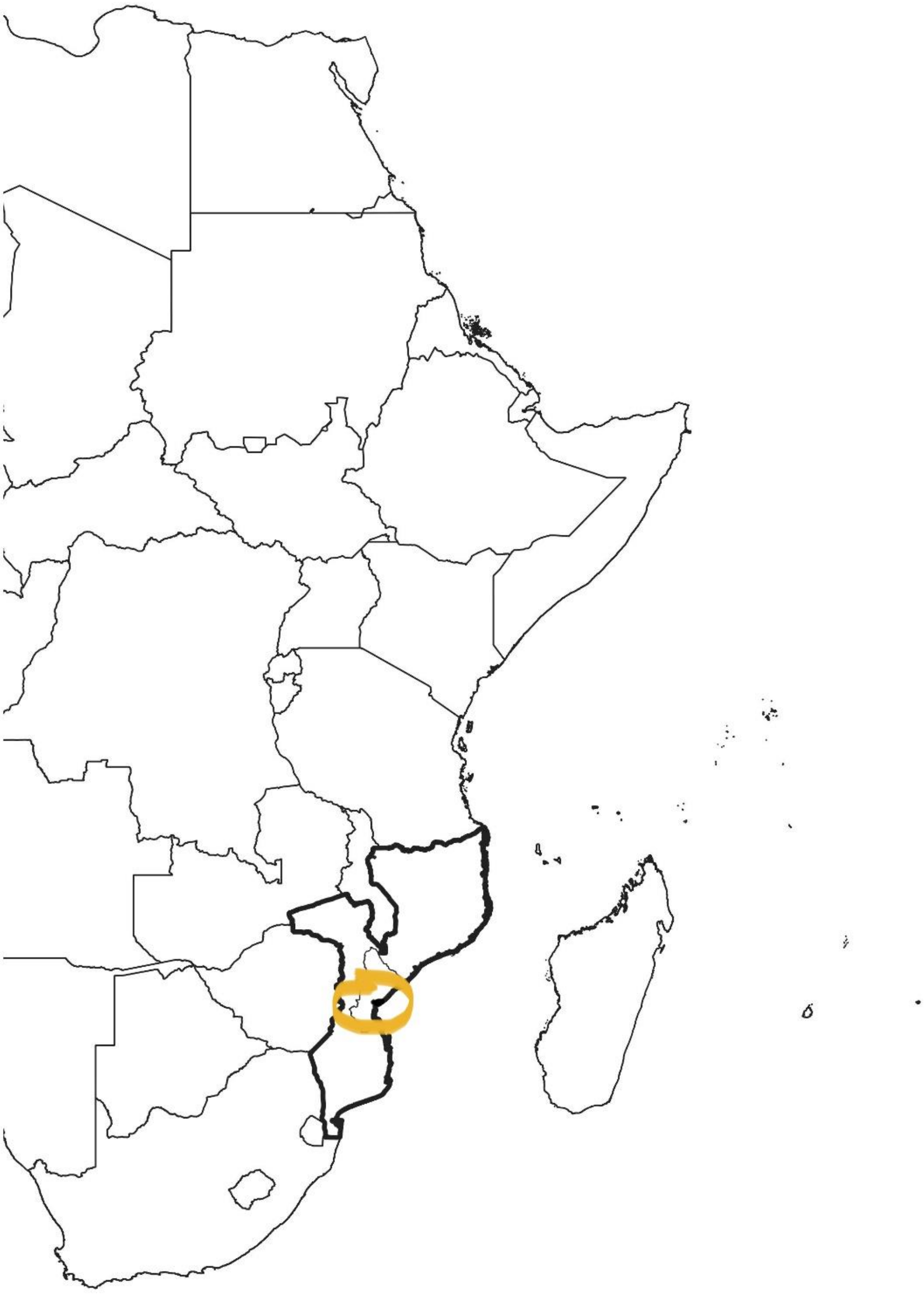
imagery, captured by a special team from the Polytechnic of Turin during an on-field mission, with the aim of supporting mapping and strengthen capacity-building.

Final considerations have then been carried through the interpretation of both geospatial analyses involving 2019 Cyclone Idai and 2021 Cyclone Eloise, unveiling an interesting common result: the devastating impact of these tropical cyclones over Beira and particularly over the informal district of Buzi, southern of Beira.

Despite vulnerability of informal settlements to hazardous events has been acknowledged by many recent United Nations reports (CES Consulting Engineers Salzgitter GmbH, January 2020), further investigations might be undertaken over potential correlation between the informal settlements system featuring the district of Buzi and possible higher exposition to hazardous events. These further considerations might involve comparison between the assessment of natural disasters in other countries and a deeper study of informal practices and their proper configurations.

Final outcomes of this research could help strengthening ordinary mapping and foster preparedness in the case of extraordinary events, throughout a more cohesive storage of data and stronger inter-agencies cooperation.

Figure 1. Localization of the city of Beira within the African continent, 1:5.000.000



Overview of geographical and socio-political context

The following paragraphs will portray a geographical and socio-political overview of the city of Beira, the influences that its intrinsic connotations and its complex historical path had on the question of urban land, therefore affecting the practice of urban planning and land management. For instance, the next sections will deeper explore the correlation between the city of Beira and natural disasters, eventually focusing on one specific area, the Mozambican Channel, whose studies over this theme have been scarcely undertaken and lack of consistent information requires further investigation, especially after the overwhelming occurrence of Tropical Cyclone Idai, whose landfall destroyed 90% of the entire city (IFRC, 18/03/2019).

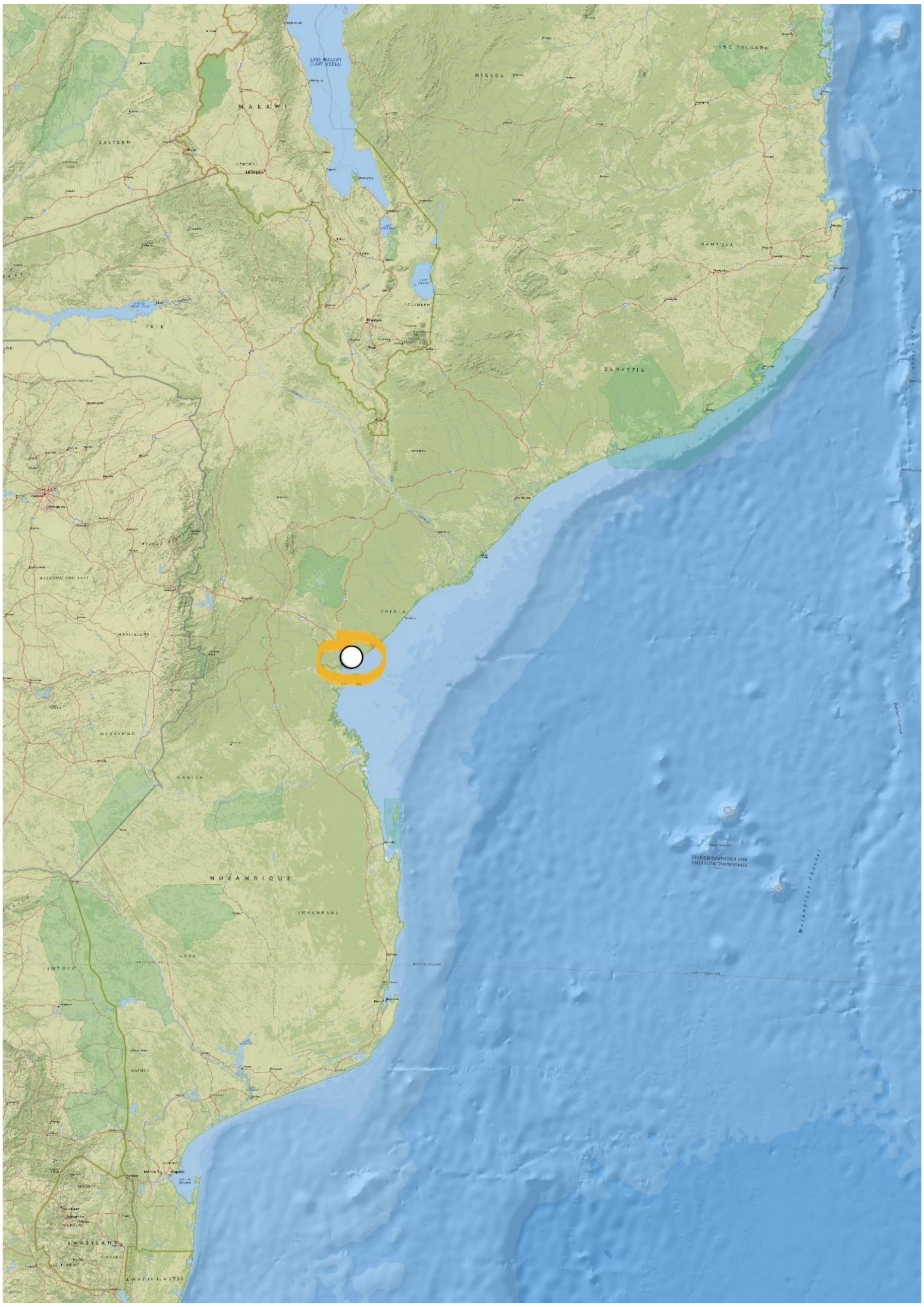


Figure 2. The city of Beira, Province of Sofala, Mozambique, 1:3.000.000

2.1 Tropical cyclones in the South West Indian Ocean

According to the Royal Meteorological Society[16], the Southwest Indian Ocean (SWIO) has been persistently affected by Tropical Cyclones, particularly in recent years, accounting for about 14% of tropical cyclones' global total (Jury, 1993). It has been acknowledged that the usual number of tropical systems occurring in the SWIO basin stands at around 12-13 per year, advocating a long-time devastating impact for the islands and the countries located on the mainland of Africa. In addition, it seems that the Southwest Indian Ocean is exceptionally influenced by spatial and temporal large-scale anomalies, that have been called atmospheric teleconnections. These climate changing conditions have been thoroughly examined in the study performed by Corene J. Matyas in 2015 (Matyas, 2015-03): indeed, one of the research's objectives was the assessment of possible influences and correlations between atmospheric teleconnections and tropical cyclones' formation in the SWIO. These relations will further be explored in the following paragraphs analysing the intrinsic configurations of the Mozambican Channel along with the main peculiarities for the formation of a tropical system within such a context.

On these premises, the city of Beira, second largest and most important city of the Republic of Mozambique, coveys an emblematic example of a climate vulnerable city, deeply affected by tropical cyclones throughout the years, notwithstanding highly expected to be growing in the future.

The combination of these factors along with the growth's expectations then requires deeper studies, especially on whether the city can foster resilience or possibly move more inland (as brought to discussion by the Interdisciplinary Master Thesis Laboratory from Polytechnic of Turin) in respect of the potential recurrence of new and stronger tropical systems. To do so, a first introduction within the city of Beira, its geographic location and configuration, its socio-political background and current state of arts will be developed in the next section. Subsequently, the following paragraphs will introduce the theme of data collection and gathering within a comprehensive geodatabase, with the peculiar aim of creating a reliable source of data from which any actor can draw data from, eventually paving the way for a global database and an historic archive of tropical phenomena and their impacts on the city of Beira.

[16] Royal Meteorological Society: United Kingdom's Professional and Learned Society for weather and climate. https://www.rmets.org/

2.2 Geographical context

Located on the eastern coast of southern Africa, the city of Beira represents Mozambique's second largest city and second most important city after the capital of the country, Maputo (Shannon, Who Controls the City in the Global Urban Era? Mapping the Dimensions of Urban Geopolitics in Beira City, Mozambique, 2019). Bordering the United Republic of Tanzania, the Republic of Malawi and the Republic of Zambia to the North, the country of Mozambique also borders the Republic of Zimbabwe and the Kingdom of Swaziland to the West together with the Republic of South Africa to the South-West. The country covers an area of around 80200 km2 and defines its eastern border on the Indian Ocean, extending a coastline of approximately 2800 kilometres along which the city of Beira situates. Capital of the Sofala province, Beira city is sited at the mouth of the Pungue river facing the Indian Ocean (19.83˚S, 34.84 ˚ E). West of Beira, the Buzi river forms an estuary encompassing the informal district of Buzi flowing along the Mozambican Channel.

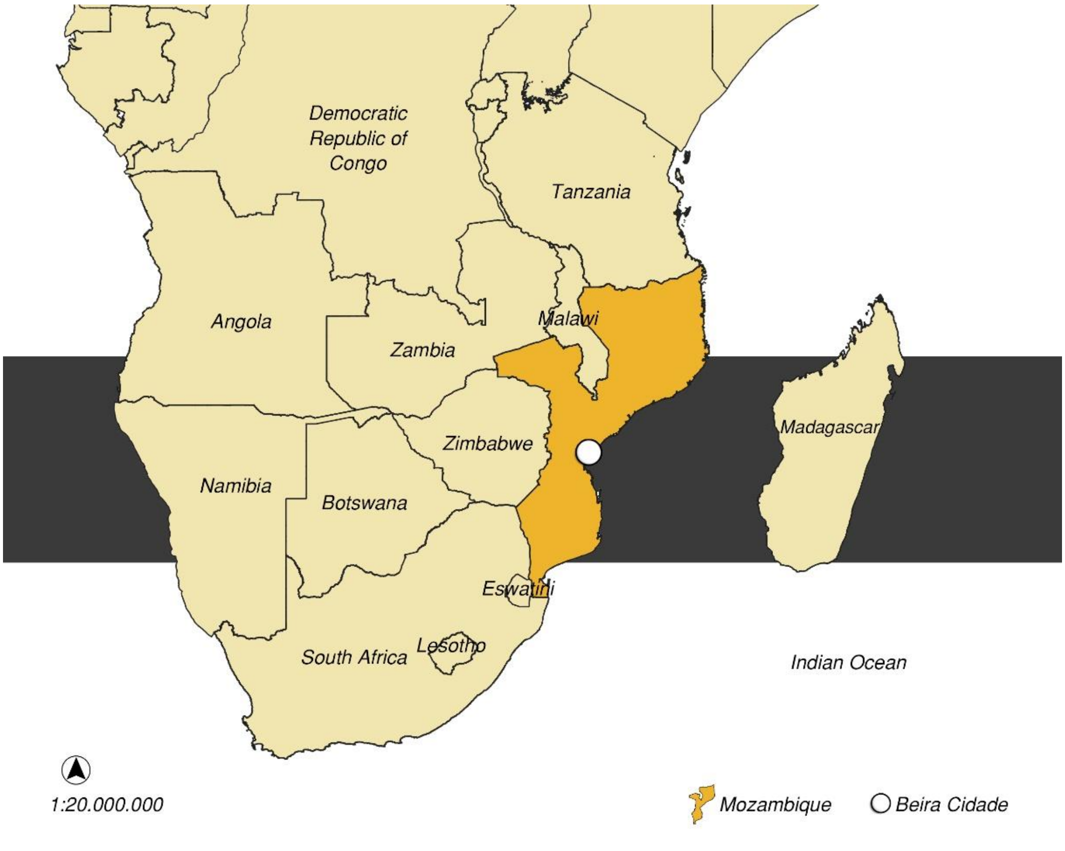


Figure 3. Localization of the country of Mozambique and the city of Beira.

2.2.1 Beira Cidade

Second largest city of the Republic of Mozambique, Beira Cidade, or the city of Beira, constitutes one of the most attractive interchange poles in the trading market of the Indian Ocean. Former Portuguese colony, the country of Mozambique and mostly, the city of Beira is known for its long-time internal fights and complex political debate between ex-communist party and national militant organization of resistance (Shannon, African Urban Development in a Post-Aid Era: the 'Dutch' approach to Urban Restructuring in Beira City, Mozambique, 2019). In the following sections we will see how these historical struggles have influenced the shape of the city and the management of its general resources. Today densely populated with one of the highest rates of poverty in the Global South, the city is further facing important environmental challenges, that are expected to worsen due to the city vulnerability to sea level rise and the growing recurrence of climate hazards, such as tropical cyclones, distinctive phenomena of the area.

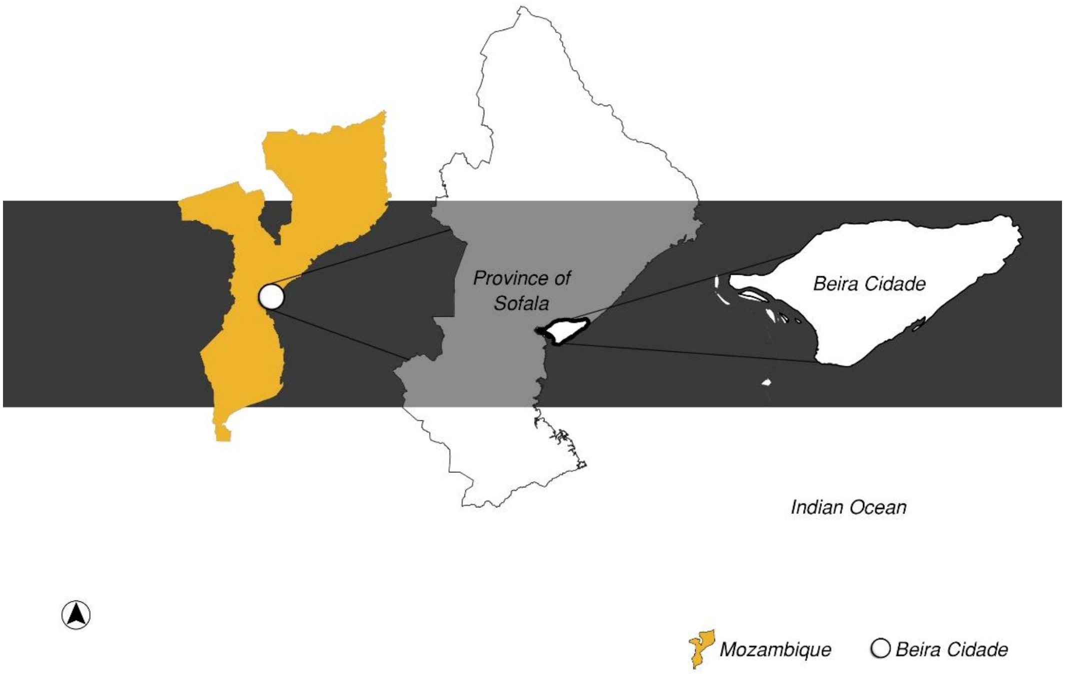


Figure 4. Localization of the city of Beira within the province of Sofala.

2.2.2 Historical overview and the urban land issue

Initially established by the Portuguese in 1887, Beira received its city-status in 1907 as headquarter of the Companhia de Moçambique (Shannon, African Urban Development in a Post-Aid Era: the 'Dutch' approach to Urban Restructuring in Beira City, Mozambique, 2019), a private charter company that at the end of the nineteenth century was leasing concessions to central Mozambique under Portuguese colonial rule. Thanks to the construction of rail, road and pipeline infrastructure that happened in the following years, connecting the city of Beira with neighbouring Rhodesia, the city evolved from a first-born coastal port settlement into a central node in a strategic hinterland corridor, which became later known as the Beira corridor (Shannon, African Urban Development in a Post-Aid Era: the 'Dutch' approach to Urban Restructuring in Beira City, Mozambique, 2019). In 1942 the administration of the city passed from this trading company to the Portuguese government who was at that time a fascist regime with imperialist ambitions that were eventually put in place in the management of the city of Beira; in particular, Portugal New State regime established a racialized dual system which saw the evolution of two different as well social so as spatial categories, identified as the *cidade de cimento* (the city of cement) and the *cidade de caniço* (the city of cane). These two categories of planning the city eventually resulted into two contrasting ways of the city evolution and management of land. The cidade de cimento or cement city was indeed a very planned land which followed colonial rules and adopted Portuguese imported visions of how to develop the city throughout the creation of specific commercial zones and Portuguese-style neighbourhoods. On the contrary, the cidade de caniço or cane city, appeared to be a colonial-free sort of development, preserving native reserves on which indigenous Mozambicans could live; as a matter of fact, the cane city was not served by any planned infrastructure that was serving the cement one and most importantly, indigenous Mozambicans were prohibited from living in the cement city. In addition, the cane city was thus administrated by expressed regulo chiefs as colonials' subordinates in charge of housing, land use and *machamba*[17] management. Mozambique was unfortunately known at that time for the extreme exploitation of workers and imposed labour that came initially with the MC and later with the intervention of Portugal. In response, Mozambique has also been globally known for its strong resistance which led to the creation of the FRELIMO party who long fought for the independence of the country. The Mozambican liberation front established a socialist-based single party state in 1975 after the first independence war and the fascist Portuguese regime being ousted from power, officially drawing the end of

[17] Machamba is a plot of land for the practice of agriculture where mostly women were working (Sheldon, 1999).

Portuguese occupation in 1974. The FRELIMO party then embraced a Marxist-Leninist approach, pushing towards new socialist reforms for the country, which involved the nationalization of land – quite a revolutionary interpretation of property and land, considering that in African urbanism «land is always someone's land» (Shannon, Otsuki, Zoomers, & Kaag, 2018)-. Other socialist-based reforms were addressing the abolition of the previous dual urban governance system, the cement and the cane city, allegedly allowing people to take up residence in former colonial elites. The socialist experiment came to an early end though; a terrible war leaded by the national paramilitary resistance group RENAMO, along with the adoption of sanctions against Rhodesia, contributed to the destabilization of the FRELIMO state and a burdensome economic decline for the city of Beira. The consequences of this period were the condition of standstill of the Mozambican urban planning along with an uncontrolled relevant influx of refugees from surrounding regions, villages and neighbourhoods. The rapid, and quite unexpected, urban expansion that resulted from the war «occurred largely outside the reach of the formal bureaucracy» (Shannon, African Urban Development in a Post-Aid Era: the 'Dutch' approach to Urban Restructuring in Beira City, Mozambique, 2019). Land management was once again a challenging issue to be tackled fast and effectively. In addition, following the fall of the Rhodesian regime in 1980, a South Africa Apartheid regime began, pursuing the war against the Mozambican state. As a result, Mozambique faced an enormous loss of territory getting the attention of international investors and stakeholders that were putting pressure to the FRELIMO state, who eventually allowed a Structural Adjustment Program (SAP) by the World Bank and IMF, signing the upcoming of international deep involvement and investment within the urban land administration, through new reforms, and massive financial inflow specifically aimed at the port rehabilitation and the construction of a true economic hub in the city. Despite the financial investment and economic benefit that was expected for the future of the city, multiple issues regarding urban land management arose again. In particular, despite the nationalization of land remained, more and more areas of the city were being privatized for development purposes through agreements between investors and the state. The FRELIMO party was in fact seeing these changes and interventions as chances to empower the state and reinforce international relations. On the other hand though, the citizens that were previously been able to invest and move to the former cement city, were now being excluded once again. These people were being displaced to the former cane city because of rising property prices along with relevant increases in food prices and wage cuts that were allowing only the international engineers and consultants working on the port and particularly on the rehabilitation of the Beira Corridor, to keep living in these areas.

In 1992 the war eventually came to an end. The costs of the war were devastating: approximately one million deaths and around five million Mozambicans displaced.

The costs of the war were devastating approximately one million deaths and around five million Mozambicans displaced. A period of peace was then established and guaranteed by peace-agreements between the FRELIMO and RENAMO parties, notwithstanding their political rivalries kept lighten up. This tense contrast enabled tangible implications within the city of Beira, which, in opposition to the growth of the FRELIMO-driven capital Maputo, was marked by urban decline and lack of investments. In addition, the two institutional reforms that have been put in place in 1990 with the purpose of rethinking and restructuring the system of urban management and city's governance eventually contributed to highlight the contrast in between the two political factions. Under international pressure, one reform was aimed at privatizing the port operations so to better attract and enable international investment and intervention, while the focus of other reform was on municipality decentralization, with the aim of fostering local power and local authorities. The latter actually paved the way towards a new level of administrative autonomy and culture of politics, that later provided the means to local political actor to reshape and embrace innovative democratic values. Particularly, former RENAMO major of the city, Daviz Simango[18], after being removed from RENAMO's candidacy because of internal threats, pursued running and eventually created a new political party: Mozambique Democratic Movement (MDM). The Democratic party found great support from Western donors; an important coalition that was not well-seen by long-time collaborator FRELIMO party. Nevertheless, MDM kept on winning subsequent municipal elections in Beira in 2013 and in 2018, strengthening ties with international stakeholders with the city of Beira becoming a massive recipient of economic international investments. Daviz Simango became mayor of the city of Beira in 2003 and remained in charge until the day of his recent death in February 2021. Simango was indeed mayor of Beira during the landfall of Tropical Cyclone Idai, which destroyed the city. Simango was known for being a man of the people and his contribution towards neighbourhoods' protection, climate change issues and his first-hand aid on field right after the cyclone's emergency will stay in the memory of the city.

Following this tragic event, the Mozambican law allows a member of the municipal assembly of the party in charge to take the office. For instance, former MDM councillor for construction and urbanisation Albano Carige became mayor of Beira after a seventeen-years term of the Simango's term.

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[18] Mr. Simango has been the mayor of Beira from 2003 until his death in February 2021. Considered one of the pioneers in the fight to global warming and long-time President of the Democratic Movement of Mozambique (MDM).

2.2.3 Urban planning and practices of «laissez-faire» in land management

Largely supported by Western companies, Mozambique was embracing a spontaneous mode of «laissez-faire» land politics (Shannon, African Urban Development in a Post-Aid Era: the 'Dutch' approach to Urban Restructuring in Beira City, Mozambique, 2019), which was allowing many activities to take place without a framework of rules or designated land regulation. Truth is the aforementioned sort of framework did not exist yet. For instance, the lack of regulation enabled a massive exploitation of land by private companies and investors in the late XIX century (ibid.). Because there was no land use destination or formal allowance of agricultural activity –main Mozambicans' source of income- no implementation of these rules could been put in practice. As a consequence, inhabitants of Beira arose against the ambiguous planning system and chiefly against an obvious elitarian favouritism. As a result, a new national law was established, with the aim of introducing legal parity in between land use titles, namely DUATs (Shannon, Otsuki, Zoomers, & Kaag, 2018), notwithstanding customary means acquisition, cadastral allocation or last, a ten-year land occupancy – which is the minimum amount of time taken into consideration for good faith occupancy-. Despite such an important step ahead on the regulative front, the administrative side still appeared quite behind, showing no improvements until a decade later, when the administrative capacity was properly addressed thanks to 2008's urban land regulations. The introduction of urban planning practices was for instance a way to formalize good-faith occupancy, which eventually became the main form of land use in accordance with the municipality capacity. In this regard though, the role of municipality remained quite negligeable in urban land governance. Therefore, the persistent ambiguity within the land use rights and actors in power, in addition to the multiplicity of contradictions eventually created a hostile territory for the majority of urban land users, uncapable of legitimizing their rights under these conditions.

The type of strategies adopted by the municipality of Beira to advise land use and regulation eventually became intitled as a practice of "state-avoidance" (Shannon, African Urban Development in a Post-Aid Era: the 'Dutch' approach to Urban Restructuring in Beira City, Mozambique, 2019), summing up the previously mentioned «laissez-faire» kind of approach that was undertaken within the city. Thus, a considerable number of 'informal' practices (Shannon, Who Controls the City in the Global Urban Era? Mapping the Dimensions of Urban Geopolitics in Beira City, Mozambique, 2019) kept growing and spreading all around the city. These practices were far from being illegal forms of land use; on the contrary, these forms became referenced as spatial configurations of 'alternative formality' (Shannon, Otsuki, Zoomers, & Kaag, 2018) socially legitimized. Moreover, the combined nature of these practices was indirectly supported by the shadow of so-called 'twilight' institutions (Ibid.). Nevertheless, from a legal perspective the social legitimacy of these 'alternative formality' practices does not authentically constitute a legal legitimacy for the urban land governance system. For this reason, the concept of these alternative practices formally remains illegal, as strictly dependent on the private sale of land.

2.2.4 Climate

Because of the low elevation and proximity to the Indian Ocean, nearby Pungwe river, the city of Beira is known for its extreme vulnerability to flooding and tropical storms, earning the title of «Mozambique's most climate vulnerable city» (Shannon, Who Controls the City in the Global Urban Era? Mapping the Dimensions of Urban Geopolitics in Beira City, Mozambique, 2019) and «one of Africa's most climate vulnerable cities» (Shannon, Otsuki, Zoomers, & Kaag, 2018). Particularly speaking about climate and precipitation, the city is characterized by tropical wet and savanna type of climate, identified by the Köppen-Geiger climate classification with the abbreviation "Aw", recalling a broad dry season – consisting of an average less than 60mm/month of precipitation during the driest month – and a mean of no more than 2500 mm/month (Morón, 2014). These information, average monthly climate data and average monthly precipitation data, are recorded respectively inside a 17-year history dataset and a 82-year dataset (ibid.).

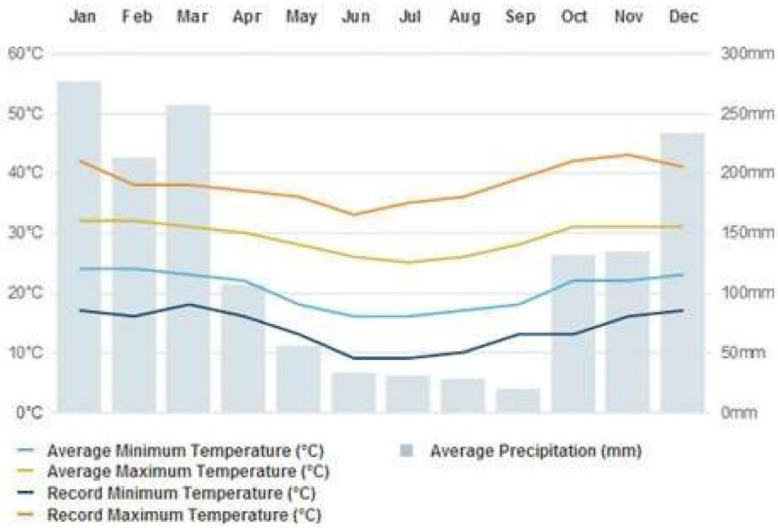

Figure 5. Maximum and minimum average temperatures and precipitation in Beira; source: Beira Urban Water Master Plan 2035.

Month	Jan	Feb	Mar	Apr	May	Jun
Avg. high [°C]	32	32	31	30	27	28
Avg. low [°C]	24	24	23	22	19	18
Avg. precipitation [mm]	272	210	259	103	62	32
Month	Jul	Aug	Sep	Oct	Nov	Dec
Avg. high [°C]	25	26	28	31	31	31
Avg. low [°C]	16	17	18	22	22	23
Avg. precipitation [mm]	30	28	21	117	119	240

Figure 6. Average maximum and minimum temperatures and precipitation in Beira; source: Beira Urban Water Master Plan 2035.

These containers of data have been fundamental instruments for the thinking and making of the latest 2035 Beira Master Plan, designed in collaboration between the Municipality of Beira, Deltares[19], NIIRAS and the Dutch engineering and consultancy firm Witteveen+Bos[20]. The plan follows a precedent short-term strategic plan that was put in place by the Municipality of Beira in 2010; the collaboration between the city of Beira and a variety of national and international actors has been fostered among the years exploring and addressing different themes, as that of climate change and systems of early warnings that will be largely discussed in the following subchapter.

2.2.5 Main planning instruments to address climate change

Because of its geographic position, its topography and the multitude of climatic events that happened through the years, the city of Beira, along with some key government agencies and international development stakeholders, identified and included many strategies aimed at tackling climate change throughout its plans (Ministry of the Foreign Affairs of the Netherlands, 2018). One of the most important plans designed to address climate change is notwithstanding The Pilot Program for Climate Resilience (PPCR) (Bank & OpenEI, 2017) approved in 2008 under the Strategic Climate Fund (SCF[21]). The program is about strategies and possible ways on how to integrate climate resilience inside planning instruments and development projects. For instance, these indications are given at a national level and can be later integrated at different scale (Ibid.), depending on the country' features and measures. Nonetheless previous strategies have been examined and intermingled throughout plans and programmes:

[19] https://www.deltares.nl/en/projects/beira-2/

[20] https://www.witteveenbos.com/

[21] The Strategic Climate Fund consists one of the two main funds established throughout the Climate Investment Funds (https://www.climateinvestmentfunds.org/) leant to address programmes and sectoral actions dealing with the challenge of climate change.

- 2006-2009 The Action Plan for the Reduction of Absolute Poverty (PARPA II), whose main focuses included the consolidation of a culture of prevention, the development of the country's capacity building, so to provide means for prevention as well as for mitigation of climate risks and, eventually, the reduction of human victims and property loss.
- 2007-2012 National Adaptation Plan. An innovative plan to deal with emergency preparedness by «strengthening early warning system» (MICOA, 2007), introducing new activities which include «mapping vulnerable areas, identifying alternative areas for reallocation and creating evacuation channels in case of calamity» (Ibid.). The plan also addresses the transfer of information among local communities by adapting these information to more traditional means of communication, closer to the disseminative ways which belong to the community. This new highlight towards mapping of potentially at-risk areas – notwithstanding flood risk, erosion-prone risk and so on- further advocates the creation of early warning system models based on the analysis of nature behaviour and the development of mitigation measures. The plan finally encourages discussion aimed at raising awareness, examine examples of good practices and inspire the making of new strategies that suit specifically the city of Beira, its coastline and its connotations.
- 2010-2014 The Five Year Development Plan aims at carrying on PARPA II objectives addressing climate change and disaster risk reduction through an enhancement of the information system to strengthen capacity building and disseminate disaster risks preventive and mitigating information among local communities. Final goal is the depletion of life losses and the saving of essential resources, such as water saving to reduce hunger and water scarcity – especially in more rural areas -.
- 2011-2014 The Action Plan for Poverty Reduction (PARP 2011-2014); this particular plan does pursue the previous PARPA II goals of climate prevention and mitigation, though adding a specific new target: that of droughts and floods mitigation as a mean to reach not only a reduction in climate vulnerability but also an improvement in the poverty percentage from approximately 54% at the end of 2008 to 42% in 2014. The Government of Mozambique further encouraged sustainability through national economic activities, particularly within the agricultural domain, primary source of income for most of the population, such as fisheries and farming, by charging the Ministry of Agriculture (MINAG) of the progress' lead.
- 2013-2025 National Strategy for Climate Change and Mitigation and Adaptation. Following the Government's approval of the Gender,

Environment and Climate Change Strategy and Action Plan in 2010 (Macamo, 2021), the interested strategy shares and seeks the same objectives envisaged by the Action Plan: prioritizing the usage of new technologies in the study of prevention and mitigation, improving response capacity by providing a more inclusive and accessible participation of both men and women within the protection and management of natural resources.

- 2014-2035 Beira Master Plan. Subsequent the acknowledgements and strategies that have been undertaken throughout the years, at local level, the municipality of Beira along with some private partners has developed the 2035 Beira Master Plan (Weelden, 2013), which focuses on multiple issues affecting the city: first of all, the port accessibility, the management of goods' flow, the extension of the infrastructural system to support an implementation of the industrial sector, the restoration of urban ecosystems and buffering of flood-at-risk areas, the enhancement of urban resilience of these flood-at-risk areas so to guarantee development also inside these areas, and last, the strengthening of coastal defence. Because of its strategic location, the port of Beira represents a turning point within international trade market. It directly welcomes goods from the African hinterland, including Zimbabwe, Botswana, Zambia, Malawi and the Democratic Republic of Congo, as well as grasping the interests of the main markets of international trade firms and routes. Finally, the plan aims to tackle the issue of climate change through urban planning, a better management of water and a more integrated system of infrastructures as an effective service. The latter indeed has brought the attention to the need for an improvement also of the sewage and drainage system, not only to ameliorate the ordinary drainage system, though to supply an approach of mitigation for potential floods or inundations and alleviate health hazards for the people of Beira.

As depicted in the section above that states main urban plans addressing climate change and main challenges for the city of Beira, it is possible to detect the leading and deep-rooted presence of national and international actors, both in the making as well as in the application of main plans. This collaboration is fundamental for the Republic of Mozambique in order to share knowledges, generate capacity building and provide support on how to tackle climate change and address specific urban challenges, chiefly when the city is struggling with unprecedent situations. As previously mentioned, the city of Beira is particularly prone to natural disasters (CES Consulting Engineers Salzgitter GmbH, January 2020), therefore requiring humanitarian participation for the occasion. Nevertheless, the support, hence inclusion of multiple stakeholders within the process of emergency can generate confusion and misunderstandings, especially when dealing with way more serious situation, such as that of latest Beira's strongest hit, Tropical Cyclone Idai. The joint of forces and expertise is therefore essential, particularly in a context that is most likely to be affected over again by natural hazards. The vulnerability of Beira is hence outlined throughout a consistent number of studies and monitoring, whom gap is mainly around one key phenomenon: the ideal conditions for tropical cyclones' genesis in the portion of Indian Ocean that faces the coast of Beira. This oceanic wedge has been identified with the name of Mozambican Channel, whom timeline of tropical cyclones has been created in the following sections.

2.3 Beira exposition to natural hazards: the Mozambican Channel

In the Southeast Africa, between the countries of Madagascar and Mozambique, an arm of the Indian Ocean covers about 1,600 kilometres and 419 km at its narrowest point, with a 3,292 meters depth and about 230 km off the Mozambican coast (Britannica, 2018). This arm eventually received the name of Mozambican Channel (MC) because of its dominant role in the XIX century trading system within the Indian Ocean and to East Asia and the Western world (Bergeron, 2014), and thank to the strategic location and uncontrolled maritime traffic along the port of Beira. Before the opening of the Suez Canal in 1869, the Mozambican Channel was playing a central role in the shipping trades between Asia, Europe and America. The artificial waterway created for the Suez Canal running across the Isthmus of Suez in north-eastern Egypt replaced the main shipping lanes that used to be under the Mozambican Channel control. Constant political instability in Egypt together with the militants' attack to the Suez Canal in 2013, whose vow was to conduct similar attacks in the future – which might involve shipments disruption, vessels' sinking, or even the obstruction of the canal and its trades for an undefined period of time – thoroughly affected the reliance of the trading system provided by the Suez Canal (Starr, 2014). Consequently, the Mozambican Channel slightly regained its status as an important chokepoint (Bergeron, 2014) entailing international maritime attention for the assurance of commercial and shipping security.

Besides, the gigantic hydrocarbon hub more recently acknowledged in East Africa, has received worldwide attention. In particular, the natural gas supply offshore north-east Mozambique and south-east Tanzania, estimated over 100 trillion cubic feet, has been defined as one of the largest gasses dispense in the world (Ibid.). The gas resources in Mozambique, Madagascar and Tanzania constitute a huge attraction for European countries – not only - that are now still attached, therefore dependent, to the Russians' gas provisions. This massive source of natural gas could solve petrol's economic dependency from Russia, though it might foster tensions between the old supplier and the new ones, creating new power dynamics. Not to mention the environmental costs of these potentially new gas excavations. Despite global commitment in the environmental crisis indeed, some energy firms keep holding massive investments offshore; regardless their choice to move to Liquified Natural Gas (LNG), which represents today the cleanest fossil fuel resource, it is still and all an emitter of carbon dioxide in the burning process and slow down the switch towards sustainable energy resources.

Additionally, the absence of maritime regulation in the port of Beira and control over the Mozambican Channel has attracted also and foremost illegal traffics, including trafficking of drugs and people. Unregulated fishing (IUU) too, is deeply affecting the managing of the maritime traffic and deeply affecting the oceanic ecosystem, letting the fishing of tuna at a dangerous level. This way of operating all over the port and waters of Beira, does not derive from a commonly developed and approved strategy, whereas it is the result of budgetary assessment for maritime security.

This set of environmental, economic and strategic issues define a precise context, the Mozambican Channel, in which, together with the hazardous exposure given by the geographic and morphological conformation of the area, contribute to increase the fragility of this territory while exposing it to potentially devastating hazardous events, already experienced in the past, as we will see in the chapter below.

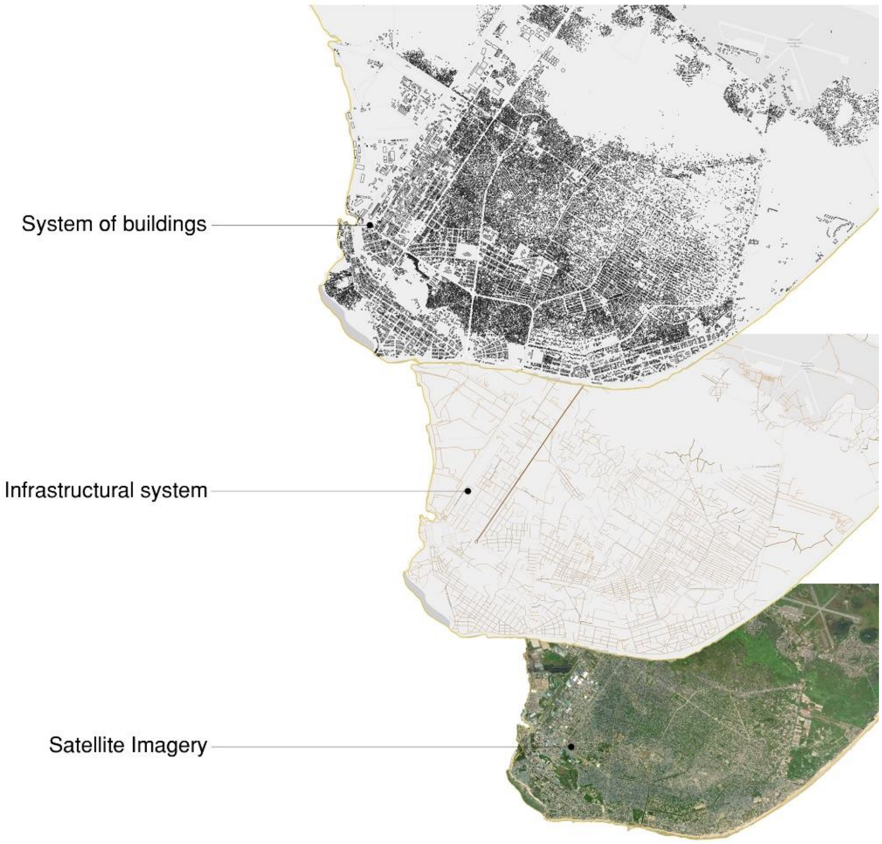

Figure 7. Layers' subdivision of Beira CBD facing the Indian Ocean; from the bottom to the top, actual Satellite acquisition of the city, OSM vector data showing the infrastructural and buidings' assets.

2.3.1 Tropical cyclones' timeline in the Mozambican Channel

As mentioned above, it is important to assess the environmental, social and political context, so to better understand the circumstances under which and where the Cyclone occurs. Another fundamental element to foster at this

point, is the recurrence of this particular event in the country of Mozambique, more specifically in the Mozambican Channel.
Studies over this topic are not many, because, as mentioned in the previous chapters, not all cyclones are supposed to make landfall; therefore, the majority of the analysis carried over tropical cyclones in this area take into consideration mainly events that actually make landfall (Klinman & Reason, 2008) or do not separate the tropical systems that do form in the Mozambican Channel from those passing through, whose generation comes from elsewhere (Mavume AF, 2010). For this reason, the timeline that will be discussed in the following paragraph will use the results achieved from one of the most recent and complete research (Matyas, 2015-03) carried over the Mozambican Channel. This study encompasses data from 1948 – year of first data availability - until 2010, importing data from the Regional Specialized Meteorological Centre (RMSC) at La Reunion, adopting specific techniques (Kruk MC, 2010) to combine GIS data and track cyclones. Moreover, as in 1979 infrared satellite imagery became available resulting in a more accurate observation, therefore assessment, of tropical cyclones in the SWIO, the analysis period has been divided into two different periods: **Period 1** collecting data from 1948 until 1979 and afterwards **Period 2** with data starting from 1980 until 2010. Therefore, it has been suggested that data obtained prior 1979 is cautiously interpreted. In addition, the breakpoint between the two periods roughly corresponds to the Indo-Pacific region climate change middle 1970s (Ash KD, 2012) and has been supported as a proper breakpoint thanks to the Mann-Whitney *U* tests (Mann H.B., 1947) that have been performed implementing all the variables concerning teleconnections and environmental conditions' relationship; it has eventually been confirmed also from Kruskal-Wallis tests (Kruskal W.H., 1952) among variables that consider median values of tropical systems' formation, categorical chi-square tests (Wilks, 1995) focusing on the frequency of the event's formation, and finally Spearman's rank correlation coefficients (Zar, 1972) examining the tropical system's attributes during its formation.
The results of the presented study eventually show that throughout 1948 and 2010, 94 Tropical Cyclones formed in the Mozambican Channel. Although the analysis conveys a medium of 1.5 TCs occurrence per year, it is also true that almost eleven years did not experience TCs' formation. On the other hand, further eleven years underwent more frequent and stronger tropical systems. The study eventually show that 54 Tropical Cyclones formed during Period 1, while Period 2 saw the formation of 40 TCs characterized by higher intensity, speed, and more curved trajectories. From the total number of tropical systems that occurred in the defined period, roughly half of them actually made landfall. Despite differences among the two periods, final remarks underline the increase in frequency, intensity and manifestation of Period 2 events. For this reason, it is fundamental to keep studying these

events and make attempts on finding similarities so to better understand and eventually predict, future scenarios.

This study has been not only an essential source of information, though, by pointing out the weaknesses and gaps of tropical cyclones research in the Mozambican Channel, it marked potential further explorations for the current research, whose aim will then be not only the damage assessment of Cyclone Idai in 2019, though the carrying on of the presented analysis, via the collection and elaboration of data from 2010 until 2021.

Beira's «strongest hit»: Tropical Cyclone Idai

3.1 March 2019, Cyclone Idai

On the 14th of March 2019 Cyclone Idai made landfall nearby the city of Beira, affecting the coastal city along with the southern districts of the province of Sofala. As discussed in the previous chapter, tropical systems are not new in the history of Mozambique, notwithstanding the country is facing a new contingency of the hazardous events. Because of climate change, the frequency of tropical cyclones is becoming more common, with a stronger intensity and moved towards the southern side of the country, where the city of Beira is located.

The cyclone's tracks that have been monitored in the days of the event occurrence proved that the previous hazardous events had somehow prepared the path to the upcoming of Idai (Kolstad, October 2020). Usually, strong winds are the most threatening feature and prevision of a tropical cyclone.

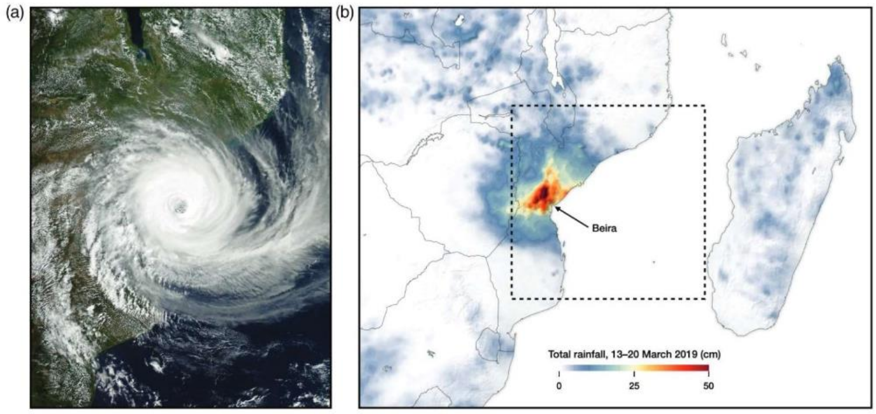

Figure 8. (a) NASA Satellite image of Idai at 11:35 UTC 14 March 2019. Source: Kolstad, Prediction and Precursors of Idai and 38 other tropical cyclones and storms in the Mozambican Channel. (Wikimedia Commons 2019). (b) Total rainfall estimation between 13 and 20 March 2019, based on NASA's imagery. Source: ibid, (NASA, 2019).

To a similar extent, water can be as dangerous as wind, if not worst. Waves and storm can indeed surge coastal inundation, while heavy rainfall can aggravate inland flooding through riverine flooding (T. Jurlina, 2019). The combination of strong winds and heavy rainfalls can thoroughly become devastating. That is why forecasts studies are so important, especially in the prevision of phenomena that might evolve in disasters with the aim of preventing human suffering and losses of all kinds (E. Coughlan de Perez, 2016). Early 2019 indeed, tropical storm Desmond made landfall roughly 200km north of Beira, marked with a wind speed of 65 km/h lasting a maximum of ten minutes according to the Météo France wesbite[22]. Despite the intensity of winds was not that significant with Desmond, the storm brought important rainfall that caused initial flooding over the region that would have later been affected by Cyclone Idai. Another tropical depression then hit Mozambique early March 2019, leading to consistent flooding across central Mozambique and southern Malawi. The storm initially involved mainly the country of Malawi, reaching dangerous water levels along the rivers, and subsequently moving back to Mozambique on the 9th of March. On the 12th of March Idai was confirmed a Tropical Cyclone as a category 3 storm, meaning extreme danger caused by a range of winds between 178 and 207 kilometre per hour (National Hurricane Center and Central Pacific Hurricane Center, 2021), as its wind speed was registered with 195 kilometre per hour for a maximum of uninterrupted ten minutes of winds. Despite the landfall quickly weakened, Cyclone Idai kept moving inland, resulting in continuous rainfall for several days that caused widespread and devastating flooding in central Mozambique, particularly alongside the rivers of Pungwe and Buzi. According to national hydrological bulletins, water levels started to arise on the 15th of March. Main considerations of the event

[22] Météo France La Réunion main provider of daily updates in respect of tropical cyclones formation within five days. It further generates cones of potential track area, based on the forecasts and the tropical system's expectation of intensity. http://www.meteofrance.re/cyclone/

and the following rainfalls that caused, include the intense and rapid extension of rivers' waters between the 14^{th} and the 19^{th} of March, as well as the remarkable slowness of water recession, that stagnated in the flooding from the event occurrence until the 6^{th} of April. The acute waters level arises overcame the normal level of waters of more than three meters, while its recession was registered with a rate of ten centimetres per day. The waters persistence over the area had further implications aside from the floodings damage per se, that is the cholera outbreak that eventually affected more than 6700 people in the province of Sofala (Africa, World Heath Organization, 2019). Reported issues in the communication afterwards state difficulties in the definition of the waters level peak. Mozambique was therefore being put at a stake from Cyclone Idai, meanwhile another tropical system was about to hit the country no more than six weeks later. On the 25^{th} of April 2019 in fact, Cyclone Kenneth made landfall in northern Mozambique, exasperating an already extreme living condition of the country.

Loss of human lives, loss of natural resources, disease outbreak, buildings and infrastructural damage and a further economic instability were the consequences of Cyclone Idai happening in the city of Beira. The humanitarian crisis that the Cyclone caused will be developed in the current study through a geo-spatial territorial analysis, aimed at understanding the actual impacts of the event over the area, its level of damage over the built and infrastructural asset including the informal settlements of the Buzi district, in the south of Beira, where the flooding has been descripted as an open-air lake.

3.2 Humanitarian and international involvement during Idai Tropical Cyclone

As previously anticipated in chapter number 2, international collaboration is essential when dealing with extraordinary events such as that of the occurrence of a tropical cyclone. Therefore, we are all quite considerably aware of the benefits that convey this sort of collaboration. According to an important evaluation (Baker, Dr. Nichols, & Afonso, July 2020) that has been drawn in 2020 by an exceptional team of expert in the emergency management, points of strength have been highlighted, showing the great assistance that has been provided by international organizations; nevertheless, a central point has been captured by a detailed interrogation concerning the weaknesses, the gaps, that this collaboration, their interconnections, the collection of data, hence the sharing of data, might have had during the process. For the purposes of the investigation, the Inter-Agency Humanitarian Evaluation (IAHE) involved major actors that intervene on the field, in addition to those who, remotely or on site, handled the collection of data and the whole emergency assessment. These actors comprehend members of the World Health Organization (WHO[23]), of the International Organization for Migration (IOM[24]), of the United Nations International Children's Fund (UNICEF[25]) and of one of the main data collectors, the World Food Programme (WFP), with the aim of better understanding the modalities and interrelations that occurred in the assessment of Tropical Cyclone Idai. Government authorities, United Nations' agencies, bilateral donors, the International Federation of Red Cross and Red Crescent Societies (IFRC), private actors, national and international clusters and eventually people directly affected by Cyclone Idai have been counted in. This examination can be considered a very much comprehensive tool to analyse strengths and weaknesses of humanitarian cooperation during Idai, throughout interviews, the data investigation, and on-field visits that have been undertaken during the collaboration's activation period.

In the case of 2019 Idai, the Government of Mozambique (GoM) <<declared a National State of Emergency on the 19th of March 2019>> (Bergeron, 2014) (Emerton, Cloke, & Ficchi, 2020) asking for international support. The appeal brought to the activation on the 22nd of March, from the at-the-time Emergency Relief Coordinator of the United Nations Office for the

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[23] The World Health Organization (WHO) is the United Nation agency working with international partners from all over the world, mainly focusing on challenges that address health and health coverage. https://www.who.int/

[24] https://www.iom.int/

[25] UNICEF is the United Nations agency primarily focusing on the rights of children from all over the world, protecting their lives and promoting a fair education for all children, helping them developing and achieving their full potential. https://www.unicef.org/

Coordination of Humanitarian Affairs (OCHA[26]) of the emergency collaboration. The mission remained active until the 30th of June, following many tight challenges, such as the manifestation of another tropical cyclone, Kenneth, which occurs in the northern part of the country only six weeks after the occurrence of Idai. Furthermore, at the time of Idai's landfall, the city of Beira and the southern district of Buzi were already struggling with food insecurity (Ibid.) that international organizations, such as World Food Programme (WFP) (Vornic, 2019) was trying to keep up with and was undertaking multiple actions to monitor and support the crisis. During Idai, the Humanitarian Country Team (HCT) of Mozambique along with the National Institute for Disaster Management (INGC) were in charge of the executive coordination for the disaster response and disaster risk reduction. The overall approach that this global collaboration provided to the cyclone resulted in an overall acceptable response. Mainly WFP, Red Cross and the Logistic Cluster of the United Nations were in charge of the collection of data. Whereas main activities on field were the result of a combined action between national authorities, such as INGC, and primarily non-governative agencies. According to the Inter-Agency Humanitarian Agency (IAHE) it can be acknowledged that the initial intervention of the joint forces has indeed been relatively prompt. The adopted methodology namely the Scale-Up intervention (Baker, Dr. Nichols, & Afonso, July 2020) encompassed a mixed intervention, whom tasks were combined and timely activated to provide immediate assistance to the 1.85 million of people that were in need (Ibid.). One of the main issues that have been undertaken was the actual possibility to reach the most affected communities in areas that were highly difficult to reach; mainly because of the hard accessibility of these areas, sorely tried by the extreme weather conditions including the heavy rains that followed in the subsequent days (Emerton, Cloke, & Ficchi, 2020).

This multi-later intervention further aimed at consolidating the power of the National Institute for Disaster Management (INGC) by aligning inter-agency forces towards one common goal, fostering INGC in the strengthening local government figures' capacity and supporting the process of decision-making, whose competence is undoubtedly Government's competence. In between though, there are many decisions to be undertaken while providing assistance on the field that we will later investigate better in the following section about WFP experience on the ground. For instance, the Scale-Up activation was effective, especially in the management of the crisis the consequent the occurrence of the cyclone: the health crisis through the outbreak of cholera, the urgent need for food and water supply, the prevention of sexual exploitation and abuse among affected communities and

[26] OCHA is the main United Nations agency in charge for the coordination of global emergencies, particularly in the occurrence of natural disasters. https://www.unocha.org/

the need for rapid solutions on whether to allocate displaced people (UNICEF, 2019).

One of the main actors involved in the assessment of Cyclone Idai has been one of the most important and recognizable branches among United Nations, hence the UN Children's Fund, whose major variety of projects that were being handled during the emergency were addressing many different issues: Health, Nutrition, Education, Child Protection, Social Protection, Communication for Development, Prevention of Sexual Exploitation and Abuse (PSEA[27]) and WASH[28], a project focusing on water sanitation and accessibility.

End of 2019, the UNICEF released an overall report (UNICEF, 2019) summarizing the activities along with final outcomes and considerations of their intervention in Mozambique from January 2019 until December 2019. In this document key information regarding each mission are provided, with details concerning final results, number of people that have been reached, with a particular attention to children and finally, also main issues and overall obstacles that have been encountered.

	Cluster/sector Response				UNICEF and IPs			
	Cluster target (Mar 2019-May 2020)	Cluster Result (Mar-June 2019)	Cluster Results (Jul - Dec 2019)	Change since last report ▲▼	UNICEF target (Mar 2019-May 2020)	UNICEF Result (Mar-June 2019)	UNICEF Results (Jul – Dec 2019)	Change since last report ▲▼
WASH								
People with access to sufficient quantity of safe water	1,558,000	872,000	305,837	▲65,837	978,000	658,000	154,065	▲27,065
People with access to appropriate sanitation facilities and receiving hygiene messages	1,247,000	561,000	372,691	▲353,091	439,000	227,000	136,934	▲32,934
Families receiving point-of-use water treatment & purification materials / products	380,000	245,000	54,713	▲11,713	156,000	88,000	36,028	▲28
Health								
Children aged 6 months to 15 years vaccinated (Measles/Cholera)[7]					620,000[8]	673,614[9]		
Children vaccinated DPT3					244,700[10]		35,334	▲20,619
Pregnant women 15-49 living with HIV receiving ART					24,400	4,138	4,208	▲2,477
Children under-five receiving a consultation					761,796	327,280[11]	343,072	▲187,371
Nutrition[12]								
Children 6-59 months screened for acute malnutrition	1,107,967	606,067	96,049	▲22,665	993,082	559,208[13]	81,770	▲8,386
Children 6-59 months receiving routine Vitamin A supplementation	501,900	408,772	47,954	NA	407,000	408,772	47,954	NA
Children 6-59 months admitted for treatment of SAM	5,600	2,212	822	NA	5,600	2,212	822	NA
Pregnant and lactating women reached with IYCF services	307,500	341,318	83,539	▲14,214	270,947	341,318[14]	79,596	▼256,806[15]

Figure 9. (a) Table showing the summary of Programme Results. Source: Unicef, Mozambique Humanitarian Situation Report n.15.

[27] https://agora.unicef.org/course/info.php?id=7380

[28] https://www.unicef.org/mozambique/en/topics/water-sanitation-and-hygiene

Education								
Children aged 6-15 years old in humanitarian situations accessing education	506,468	123,751	20,991	▲5,863	239,497	72,497	31,435	▲3,666
Children aged 3-5 years old in humanitarian situations accessing play-based learning	62,744	5,344	57,388	▲47,245	38,344	5,344	6,280	No Change
Child Protection								
Children receiving psychosocial support through Safe Spaces	123,648	31,412[16]	19,481	▲17,554	44,725	13,771[17]	17,770	▲15,998[18]
People (re) issued with birth registration documents					105,000	60,612	12,000	No change
People receiving information on prevention of and response to violence, abuse and exploitation, including GBV and SEA					160,000		65,999	NA
Separated and unaccompanied children are identified and are in family-based care or an alternative care	100% target on UASC identified	75			400	75[19]		▲65
Children receiving case management services	6,200		3,859	NA	3,000		642	NA
Social Protection								
Affected households supported through joint multipurpose value vouchers					23,000		22,167	▲627
Household with children under-5 supported with a Shock Responsive Child Grant					10,000		2,595 (enrolled)	NA[20]
Communications for Development								
People reached with key lifesaving and behaviour change messages on health, nutrition and safe and appropriate sanitation and hygiene practices.					990,000	987,776	537,600	▲396,532
Prevention of Sexual Exploitation and Abuse (PSEA)								
% of humanitarian partner (including government) trained on PSEA skills[21]					100%		80%	NA

Figure 9. (b) Table showing the summary of Programme Results. Source: Unicef, Mozambique Humanitarian Situation Report n.15.

Concerning the process of recovery and rehabilitation, the document outlines the approach that has been adopted, follows the strategy of resilience, namely the build back better strategy, that has been delineated at national level with the aim of re-building the city of Beira, strengthening the previous asset of the city also through a stronger and wider inclusion of gender, psychological assistance (PSS) and a more accessible system of education to foster local capacity and expertise (Ibid.). Among the proposed activities towards these important goals, the reconstruction of the school and of new classroom also in more rural areas, supported by specific training and innovative programmes. Nevertheless, the same document anticipates the presence of «several gaps in the response and the recovery phase» (UNICEF, 2019). Particularly, it reports «several districts in Cabo Delgado, Manica and Sofala remain under-served or un-served, an issue raised by the government and cluster coordinator». This phenomenon has further been demonstrated by the maps elaborated by the Logistics Cluster[29] – that will later be discussed in the expressed section 3.3.2 Interpretation of Logistic Clusters and World Food Programme cartographic representations – showing the

[29] The Logistic Cluster is the World Food Programme agency for coordination and support of missions and logistics during emergencies. https://www.wfp.org/logistics-cluster

absence some important services in the more rural areas, also scarce connected with the centre of Beira city. Roads' accessibility had further been constrained by the heavy rains that subsequent the event and continued during the phase of recovery. As one of the main real-time supporter of the Government of Mozambique, after the Inter-Agency Standing Committee (IASC) activation for intervention, UNICEF was recognized as primary coordination cluster for education and nutrition and yet, the final report, previously discussed, also conveys within these challenges, it was hard to manage and combine data (Baker, Dr. Nichols, & Afonso, July 2020), as nutrition was considered also parts of the health system, whose data was collected and managed also by other clusters (Ibid.).

By taking into account these premises it can be said that inter-agency cooperation has had a positive impact during the assessment of the 2019 Tropical Cyclone Idai. However, the gathering and sharing of the data outlined a completely different outcome. As we will deeply investigate in the following section, this multi-later approach led to an excessive number of actors dealing with data collection; thereby also data transfer, sharing of information, implementation of the elaborated data to address specific issues or undertake further arrangements or investigations brought to an inconsistency of the data.

3.3 Idai collection and multi-sources approach

Taking into consideration the previously mentioned Evaluation over the Inter-Agency activation that has been operating within the city of Beira after Cyclone Idai, important information regarding data management have emerged. In particular, the report states:

"After a promising beginning, the international humanitarian system struggled to develop a user-friendly system to collect, analyse, and communicate the assessment and monitoring data needed to guide decision-making during the successive phases of the response." (Baker, Dr. Nichols, & Afonso, July 2020)

It further declares that three of the involved organizations gave their permission to combine data and create a unitary cell for the assessment; these three additionally deployed internal prepared personnel to share technical expertise and join resources. Regardless these steps forward and these agencies' availability, the proposed cooperation regarding data never reached fulfilment due to the «rapid turnover of the coordinators and the lack of consensus on a shared system for data management» (Baker, Dr. Nichols, & Afonso, July 2020). This sort of approach did not only compromise cohesion of data among agencies, but further weakened the operative and decision-making processes of the local authorities, unable to reach the big picture and eventually assess overall interventions or strategies. This confusion has later been shown both in the preventive measures – due to an inconsistent preparedness planning and early warning system – as well as in the response action, following the aforementioned reasons that did not guarantee a unitary work. For instance, the diverse issues (food insecurity, outbreak of cholera, affected areas inaccessibility, and others more..) that have been tackled after Idai have mainly seen a sectoral sort of approach, strictly depending on the agency "in control" of the question. The Inter-Agency Evaluation reports an overall data processing and sharing would have with no doubt brought relevant benefits to the general management of the crisis. Notably, the historical and political context of the city of Beira, its past as a former Portuguese colony along with an unstable governative structure handling the question of urban land contributed to increase uncertainty about comprehensive structure in the ordinary planning and land management. Therefore, in the occurrence of extraordinary events, such as that of natural hazards, namely the Tropical Cyclone Idai, this uncertainty reflects on the preventive measures, the ongoing and post-event adoption of strategies and keeps decentralize decision-making and technical assessment among a variety of actors. The Inter-Agency Evaluation reveals an attempt on a more participatory process within the gathering of data for the prevention of sexual exploitation and sexual abuse throughout the Multi-Sectoral Rapid

Assessment (MRA); it resulted as a good starting point, howbeit it did employ delays and minor issues that show the process should be improved.
Hence, among the several factors that somehow influenced the total effectiveness of the response, the scarce involvement of civil society organizations (CSOs). The lack of community-based preparedness or even experience with large-scale hazards contributed to delay emergency preparedness and subsequent response to the event. In addition, an efficient preparedness to the event was limited by the poor collaboration among data collectors. In particular, international clusters closely cooperated with private sectors to combine data and address certain issues and/or affected areas; anyway, the absence of an overall database, hence of a comprehensive strategy led to inconsistent undertaking of the response phases. The International Journal of Disaster Risk Reduction further states that scientific forecasts are more and more developed with the aim of creating fundaments and ground to better study the phenomenon of tropical cyclones in the region and foster preparedness. Despite progress in this regard has been made, the report also claims that the mission undertaken by the World Meteorological Organization (WMO[30]) in respect to Idai tropical cyclone, has emphasized gaps and weaknesses apropos Idai flood warnings, maps and overall accuracy to address preparedness and response.

The Sendai Framework for Disaster Risk Reduction (SFDRR[31]) acknowledges states and governments the main responsibility to set and implement disaster risk reduction' policies and strategies within their countries; nonetheless, the task can and must be supported by international organizations with specific technological skills and competences to assist these policies. The main problem though is given by the absence of "long-term goal". For instance, these cooperation and missions with international agencies are activated quite always in the single occurrence of an event. As previously uttered indeed, also in the case of Idai's landfall, international cooperation and their assistance has become operative only after the President of Mozambique called state of emergency. Real-time analyses were put in place to address current state of emergency, yet carrying the gaps and delays reported before. On the contrary, when Cyclone Kenneth occurred six weeks after Idai, in the north of Mozambique, the missions were still on, therefore forecasts bulletins were faster and more effective to prepare. Under these terms, the response undertaken with Kenneth can be considered more effective, nevertheless, issues on where and how combine this data started to arise. The International Journal of Disaster Risk Reduction eventually conveys how intricate is the current system of humanitarian

[30] https://public.wmo.int/en

[31] The 2015-2030 Sendai Framework is the United Nations framework aimed at reducing the human, spatial and social impacts of disaster risks through the adoption of peculiar measures. https://www.undrr.org/publication/sendai-framework-disaster-risk-reduction-2015-2030

cooperation, hence the need for a more interconnected system aimed at enabling both producers as well as users of data and information within a stronger and more cohesive network.

To conclude, the lack of coherence and integration among data and information coming from many different sources is further highlighted in the indications provided by the different plans put in place for the city of Beira. The mix of actors involved in the collection, elaboration and production of data eventually affects the implementation of the final plan, hence a clear understanding from the public or external actors of the reliable plan and data. This finally generates delays in emergency response that could be addressed and reinforced through a more cohesive and global union of data and information where every actor could access, interrogate, modify, improve and update data, finally avoiding ambiguous and confused information.

3.3.1 World Food Programme event assessment

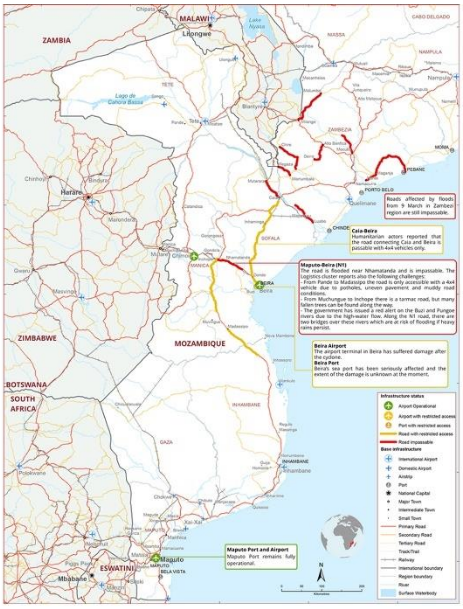
As previously anticipated, one of the primary agencies involved in the assessment of Tropical Cyclone Idai is the World Food Programme. Being one of the most important humanitarian organizations dealing with natural disasters, particularly focusing on the food security issue and the accessibility to water and primary goods, the WFP agency became operative as soon as a country enables the state of emergency and activate the protocols for humanitarian interventions. For instance, in the occurrence of Idai, the World Food Programme sent an expert team of members to Beira, to collect data on field and elaborate the most rapid and effective set of products to be used as base for the operations to undertake on the ground. Thanks to Professor Boccardo, I had the great chance and opportunity to talk with one of the two World Food Programme analysts that carried on the surveys for Tropical Cyclone Idai: Mr. Stefano Cairo. This talk eventually conveyed in multiple online meetings of exceptional importance for this study. Its contribution has allowed me to understand which main difficulties have been encountered in the assessment of the event and how the whole process of the intervention is conducted. Because the country of Mozambique is still considered under the state of emergency at the WFP corporate level, no official interview can be transcript, even so the key considerations and acknowledgments can be reported.

On the first place, the lack of coordination inter-agencies and scarce system of communication has been confirmed by the WFP expert, underlining the fact that the working conditions were inevitably challenging, meaning scarce internet connection on the field, the absence of a common working place and the overall chaos and confusion due to the continuing of tropical rains that pursued in the days and weeks following the event. The overall physical impacts of the cyclone on the city of Beira were therefore visible and particularly moving. The southern informal district of Buzi has been described as «an open-air lake» by the expert. The extreme conditions for the delivery of help and support have been professionally overcame throughout the provision of quite rapid geospatial products, whose main purpose was the identification of feasible streets explicitly aimed at reaching the most affected areas and provide rapid assistance. For this reason, the accountability of the elaborations is considered sufficient when the datum is at least 40% reliable. On these grounds, the analysis is reckoned as acceptable and implemented as tool for the interventions. In addition, the exiguous supply of data at national level often risks to lack accountability or even contrast the data developed and produced from different agencies and organizations.

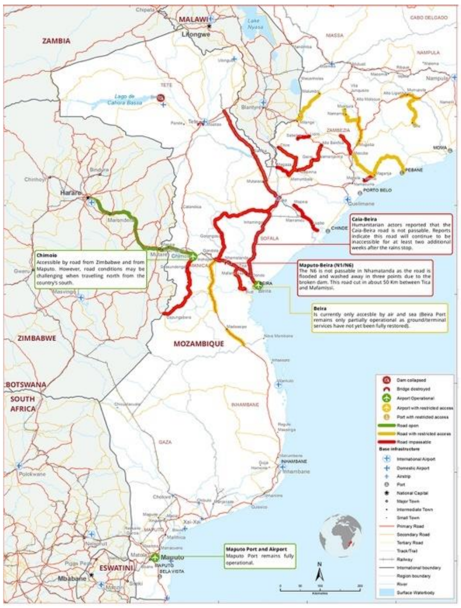
3.3.2 Interpretation of Logistics Cluster and World Food Programme cartographic representations

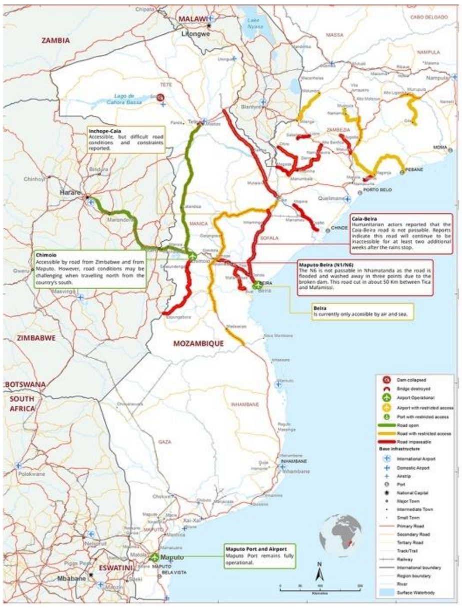
Among the multiple agencies that intervene in the gathering and elaboration of data, mainly two of them were in charge of the infrastructural system: Logistics Cluster and World Food Programme. Their task was to combine all the information available about the road system during the days of the event so to produce clear and effective cartographic representations, that could serve other agencies or the World Food Programme self in the supply of services and assistance. In particular, these elaborations could both determine decision-making as well as providing a mean to recognize accessible roads in the real-time assistance. As discusses in the previous section, the World Food Programme agency for example, is the frontline agency in charge of food and essential items' delivery. In the occurrence of a natural disaster such as that of Tropical Cyclone Idai indeed, WFP must act fast and effectively. To do so, cartography and data are required so to guarantee a successful assistance. Timing is also key to guarantee the success of the operation. Therefore, it might occur data and maps are incomplete or imprecise when undertaken. According to Mr. Stefano Cairo fundamental contribution, it became clear emergency requires urgency. As a consequence, the maps reported below showing roads' accessibility in the days and weeks that follow the event also reveal which infrastructural bodies have been considered.

These maps further highlight the huge difficulties in accessibility that the infrastructural asset underwent. The collection of maps reported below include days that precede the events – 16th and 18th of March -, the day of the landfall – 19th of March – and subsequent key days, such as the 20th, the 21st and the 23rd of March when the road system was completely inaccessible, followed by the 24th , 28th and 29th of March when main infrastructural asset serving Beira was becoming reachable again, and finally the 10th of April as a comprehensive map of the situation three weeks after Idai's landfall.



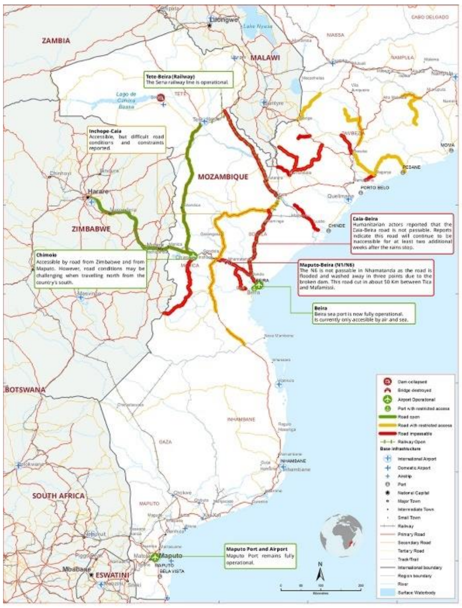
Figures 10 and 11. WFP maps of access constraints concerning the days that precede the landfall of Tropical Cyclone Idai, as per the 16th (image on the left) and 18th (image on the right) of March 2019. Source: World Food Programme, Logistic Clusters access constraints.

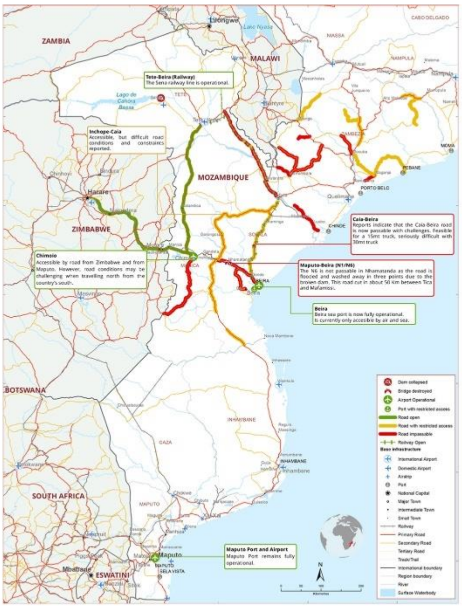




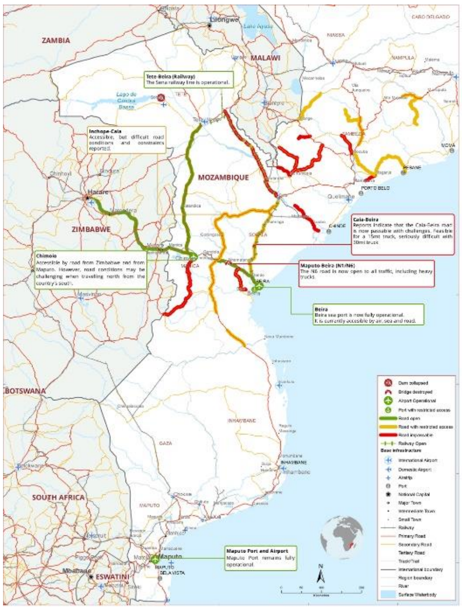
Figures 12 and 13. WFP maps of access constraints on the day of Tropical Cyclone Idai landfall (19th of March 2019, image on the left) on the coast of Beira and the day that followed (20th of March 2019, image on the right). Source: World Food Programme, Logistic Clusters access constraints.

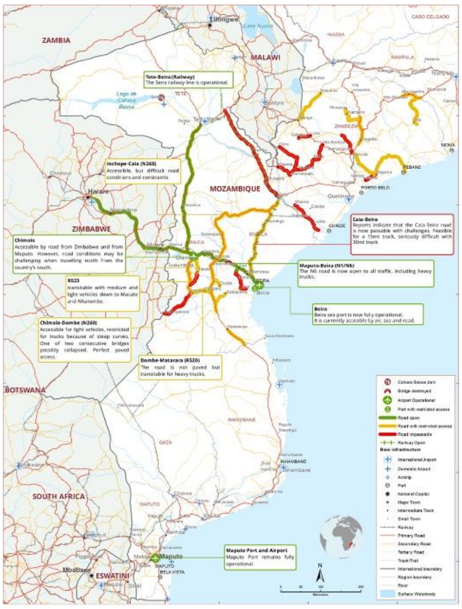
Main considerations that occur when analysing these maps is the data simplification, meaning the previous classification that has been applied when detecting the water extent over the system of roads, focusing primarily on the principal infrastructural bodies to fasten the process of damage assessment and provide almost immediate products to the agencies on the field. These information are essential to support decision-making, hence providing an instrument to redefine an untypical situation and its temporary context. These analyses allow operative agencies to intervene, conscious of which road is accessible, which one might be transitable with restrictions, possible obstacles or in challenging conditions.





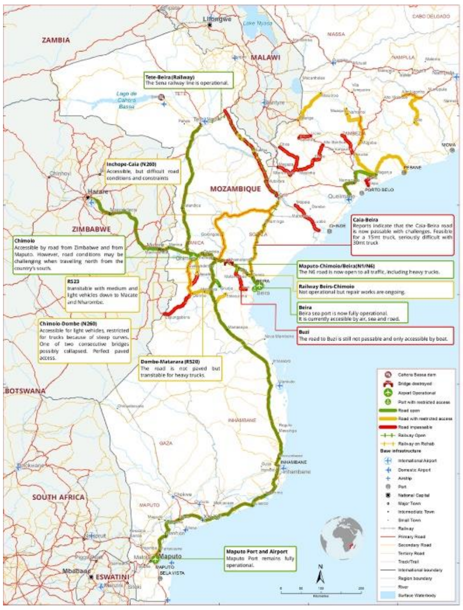
Figures 14 and 15. WFP maps of access constraints concerning the days that followed Tropical Cyclone Idai landfall (21st of March 2019 - image on the left- and 23rd of March – image on the right -). Source: World Food Programme, Logistic Clusters access constraints.

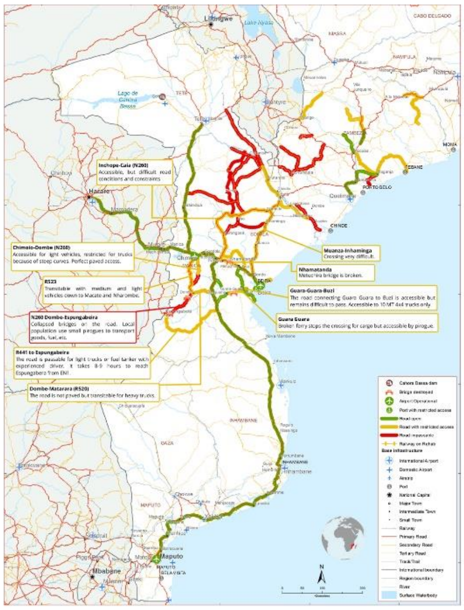




Figures 16 and 17. WFP maps of access constraints concerning the days that followed Tropical Cyclone Idai landfall (24th of March 2019 - image on the left- and 28th of March – image on the right -). Source: World Food Programme, Logistic Clusters access constraints.

Analysing the reported maps, it can be said that this shortage of information is **effective** in terms of logistic, **yet incomplete**. Final implications highlight the importance of fast assessment to respond the emergency, even though with a limited data framework. As a consequence, more specific areas, hence particular situations, might be excluded and need further and deeper assessment. This consideration chiefly conveys the more rural areas, where already pre-existing infrastructural service was presenting weaknesses and limited resources.





Figures 18 and 19. WFP maps of access constraints concerning one of the days that followed Tropical Cyclone Idai landfall (29th of March 2019, image on the left) and one representation of the situation three weeks after the occurrence of the cyclone (10th of April 2019). Source: World Food Programme, Logistic Clusters access constraints.

When further examining the two maps, some important aspects can be detected. In particular, while in the first map it can be acknowledged a major accessibility of the southern connections and roads' system, it is also evident that the system of infrastructure featuring the more rural areas, such as the informal district of Buzi is still not accessible and present notable challenges in reaching the area, exclusively feasible by boat. For instance, the situation on the 29th of March, fifteen days after the event, is still far from being effectively solved.

Three weeks after Tropical Cyclone Idai made landfall in the city of Beira, on the 10th of April, the state of arts can still be considered critic. As a matter of fact, despite the main axes and primary connections crossing the city of Beira, a considerable number of streets still present difficulties and limited access. In addition, the heavy rains that pursued in the weeks that followed the event, worsen the feasibility and intervention of the humanitarian agencies on the field. As shown in the figure, some important infrastructural connections, such as bridges have collapsed and are still unrecovered almost a month later – see street N260 Dombe-Espungabeira-. Consistent roads' restrictions do not only limit international intervention, though it generates chaos and troubles for citizens in need to move to safer areas.

To sum up, the extreme conditions under which these cartographies have been developed already outline a good success and an efficient tool for decision-making and on-field action. Nevertheless, many difficulties, inaccuracies and data gaps – such as a considerable restriction of the analysed system of infrastructure, excluding the secondary and tertiary system, and the more rural, unpaved, local road system- underline the weaknesses and lacunes of the Mozambiquan data system and the inter-agencies mode of cooperation.

3.4 The need for a global and comprehensive geodatabase

Following the considerations previously discussed, the need for a comprehensive set of data, hence a global geodatabase, becomes clear and urgent. This condition is important both in the prevention, as well as in the post-disaster assessment. In this regard, the World Bank has reinforced this need throughout one the latest reports (CES Consulting Engineers Salzgitter GmbH, January 2020) debating Beira and its assessment a year after the hazardous occurrence. In particular, the document discusses some of the nature-based solutions[32] that have been implemented in the most affected areas by the cyclone, with the aim of re-building a stronger Beira and develop adaptive solutions to this climate challenge. One of the projects discussed refers to the rehabilitation of the Chiveve River[33] along with a practice of resettlement of the informal households that were established along the river's wetland. While describing the phases that have been undertaken in the making of the project, some important considerations concerning spatial data and comprehensive dataset have been acknowledged. In detail, despite the drawing of both the planning and the design of the project has been defined by the same consortium of consultants – INROS LACKNER (IL[34]) and CES Consulting Engineers Salzgitter[35] in collaboration with AIAS and KfW (CES Consulting Engineers Salzgitter GmbH, January 2020) – many issues regarding the consistency and cohesion of data have emerged. The World Bank eventually acknowledges «**it would be useful if municipalities had "base data" sets for their own use as well as for consultants** working on projects in their jurisdiction» (CES Consulting Engineers Salzgitter GmbH, January 2020) and further adds «**this would ensure that all technicians and consultants work with the same set of data** and therefore the same base assumptions, **reducing costs and time of data collection and increasing quality and compatibility of outputs**» (Ibid.). During the implementation of the design project indeed, some interference occurred that were not predicted in advance: first, the necessity of market vendors - belonging to the informal communities to be displaced - to use the space and secondly, the high quantity of solid waste and saturation of soil riverine, impeding any earthworks or foundation preparation (CES Consulting Engineers Salzgitter GmbH, January 2020).

[32] Nature-based solutions or NBs can be considered adaptive measures to social challenges with the aim of protecting, managing or restoring natural or anthropical ecosystems.

[33] The Chiveve River crosses the city of Beira and is today object of a consistent variety of rehabilitation projects.

[34] https://www.inros-lackner.de/en

[35] https://www.ces.de/

Despite the fact that these information might appear as parallel and not related, instead both of them could have been implemented and acknowledged within the same data container. A global geodatabase could indeed incorporate data referring to the topography, the geology, specific soil characteristics or the quality of water of a basin and so on; at the same time, the same geodatabase could include a classification of land use, services and utilities, extremely useful to better understand the context and its everyday usage.

The previously mentioned document further claims that also data management should be improved (CES Consulting Engineers Salzgitter GmbH, January 2020) throughout the creation of geographic information system GIS-based products to be addressed in ordinary mapping, used as a decision-making supportive tool, and finally, be stored and constantly implemented to recall in case of an emergency. This operation could foster ordinary cartography and the developing of preventive measures, so as fasten up processes of emergency assessment and recovery. The World Bank official report points out that already in the study of feasibility that has been undertaken for the project, gaps concerning the environmental conditions of the project area along with important connotations and features of the area. Therefore, an addendum had to be prepared and made available; nevertheless, because of the multitude of agencies and actors involved in the data gathering and elaboration, important gaps respecting data collection and production were found out. These discoveries during the design phase and the feasibility study slowed down the whole process and unintentionally generated problems referring the elevation reference of each data source and subsequent geographic projection of the datum.

These final considerations found unluck similarities with the current study of research; personal difficulties have been hence encountered while searching and collecting data from the extremely vast network of organizations involved in the Tropical Cyclone Idai's assessment, as well as for the downloading of consistent and proper data concerning ordinary mapping and current state of affairs.

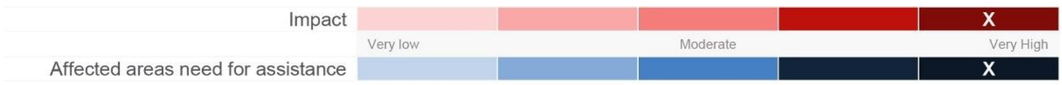


Figure 20. Identification of the levels of impact and areas in need that required urgent assistance during Idai. Source: INGC, OCHA, Mozambique Rapid Assessment (MRA) 2019.

Following the outlined premises, the need for a global geodatabase to refer to, particularly during extraordinary circumstances, has proven to be an urgency, acknowledged at every level of engagement within the context: from academic studies to emergency assessment.

3.4.1 Global geodatabase and notions of data harmonization

Despite the term geodatabase has acquired a variety of connotations and definitions, it can be generally identified as a geographic referenced system of data. For instance, its primary feature is the geographic location of the data it comprehends, defining the essence of each datum. The latter can be considered as geographic entities, such as phenomenon of the real world whom attributes reflect its space at a given time. These attributes can further convey more about each datum, through intrinsic characteristics of the object, which may vary from its natural composition, its position, its usage and an uncountable number of meanings that can be given to the datum. The potential of geodatabase is very much wide, since its dataset composition can smoothly follow the indications of the user, therefore create a unique set of data, a specific environment of different information every time, depending on the requirements and purposes of creation. In addition, a global geodatabase could enhance communication among agencies and data collectors, fasten up processes of decision-making and generate an organized and reliable set of information to whom address during emergencies.

As deeply examined in the previous sections, in the occurrence of an unprecedent event, which might correspond to the manifestation of a natural hazard such as Tropical Cyclone Idai, a massive layout of actors intervenes, both at local as well as global level, so as within public or private domain. Regardless the obvious benefits that this kind of cooperation provide, the focus here is on the reliability of the available data. The previously mentioned lacks of coherence and inter-changeability of data has proved data discrepancy and the fog among valid and most recently updated portals. For this reason, collection and storage of consistent data is essential.

The process of data harmonization operates in this way, reconciling data formats into one comprehensive dataset considered proper, eliminating the redundancy of data and assuring data compatibility and consistency. This operation significantly facilitates data interoperability among international agencies and enhance interpretation of data that no long need to be compared with data coming from other sources. Data harmonization further enables higher data quality, reducing potential errors in the processes of search, download and projection, and eventually supply a clearer and more organized data structure. This procedure can be gathered by the creation of a global geodatabase, considered as an homogeneous system of georeferenced data that can constantly be implemented and enhanced throughout specific allowances on data modifiability and foster an effective cooperation and agency' coordination.

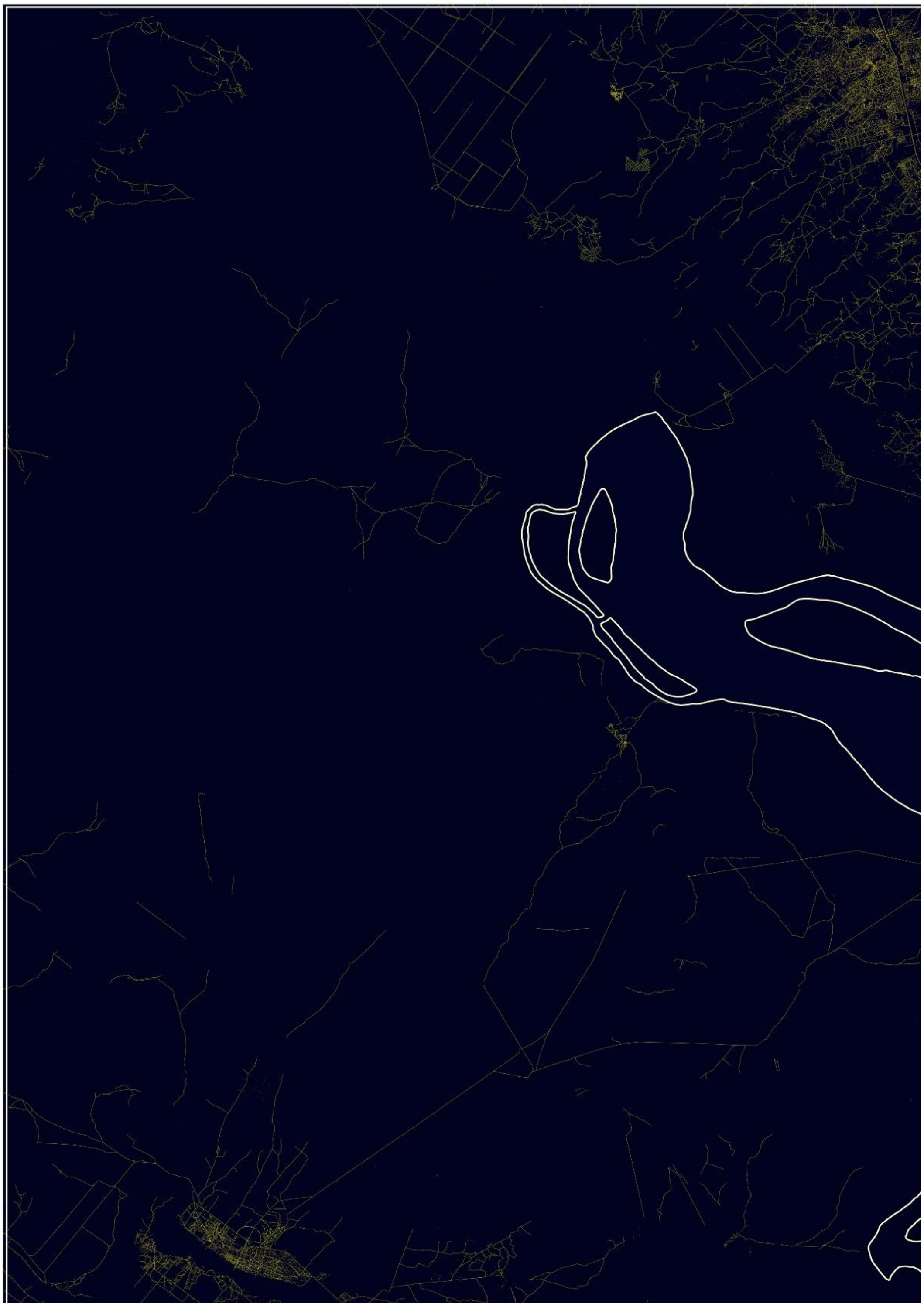
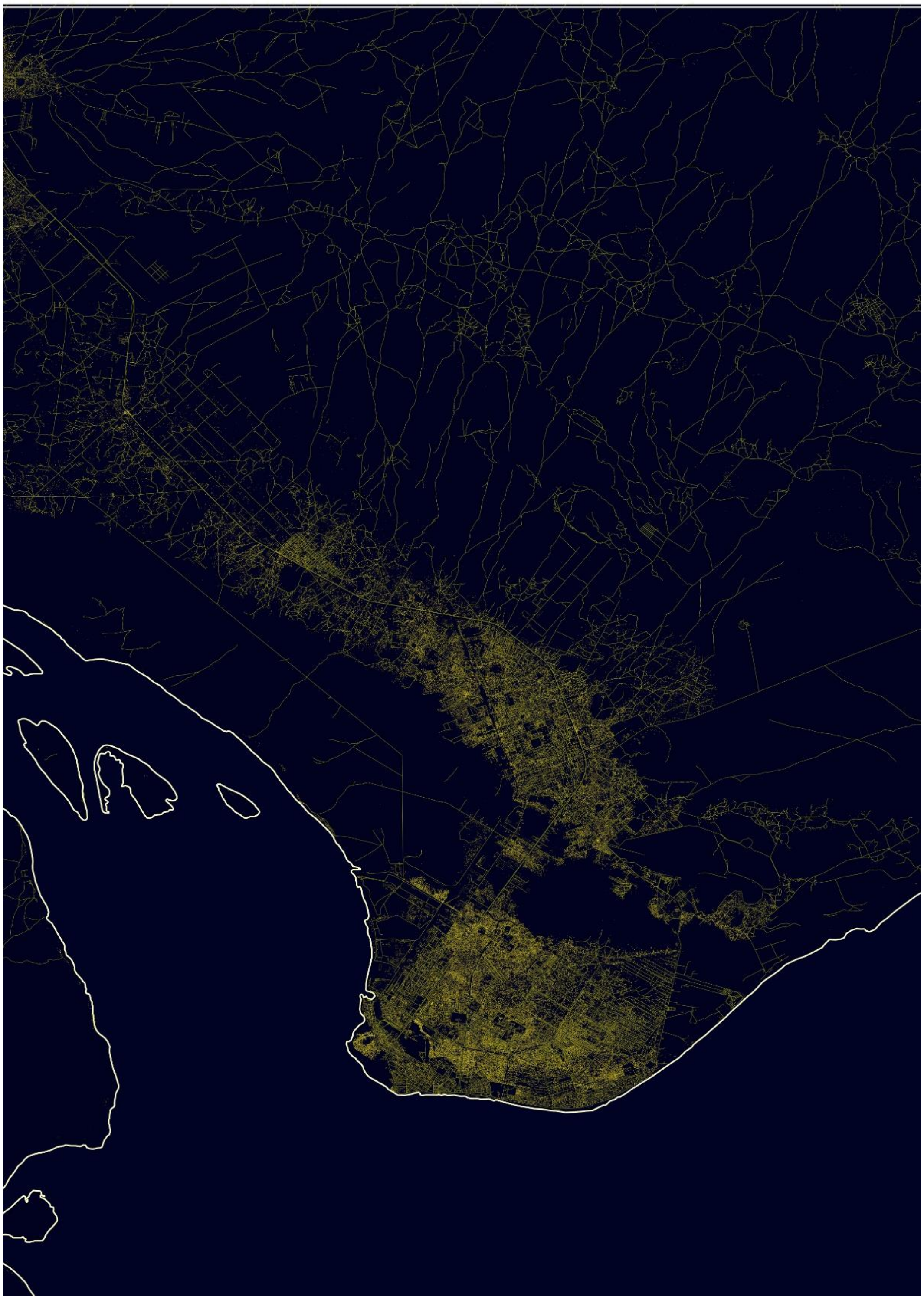


Figure 21. System of buildings and infrastructures featuring the coast of Beira.



Creation of a new global geodatabase

The monitoring and assessment of natural hazards represent a common subject of work and research in the field of remote sensing and territorial analysis, using geographic information systems, such as ArcGIS that has been employed for the development of the current analysis.

In order to better understand the spatial implications of Cyclone Idai on the territory, a new spatial geodatabase has been created.

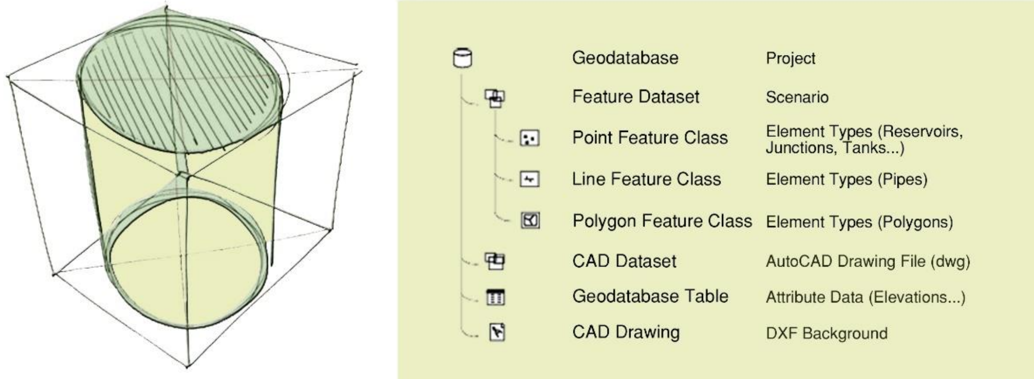


Figure 22. Internal structure of a File Geodatabase.

The Geodatabase is a physical storage for geographic information aimed at collecting data, along with the ability to manage and elaborate it, eventually realizing cartographic representations. It operates as a fundamental tool in emergency assessment because it allows editing, implementation of data, its classification according to specific rules, import and export of data coming from different sources, while guaranteeing a common system of reference. Moreover, the georeferenced data can be positioned on specific surfaces, such as satellite images, that can also be overlapped and compared for a better comprehension of the actual status of the analysed area, acknowledging past and present situations. In particular, it involves satellite data from 2010 onwards, with the aim of pursuing an already existing study (Matyas, 2015-03) of the tropical systems in the Mozambique Channel (MC) which includes an overall panorama of these phenomena from 1948 to 2010. This method allows a first comprehension of the event's impact on the territory through photointerpretation and will be further explored with the damage assessment of the vector data collected among the different open sources data, so to achieve a deeper level of detail of the actual damage.

Four main phases have been adopted in the making of cyclone Idai territorial analysis:

1. The search and collection of raster and vector data among multi-sources data engines (Copernicus Open Access Hub, Earth Observation EO Browser, Open Street Map – OSM, Humanitarian OpenStreetMap Team – HOT; United Nations Institute for Training and Research – UNITAR, World Food Programme- WFP, and Logistic Cluster);
2. The creation of a new file geodatabase;
3. The setting of a new mosaic dataset within the geodatabase aimed at including and comparing the collected satellite imagery;
4. The elaboration and interpretation of the data and corresponding outcomes.

4.1 Collection of multi-sources data: Open Street Map (OSM) and United Nations Institute for Training and Research (UNITAR)

When dealing with emergency mapping in developing countries particularly, one of the most critical issues is given by the lack of complete or reliable information. Specifically, taking into account the fact that many different stakeholders are usually involved in this sort of analysis, a consequent multiplicity of platforms is used in the assessment making. This often results in a scarcity of cohesion among the available data. For this reason, the first step undertaken in the making of the current analysis has been a deep look among the available data sources, both local and global. Being Mozambique an old Portuguese colony, many cartographic data relative to the energetic sector in particular, has been carried by the Portuguese branch Portugal Energia[36] but concerning spatial planning or territorial management, mostly global humanitarian organizations such as United Nations Institute for Training and Research (UNITAR) and World Food Programme (WFP) have given their important contribution and provided the major amount of data collected in missions and later elaborated. The Mozambique Data Portal has been with no doubt an interesting source of data, especially for the understanding of the country urban and rural growth thanks to the statistics data developed by the United Nations Department of Economic and Social Affairs. Reviewed in 2018, it provides an overview of the estimated size of urban and rural population in developing countries from 1950 to 2018. It eventually presents some projections about the potential development of this phenomenon until 2050. None of this information though is available in shapefile or digital vector format able to be read and elaborated in ArcGIS. In this regard, also the Italian embassy in Maputo has been appealed for the data concerning rural and urban growth in the city of Beira or more generally in Mozambique; unfortunately, no feedback has been received. For this reason and lack of overall data availability, the study of the rural and urban growth in the area has been interrupted and the focus of the analysis has moved more towards the spatial impacts and consequent social and spatial implications of the event.

The vector data regarding the built environment and the current infrastructural system has been downloaded from the Humanitarian OpenStreetMap Team (HOT) and Open Street Map (OSM) platforms. The whole geopackage contained other essential data, such as *water bodies* – for a true comprehension of the state of ordinary geomorphology of the area- *waterways, land use* data and the *transport* shapefile, showing the connections among the infrastructural assets.

[36] https://www.portugalenergia.pt/

Another very important data source has been the United Nations Institute for Training and Research (UNITAR) website, whose maps show the waters extent over Sofala Province, including Beira and Buzi district, between the 13th and 26th of March 2019, the time period when Cyclone Idai hit Mozambique. This information can be downloaded in multiple formats, including pdf, shp or gdb formats depending on the research usage.

For this particular analysis, the *water extent* layer that has been put in place is the "*Satellite detected waters extents, as of 19 and 20 march 2019 over the Sofala province, Mozambique*" provided from the UN training arm United Nations Institute for Training and Research (UNITAR), whose focus through the years has been the assistance and learning activities' provision to those countries who live in fragile contexts or have just turned independent from ex-colonizers, therefore lack of structured and transparent system of territorial management. UNITAR is involved in multiple humanitarian programmes, collaborates with ministries in the developing of public policies regarding global and local challenges. While fostering education and research, it also provides a programme on operational satellite applications, named UNOSAT. UNOSAT supplies satellite imagery and satellite analysis, usually implemented to monitor hazardous events or help decision makers in solving conflicts. The UNOSAT Flood Portal moreover provides satellite-derived flood data in GIS vector data format. For the current analysis, UNOSAT vector data referring to the flooded surface has been extracted from Sentinel-1 acquisition over the 13th and 14th satellite imagery, 19th and 20th, and eventually 26th of March. Even though the cyclone made landfall between the 14th and the 15th of March, **the data concerning the following days represents a turning point in the assessment of the disaster's impacts** on the land; this last data in fact includes the significant amount of water that has enlarged consistently the event's water extent **because of the heavy rainfalls that occurred right after the event**.

The data collected on the 13th and 14th of March encompasses about 20,100 sq km, whose 228,300 ha of lands identified as flooded[37]. At the same time, the data that has been gathered on the 19th and 20th of March 2019 within the Sofala province, seems to show a total of 2,165 sq km of flooded lands over about 42,590 sq km of analysed area[38]. Eventually, water extent data referring to the 26th of March appears to be consistently reduced in terms of flooding percentage, along with an analysed area of about 42,590 sq km, of which a total of 567 sq km indicated as flooded[39]. As a means to develop the current research, and especially to show the water extents evolution during the days, the whole set of data has been downloaded; while for the damage assessment of the buildings and infrastructures' systems, the

[37] https://unitar.org/maps/map/2873
[38] https://unitar.org/maps/map/2875
[39] https://unitar.org/maps/map/2881

water extents' data referring to the 19th of March has been employed as overall flooding most-relatable estimation data.

On the other hand, the satellite imagery that has been used both as base map but mostly in the making of the photointerpretation analysis, has involved a variety of remote sensing engines -that will be explored more in detail in the following chapter-. The examination of clear and accessible satellite images in fact, has been carried through the acquisitions regarding the months of January, February, March and April, for each of the following year: **2018 for pre-event data**, **2019 as for the event data** and finally **2020 for the post-event data**.

4.2 Satellite imagery

Satellite images can also be implemented as «geo-information reference layers» as per base maps to support the analysis, as quoted in the Emergency Mapping Guidelines paper by the International Working Group on Satellite-based Emergency Mapping (IWG-SEM).

When looking for satellite imagery, there are multiple satellites among which to choose. Their product eventually changes according to their features and the processing level. Main engines for satellite data visualization, discover, comparison and download are Copernicus Open Access Hub and Earth Observation (EO) Browser, both including full resolution images from a rich set of sensors, such as Sentinel-1, Sentinel-2, Sentinel-3, Sentinel-5P, archives from Landsat 5, 7, 8 and others. This paragraph will focus on the main ones implemented in remote sensing analysis that have been a point of investigation in the making of the Mosaic Dataset. Sentinel-1 is an active radar sensor, particularly used during emergency situations, because of its ability in filtering cloud cover, hence better capturing water. For this reason, Sentinel-1 is highly implemented during emergencies such as flooding detection and analysis. On the other hand, Sentinel-2 is an optic sensor at a high resolution (approximately from 10 to 60 meters of ground sampling distance GSD), composed of two sensors A and B, the first one launched in 2015 whereas the second one in 2017, with a revisit time of about five days when the two work simultaneously and about ten days when just one is operating. Sentinel-2 is then used for vegetation monitoring as well as for keeping track of land cover changes, coastal water or lakes' pollution, through Multispectral and Infrared Imager. Finally, Sentinel-3 products are used when monitoring ocean forecasting as well as environmental observation because of its remarkable level of accuracy and reliability when measuring consistent land surfaces, or oceanic surfaces. Another essential satellite program is the collection provided by the Landsat mission[40]. In 1972 the U.S. Geological Survey (USGS) started its collaboration with the U.S. National Aeronautics and Space Administration (NASA) and launched the first Landsat mission. Since then, Landsat satellite keep acquiring Earth's surfaces data with optimal ground resolution and spectral bands that help the assessment of climate change, urbanization and other global challenges and phenomena. Landsat 8 is the most recent satellite from the homonymous mission and is usually implemented in land uses evaluations, changes in ecosystems and disaster's response. The choice of the satellite eventually depends on the objective of analysis. Afterwards also the processing level of the product can be selected. This usually implies a 1st level of processing for satellite products whose need is immediate. On the

[40] https://www.usgs.gov/core-science-systems/nli/landsat

contrary, a 2nd level of processing is preferable when the focus of the request is more on the data accuracy and resolution level, rather than the rapidity of the product availability, giving the fact that level 2 requires more time to be elaborated since it takes in consideration also the forecast conditions. Speaking of which, also the cloud coverage percentage can be set in the definition of the product type, as well as the relative orbit number, put in place to better localize the area of interest. Depending on the mission, more level of satellite data processing can be found.

At the end, the resolution index and representation symbology can be selected. It might occur that some areas lack of imagery, either in time frequency or in spatial detection. In any case, if the colour bands are available, it is possible to create a raster as per type of representation aimed to achieve.

Because of data availability – lack of second level processed data for the acquisition period of interest both in 2018 and 2019 - the current analysis has downloaded and implemented the spectral bands from Sentinel-2 using Earth Observation (EO) Browser.

4.3 Creation of a spatial geodatabase for the event assessment

The first step for the creation of the Geodatabase for Beira has been the acknowledgment of the spatial reference system that can be found through the *epsg.io* [41] platform, the search engine for the identification of the correct spatial reference system among global datasets, that works in relation to the inserted coordinates or the typing of the geographic location on the map available in the homepage.

Figure 23. Homepage of the epsg.io spatial reference engine. Source: epsg.io official website.

As showed in the image below, the Reference System for Mozambique is the EPSG:32736 WGS84/UTM zone 36S.

This information will be fundamental for the first settings of the Geodatabase creation and will guarantee the correct georeferentiation of the data components that will be imported.

After initiating the ArcGIS Desktop software and opening a new blank project, the next step is to open the Catalog window (icon in the Toolbar section), which will be used during the whole database making; then select the destination folder for the Geodatabase storage, right click on it with the mouse and choose *New* option. Here a whole list of different objects will be presented, plus there will be two types of Geodatabase to choose between: *File Geodatabase* and *Personal Geodatabase*. Because this last one has been overcome by the File Geodatabase for its improvements in performance, data managing, sharing and storing, the preferred choice is the File Geodatabase, renamed "Beira_Geodatabase.gdb".

[41] https://epsg.io/

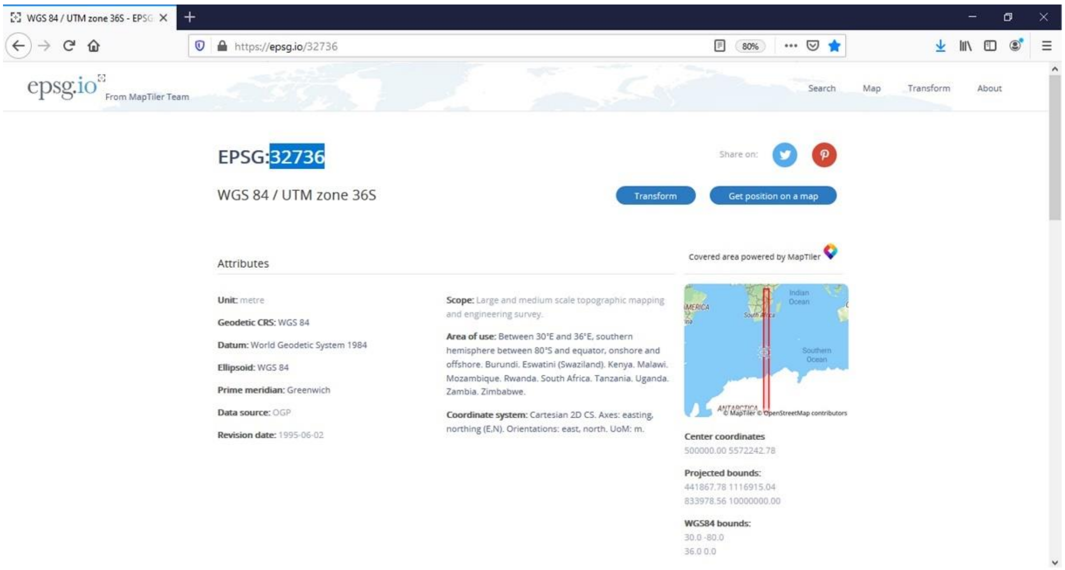


Figure 24. Mozambique spatial reference system research on the epsg.io platform. Source: epsg.io official website.

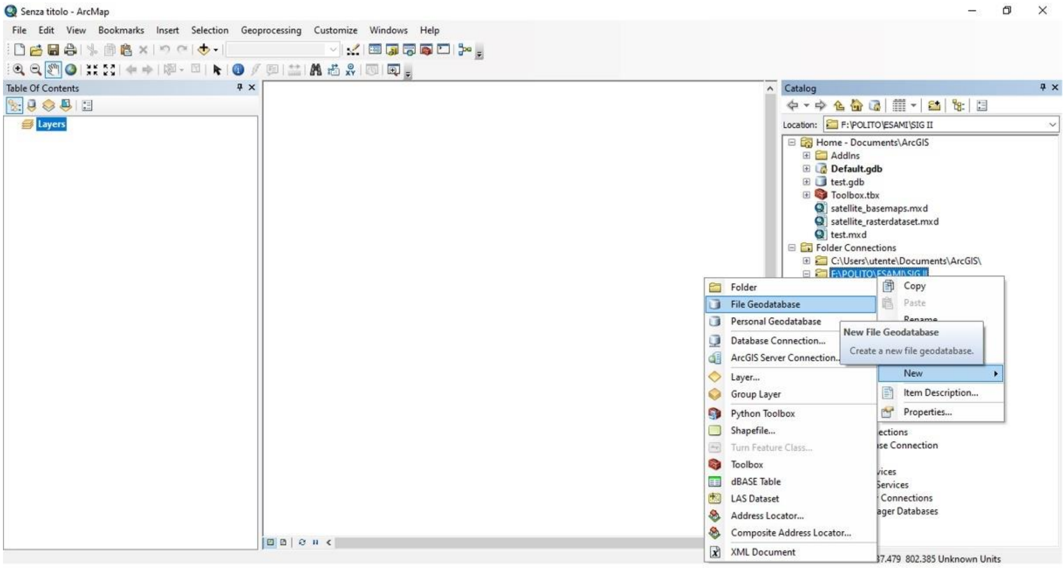


Figure 25. Creation of a new File Geodatabase using ArcGIS software.

This operation has been repeated similarly so to create an inside storage, the Feature Dataset, that will keep the same Reference System for all the Feature Classes aimed to be created inside. The process has been the same: selection of Beira_Geodatabase.gdb / right click with the mouse / *New* / *Feature Dataset* / name the new feature dataset and set the previously checked referenced system: EPSG:32736 WGS84/UTM zone 36S. No elevation component has been set in this specific case and the tolerance value chosen has been 0,01m, aiming at achieving higher performance with less occupied space. At this point the structure of the new Geodatabase is set and needs to be filled.

4.3.1 Creation of a multitemporal satellite dataset

A Mosaic Dataset is a collection of raster datasets, hence images, viewed and stored as a catalogue. This means its products can be accessed both as individual raster (images) as well as a single mosaicked image; since the Mosaic Dataset can be queried based either on time or date attribute.

Thereby, Mosaic Dataset represents the ideal dataset for storing temporal data in different projections, resolutions, or bands' number.

For instance, satellite-based Emergency Mapping (SEM) is considered an essential tool in the assessment and managing of a hazardous event, either in the preparedness as well as in the crisis-response phases. In particular, impact mapping analysis requires a collection of satellite data acquired before and after the event occurrence, so as to better understand the previous and current scenario. In this case 2018, 2019 and 2020 satellite imagery has been employed. Aim of this comparison is to get a first perception of the water extents and to verify the presence of any visible event's consequences through photointerpretation. Despite photointerpretation's weak accuracy, this method can still turn out as an effective tool when dealing with relevant natural events, such as cyclones, hurricanes or floodings, especially to better visualize and compare the water extents borders.

4.3.2 The implementation of the Mosaic Dataset using EO Browser Data

In EO Browser all thirteen bands regarding images belonging to a similar sensing period between May and June of each year have been downloaded and imported in the previously created Beira_Geodatabase.gdb.

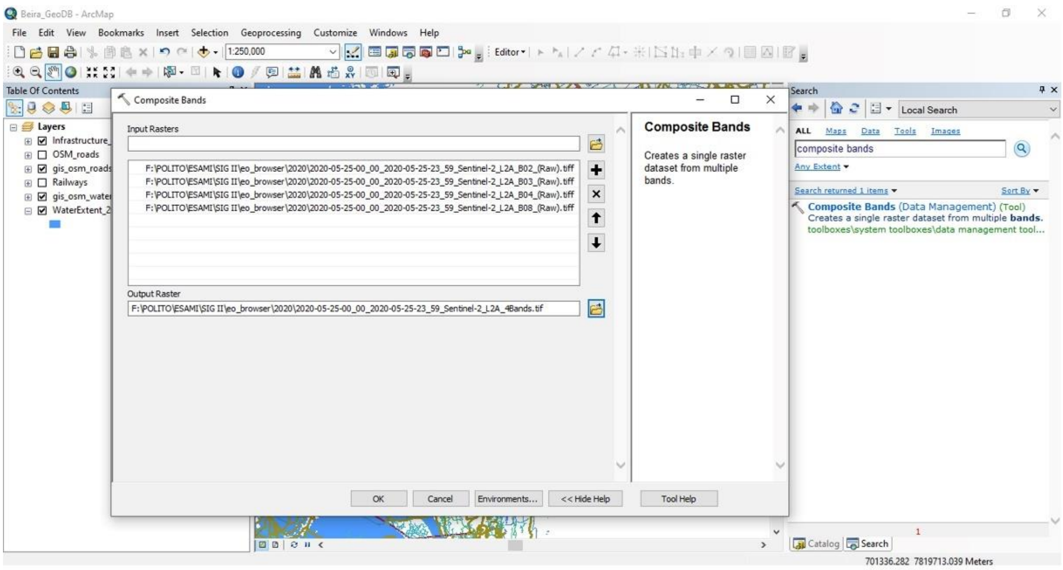


Figure 26. New raster composition using the Composite Bands tool.

Then, for each year a new raster has been created through the combination of 4 bands (Band 2, 3, 4 and 8) using the Composite Bands tool.

The choice of these bands in particular is linked to the sort of symbology willing to be applied in the current post disaster analysis: the True Colours (432 bands composition) and the Infrared one (843)[42]. Aim of the infrared composition is the study of natural resources. That is why it is widely applied when dealing with hazardous events or vegetation studies. The infrared usually implies different tones of red to represent live vegetation. The darker the red, the more vigorous the vegetation. A lighter red might signify an unhealth vegetation or a less dense one. In this specific analysis, the blue shades representing water will be the centre of attention, as their extent will be compared to the True Colours image, to better visualize the flooding extent compared to the existing water bodies.

Subsequently, once this operation has been completed, it has been possible to build the new Mosaic Dataset, by right clicking on the Beira_Geodatabase.gdb and picking *New / Mosaic Dataset*. At this point, after choosing the name and set the reference system of the mosaic dataset, it is fundamental to set "*None*" in the *Product Definition* option so as to leave it generic and eventually choose "4" in the *Pixel Properties* in order to set four acceptable bands in the defined Mosaic Dataset (which is the number of bands decided to be implemented in the following study, though it really depends on the research connotation). The Mosaic Dataset is now assessed, though it still needs to be filled. To do so, it is necessary to right click again on it in the Catalog list and choose the *Add Rasters* option and consequently import the four-bands rasters corresponding to 2018, 2019 and 2020.

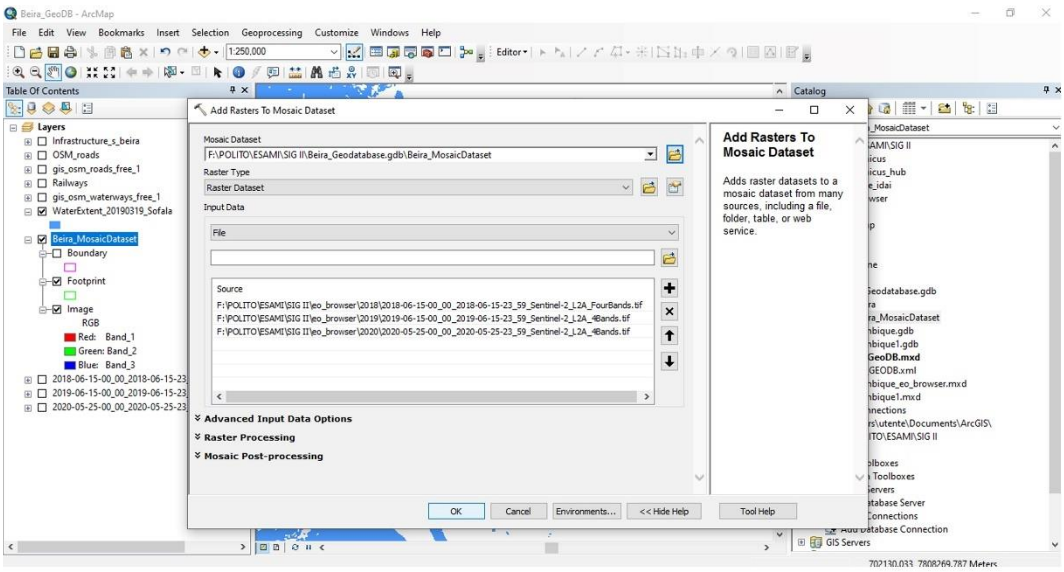


Figure 27. Adding of the raster data within the new Mosaic Dataset.

[42] https://www.usgs.gov/faqs/what-do-different-colors-a-color-infrared-aerial-photograph-represent?qt-news_science_products=0#qt-news_science_products

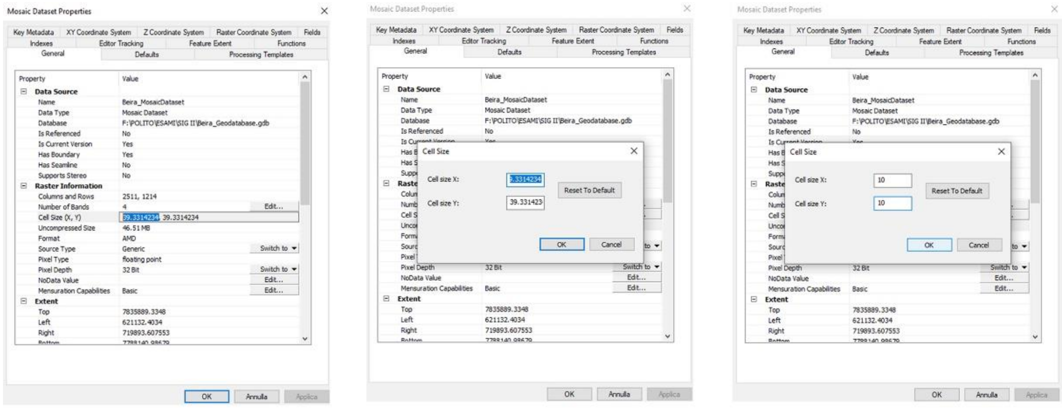


Figure 28. (a) Cel size selection, (b) definition of the cel size and (c) setting to 10 per cel size.

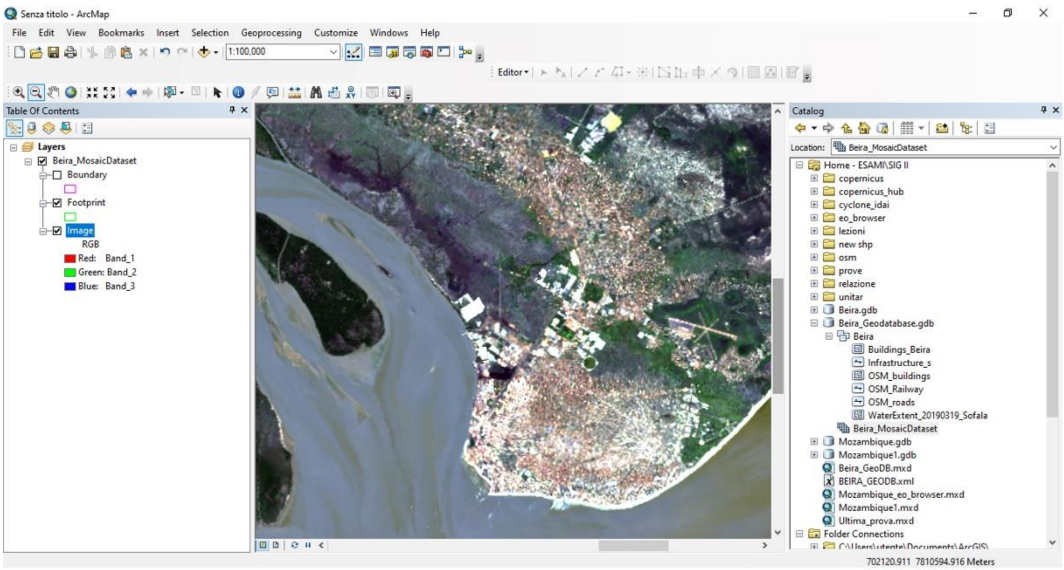


Figure 29. Satellite image of Beira with low resolution.

As soon as the tool runs, it is possible to visualize one of the three images composing the dataset, which can be easily exchanged by activating a Definition Query from the dataset self: *Properties/ Definition Query/ Query Builder* and eventually picking one of the available values. Moreover, it is possible to enable time on the layer for an automatic exchange of images, which will be shown according to the time settings defined.

After picking the first image to be visualized on the project, the True Colours bands' composition has been applied from the Image's *Properties* on the Dataset layer, but when zoomed in for a better comprehension of the area, quite a weak resolution of the imported images has been noticed.

This low resolution made almost impossible to distinguish the building asset and led the photointerpretation quite difficult. For this reason, the resolution has been improved inside the dataset properties in the Catalog list.

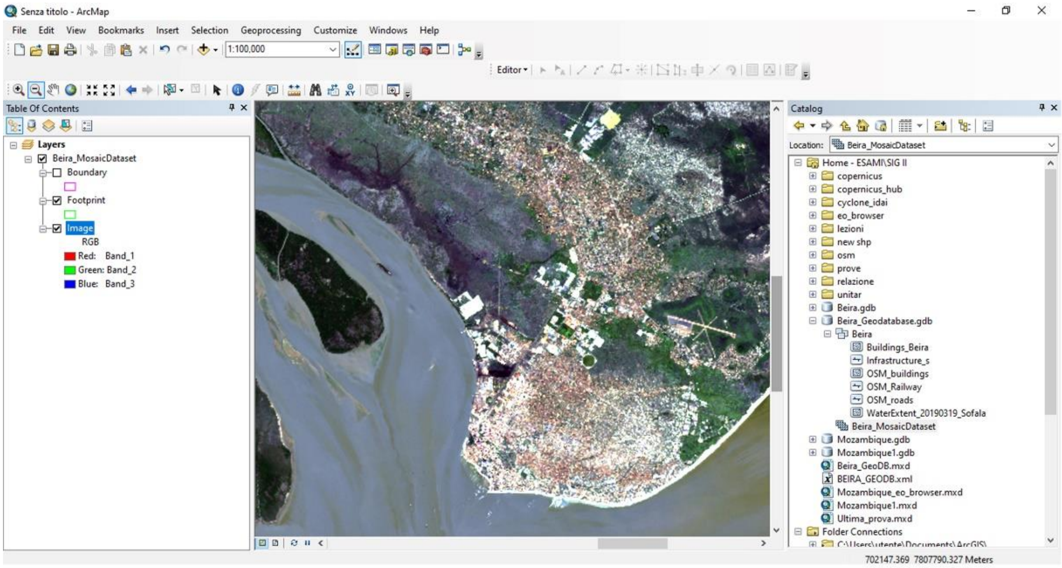


Figure 30. Satellite image of Beira after the resolution's improvement.

As shown in the figures, the improvement was immediately visible on the image and led to a better comprehension of the context: 0,01m, aiming at achieving higher performance with less occupied space.

4.3.3 First hazard assessment

The water extents information has played a key role in the comprehension of the weakest and most vulnerable zones, whose condition is still at high risk because of their great exposition towards the Indian Ocean and the total absence of a resilient system of defensive structures. Particularly, the overlapping UNITAR water extent over the OSM data allows a more detailed assumption of the infrastructures and buildings' post-event status. For this operation, the *Select by Location* geoprocessing tool (*Figure 31*) has been used.

This method allows a selection of features based on their spatial relationship with the features coming from another source layer. In this case it has been possible to generate a selection of all the infrastructures that intersect with the water extent layer, at a different level, meaning they could have possibly been affected by the Cyclone Idai. The spatial selection method allows various options of possible relation between target layers and the source layer. Once the option is set, the tool runs, and the selected features will be visible both on the project and in the layer's *Attribute Table* (*Figure 32)*.

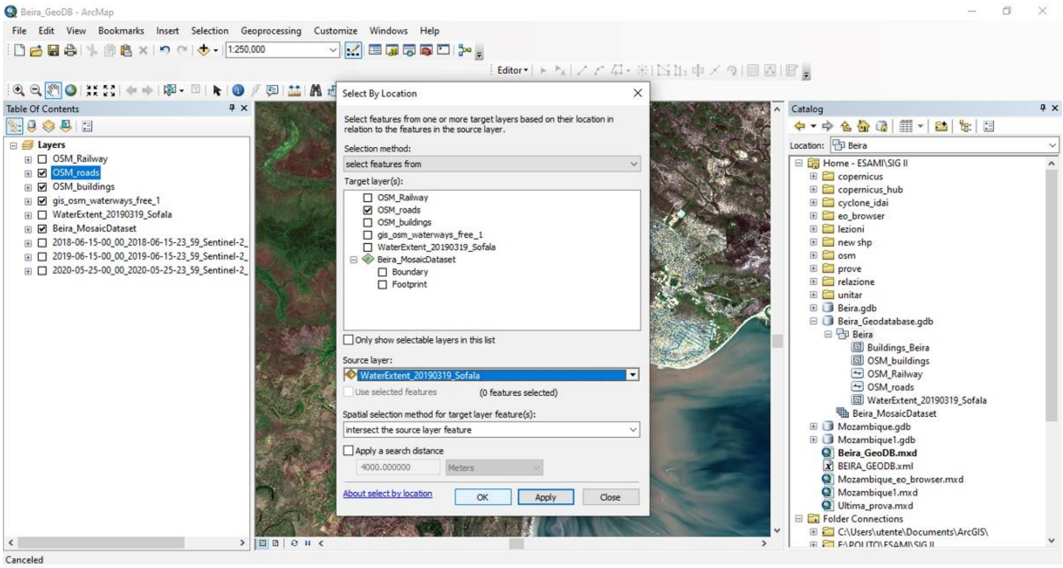


Figure 31. Select by Location tool intersecting the system of infrastructures with the water extent layer.

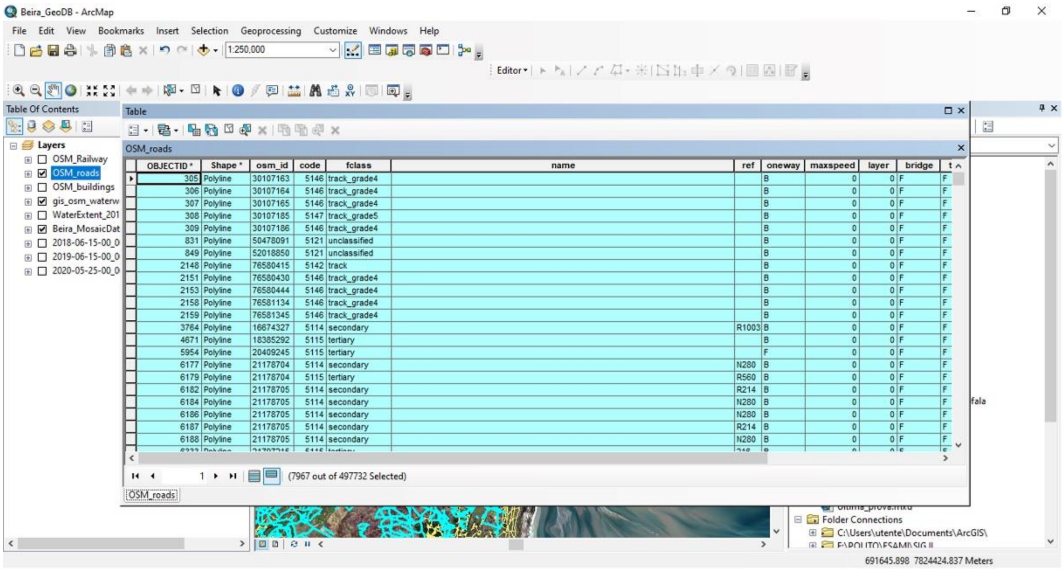


Figure 32. Selected features inside the layer's Table of Attributes.

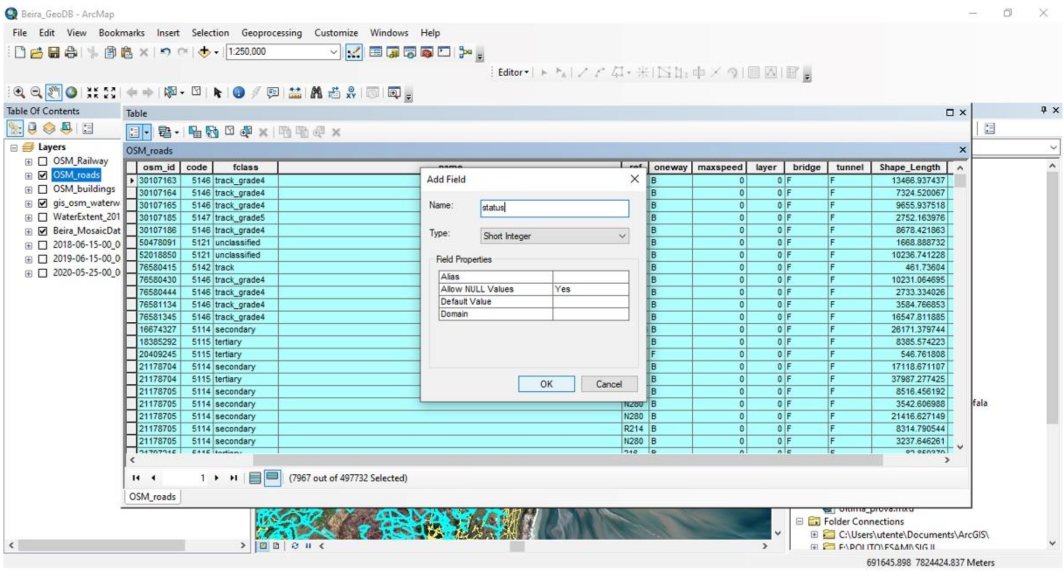


Figure 33. Creation of the new field "Status" within the layer's Table of Attributes.

The first selection of data has been ruled with the "i*ntersect the source layer*" option, meaning there might have actually been a damage due to the intersection of the infrastructural system and the water extent layers. To keep record of this first gathering, a new field "*Status*" has been created inside the Attribute Table (*Figure 33*) of the OSM layer and coded with the "1" value, using the *Field Calculator* tool.

Following this first classification, it has been possible to identify the features that had no intersection at all with the water's extent layer, by simply switching selection through the appropriate icon-button inside the same Attribute Table. This simple operation allows a new result that has been coded with the "3" value, as opposed to the previous research. All the features classified with value *3* indeed, consist of the infrastructures that had no intersection with the water's extent layer and that, could potentially be considered safe and feasible roads. The last operation has been the *Select by Location* applied for all the features *completely within the source layer*, to which the "2" value has been applied. By analysing this final gathering, clearly many of the selected features already appeared classified with the "1" value in the Attribute Table, because indeed, they do intersect with the source layer; still, by applying this one selection at the end, a more accurate estimation of the infrastructure's status can be achieved, since it defines the infrastructures that have totally been covered by the water's extent. This final selection has been implemented and updated with the final coding.

The same procedure has been adopted and replicated for the built environment, by classifying the buildings' features in relation to the water's extent layer. In conclusion, **a new symbology has been imposed**, **aimed at better representing the level of potential damage** that has been identified for all features.

4.3.4 Final consideration over Idai impact assessment

Through the elaboration of the available existing data and its final interpretation, it has been possible to make some conclusive assumptions about Cyclone Idai consequences over the built environment and the system of infrastructures. Because many analyses have been undertaken over the central area of Beira, namely, the coastal area where the port and the economic centre are located, a deeper focus on the neighbour district of Buzi has been depicted. As a matter of fact, one of the most affected areas has therefore been the informal district of Buzi, south-west of Beira city; yet, the lack of feasible data and urgency for intervention have restricted the focal point to Beira and its central area. The present study aims therefore to enrich the existing analyses, providing a comprehensive tool on which more data can be gathered and managed, as well as reached fast and easily while addressing an emergency.

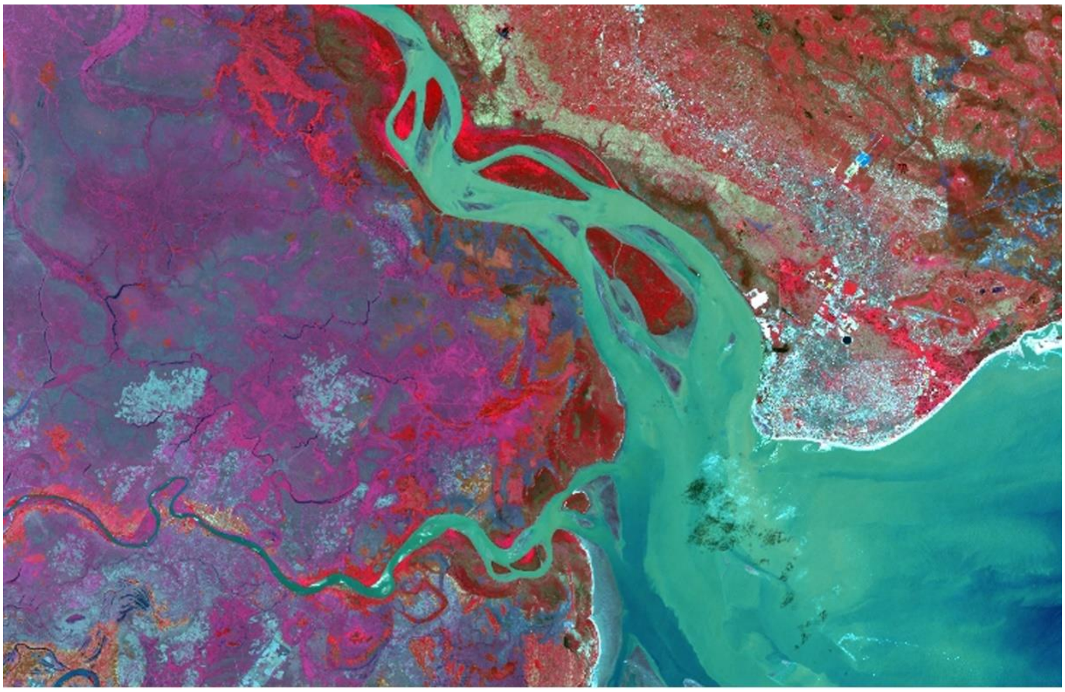


Figure 34. Infrared satellite imagery and Idai's water extent over the district of Buzi on the day of the system's landfall, 19th of March 2019.

From the Infrared satellite images and the UNITAR waters extent boundaries, it seems that the Buzi district in particular has been almost completely overflooded. As acknowledged from the photo-interpretation and UN-Habitat papers about the topic, this area used to be the house of thousands of farmers working in agricultural fields for food and commerce, that now went lost. The satellite base map (figure) depicts some brighter spots under the purple stain representing Idai waters extent. We can assume these lighter spots might represent the most impacted agricultural fields and highlight the loss of natural resources.

Speaking about the infrastructures and buildings' assets though, a True Colours composition (*Figure 35*) has been used for the base map, so to better highlight the different colours adopted for the estimated damage classification.

Starting from this True Colours composition and the superimposing of the water extent layer of the system of buildings and infrastructures, a new classification has been established. In light yellow the "*potentially safe infrastructures/buildings*", in orange the "*potentially affected infrastructures/buildings*", meanwhile in a darker red the infrastructures and/or buildings that are highly supposed to be damaged by the cyclone. Each new colour has been attributed to a numerical value depending on the level of damage and inserted in the previously shown new column "Status" within the tables of attributes of each layer involved, namely the system of buildings and infrastructures. New data could be implemented afterwards to better identify spatial damages also over the natural asset; equally a deeper analysis on which kind of buildings have been affected the most, based on the buildings’ typology, could secondly be assessed. Because of time and resource limitations, the following study mainly focuses on the spatial impacts over buildings and infrastructures regarding the informal district of Buzi. Nevertheless, the comprehensive geodatabase also includes water extents and data belonging to central Beira and the whole province of Sofala.

Figure 35. True colours composition featuring the satellite imagery superimposing Idai’s water extent over the district of Buzi on the day of the system’s landfall, 19th of March 2019.

Despite the difference between some orange and red infrastructures, it has been doublechecked through a closer photo- and UNITAR data interpretation, resulting in a slight difference based on the fact that some roads were completely overflooded, while others have partially been impacted, still unsure to what extent.

After analysing the attribute tables of the OSM data, both the buildings and the infrastructures assets, and foster the knowledge on the event using UN-Habitat papers, it can be said that the most impacted areas also seem to be the poorest ones. The overflooded Buzi district was indeed an agricultural zone, where many citizens were living in extremely poor conditions and the majority of the damaged infrastructures are most likely to be the linking roads between their huts and the fields.

From an urban planning perspective, this means an urgent need for the creation of more resilient and inclusive places. Reinforcing these fragile areas does not only mean making them safer, which is an undoubted necessity, but also strengthening them from a social point of view, looking for more inclusive and accessible solutions for the future.

January 2021, Cyclone Eloise

Less than two years after the devastating landfall of Tropical Cyclone Idai, a new tropical system generated in the Mozambican basin on the 23rd of January 2021: Tropical Cyclone Eloise. Only a month before, another tropical system was breaking over the coast of Beira and the whole province of Sofala once again. The uttermost vulnerability of the area to climate relate events has unfortunately been reconfirmed, while the Mozambican territories have been deeply worn out. «According to the National Institute for Disaster Risk Management and Reduction (INGD), 441.686 people have been affected» reveals the IOM UN Migration Situation Report I (Migration, 2021),adding «over 56.000 houses were severely destroyed» finally counting 43,327 displaced people together with 34.566 people that have been evacuated (ibid).

The new tropical system has been analysed under the United Nations Bulletin 11 and required once again the intervention of international and humanitarian agencies who were still engaged in the assessment and recovery of former cyclone Idai. In addition, internal conflicts burn out and spread from the city of Cabo Delgado and spread all over the Northern part of Mozambique.

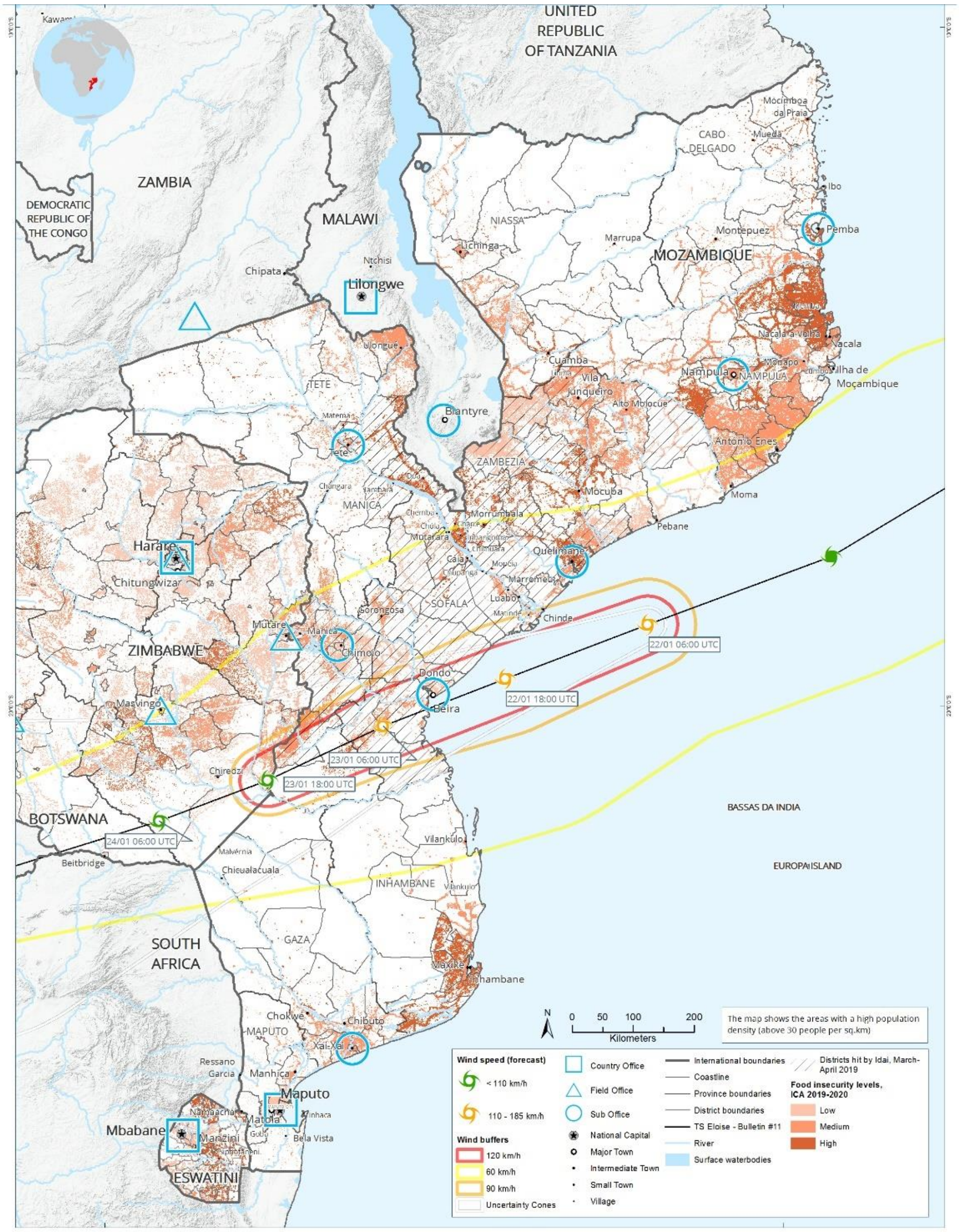


Figure 36. World Food Programme Regional Overview concerning Tropical Cyclone Eloise, showing the system's track and wind buffers involving the city of Beira and the district of Buzi within the 120km/h wind cone. Source: World Food Programme, Regional Overview – TS Eloise, ICA FI levels 2019-2020 & Tropical storm track, bulletin #11, 22 January 2021.

5.1 Data implementation

As previously mentioned for the assessment of Tropical Cyclone Idai (Chapter n.3.3.1) a crucial source of information and data has been provided by one of the main World Food Programme spatial analysts working on the emergency assessment. During one of our talks indeed, the authenticity of its experience on field and, within the organization has revealed another very important aspect: the pre-existing vulnerabilities characterizing the areas of Beira and Buzi concerning food security. This aspect has marked a decisive role in the assessment of cyclone Eloise. In a first moment indeed, the two hazardous events might have been inspected separately, as many organizations choose to do, once again mainly for the urgency that emergency assessment and support requires.

The creation of the foregoing geodatabase though, further permits the implementation of data gathered and accomplished in a secondary moment. This constitutive feature of a spatial geodatabase outlines the importance of this tool within the domain of emergency assessment allowing a simultaneous analysis of both the events. Respectively, the evaluation of the two natural phenomena inevitably generate inconsistency if the affected area is shared and the spatial impacts actually have a chance to be put together, compared and assessed in detail. One of the main issues that has been encountered from humanitarian agencies in the assessment of cyclone Eloise (Migration, 2021) relays in the actual understanding of which areas were still suffering, hence recovering from the impact of prior cyclone Idai, which ones might have been affected twice, as well as those who were new victims of Eloise. The harmonization of this whole set of data could also ease the overall emergency assessment, disclosing significant considerations regarding the areas and communities that, on the contrary, have never been affected. This important acknowledgement could guide and support the identification of potential safe spots within the vulnerable area and aid the processes of decision-making in respect to the phases of recovery and possible resettlement. The latter has indeed proven to be a weak point, as reported in the emergency report «although the resettlement sites established in the aftermath of Cyclone Idai 2019 were not flooded and proved to be safe locations, Cyclone Eloise affected the shelter and Water, Sanitation and Hygiene (WASH[43]) structures in many sites» (Migration, 2021).

At this point the purpose of the new geodatabase also conveys **the integration of multiple hazardous events**, so to achieve the most comprehensive picture. Due to shortage of data at the time of the survey data gathering, different analyses compared to Idai's assessment have been undertaken, yet focusing on the spatial impacts of the new tropical system over the city of Beira and particularly over the district of Buzi, which, once

[43] https://www.unicef.org/mozambique/en/water-sanitation-and-hygiene-wash

again, has underlined the fragility and great exposure of its territory in relation to tropical systems.

5.1.1 Eloise flood extent and damage assessment

Taking into consideration the shortage of available data at the moment of the survey' data inspection, valuable material was promptly made accessible from the World Food Programme and the Logistic Clusters division.

By means of the shapefiles that WFP collects throughout the Global Disaster Alert and Coordination System (GDACS[44]) immediate emergency maps and analysis are produced by WFP Automatic Disaster Analysis and Mapping (ADAM[45]) system. This methodology allows WFP to keep track of the cyclones' evolution and provide a rich set of diversified data, among which the *wind buffers*, the *tropical storms nodes* and the *trajectories of the cyclones*. Each of these data is essential to better understand the genesis of the tropical system, its main direction, trajectory and point of break and has been included in the previously created comprehensive geodatabase. Besides, data concerning Eloise flood extent has been additionally implemented in the geodatabase. Contrary to the water extent layer referring to cyclone Idai – causing issues given the considerable number of different shapefile available and timely updated – the one referring to the extension of Eloise conveys a medium of the water extents that has been calculated between the 20th and the 27th of January 2021, together with that observed between the 6th and the 13th of February 2021, all within the same vector datum: *moz_bnd_adm2_wfpge*. The World Food Programme primarily enact this type of data for the assessment of agricultural and cultivated surfaces that might have been affected. Main source of income for many Mozambican citizens therefore derives from the agricultural export and domain; as well as, representing inner source of food. This kind of loss inevitably worst the already exacerbated circumstances of the Sofala province, where WFP provides assistance and support to most rapidly handle the food crisis.

Throughout the merging and calculation of the data cited above, the *moz_bnd_adm2_wfpge* datum also contains a specific attribute referring the vulnerability to flooding, based on the Integrated Context Analysis (ICA[46]) which analyses the level of risk towards hazardous events in time. The datum further includes the estimation of flooded cropland surfaces (CRA) that helps identifying the category of flooding vulnerability of the inspected area.

[44] https://www.gdacs.org/
[45] https://geonode.wfp.org/adam.html
[46] https://geonode.wfp.org/imaps/ica/

Figure 37. Integrated Context Analysis (ICA) classification showing the high level of vulnerability to flooding of the district of Buzi in red and the medium value of risk of the city of Beira in orange.

By observing the cartographic representation of the ICA classification, chief consideration conveys the highlighted vulnerability of the informal district of Buzi. According to the attributes of the Integrated Context Analysis indeed, the district of Buzi relies under the Category 2 of ICA ranking, meaning «intermittent vulnerability to food insecurity patterns [...] related to either shocks (natural or man-made) or seasonal factors» (World Food Programme, 2018), eventually adding «if shocks are a cause, a recovery focus may be suitable» claiming «high shocks risk argues for DDR including early warning and preparedness» (ibid).

5.1.2 Estimation over Eloise and Idai analysis

Following the happening of Tropical Cyclone Eloise, the country of Mozambique was coming out devastated from the impacts of the latest tropical system, the internal conflicts bursting out in the north of the country and the profound wounds left from prior cyclone Idai in 2019. As a consequence of this demanding condition of the country, a Multi-Sectoral Needs Assessment approach has been undertaken (IOM DTM; INGD, 06/04/2021) in accordance with Mozambique's National Institute for Disaster Management and Risk Reduction (INDG) and IOM DTM (Displacement Tracking Matrix). The assessment mainly addresses the most affected areas of the Sofala province, among which the informal district of Buzi belongs and has resulted to be one of the most devastated from the recent tropical cyclones. Cooperating also with the World Food Programme, aim of the Multi-Sectoral Assessment was the collection of data concerning the main impacts along with the main and most urgent needs after the multiplicity of crises engaging the whole territory. According to the DTM, the principal source of livelihood of all districts impacted by the cyclones has always been agriculture (IOM DTM; INGD, 06/04/2021). The intense floodings and rainfalls that followed the hazardous events led to ruinous damages over the anthropic as well as over the natural environment. As reported in the document (ibid), «in 85 per cent of localities, **the main impact on livelihoods** and economic activities **came from productive lands being flooded/damaged**», still «in 100 per cent of localities, it was reported that the affected population has continued access to farming lands». It has also been accounted that in the majority of localities the farmland can be from 1 to 2 or more hours walking. Taking into consideration these premises, along with the devastating impacts of tropical cyclones Idai and Eloise over the land and the already poor infrastructural system featuring the district of Buzi and the most rural areas surrounding the city of Beira, further considerations might be disclosed over accessibility, safety and resilience that characterize the existing infrastructures to flooding and heavy rains. Following the geospatial investigation that have been undertaken within the making of the comprehensive geodatabase, many of the gaps delineated in the analyses that have been assessed at the beginning of the emergency, do relate to this set of secondary, more rural streets, connecting the houses of the farmers to the agricultural crops. When including them within the geodatabase, these minor infrastructures acquire the same attention of the other major infrastructures that have been impacted. Eventually, they became relevant component of the whole infrastructural asset and underline the importance of minor connections, chiefly employed in the everyday life of Mozambican citizens.

To sum up, many investigations have been carried out also in regard to the number of exposed populations to both events. The World Food Programme has released two main reports – *IDAI 2019, Population Exposure Estimation based on bulletin n. 21* and *ELOISE 2021, Population Exposure Estimation based on bulletin n. 11* - highlighting the number of exposed persons as for speed, therefore strength, of the winds coming towards the area. Three wind buffers have been identified, respectively 60km/h, 90km/h and 120km/h. Thanks to this categorization, a more exhaustive understanding about the actual level of impact on people and land can be perceived. Concerning the city of Beira, the analyses report a total of 452.518 people estimated to be exposed to 2019 Tropical Cyclone Idai, all within the major 120km/h wind buffer (World Food Programme; Automated Disaster Analysis and Mapping, ADAM, 2019). Every wind speed buffer has been produced by GDACS (JRC) (ibid). Meanwhile, 503.029 persons are assumed to be exposed to 2021 Tropical Cyclone Eloise (World Food Programme;

Automated Disaster Analysis and Mapping, ADAM, 2021), still within the 120km/h for the city of Beira. The estimations of people exposed to the events has been calculated using a 1km resolution LandScan raster, particularly LandScan Database 2015 and still need validation on the field (ibid).

On the other hand, data reflecting the number of exposed populations in the district of Buzi splits among the different wind buffers. For instance, 12.877 people have been calculated inside the 60km/h wind cone, whereas 102.328 within the 90km/h cone and finally, 72.820 potentially exposed people within the 120km/h wind buffer, for a total of 188.025 exposed people to the 2019 cyclone Idai.

MOZAMBIQUE	Inhambane	Govuro	40,950			40,950
		Inhassoro	24,752			24,752
		Mabote	297			297
	Manica	Barue	142,659	18,291		160,950
		Cidade de Chimoio			310,298	310,298
		Gondola		86,295	246,985	333,280
		Machaze	63,614			63,614
		Macossa	34,157	3,332		37,489
		Manica	2,989	73,246	202,041	278,276
		Mossurize	174,879			174,879
		Sussundenga	32,528	112,877	18,818	164,223
	Nampula	Angoche	175,371			175,371
		Moma	141,952			141,952
	Sofala	Buzi	12,877	102,328	72,820	188,025
		Caia	90,128			90,128
		Cheringoma	54,719	6,839		61,558
		Chibabava	92,229	37,339	1,517	131,085
		Cidade da Beira			452,518	452,518
		Dondo			169,301	169,301
		Gorongosa	81,435	74,448		155,883
		Machanga	61,356			61,356
		Maringue	63,728			63,728
		Marromeu	155,621	11,615		167,236
		Muanza	701	17,581	18,265	36,547
		Nhamatanda		41,796	234,691	276,487
	Zambezia	Chinde	130,042	3,172		133,214
		Cidade de Quelimane	237,292			237,292
		Inhassunge	99,498			99,498
		Maganja da Costa	49,924			49,924
		Mopeia	131,975			131,975
		Namacurra	96,438			96,438
		Nicoadala	189,864			189,864
		Pebane	7,418			7,418
MOZAMBIQUE - TOT			2,389,393	589,159	1,727,254	4,705,806

Figure 38. IDAI-19 Population exposure estimation based on Bulletin n. 21. Source: World Food Programme, ADAM analysis 2019.

Regarding the exposed population for 2021 system Eloise, data reveals 847 persons are included in the 60km/h cone, while 14.991 people are part of the 90km/h, lastly 151.509 people exposed in the 120km/h wind buffer. Total exposed population in the Buzi district is assumed to be 167.347.

	Nampula	Angoche	167,874			167,874
		Mogincual	225			225
		Moma	211,345			211,345
	Sofala	Buzi	847	14,991	151,509	167,347
		Caia	176,967			176,967
		Chemba	2,954			2,954
		Cheringoma	52,351	2,636		54,987
		Chibabava	1,782	9,548	115,363	126,693
		Cidade da Beira			503,029	503,029
		Dondo	1,997	64,112	108,014	174,123
		Gorongosa	171,942			171,942
		Machanga	33,581	16,173	2,967	52,721
		Maringue	67,338			67,338
		Marromeu	140,392	7,445		147,837
		Muanza	17,438	18,044	4,428	39,910
		Nhamatanda	250,757	48,744	87	299,588
	Tete	Mutarara	35,586			35,586
	Zambezia	Chinde	83,963	47,616		131,579
		Cidade de Quelimane	330,098			330,098
		Inhassunge	86,462			86,462
		Maganja da Costa	228,700			228,700
		Mocuba	29,327			29,327
		Mopeia	128,888			128,888
		Morrumbala	160,389			160,389
		Namacurra	228,150			228,150
		Nicoadala	170,366			170,366
		Pebane	139,853			139,853
MOZAMBIQUE - TOT			4,472,589	334,612	1,122,942	5,930,143

Figure 39. ELOISE-21 Population exposure estimation based on Bulletin n. 11. Source: World Food Programme, ADAM analysis 2021.

The aforementioned data has been implemented within the new comprehensive geodatabase for a better comprehension of the overall vulnerability of the area to the tropical events. Thoroughly, the "*MOZ_WorldPop2020_UNadj.tif*" and "*MOZ_NOAA_VIIRS_monitoring20210127_20210120.tif*" cumulative data over the population exposure approximation have indeed been implemented in the comprehensive geodatabase.

Lastly, it can be argued that data harmonization within a global and comprehensive geodatabase helps the overlapping, hence comparison of the available data, eventually fostering the actual identification of exposed people, namely in relation to Idai, to Eloise or to the phenomena. Further investigation could be inserted afterwards, in addition with future predictions over urban growth, population's expectation of growth along with projections over potential replicability of hazardous events. The whole data package could serve processes of decision-making, especially concerning the implementation of climate-related adaptive measures.

Final assumptions: research limitations and further developments

Eventually analysing the process of research and the methodology characterizing the whole study, valuable final considerations can now be drawn. Heretofore, it is important to acknowledge the identification of a restricted data framework as main source of information that has been employed for the making of the presented survey. In particular, only official reports and bulletins of hazardous events from humanitarian agencies along with yearly reviews released from the previously mentioned organizations have been taken into consideration. For what concerns geographic and spatial data instead, only available, and accessible set of data from the analogue agencies has been implemented. Specifically, data referring to the days of the events, Idai 19th of March 2019 and Eloise 23rd of January 2021, along with data representing the situation in the days prior and subsequent the two events has been utilized. For instance, being the country of Mozambique still under the state of emergency, monthly, if not even daily data updates and reports are issued and released. As a consequence, a definition of feasible data was necessarily to be established, covering up to the 18th of March 2021, whereas main information from official reports and reviews continue to 2021.

The following sections will then portray the final remarks and results obtained throughout the geospatial damage assessment analysis, ultimately reviling important reflections over the exposure of Beira's southern informal settlements to natural events and potential further developments over this topic. The importance of comprehensive geodatabases will in the end be highlighted and the actual replicability of the adopted methodology within different territorial contexts, such as the country of Malawi, will be presented.

6.1 Beira, after the storm.

The aim of the presented multi-source data collection and subsequent geospatial analysis was the fostering of the studies and results carried out by humanitarian agencies within a unitary and more reliable repository of data. Despite the great value of their contribution during the emergency assessment and on-site rapid support, many gaps and data restrictions have been acknowledged. The purpose of the current study indeed conveys the integration of existing analyses throughout the assessment of the spatial impacts over the whole system of infrastructures and built environment, without any data limitations.

The result is then a **deeper analysis that portrays a wider context and examines also "minor" infrastructural bodies**, namely secondary or tertiary roads, that usually characterize the urban pattern of most rural areas serving the houses of farmers spread among the agricultural fields. To better implement the existing analyses, the current study further focused on the damage evaluation of Beira's southern informal district of Buzi, whom spatial data was very scarce and quite difficult to find. For instance, the poor infrastructural asset serving the area, the weak building's fabric along with the total absence of updated spatial information within a comprehensive geodatabase, ensued important delays during the on-site assistance and remote assessment of the true impact and potential level of damage of both Idai as well as Eloise tropical cyclones. As a matter of fact, when TC Eloise occurred less than you years after, these cartographic weaknesses emerged again, creating inconsistency and confusion over food security, actual needs and increased displacement of people between Eloise's impact and still Idai's.

The creation of the global and comprehensive geodatabase hence solves these issues, simplifying and speeding up the assessment of the current state of facts, by enabling a more accurate definition of actual impacts over the land and the built environment, avoiding any data limitations. It further permits the overlapping of both cyclones Idai and Eloise water extents, as well as of the data referring to the spatial damages. This operation helps *identifying most affected areas*, *which communities might have been affected twice*, and finally advises the definition of *potential safe spots* – key elements in the eventuality of a new tropical phenomenon-.

As largely discussed in the first chapters of this study for instance, 14% of global total tropical systems generate in the South West Indian Ocean (12 to 13 cyclones each year) (Matyas, 2015-03); an enhancement in the preventive measures is therefore necessary. In this regard, the new comprehensive geodatabase constitutes the starting point of a potential archive of tropical systems that occurred in the past years, which helps in better understanding potential correlations between the events, while examining the exposure of some territories in comparison to others, namely the district of Buzi. One of the most interesting assumptions that has been gained throughout this survey reveals the great fragility and exposition of this informal settlement to both analysed tropical systems. In this respect, new investigations could be undertaken over the socio-urban connotations featuring the district of Buzi, particularly if the informality of its urban development could somehow display an intrinsic form of major vulnerability in comparison with the planned environment. This question would undoubtedly require deeper investigations, studies, and juxtaposition of data and case studies coming from different contexts.

Besides, any further data or investigation could be implemented in the new geodatabase, as this methodology allows the implementation of upcoming data that might be accomplished afterwards. Data gathered in different time and format does not represent an obstacle; on the contrary, it aids the enrichment of the dataset towards the most complete and reliable source of data. Under these premises, it is possible to grasp the efficacity of the methodology and the simple replicability of its application. The following final paragraph indeed will present the replication of the data collection activity within a new comprehensive geodatabase for different provinces in Malawi, where also drone imagery has been integrated and analysed.

6.2 Replicability of the methodology: the UP4DREAM project

Tropical Cyclone Idai has affected multiple countries facing the Indian Ocean. One of the affected countries has been the country of Malawi, where the United Nations Children's Fund (UNICEF) has undertaken incredible actions to help and sustain recovery and prevention for future events. One of the main projects, the UP4DREAM project[47] has involved the collaboration of Polytechnic of Turin's expertise regarding emergency assessment, with the aim of gathering data, developing analyses, and providing capacity-building on site (Calantropio, et al., 2021). Notably, a team of experts from the Polytechnic has been on site at the beginning of 2020 to collect data with drones and work with students from the University of Agriculture and Natural Resources and Mzuzu University. The data has later been implemented within one comprehensive geodatabase, along with raster data from satellite imagery and available vector data so to re-create the damage assessment parallelly developed for the country of Mozambique. In terms of technical application, the main difference between the two geodatabases stands in the additional drone imagery that, as shown in the images below, permits a higher definition of the datum, both in terms of resolution as well as vector localization throughout the usage of the DEEP technology, an innovative technology that extracts building footprints from UAV imagery (Calantropio, et al., 2021).

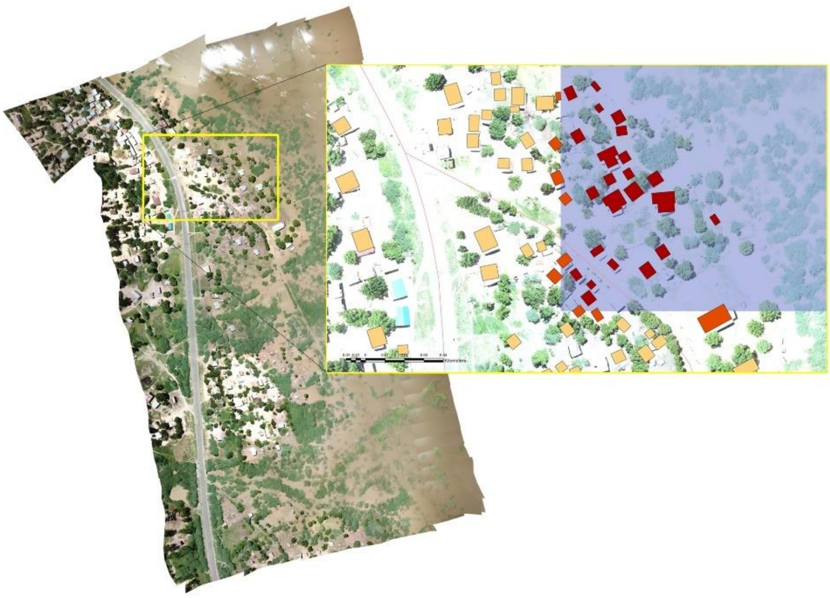


Figure 40. UAV orthophoto of Bangula district, Malawi. FigureB: damage assessment of the buildings superimposing the OpenStreetMap footprints and UNITAR water extent of TC Idai over the UAV orthophoto.

[47] https://www.int-arch-photogramm-remote-sens-spatial-inf-sci.net/XLIII-B5-2021/65/2021/

The originality of this project stands in many aspects: first of all, the very first United Nation example of a technology-friendly integrated airspace specifically outlined for humanitarian purposes. Secondly, the unique collaboration between the Government of Malawi, UNICEF Malawi, together with the team of partner universities that has been fundamental for the employment of drones in the collection of humanitarian imagery. UP4DREAM eventually conveys an unprecedent level of mapping accuracy and detail achieved through this combination of satellite imagery and Uncrewed Aerial Systems, UASs – also referred as Uncrewed Aerial Vehicles, UAVs –data.

To sum up, the collection and integration of diversified set of data is relevant not only in emergency assessment, yet also in ordinary planning. The creation of a comprehensive geodatabase indeed, provides an essential tool to support ordinary processes of decision-making, while enhancing existing cartography; at the same time a comprehensive geodatabase outlines a common and reliable source of data that can foster the assessment of ordinary planning, as well as speed up and strengthen the assessment of extraordinary events, namely tropical systems.

This thesis goes to my families: the one I had the luck to born into, the one I get to spend every bite of this life, and the one spread all over the world,
notwithstanding time and distance,
always by my side.
Eventually, this goes to my beloved zia Pepi, the one and only who taught me all I know, all I remember and push me to be the best human being I can be.

Grazie,
JC

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