

Participatory Natural Hazard and Climate Change Risk Mapping Study - Inhambane and Maxixe, Mozambique

Methodological manual

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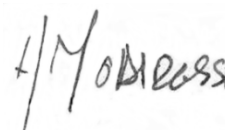


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1. Introduction

1.1. BACKGROUND

This report is one of the deliverables of the study “***Natural Hazard and Climate Change Risk Mapping and Participatory Processes for Inhambane and Maxixe, Mozambique***” funded by the World Bank (Contract 7154692, 2010-2011). This study was carried out with the participation and full implication of INGC.

The specific objectives of the study were to carry out natural-hazard and climate-change-vulnerability mapping and spatial analysis, and to establish the best options for a participatory process and recovery in full consultation with the exposed populations.

The study focused on developing viable options for urban requalification and coastal roads suffering from coastal erosion, taking into account the socio-economic situation of the population, and environmental and land-use norms. The study resulted in a detailed and costed proposal so that, as soon as INGC can secure the funds for investment, it can proceed with implementation.

The study developed a methodology with the further objective of replicating this ‘Participatory Process’ in other urban and coastal areas that are vulnerable to the effects of natural hazards and climate change in Mozambique.

1.2. NATURAL DISASTERS IN MOZAMBIQUE

Among the natural disasters affecting Mozambique, the most frequent is flooding, followed by epidemics, cyclones and drought (*Figure 1*).

The results of the 2008 Queface study, included in the INGC report, show an increase in the number of natural disasters between the 1950s and the period 2000 to 2010 (*Figure 2*). Of course, disasters commonly are interdependent (cyclone → flooding → epidemic, or drought → epidemic) (*Figure 1*). Indeed, we can see that the hurricanes will frequently cause floods, which are responsible for landslides, mudslides, and at times of epidemics when water remains for a long time.

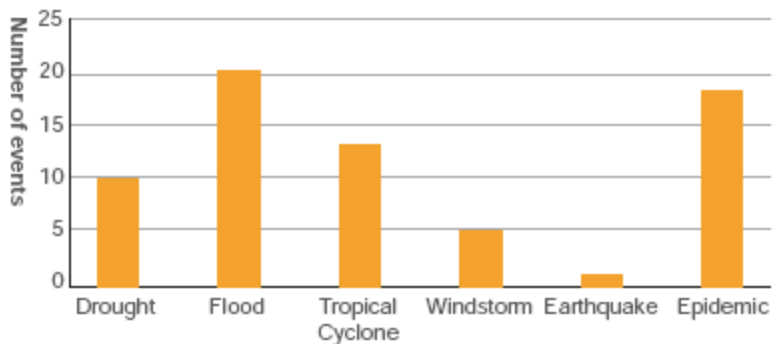


Figure 1: Number of natural disasters in Mozambique between 1956 and 2008 (Source: INGC)

Mozambique’s current vulnerability to natural disasters is also illustrated by the list of 10 major disasters in terms of loss of human life, which affected the country between 1956 and 2008 (Figure 3). Among them, the great drought of 1981 to 1985 has undoubtedly been the greatest natural disaster in the country's history, with almost 100,000 deaths, but climate causes alone cannot explain the seriousness of the event that was exacerbated by civil war, internal refugees, disrupted agriculture, and difficult access to food). The main floods (cheias) of 1971, 1977 and 2000 caused the death of almost 1600 people (Figure 3), and the 2000 floods alone affected 4,500,000 people. Cyclones are equally important in terms of victims (deaths or affected persons), as attested by the 1984 and 1994 events.

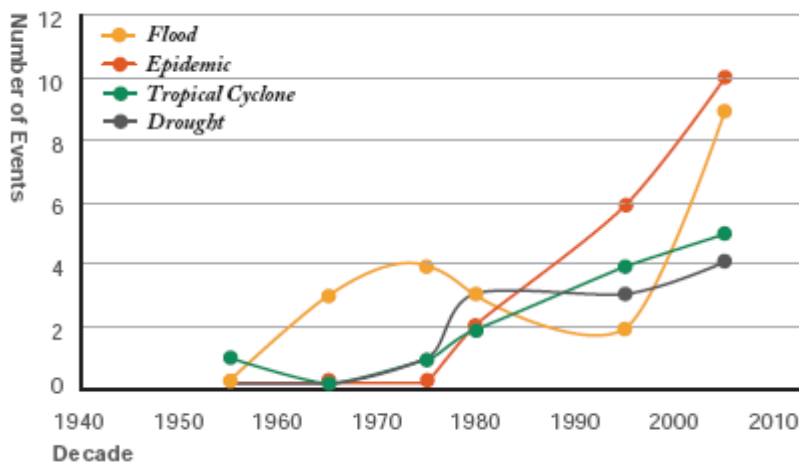


Figure 2: Number of natural disasters in Mozambique by decade between 1956 and 2008 (Source: INGC, according to Queface, 2008)

The search for and evidence of past and current climate change trends, through major climate events leading to disaster in terms of number of victims or of people affected, cannot alone constitute a basis for proof. Thus, though 5 of the 10 main natural

disasters recorded between 1956 and 2008 occurred between 1990 and 2000, it should not be concluded that there has been an increase in the frequency and/or intensity of dangerous weather phenomena, nor—and more importantly—that there has been an increase in the exposure of people to hazards for non-climatic reasons, such as demographic change, or the migration of people moving onto land not suitable for habitation. From the 4 main types of natural disasters (flooding, epidemics, cyclones and drought) it can be seen that flooding and epidemics mainly affect the central and southern regions (*Figure 3*)

Nº	Tipo de Desastre	Ano	Localização	Número de mortos
1	Secas	1981/1985	Maputo, Gaza, Inhambane, Manica, Sofala e Zambézia	100,000
2	Cheias	2000	Maputo (Matutuine, Manhiça, Magude e Marracuene), Gaza (Mabalane, Chokwé, Chibuto, e Xai-Xai), Inhambane, Sofala, Manica e Tete	800
3	Epidemias	1997/98	Cidade do Maputo, Maputo, Gaza, Inhambane, Manica, Sofala, Tete e Zambezia	619
4	Epidemias	1990		588
5	Epidemias	1992		587
6	Cheias	1971	Zambézia	500
7	Cheias	1977	Gaza	300
8	Ciclones tr.	1994	Nampula, Zambézia, Manica e Sofala	240
9	Epidemias	1983	Maputo, Gaza, Inhambane, Manica, Sofala e Zambézia	189
10	Ciclones tr.	1984	Maputo, Gaza, Inhambane	109

Figure 3: The ten worst natural disasters, in terms of loss of life.

1.3. OBJECTIVES OF THE MANUAL

The general objective will be to give a methodology for increasing global resilience of highly vulnerable areas in coastal cities facing present climate hazards and future climate changes. The other three objectives are more specific:

1. to assess for the present-day natural hazards (flooding, soil- and coastal erosion) and induced sea-level-rise effects for 2030, 2060 and 2100;
2. To increase the awareness of city stakeholders of the impact of coastal disasters and climate change, in order to prepare better reactions when faced with emergency situations, as well as to deal more efficiently with related subjects such as land-use and construction planning;
3. To lay out guidelines for including, at an early stage, the communities of the cities and their surroundings in the selection and evaluation of potential options for increasing overall resilience when faced with present and future climate change. This means adaptation measures and urban options in full consultation with exposed populations (participatory process)

These three objectives entail maximum participation of the exposed communities and of other relevant local and national stakeholders in all phases of the process. These phases include problem identification, planning, implementation, monitoring and

evaluation, which is very much in line with the participatory approach mentioned in (v) of the next section, i.e. "being actively involved in joint analysis and action plans".

1.4. WHAT IS A PARTICIPATORY PROCESS?

Participation means different things to different people and organizations. It can be applied in many different settings and ways such as¹:

- (i) People can be told what is going to happen or has already happened, including a number of variations of this approach (i.e. mostly top-down);
- (ii) People can participate by being consulted in a situation where external agents define both problems and solutions, in order to modify these in the light of people's responses;
- (iii) People can participate by providing resources, such as labour, in return for food, cash or other material incentives;
- (iv) People can participate by forming groups to meet predetermined objectives related to a certain intervention;
- (v) People can also participate by actively being involved in joint analysis, which leads to action plans and eventually the formation of new local institutions or the strengthening of existing ones. This tends to involve interdisciplinary methodologies that seek multiple objectives and make use of systematic and structured learning processes;
- (vi) People can participate by taking initiatives independent of external institutions to change systems.

Depending on the context, the different approaches can be valid and relevant in different ways and moments during a given intervention. Adequate contextual analysis and on-going monitoring and evaluation are essential in determining the best approach at a given point.

1.5. STUDY METHODOLOGY

In general and in line with its piloting nature, a study follows what is commonly referred to as a "program/project cycle management", which is the term given to the cyclic process of planning and managing programs and projects.

Different organizations give different names to the program/project cycle, but they all cover the same basic phases, namely: planning (sometimes called design), implementation, monitoring and evaluation. Increasingly, people are thinking in terms of a program/project 'spiral' rather than a 'cycle', not only because within a program/project period there will be multiple reflections and re-planning events, but also because in real terms, at the end of a cycle, the accumulated knowledge should

¹ Adapted from Pretty et al. (1995): Participatory Learning and Action. A Trainer's Guide

be used for planning a new program/project and for contributing to the broader organizational learning.

The study relies on a combination of methodologies. These aimed at investigating the various technical and social issues that define the baseline and context of the receiving natural and socio-economic environment in the studied city, as well as at promoting participation of the various stakeholders and their learning process.

A socio-economic study is typically subdivided into a quantitative and a qualitative approach. The present study can be seen as a combination of both baseline studies and contextual analysis, which are usually considered in any well-structured project/program cycle.

A **baseline** provides a detailed picture of the target populations' situation in relation to the objectives and indicators at the start of an intervention. This is the first set of data that is collected about project indicators, providing detailed information about the current situation (before the project/program has started) so that later, when the information is collected again, any evolution becomes apparent.

A **contextual analysis** or assessment of needs provides a bigger picture about the context to inform project/program design and thus is not specific about sub-groups or target groups within the broader population. It is expected to provide information needed for identifying the broad program objectives.

Quantitative studies consist of a survey administered to households². Statistical methods must be applied in this kind of exercise, to ensure that the studied population is representative of the overall target population. The quantitative study questions families in the *Bairros* (neighbourhoods) chosen for the study.

Qualitative studies in this specific case consist of community mapping and histograms:

Community mapping is a participatory exercise where the community draws a map of their neighbourhood and identifies its limits, the main access roads, and the available public services, such as schools, hospitals, and markets. The community is also asked to identify the areas in their neighbourhoods that are vulnerable to natural hazards, such as flooding and erosion.

Histogram: This tool requires the community to draw a timeline of the most important historical events that have occurred in their neighbourhood. In line with the topic of this study, the communities are asked to designate the natural disasters that have occurred in order to verify their recurrence.

Based on the drawn lines and events mentioned, a discussion ensues on how their neighbourhood came to exist, how it is governed, and what mechanisms they have for managing natural disasters.

² For the Inhambane and Maxixe study, the questionnaire was administered to 300 households in all 4 neighborhoods

A problem is that human memory is often short for most natural hazards, except in relation to the worst natural disasters, or those that have occurred in the past five years.

After the community mapping and histogram exercises are conducted, it might become apparent that a *neighbourhood* was erroneously designated as a vulnerable neighbourhood, while as a matter of fact it may even be one of the least vulnerable neighbourhoods in the studied city. Therefore, after consultation with the community members, it is possible to choose a more vulnerable neighbourhood.

In addition to the above, local field investigations of physical phenomena, analyses of reports on past disasters, and the exhaustive collection of relevant data (reports, scientific papers, maps, satellite images, etc.) are necessary to identify and map the local hazards affecting the communities.

An adequate methodology is based on deriving reference disaster events (“intensity”, frequency maps, including climate change) from partial and localized data and from historical events, for the whole studied domain.

2. Climate and climate change in Mozambique

2.1. CURRENT CLIMATE CONTEXT IN COASTAL AREAS OF MOZAMBIQUE

The effects of climate change in Mozambique are introduced by an analysis of climate variables (temperature, precipitation) and natural disasters from 1960 to the present day.

2.1.1. Temperatures

Each analysis was carried out for the three major regions in Mozambique: the north, centre and south. Past trends were supplied for temperatures (INAM 2009, Queface 2009). An increase in maximum temperatures for the months of March to April and September to November of 1.1°C was observed in the north of Mozambique between 1960 and 2005. This increase reaches 1.6°C for maximum DJF³ temperatures in the central part. Heat-wave periods increased by 9 days between 1960 and 2005, and the number of cold days and nights decreased over the same period. In the southern regions of Mozambique there are no clear trends.

2.1.2. Precipitations

INGC's reports indicate that there is no significant trend in precipitation. , Nevertheless, it can be observed that the rainy season arrives later than before (INAM 2009). Rain-free periods (continuous dry days) have tended to increase during March to May and September to November in the north-east of the country.

2.1.3. Cyclones

The coastal areas of Mozambique are regularly affected by tropical storms and cyclones. Between 1980 and 2007, 56 tropical storms and hurricanes affected the area of the Mozambique Channel (*Figure 4*).

Of these 56 cyclones and tropical storms, only 15 (25%) reached the coast of Mozambique (landfall cyclones). Four of these reached the northern provinces, eight reached the provinces of the centre, and three the provinces of the south. More worrying has been the increase in frequency of these storms: four occurred from 1980 to 1993, while the other eleven were in the period from 1994 to 2007. In addition the intensity of the cyclones that hit the coastal regions of Mozambique during the second period, also increased (*Table 1*).

Another illustration (*Figure 5*) of the frequency of cyclones affecting the coastal provinces of Mozambique is given below. This figure shows the number of cyclones

3 DJF – December, January and February

that have hit each district between 1970 and 2000, knowing that each cyclone may have affected several districts. *For example, the district of Inhambane has been hit 4 or 5 times between 1970 and 2000.* However, when it is said that a cyclone affected a district, there is no information about what was the main involved phenomenon (wind, waves, surges, rain, flooding), and if it was strong or moderate.

The INGC study nevertheless indicates that the number of cyclones is too small for drawing any meaningful conclusions about trends. More than being due to climate change, these differences may only be related to natural climate variability. It would take a longer record of observations before drawing any definitive conclusions on the trends of occurrence of intense cyclones. The record must be long enough to remove average variability, so that the trends induced by climate change can be revealed.

2.1.4. Mean sea level

The information available from the report of the INGC 2009 study recalls that “any analysis of sea-level rise requires careful and consistent observations of sea level over several decades”. Such records are not available in Mozambique. A relatively long record of annual mean sea levels is available for Maputo from the Permanent Service for Mean Sea Level (PSMSL), which applies rigorous quality checks on the original observations supplied by INAHINA in Mozambique. Past mean sea-level evolution over the period 1960-2002 is given in Figure 6.

After analysis of the overall records of tectonically stable areas (limited to Mozambique and South Africa), INGC concluded that records are consistent with the most accurate global trends on the order of 1.3 to 2.3 mm per year. Consequently, these global values of recent sea-level rise can be extrapolated, cautiously, to the coast of Mozambique, as they reflect the best available estimates of recent trends, and better than those deriving from global observations.

No special meaning must be given to the recent acceleration (1993-today) of sea-level rise measured in Maputo. It is uncertain whether this higher rate from 1993 to 2003 reflects a decade of change related to climate variability, or an increase in the long-term trend. As yet, no analysis has been made of sea-level records all along the coast and of the representativeness of Maputo records, to test whether this acceleration is to continue or not in the future, or how fast it is.

	TS	Cat 1	Cat 2	Cat 3	Cat 4	Cat 5
Nov	2	0	0	0	0	0
Dec	4	1	0	0	2	0
Jan	9	6	0	2	1	0
Feb	8	2	4	0	2	0
Mar	3	3	2	0	0	0
Apr	1	1	1	1	1	0
Total	27	13	7	3	6	0

Figure 4: Distribution of tropical storms and cyclones in the Mozambique Channel from 1980 to 2007 (source: INGC Alterações Climáticas Relatório, 2009 - Ciclones e da Subida do Nível Médio das Águas do Mar)

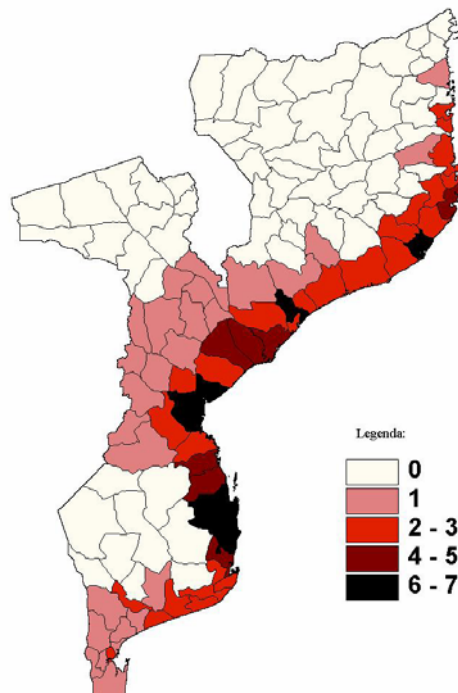


Figure 5: Occurrence of cyclones in Mozambique. Number of cyclones that affected districts of the coastal provinces of Mozambique between 1970 and 2000.

(Source: After INAM, In Consultec-Salomon Lta – Plano Integrado de gestão de recursos hídricos da provincia de Inhambane – Relatório Final – Setembro 2009)

Ano	Nome dos Ciclones ou Tempestades Tropical	Velocidade do Vento (km/h)	Rajadas (km/h)
1975	Blandine	Sem informação	Sem informação
1976	Danae	Sem informação	Sem informação
1978	Angele	152	Sem informação
1981	Edwige	Sem informação	Sem informação
1987	Doaza	133	200
1988	Hely	97	122
1989	Iana	70	102
1991	Debra	48	63
1994	Nadia	175	Sem informação
1995	Fodah	110	180
1997	Gretelle	140	180
	Josie	130	222
1998	A19798	60	Sem informação
1999	Alda	130	90
	D19899	95	Sem informação
2000	Leon/Eline	185	Sem informação
	Gloria	86	Sem informação
	1319992000	86	Sem informação
2001	Dera	86	Sem informação
2002	1120002001	80	Sem informação
2003	Japhet	185	Sem informação
2006	07 - 20052006	52	Sem informação

Table 1: Tropical storms and cyclones affecting Mozambique over the period 1975-2006

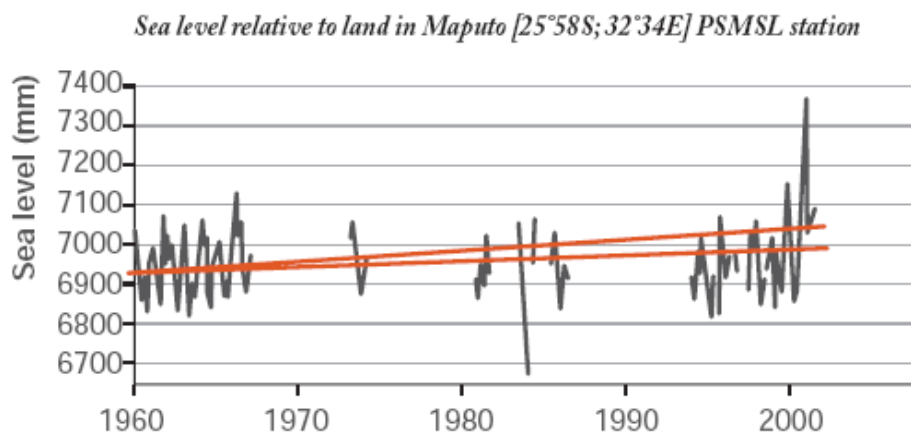


Figure 6: Relative mean sea levels in Maputo from 1960 to 2002
 (Source INAHINA 2008, in INGC Alterações Climáticas Relatório, 2009 - Ciclones e da Subida do Nível Médio das Águas do Mar)

2.1.5. Extreme sea levels – tides and storm surges

Extreme sea levels have been studied in some Mozambique ports. The study “*Ciclones e da Subida do Nível Médio das Águas do Mar: INGC Alterações Climáticas Relatório*” provides, for three ports, the characteristic values for the maximum sea levels for the study return periods of 1, 10, 100 and 1000 years, compared with the average local sea level (*Table 2*). Data for the highest astronomical tides (MAMA) were also provided.

The difference between maximum heights and highest astronomical high tides (MAMA) gives a surge value⁴ for each return period (*Table 3*). The values corresponding to a 1-year return period will not be used.

No such data are available for the port of Inhambane. However, considering that:

- (i) The characteristics of the astronomical tides in Maputo and Inhambane are close in terms of sea levels;
- (ii) The surge values (*Table 2*) are similar for Maputo and Beira, located respectively to the south and north of Inhambane; and
- (iii) The characteristics of the locations of ports are to some extent similar, lying in estuary areas or at the end of a bay;

the following approximation will be made.

Surges in the port of Inhambane for the data periods of 10, 100 and 1000 years are, respectively, 50 cm, 100 cm and 150 cm. These are order-of-magnitude values. For this study, the 1000-year return period will not be used⁵.

Port	1 year	10 years	100 years	1000 years	MAMA
Maputo	178 cm	225 cm	270 cm	315 cm	178 cm
Beira	346 cm	390 cm	440 cm	490 cm	340 cm
Nacala	185 cm	234 cm	272 cm	312 cm	205 cm

Table 2: Comparison between maximum sea level (in centimetres) for a given return period and the highest astronomical tides (MAMA, Maré Astronómica Mais Alta), compared with average sea level values. (Source INGC⁶)

4 This is very much an approximation. Extreme levels may occur at times other than high tide. Maximum surges may be higher than the surges given here, but the extreme one-off level, for a given period, remains lower than the extreme levels given in *Table 3*.

5 A 1000-year return period is not suitable for characterizing the coastal flooding risk to inhabited areas

6 *Ciclones e da Subida do Nível Médio das Águas do Mar: INGC Alterações Climáticas Relatório*

Port (region)	10 years	100 years	1000 years	MAMA
Maputo (south)	47cm	92cm	137cm	178cm
Beira (centre)	50cm	100cm	150cm	340cm
Nacala (north)	29cm	67cm	107cm	205cm

Table 3: Surge estimates for data-return periods based on highest astronomical tide levels (MAMA, *Maré Astronómica Mais Alta*), compared with average sea level values.

The Inhambane/Maxixe study provided local values of extreme storm surges, using a rough approximation (Table 4).

Inhambane Port	Return period	
	10 years	100 years
Surge	50 cm	100 cm
MAMA (2010)	160 cm	160 cm
Extreme sea level	210 cm	260 cm

Table 4: Surges, maximum astronomical tide levels (MAMA) and extreme levels used for Inhambane. The highest astronomical tide level (MAMA, *Maré Astronómica Mais Alta*) and extreme sea levels are compared with the average sea level (193 cm) or data from terrestrial maps.

2.2. FUTURE CLIMATE TRENDS

Our presentation focused on climate change that may affect the risks of flooding, soil- and coastal erosion, and coastal flooding. Changes to these risks in the future would be due to:

- Changes in land use, such as urbanization, rendering the land impervious, road building, changes to runoff drainage, or intensive agriculture without anti-erosion practices;
- Changes in rainfall patterns (intensity/duration/frequency);
- Rises in average sea levels;
- Increase in wave height in the estuary due to local winds;
- Increase in the frequency/intensity of waves and surges due to cyclones.

In addition, we present climate-based elements (future trends) that can be taken into account for the scenarios to be considered for 2030-2060-2100, which have an impact on the risks of flooding, soil- and coastal erosion, and coastal flooding. These trends are in precipitation, cyclones, and average sea levels.

The trends provided in this study result from 7 general-circulation models (GCMs) developed within the context of the IPCC work on a 200 to 300 km spatial-scale grid.

2.2.1. Precipitation

The 2009 INGC report acknowledges that past rainfall trends are much more heterogeneous than those relating to temperatures. Furthermore, the indices that gave rise to the main research concerns are the persistence of rain-free days (MAM⁷ and SON seasons), the duration of dry periods, the starting date of the rainy season, and evapotranspiration (PET). Changes in rainfall over four seasons between 2046 and 2065 are dealt with by integrating PET. The results are expressed in terms of the increase or reduction of precipitation per day (mm/day).

Figure 7 shows changes to the average rainfall expected between 2046 and 2065 in Mozambique for the DJF (⁸) and MAM seasons. It can be seen that overall precipitation will increase for DJF and MAM, with the coastal zones being the most affected (between +1.0 and +1.5 mm/day). The actual average figures are around 1 mm/day for the earlier period and 1.5 mm/day for the later one, over a 20-year period. These figures do not say anything about changes in rainfall intensity.

No relation is known between these seasonal average recorded rainfall and increases in rainfall frequency or rainfall intensity.

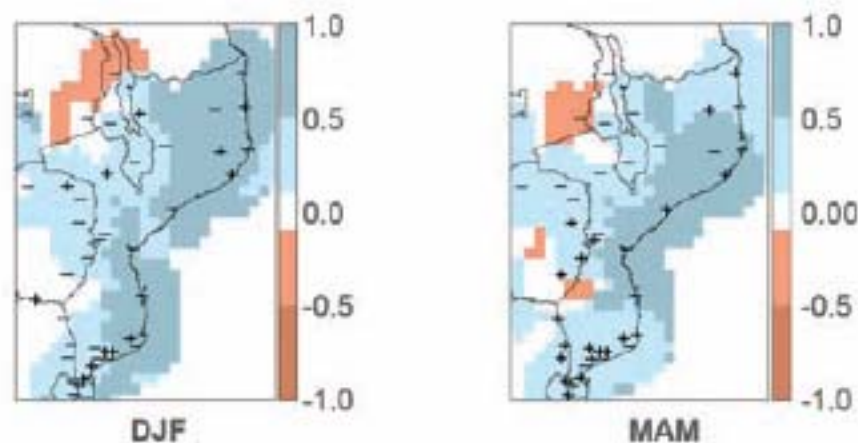


Figure 7: Changes to average daily rainfall (mm/day) in December to February (left) and March to May (right) for 2046-2065

Another result has also been provided, which presents changes to average daily rainfall over the 12 months of the year, for 2046-2065 and 2080-2100, and for the four regions (north, centre, south, coast). These elements are relevant for research into the future of agriculture, and for surface-water and groundwater management.

⁷ DJF: December-January-February; MAM: March-April-May; JJA: June-July-August; SON: September-October-November

⁸ DJF = December, January and February.

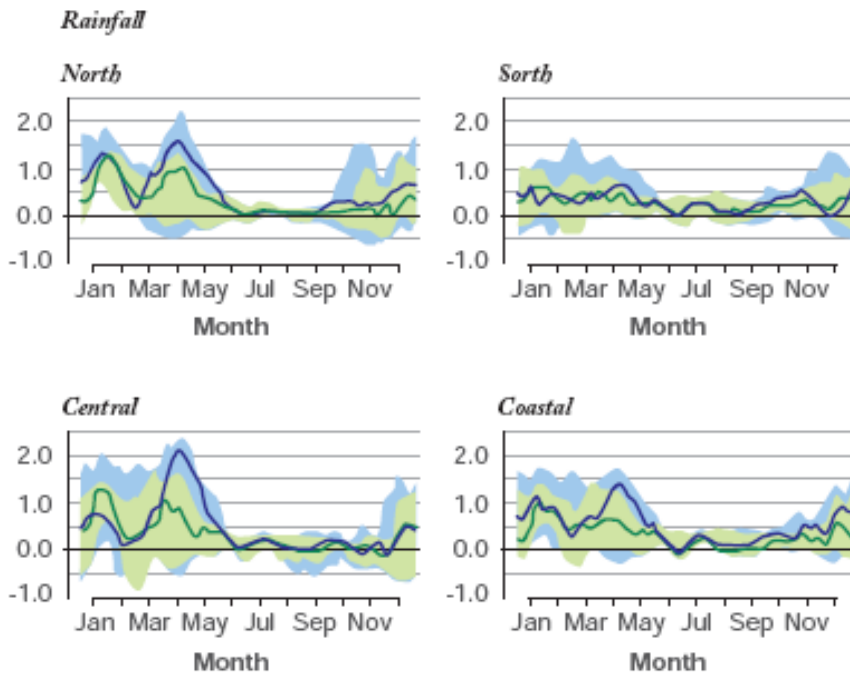


Figure 8: Changes in average daily rainfall on the four regions (north, south, centre and coast) for 2046-2065 (green line = average, green area = variations) and 2080-2100 (black line – average, blue area = variations). (Source: INGC, 2009)

Variability of rainfall in Mozambique and more generally in Southern Africa, is related to global oscillation patterns, such as the El Niño-Southern Oscillation (ENSO, see Fauchereau et al., 2003, 2009), and the Madden-Julian Oscillation (MJO, see Chang-Hoi Ho et al., 2006). Most studies focus on rainfall at a seasonal time-scale, with a special interest in rainfall deficits (droughts) that can have a major impact on agriculture and food availability.

General circulation-model experiments suggest that the unprecedented global warming during the latter half of the 20th Century may result in a more intense hydrological cycle, associated with an increase in the frequency and/or intensity of heavy precipitation. Testing this assumption for South Africa, Fauchereau et al. (op. cit.) mentioned that there was no significant trend in the Southern Africa Rainfall Index throughout the century; they also mentioned that only parts of South Africa experienced a significant increase in the probability of extreme precipitation. However, they also proposed the hypothesis that increases in rainfall variability during the last decades of the 20th Century were more or less a return to a similar variability that prevailed in the early decades of the century, when average temperatures were significantly lower than today. The conclusion is that, over what is commonly named the “century of unprecedented global warming” and in opposition to the implications of nearly all experiments based on scenarios of $2 \times \text{CO}_2$ GCM, there has been no clear change in

either Southern African rainfall variability, or in the mean value of the Southern African Rainfall Index.

The efforts made to get comparable results that will be useful for modelling wave height and flooding on a Mozambique-wide scale, in order to get future scenarios for 2046-2065 and 2080-2100, have been unsuccessful so far. The authors recognize that scientists are still unable to predict the intensity of future daily rainfall; however, this is necessary for the analysis of waves and flooding.

Uma importante conclusão desta abordagem de modelagem proposta foi que a metodologia de modelagem estatística é actualmente baseada nas observações históricas e assim é incapaz de projectar intensidades diárias de pluviosidade para além da que é actualmente experimentada num certo local. Ela, portanto, subestima as cheias de máximo potencial num futuro clima, embora possa captar alterações na frequência de grandes cheias. A pesquisa actual procura resolver este assunto no futuro próximo.

Table 5: Extract from “Modelagem do risco de inundação” in *Análisis das Mudanças Climáticas: INGC Alterações Climáticas Relatório, 2009*

Nevertheless, changes in land use (urbanization, road building, etc.) and the absence of any urban- and road-runoff management are the main causes for the increase in flooding in an urban and suburban environment.

2.2.2. Cyclones

The participants of the WMO (World Meteorological Organization) International Workshop on Tropical Cyclones (2006) wrote a Statement on Tropical Cyclones and Climate Change (IWTC) to synthesize recent research. Cyclones require warm sea-surface temperatures, low vertical wind shear, and high values of large-scale relative vorticity in the lower layers of the troposphere. Thus, with the increasing sea-surface temperatures, as shown in most tropical ocean basins (IWTC-6, 2006), it is widely expected that cyclone frequency and intensity will increase. However, Vecchi et al. (2007) have shown that thermodynamic atmospheric properties also have an important role, complicating the analysis of cyclone genesis and future trends.

Regarding past observations, Webster et al. (2005) and Emanuel (2005) showed significant increases in observations of the intensity of cyclones [at the global scale (from 1975-2004) and in the Atlantic and West Pacific basins (during the last 50 years), respectively], but these results have been strongly discussed (IWTC-6, 2006). The significance of the observed trends is questioned due to issues arising from data availability, the evolution of data-analysis methods, and the length of the available time series. The evolution in data-analysis methods may favour a bias toward higher-intensity events in more recent years (IWTC-6, 2006), and short time series may be

biased by the potential impact of other inter-annual- to decadal-scale processes. On a global scale, the primary factor affecting the frequency and track of tropical cyclones on inter-annual time scales is the ENSO phenomenon (IWTC-6, 2006). In the southwest Indian Ocean, Ho et al. (2006) and Mavume et al. (2009) showed the importance of ENSO and MJO variability, showing a relationship between the phase of these ocean-atmosphere fluctuations and the frequency and tracks of cyclones in inter-annual and intra-seasonal scales, respectively.

Webster et al. (2005) showed an increase in the number of intense cyclones between the periods of 1975-1989 and 1990-2004 (nearly doubling), but concluded that the “attribution of the 30-year trends to global warming would require a longer global data record and, especially, a deeper understanding of the role of hurricanes in the general circulation of the atmosphere and ocean, even in the present climate.” An updated review article by Knutson et al. (2010) concluded, by taking into account the limitations in interpreting past observations, that there has been no significant change in the number of cyclones during the period 1970 to 2004 (with the exception of the North Atlantic).

Thus, as indicated in 3.1.3, below, no significant conclusions about present-day trends in frequency and intensity of tropical cyclones can be used for proposing future scenarios. For that reason, an alternative approach was investigated for identifying projections of future tropical-cyclone characteristics based on climate modelling.

Global projections of future cyclone frequency and intensity are made with global circulation models that currently lack sufficient horizontal resolution for a proper representation of cyclones. The highest achieved resolution is approximately 20 km, whereas it has been suggested that a resolution of about 1 km is required to adequately represent the inner structure of a cyclone (Oouchi et al., 2006). However, many global models do represent cyclones, with wide variations in the results of these studies, though there is an overall trend in the global scale of a decrease in the frequency of cyclones and an increase in their intensity (Emanuel et al., 2008). Knutson et al. (2010) summarized current global model predictions of a -6 to -34% decrease in frequency, with “low confidence” in projected changes in individual basins, and a +2 to +11% increase in intensity, although changes may not occur in all tropical regions. The trend of increasing cyclone intensity is not observed in low-resolution models, and current studies may thus underestimate future cyclone intensity. Therefore, Knutson et al. (2010) emphasized the importance of developing higher-resolution models for studying the potential trends in hurricane intensity.

Projections at regional scales continue to have a low confidence, due to the differences in global-climate model projections needed for forcing the downscaling of the models, as well as to uncertainties in changes in the large-scale tropical climate. The effects of these changes on tropical cyclones need to be addressed, in order to improve global and regional projections (Knutson et al., 2010). When evaluating regional results, the IPCC report in 2007 concluded that there is “little modelling guidance on possible changes in tropical cyclones affecting the southeast coast of Africa,” emphasizing that change in the frequency and intensity of cyclones off the coast of Africa remain uncertain (Christensen et al., 2007).

Thus, the recent trends in observations and the results of long-term model simulations (despite variability between results) suggest that climate change will affect the

characteristics of tropical cyclones in the southwest Indian Ocean with an increasing trend in intensity, and that cyclone frequency may probably decrease in the early part of the cyclone season.

2.2.3. Mean sea level

The global mean sea-level rise projections derive from IPCC-PIAC 2007 for different social and economic development scenarios in this 21st Century. In its projections of future climate change throughout this century, the IPCC-PIAC draws a set of model sea-level rises for 2090-2100 based on 1980-1999 sea levels, providing an increase in of 180 mm to 590 mm by 2100, depending on the emission scenario used.

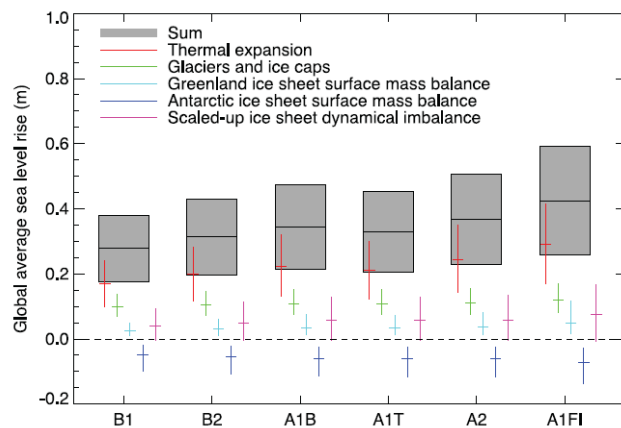


Figure 9: Prediction of sea-level rise for different climate scenarios (after Meehl et al., 2007)

Other projections are given below. Sea-level-rise values are proposed for 2030, 2060 and 2090.

Table 6: Scenarios of global sea level rise (in INGC, after Nicholl and Tol, 2006)

RECE	A1FI	A2	B1	B2
2030	80mm	80mm	80mm	80mm
2060	180mm	160mm	120mm	160mm
2090	340mm	280mm	220mm	250mm

Rahmstorf notes that the dynamics of sea-level response to a temperature change is unclear, but that during the 20th Century, the following relationship was satisfied:

$$\frac{dH}{dt} = a(T - T_0)$$

In response to an increase in average temperature, sea level initially rises at a rate proportional to the temperature difference. Subsequently, after a period that may reach a few centuries of adjustment, the sea level stabilizes, but at our time scale, within a century, the original dynamics of the phenomenon must be considered. Using this relationship, Rahmstorf predicts a rise in sea level between 50 cm and 140 cm, depending on the scenario, that is to say higher values than those proposed by the IPCC. Rahmstorf therefore recommends not excluding rates of rising sea levels greater than those predicted by the IPCC, and to retain for example the **value of 1 m by 2100 for adaptation measures purposes.**

2.2.4. Storm surge and swells

Future storm-surge and wave-height hazards are directly linked to the future cyclonic and tropical-depression hazard. There are available trends for extreme storm surges and swell along the coasts of Mozambique.

3. Climate change scenario

3.1. FUTURE MEAN SEA LEVEL

In relation with the natural hazards considered in this study (flooding, erosion and coastal flooding), only sea-level-rise scenarios can be introduced for assessing their effect on the increase (or not) in coastal flooding hazards.

Until now, the only studies on the consequences of sea-level rise along the coast of Mozambique considered a rise of 5 m. This is an extreme scenario (considered by some authors and models from melting ice caps) that has the advantage of mapping flooded areas even if knowledge of the topography (DEM) is rough.

Here, we recommend adopting a scenario of a sea-level rise of:

- 20 cm by 2030
- 50 cm by 2060, and
- 100 cm by 2100.

3.2. FUTURE CYCLONES VS. FUTURE EXTREME WAVES AND STORM SURGES

As future cyclonic activity in relation with climate change is not quantified (see 2.2.2) by another way than qualitative scenarios ("*Higher frequency and higher intensity*" or "*Lower frequency and higher intensity*"), it is proposed to consider waves, storm surges and wind to be used for coastal-hazard purposes (marine flooding, extreme coastline erosion, etc.), the values being obtained from numerical models.

The marine submersion of coastal areas results from the conjugate effects of tide, atmospheric surge (due to wind and low atmospheric pressure), wave set-up (local elevation of the mean sea level due to wave breaking), and wave swash (oscillation of a water sheet on both side of the mean water level due to the impulse of breaking waves). The maximum level reached by the water is the run-up (*Figure 10*). Along the coast of Mozambique, the meteorological events responsible for such phenomena are cyclones and austral waves. In a climate change context, extreme water levels may be increased by the sea-level rise.

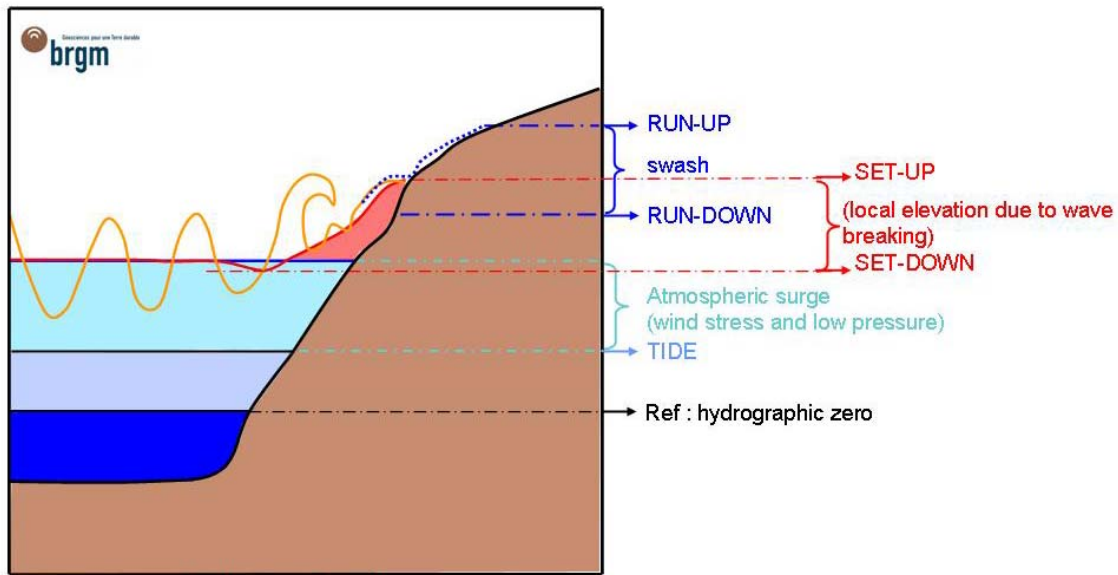


Figure 10: The different causes of water-level variations during meteorological events

3.2.1. Determination of cyclone events and austral-wave scenarios

Although satellite data are available from the early 1960s, the best historical track records are not complete before 1970 with the increase of satellite coverage and analysis techniques. Concerning long-term global re-analysis, they properly reproduce neither the cyclonic wind fields nor the cyclonic wave fields, because of their coarse spatial and temporal resolution. As cyclones are very occasional events, very long-term data are needed for a statistical analysis. Thus, the use of a probabilistic approach for assessing the marine flooding hazard due to cyclones is made harder by the lack of accurate long-term data.

One of the possible solutions is to use a deterministic approach by building several scenarios based on reference destructive historical events or synthetic cyclones. The latter consists in choosing a very intense tropical cyclone that occurred near the study area, and then translating its track so that this impacts the study area. This approach allows assessing the impact of physically plausible tropical cyclones with the worst configuration for the studied area.

For example, this method was used in a recent study to determine the extreme wave characteristics around Reunion Island (Pedreros et al., 2010). The track of cyclone Geralda was translated so that the waves hit the northern coast of the island. Then, the cyclonic wind fields were generated with a parametric model (Holland, 1980), using the parameters of best-track data from Meteo-France. This method also allowed carrying out sensitivity tests in a climate-change context, through modulating the intensity of the cyclone scenarios.

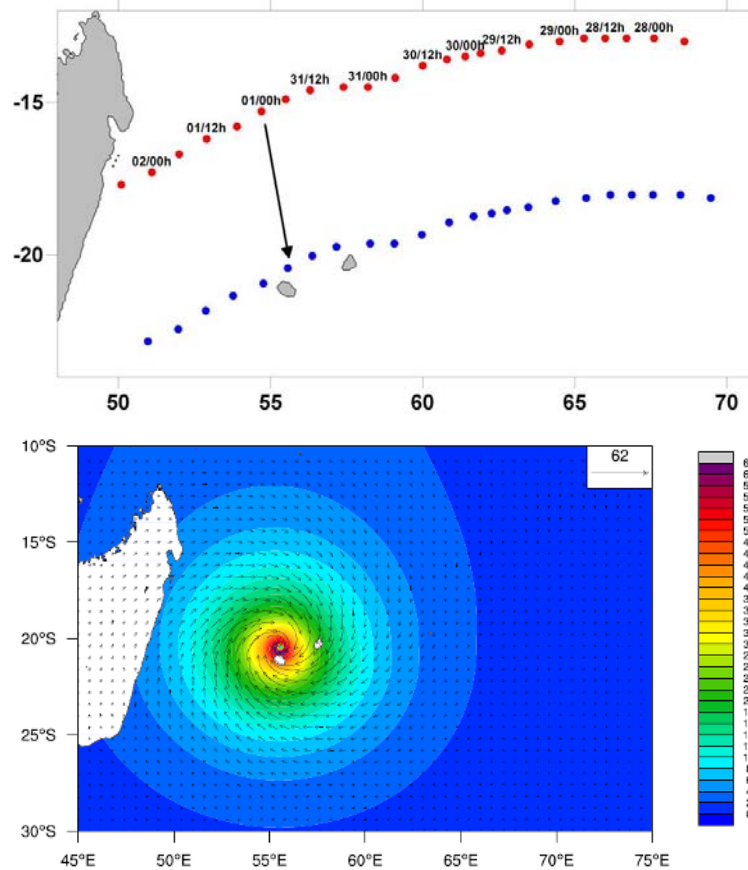


Figure 11: Example of a synthetic cyclone based on the track of cyclone Geralda for the study of extreme waves on Reunion Island (Pedreros et al., 2010). Top: real track of Geralda (red) and track of the synthetic cyclone (blue). Bottom: cyclonic wind field of the synthetic cyclone generated with a parametric model (Holland, 1980) and the best track data from Meteo-France.

For the Indian Ocean, the JTWC (Joint Typhoon Warning Center) provides the best track archives of historical cyclones from 1945 to 2010⁹. These archives contain the main cyclone parameters (track, central pressure, maximum wind intensity, radius of maximum wind, etc.) that are used in parametric wind models. Figure 12 shows the track of cyclone Favio that occurred in February 2007 and made landfall in Mozambique at the maximum of its intensity (4/5 on Saffir-Simpson scale).

⁹ http://www.usno.navy.mil/NOOC/nmfc-ph/RSS/jtwc/best_tracks/

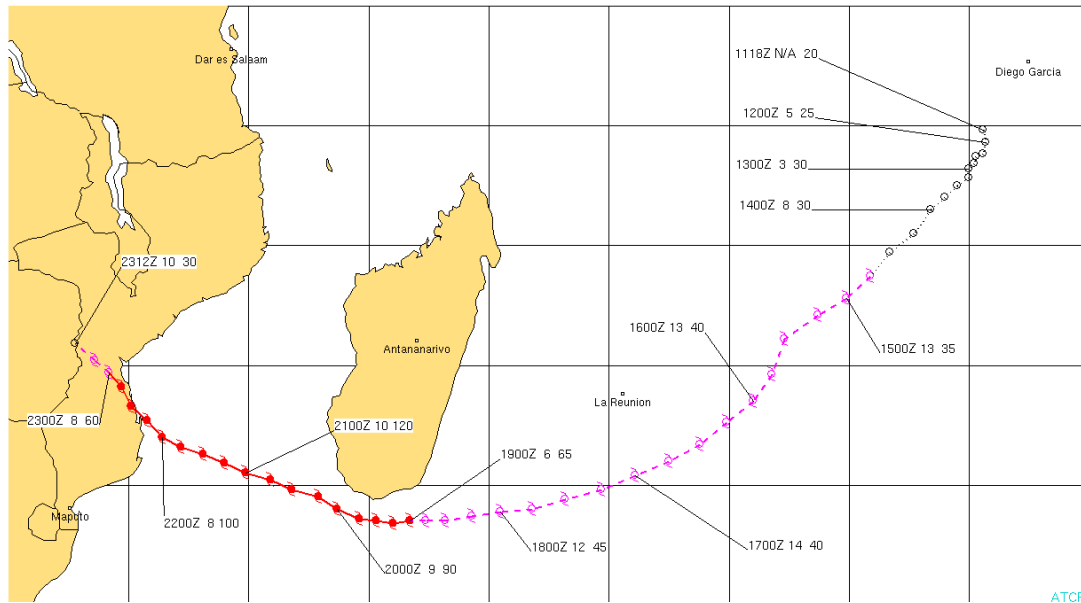


Figure 12: Tropical cyclone Favio best track (JTWC: annual tropical cyclone report - 2007)

Concerning austral waves, a probabilistic approach should use a long-term time series of global models like the Wavewatch-3 re-analysis from the NOAA. First, a wave classification is required for isolating the austral-wave climates from the time series. For example, a K-means algorithm is adapted to the classification of wave climates (Butel et al., 2002).

	Wave climate	Hs	T	D	Occurrence
Austral Waves	Southern waves, annual	1,5 m	14,9 s	201°	7,1%
	Southern waves, summer	1,9 m	12,5 s	202°	10,0%
	Southern waves, summer	2,2 m	11,0 s	183°	5,6%
	Southern waves, summer	2,3 m	10,4 s	162°	4,9%
	Southern waves, summer	2,4 m	16,5 s	198°	3,8%
	Southern waves, summer	2,4 m	14,0 s	199°	8,8%
	Southern waves, spring, autumn, winter	1,2 m	12,7 s	201°	11,9%
	Southern waves, winter	1,1 m	10,7 s	187°	7,4%
	Southern waves, winter	1,0 m	8,8 s	155°	7,9%
	Southern waves, winter	1,6 m	9,5 s	155°	8,4%
SW Monsoon	spring, autumn, monsoon summer	1,7 m	5,5 s	262°	3,8%
	spring, autumn, monsoon summer	2,3 m	6,8 s	243°	3,9%
	summer, monsoon summer	2,6 m	6,7 s	276°	4,5%
NE Monsoon	winter, NE, monsoon winter	1,3 m	5,6 s	66°	3,7%
	monsoon, winter	1,5 m	5,6 s	21°	8,4%

Figure 13: Example of wave classification with WW3 re-analysis time series at point 5°N/78°45'E performed for the SIIRM project in Sri Lanka (Garcin et al., 2009)

Once an extreme austral-wave climate has been identified, an extreme-value analysis will calculate extreme wave heights and the associated return periods. General Extreme Value (GEV) distributions and the Pareto Distribution (GPD) are the common distributions used for extreme-wave analysis.

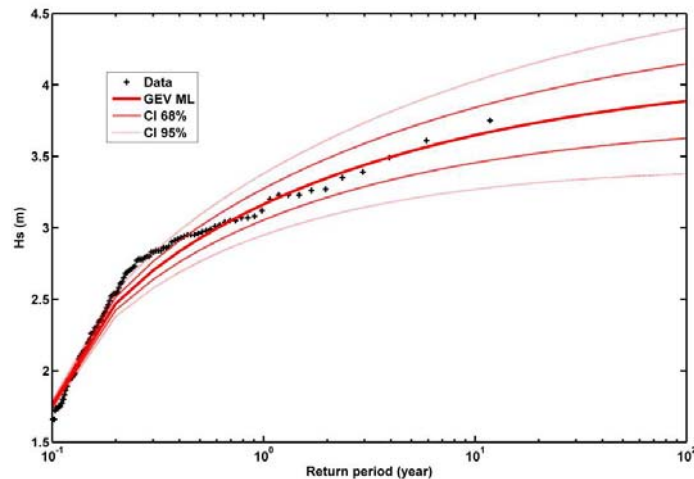


Figure 14: Example of statistical analysis at 5°N/78°45'E performed for the SIIRM project in Sri Lanka (Garcin et al., 2009)

3.2.2. Assessment of marine flooding hazard

For determining the extreme sea levels for the selected scenarios, the main steps are:

- Numerical modelling of atmospheric surges and waves and determination of the maximum wave set-up and swash amplitudes for each scenario;
- Consideration of the maximum tidal range;
- Estimation of the sea-level rise (if sensitivity tests in a climate change context are performed).

Bathymetric and topographic data must be collected for the numerical modelling. For large scales, GEBCO (General Bathymetric Chart of the Oceans) provides gridded topo-bathymetric data with a one-minute resolution, available from the British Oceanographic Data Centre (BODC) website. The topo-bathymetric SRTM30_PLUS DEM data (Becker and Sandwel, 2008), gridded at 0.0083°x0.0083°, can also be used.

For the local scale and especially for marine flooding-hazard mapping (typically when a study deals with an urban area), higher resolution topo-bathymetric data are required. If not available, such data must be collected, for example, with a high-resolution DEM obtained with satellite stereo-radar imagery (ALOS) or with the LIDAR technique (very expensive). This DEM acquisition will be done during low tide.

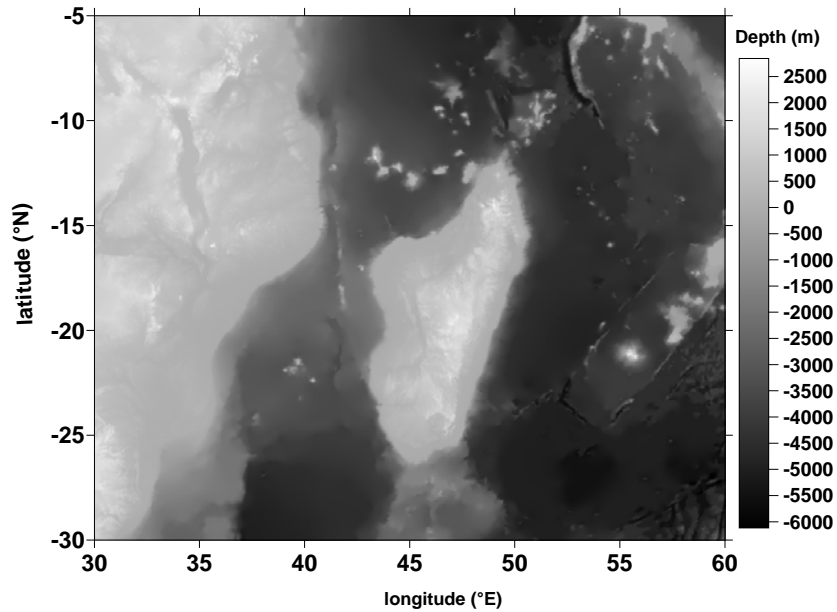


Figure 15: Topo-bathymetric data from GEBCO near the Mozambique Channel

For wave modelling, the Wavewatch3 model (NOAA) can be used for offshore waves and the SWAN model (Delft University) can be used for nearshore waves. Figure 16 shows an example of cyclonic-wave modelling near Reunion Island. For the atmospheric surge, ROMS (Rutgers University & UCLA) or MARS (Ifremer, France) are commonly used for both scales.

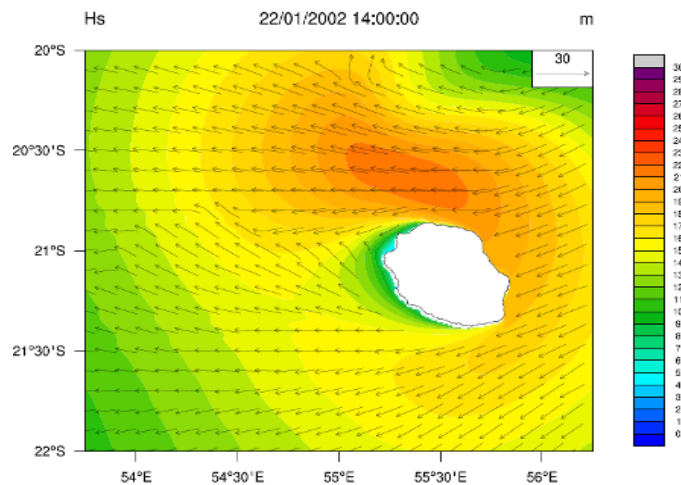


Figure 16: Example of wave field modelled near Reunion Island for cyclone Gamède with parametric wind fields and the SWAN model (Delft University).

The wave setup and amplitude of the swash can be deduced from the wave characteristics using empirical formulas (Stockdon, 2006).

The extreme sea level for each scenario (run-up) is the sum of (i) the selected tide level, (ii) the wave setup, (iii) the swash amplitude, (iv) the atmospheric surge, and (v) the sea-level rise (if considered).

3.3. PRECIPITATION: EXTREME RAINFALL INTENSITIES

There is no existing scenario for predicting the evolution of precipitation intensities in relation with global climate change. For flood-hazard mapping in urban areas, it is recommended to keep using the IDF curves now used in Mozambique, even if climate change may affect extreme rainfall events.

The consultant will then decide to consider (or not) an increase coefficient if necessary.

To assess the quantities of rain that may be involved during extreme rainfall events, it is recommended to use the IDF curves produced in “Regulamento dos sistemas publicos de Distribuicao de Agua e Drenagem de Agua Residuais” 2003 (see Appendix 1) designed for the Maputo area (Figure 18), and then to introduce a “local” coefficient.

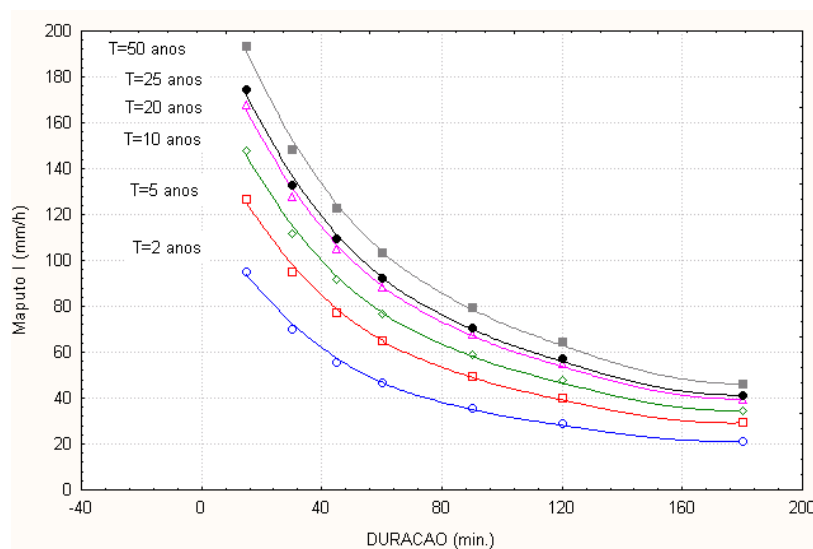


Figure 18: Intensity Duration Frequency curves for Maputo

Mozambique is divided into five climatic zones (Maputo/Matola, Zone A, B, C and D. Each zone is characterized by a coefficient K (K=1 for Maputo/Matola region). An example is given for region “A” (e.g. Inhambane). Using these curves (or a and b parameters), the probable frequency values for rainfall lasting less than three hours are defined (Table 7).

IDF INHAMBANE						
Coefficient k=0.8	Return period (years)					
	2	5	10	20	25	50
Duration (minutes)	mm	mm	mm	mm	mm	mm
60	36	49	58	66	69	77
120	47	65	77	88	92	103
180	55	76	91	105	109	123

Table 7: Estimated values of rainfall in the coastal area of Inhambane province, for a rainy-event duration of 1, 2 and 3 hours and for different return periods

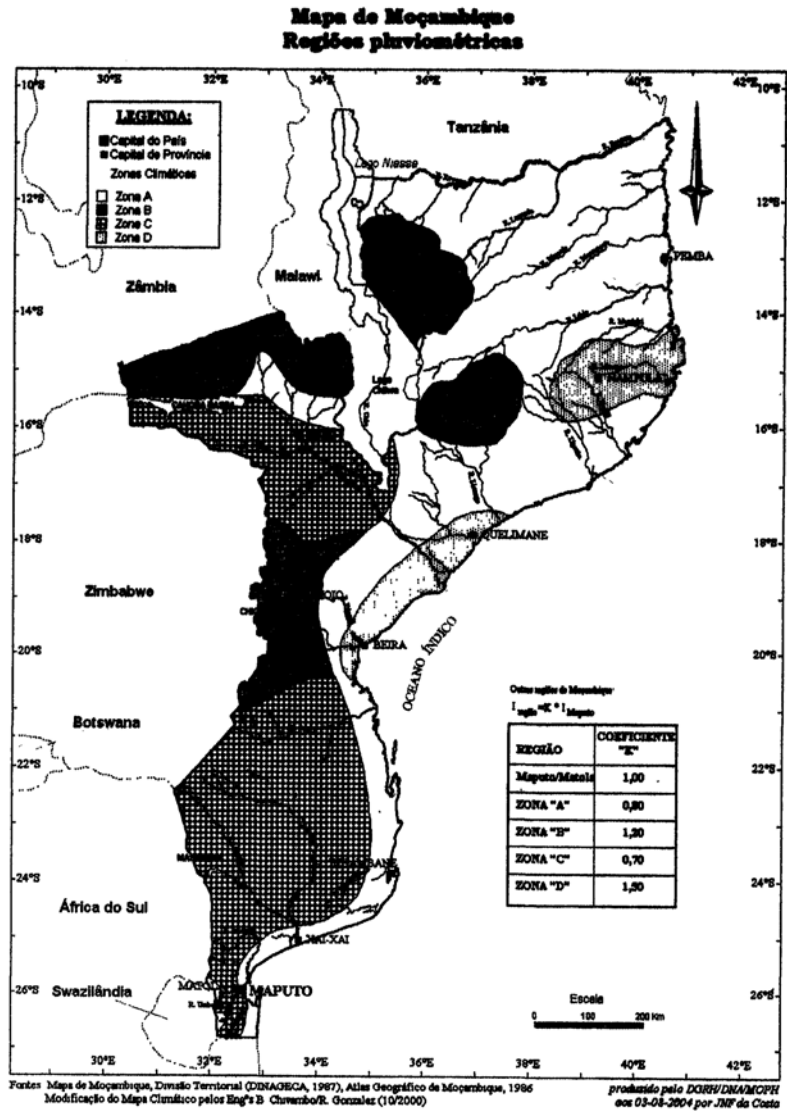


Figure 19: Rainfall regions of Mozambique – Map of K coefficient

4. Characterization of the Context

This part of the study is intended to verify the present situation in the target areas and to gather information on the socio-economic status of the communities, their culture and their perceptions and coping mechanisms in terms of natural calamities.

4.1. SOCIO-ECONOMIC CONTEXT

The methodology used to verify the present situation in target areas is both qualitative and quantitative.

4.1.1. Qualitative study

Community Mapping

- Communities draw a map of their neighbourhood and identify its limits, the main access roads and available public services, such as schools, hospitals, and markets. They are also asked to identify the areas in their neighbourhood that they consider to be vulnerable to natural hazards, such as flooding and erosion. Heads of *quarteirões* and neighbourhoods participate in this exercise. Elders are also involved, which is beneficial for gaining access to the collective memory on natural calamities that have occurred over the years. Around 10 to 15 people are needed to participate in this exercise for each studied neighbourhood.

Below is an example of a community map from the neighbourhood of Chalambe 2 in the town of Inhambane:



Figure 20: Community Map of Chalambe 2, Inhambane

Histogram

- This work requires the community to draw a timeline of the most important historical events that have occurred in their neighbourhood. In line with the topic of this study, they are

asked to designate the natural disasters that have occurred, to verify their recurrence. Based on the drawn lines and events mentioned, a discussion ensues on how their neighbourhood came to exist, how it is governed and what mechanisms they have in place for managing natural disasters. A problem with natural hazards is that human memory is short for most, except in relation to the worst natural disasters or those that occurred in the last 5 years. Below is an example of a histogram for the neighbourhood of Chambone in the town of Maxixe:

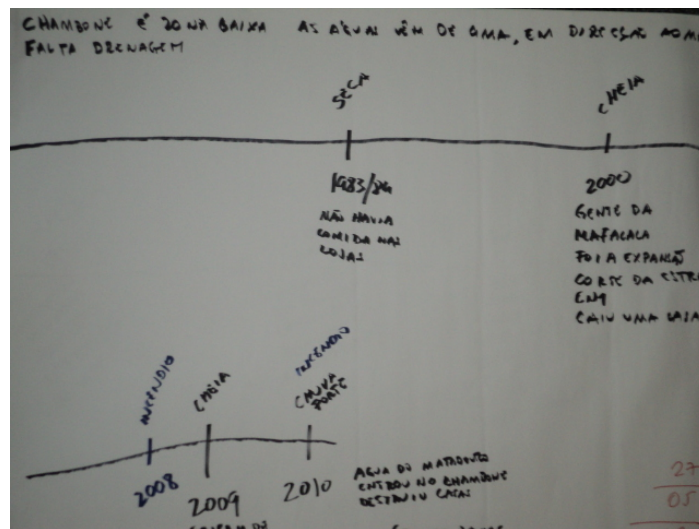


Figure 21: Histogram for the neighbourhood of Chambone, Maxixe

4.1.2. Quantitative study

The quantitative study allows for the collection of numerical baseline data on the socio-economic conditions of the households in the neighbourhoods selected for the study, it is in the form of a survey by questionnaire (Appendix 3). The study should cover a large number of households in order to produce significant results. In the case of the Inhambane and Maxixe study, 300 households were interviewed in 4 neighbourhoods, or 75 households per neighbourhood. In fact, in order to obtain a representative sample, a minimum of 75 households should be interviewed per neighbourhood.

Cluster sampling is used for selecting the households to be interviewed. The constituents within a cluster should generally be heterogeneous enough to make each cluster representative of the total population. An example of how this sampling works is presented in the box below:

Cluster sampling was used for selecting the households to be interviewed by taking the total number of households living in a Quarteirão and dividing it by 28. This number was chosen because there was a need to interview a total number of 25 households in each Quarteirão and 3 were added in to cater for households that would eventually need to be substituted. The outcome of this calculation was the interval counted between the households chosen to be interviewed. For example: in the town of Inhambane in Bairro Liberdade 3, Quarteirão 4, there was a total of 102 households, which, when divided by 28, resulted in 3.6. This was then rounded up to give an interval of 4.

The questionnaire (Appendix 3) is to be divided into the following 9 sections:

- Identification of the interviewee,
- Information about the head of household,
- Characteristics of the household,
- Access to services,
- Socio-economic indicators of the household,
- Housing characteristics,
- Migration patterns,
- Social networks,
- Natural calamities and adaptation measures.

Below is an example of types of questions in the questionnaire (Appendix 3):

SECTION H: NATURAL HAZARDS AND ADAPTATION MEASURES	
1.	In what period of the year does it rain most? From month __ __ to month __ __
2.	During that period, how do the rains affect your Bairro? <i>(more than one answer, don't read the options)</i> 01 It doesn't normally affect the community 02 The water runs uncontrollably through the Bairro 03 The water that runs creates holes 04 The water that runs brings waste 05 The water enters the houses 06 Many houses fall 07 Some houses fall 98 Other (specify) _____)
3.	How did the last rains affect your house? <i>(more than one answer, don't read the options)</i> 01 They didn't affect your home (if 01 pass to question __ 02 The water entered your home 03 The water entered your garden and created holes 04 The water brought waste 05 The water partially destroyed your house 06 The water completely destroyed your house 07 The water destroyed your latrine 98 Other (specify _____)

Figure 22: Excerpt from the questionnaire used in Inhambane and Maxixe

The indicators used for measuring the vulnerability of the populations in relation to natural hazards and climate change, were specifically the housing characteristics of the communities, including types of houses built in the neighbourhoods and what sort of sanitation system they have. For example, if a house is made of precarious materials such as straw/vegetation and the household utilizes a traditional latrine, one can deduce that this household would not be able to withstand the effects of heavy rains or floods.

In addition, another aspect that was looked at was the occurrence of natural disasters, the kinds of local adaptation measures that are applied for mitigating the effects of such adverse events, and

the institutions/people helping in the event of a natural disaster. For example, a household is more vulnerable if it is exposed to more than one type of hazard, and is even more vulnerable when there are no institutions to provide them with aid when needed.

Finally, the socio-economic standing of the communities also contributes to their vulnerability to natural hazards. In order to determine the socio-economic status of the studied communities, their education levels, household possessions, access to services, types of professions and income/expenditure were analysed. These data establish whether or not the household can recover from a natural disaster; this recovery can involve either rebuilding of their homes or having to receive medical care.

Below, there is an example of the results obtained from the study carried out in Inhambane and Maxixe.

- ✓ Communities are not affected by natural hazards and climate change, due to their magnitudes or strength, but rather due to the lack of urban planning in their neighborhoods and of mechanisms for mitigating the effects of such calamities (e.g. drainage systems for facing heavy rains);
- ✓ Many of the areas that the communities have settled in are unsuitable habitation areas according to the INGC and also to the urban planning expert. The reasons for settling in these areas are due to their closeness to both public services (schools, hospitals, etc.) and the work place;
- ✓ Communities moved to these areas during the civil war or shortly afterwards, and the population of these Bairros increased so fast that the Municipality did not have time to plan the Bairros accordingly, with roads, laying out housing plots, and giving them access to electricity and water;
- ✓ The responsibility for increasing the global resilience to natural hazards and for creating mechanisms to mitigate the effects of these threats lies in the hands of the Municipal Government and not those of the communities, although knowledge and aid of the Local Leaders in relief efforts should be taken into account as the community trusts them:
 - Chalambe 2 in Inhambane and Mazambanine in Maxixe lie in a mangrove swamp and on the beach incorporating the 100 m protection area, which consequently should not have been inhabited;
 - Liberdade 3 in Inhambane and Chambone in Maxixe are less exposed to natural hazards, but urgently require urban planning measures such as subdividing of the land and installing drainage systems.

4.2. IDENTIFICATION OF RELEVANT STAKEHOLDERS

It is important that different strategies are applied at different stages of the project to ensure an inclusive, balanced and fair participation of all relevant stakeholders. There is no size that fits all projects and/or the different stages of a same project. Where relevant, the various stakeholders should be informed and consulted, they should contribute resources, form groups, and participate in contextual analysis, project/program formulation, implementation, monitoring and evaluation, etc.

A first step taken for ensuring an inclusive and fair participation process is to conduct a stakeholder analysis. Stakeholder analysis (Appendix 2) is a way of conducting social analysis and participatory work in relation to projects and policies. This form of systematic analysis tries to identify:

- Who are the key stakeholders?
- What are their interests in the project or policy?

- What are the power differentials between them?
- What relative influence do they have on the operation?

Answers to these questions allow the project managers and policy designers identifying the institutions and relations that, if ignored, can have a negative influence on projects and policies. Or, conversely, if considered, they can be the foundation for strengthening projects and policies.

There are four steps in conducting a Stakeholder Analysis¹⁰:

- Identifying Key Stakeholders: narrow the field of stakeholders from all who potentially affect or are affected by the proposed intervention.
- Determining Stakeholders Interests: define the expectations, benefits, conflicts of interests with the project, and resources that may be mobilized.
- Determining Stakeholders Power and Influence: determine the effect stakeholders can have on a project or policy, for example in controlling what decisions are made or in facilitating or hindering its implementation. Stakeholders' interrelationships are as critical to consider as their individual relationship to the project or policy.
- Formulating Stakeholder Participation Strategy: plan for stakeholder participation, taking into account interests, influence and power, as well as level and timing of participatory activities.

An example of a matrix for stakeholder participation in Inhambane and Maxixe is shown below:

Stakeholder	Activities					
	Mapping	Vulnerability mapping	Adaptation measures	Urban identification of options	Estimated costs	Knowledge transfer
Coordinating Council for Disaster Management	C	I	I	P	P	P
Technical Council for Disaster Management	C	C	C	P	P	E
Municipality	I	C	C	E	P	E
Traders	I	C	I	C	P	I
FIPAG	I	C	P	P	C	I
EDM	I	C	P	P	C	I
Religious communities/leaders	I	C	I	C	I	I
Community leaders	C	C	E	P	E	E
Community members	C	C	P	E	P	I
Media	-	I	-	I	-	E

Table 8: Stakeholders' Participation Matrix

10 World Bank. (2010). *Stakeholder Analysis*. <http://go.worldbank.org/ZVLKD48760>. Retrieved 8/26/2010.

For each phase there is a corresponding letter that signifies the following:

- I - Information sharing (one way flow) C - Consultation (two way flow)
P - Collaboration (control over decision making) E - Empowerment (more transfer of control)

In this context, the following groups of stakeholders must be identified and involved in the process, namely:

- Residents in the target bairro(s),
- Local leaders in the bairro(s),
- Economic agents in the bairro(s) (e.g. shop owners, traders, small scale industry and craftsmen, etc.),
- Representatives of health, education and social welfare sectors working in the bairro(s),
- Relevant technical staff within the local municipality,
- Elected councillors within the local municipality,
- Service providers at municipal level (e.g. water supply and electricity),
- Other local and provincial government institutions,
- Relevant INGC staff at local, provincial and national level,
- Relevant representatives of the civil society (national and international NGOs),
- The funding agencies,
- The media.

Each stakeholder and their relationship or stake with the project is then briefly described. Their links, benefits, interests and contribution in matters of disaster management and natural hazards is also illustrated. An example of the details resulting from this exercise can be seen in Appendix 2 "Stakeholders Analysis Report".

The involvement of representatives from the above indicated groups is done through the use of Key Informant Interviews and Discussions, Focus Group Discussions and public meetings during:

- (i) Project Start Up;
- (ii) Mapping;
- (iii) Natural Hazard and Climate Change Vulnerability Mapping and Identification of Areas at Risk;
- (iv) Mitigation Measures; and
- (v) Participatory Processes.

The stakeholder analysis and involvement confirms the fact that it is important to apply different strategies at different stages of the project, ensuring an inclusive, balanced and fair participation of all relevant stakeholders.

4.3. FIELD SURVEY: NATURAL HAZARD IDENTIFICATION

This section illustrates the presence of the different natural hazards that are most common in the study zone, for example heavy rains, high tides, flooding, strong winds/cyclones and fires. This is done through field work and visits to the local consequences of past events, together with local and national Authorities (INGC).

Field surveys are done at several stages of the study, and certainly during definition and precision of objectives, and observation and analysis of hazards (past and present events and damage). This field work should be done by specialists of the project, with the presence of local specialists implicated in urban management. Talking with local inhabitants is clearly very important in order to compare different declarations.

The survey allows understanding the importance of the different kind of natural hazards, identifying them and, above all, replacing them in the local context, taking into account the vulnerability. The example of the Maxixe/Inhambane project is quite clear: the first survey (April 2010) allowed adapting the initial methodology in order to integrate the specific context, such as recent population increase meaning an increased vulnerability, or medium to low hazard levels for erosion or flooding, except in built-up areas.

In addition, it allowed acquiring the observation points used for model calibration and validation.

Figure 23 shows the position of points collected with the GPS on a map, while Figure 24 shows an example of the data collection sheet for flooding and erosion observations. Geo-localization is a major point, allowing the later overlay with vulnerability and hazards maps.

If looking specifically at erosion and flooding hazards, the following items should be recognized, noted and mapped:

- Outlets with damage observed from recent flooding, such as gullies and sand deposits;
- The type of damage;
- Land-use coverage;
- Roads and tracks;
- Gullies.



Figure 23: Field-point observations with basic networks (river and roads)

GPS Point	Localisation	Slope	Landuse	Observations	Date	Altitude	Hydro
988	Inhambane	plat	urbain	INGC	18/05/2010	3.3	
989	route Inham-Maxixe		urbain	petites parcelles loties	18/05/2010	13.6	
990	route Inham-Maxixe	plat	Coco, maison		18/05/2010	13.3	
991	route Inham-Maxixe	valloné	Coco, herbe, manioc		18/05/2010	13.3	
992	route Inham-Maxixe	plat	zone humide		18/05/2010	10.2	
993	route Inham-Maxixe	hauteurs	manioc, mangue, coco		18/05/2010	24.6	
3	Maxixe		urbain, petites parcelles	Maxixe	18/05/2010	15.3	
4	Maxixe		urbain	poste pluvio Maxixe	18/05/2010	12.9	
5	Maxixe		zone urbaine peu dense	arbres, jardins	18/05/2010	14.8	
6	Maxixe		ouvrage sur route	fait en 2009.	18/05/2010	10.7	decembre 2008, fortes pluies, inondations, co
7	Maxixe		ouvrage sur route		18/05/2010	17.4	déjà déchaussé sur partie aval + érosion de b
8	Maxixe		urbain en amont	travail tracto en cours	18/05/2010	24.2	inondation 2000/2008,
9	Maxixe		pont	construit en 2000	18/05/2010	23.4	canyon profond 6m, aménagements abimés
10	Maxixe		urbain	hopital	18/05/2010	29.4	gros aménagements, bati sur 5 niveaux
11	Maxixe		urbain	50m en amont de point 10	18/05/2010	18.2	
12	Maxixe		habitat peu dense	potagers et maisons sous co	18/05/2010	47	
13	Maxixe		route	habitat peu dense	18/05/2010	56.8	détruite en 2000, dans lit rivière,
14	Maxixe	plat	tallweg	faible imperméabilisation, be	18/05/2010	61.4	confluence de ruissellement en zone construi

Figure 24: Example of a field-point observations table



Figure 25: Geo-localized observations made in the field

5. GIS Design and Implementation

A Geographic Information System (GIS) is one of the main tools for urban-data management. This is particularly true when assessing risks and preparing urban-requalification plans. Therefore, GIS use represents a crucial component of our methodology.

Before discussing the setting up and use of GIS in more detail, some basic rules must be highlighted:

- A GIS is a powerful but very complex tool. **Highly professional skills are required for the efficient and correct processing of GIS data.**
- As a GIS implies an almost daily evolving database, it is extremely important to control the existence of potential divergent versions through several sites. Various techniques exist to avoid such inconsistency, but the most efficient one consists in maintaining **a single reference version under the responsibility of a data manager**. This version may be duplicated in different sites. If modifications are made anywhere, these modifications must be validated by the data manager and recorded in the reference version;
- GIS databases are complex and to allow the possibility of easily retrieving any data (and their characteristics), the data manager must strictly organize the information and update metadata in real time. **The data organizational structure must be prepared prior to any implementation**. This involves the design of a conceptual model describing the data structure in detail. Similarly, the metadata must be completed in real time when new data sets are integrated. Conceptual Data Models as well as metadata must be updated continuously during the lifetime of the GIS;
- In view of the complexity of the database, it is strongly recommended to clearly identify the content of each cover (or table); i.e. one cover must concern a single topic like, for example, buildings. For other topics, like streets or flood hazard, other specific covers must be created.

Another crucial point must be emphasized concerning the required information: for risk studies, **two data sets are required**:

- A topographic base map at a scale compatible with 1:5,000. If such maps do not exist, very high resolution (VHR) satellite images must be purchased in order to set the reference base for any mapping. For the Inhambane/Maxixe study, a GeoEye image has been acquired. Such images with a spatial resolution of 0.5 m are fully compatible with our purpose.
- A high-resolution Digital Elevation Model (HR DEM). This allows representing the surface morphology. For the Inhambane/Maxixe study, a DEM was calculated with a spatial resolution of 5 m from Alos satellite images, which then allowed calculating slopes, watersheds and natural hydraulic drainage systems.

Nevertheless, it must be noted that both VHR satellite images and HR DEM have significant costs (for instance, the cost of acquiring the images for the Inhambane/Maxixe study and of the corresponding processing was over 10,000 Euros)

5.1. CONCEPTUAL DATA MODEL

Depending on available information, different scales of accuracy may be used for mapping. Nevertheless, it must be reminded that on a single map, all information must correspond to the same level of precision in order to avoid any topological incoherence.

Three levels can be defined: national, provincial, and urban. Each of these levels is then stated through different domains.

5.1.1. National and provincial levels

A first scale corresponds to data acquired at national level. This means data with an accuracy compatible with mapping scales ranging from 1:1,000,000 to 1:250,000 for the national level, and from 1:250,000 to 1:50,000 for a provincial level.

At these scales, different domains can be considered:

- Administrative limits: country, provinces, districts, main cities,
- Topographic maps (1:250,000 and 1:50,000),
- Roads and communication infrastructure,
- Drainage network, coastline and wetlands,
- Soil maps and land use,
- Geology: geological map and contours, faults,
- Geomorphology: Digital Elevation Model (DEM).

5.1.2. Urban level

The urban level corresponds to map scales ranging from 1:50,000 to 1:1,000. Data can be organized in different domains:

- Administrative limits: *municipalities, city, neighbourhoods, blocks*;
- Geomorphology and drainage:
 - HR DEM and slopes,
 - coastal cliffs,
 - water catchments,
 - depressions and thalwegs,
 - wetlands,
 - beaches and dunes.
- Soils and land use;
- Urbanism and infrastructures:
 - urban fabric,
 - roads and streets,
 - strategic buildings (official buildings, buildings sheltering highly vulnerable population elements like schools and hospitals),
 - water and electricity supply facilities,
 - sewerage systems (rain and runoff, waste water).
- Natural hazards:
 - runoff and erosion,
 - flash floods,
 - marine floods,

- cliff and coastal erosion.
- Risk maps
 - hazard maps,
 - risk maps for the different types of exposures.
- Adaptation measures
 - outlet and culvert locations,
 - areas where specific works are needed.

As stated before, very high resolution satellites images are a fundamental base for hazard and risk mapping assessment. They are gathered within a specific domain.

5.1.3. UML representation

Depending on the availability of information, the UML¹¹ representation is more or less complex and is presented on Figure 26.

Systematically, the same abbreviations are used for hazards and elements at risk. An example is given in Table 9, below.

Hazard abbreviation		Element at risk abbreviation	
CF	Coastal flooding	B1	Wooden hut
DR	Depression flooding	B2	Masonry house
CC	Coastal cliff erosion	B3	Concrete building
BD	Beach/dune erosion	S1	Water supply facility
TF	Thalweg floods	S2	Energy supply facility
SF	Street floods	S3	Sewerage (sanitation, etc.)
		R1	Unpaved roads
		R2	Asphalted roads

Table 9: Example of abbreviations for hazards and exposures

11 UML: Unified Modeling Language

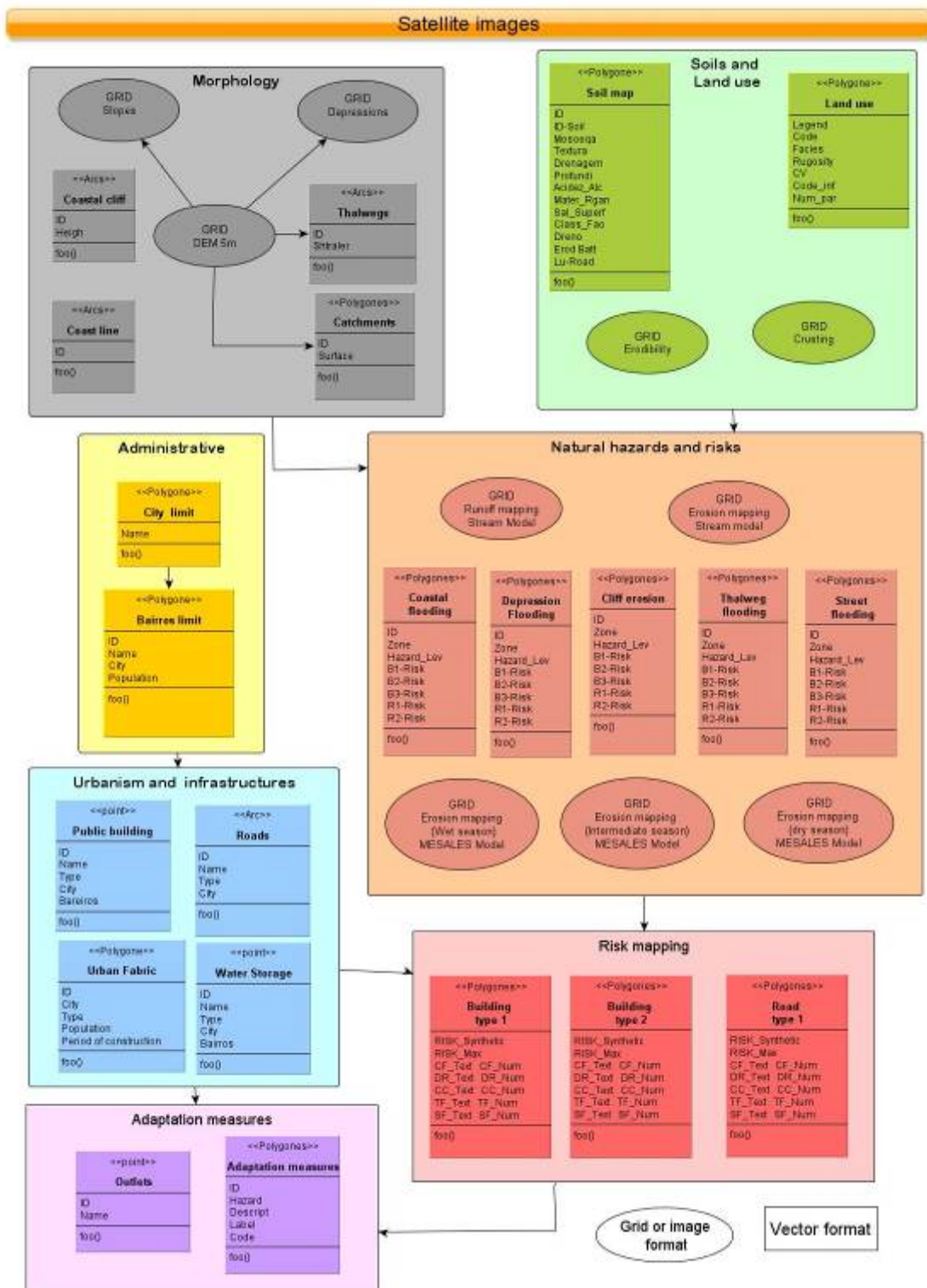


Figure 26: Example of UML representation (urban level for the Inhambane/Maxixe GIS)

5.2. PHYSICAL DATA MODEL, METADATA AND GIS IMPLEMENTATION

A typical urban GIS represents a volume of several gigabytes (almost 3.4 Gb for the Inhambane/Maxixe GIS).

5.2.1. Data formats

ESRI ArcGIS and ArcView are the preferred GIS software. They are already installed and used at INGC.

Vector information is stored in ESRI shape format or in ESRI Geodatabase format.

Shape files are preferred to Geodatabase, to avoid any version conflicts with possible older ArcView or ArcGIS software versions. However, the conversion between these two ESRI formats can be easily done at any moment.

Images are stored in TIFF or GEOTIFF formats.

Grids are stored in ESRI Grid format.

5.2.2. Metadata

Metadata describe information gathered within the GIS. They record information on:

- Data title: short description of considered information;
- Mode of acquisition;
- Year of creation;
- File information: directory (where you find it in your computer), file name, projection system, objects type (polygon, arc, etc.), format;
- Addressed topic: erosion, built-up environment, urbanism, etc.;
- Comments on the source and mode of creation;
- Operator (first and possible secondary);
- Localization name;
- Geographical extension (east-west and north-south);
- Datum¹².

It is worth noticing that accuracy is treated through the classification in National, Provincial and Urban levels.

It is also crucial to emphasize the importance of Datum. The same coordinates (longitude/latitude) calculated on a different datum can correspond to different points that may be a few hundred metres distant. A GPS usually calculates coordinates on the WGS84 datum.

¹² Datum corresponds to the geometric shape (ellipsoid) that is used for representing the Earth. The world's most commonly used Datum is WGS84.

5.2.3. Physical implementation of hazard and risk information

Hazard mapping:

Depending on the context, different phenomena can be considered for hazard mapping (for example, floods, erosion, etc.). Each corresponds to a specific cover. All covers have the same structure.

There are several ways of presenting hazard mapping, depending on the assessment method. The two most used ones are polygons and grids.

Each polygon or grid element is informed with:

- One Hazard level attribute expressed through a text format with 4 possible values (L-Low, M-Moderate, H-High, VH-Very High), which can correspond to numerical values for grids;
- For polygons only, several attributes express the corresponding risk for the different categories of elements at risk. From the risk matrix, these values are used for presenting the level of risk for the concerned type regarding the level of hazard: L-Low, M-Moderate, H-High.

Risk mapping:

Risk maps present the probabilities of damage for the different categories of elements at risk. A specific cover has to be designed for each category of elements at risk. All covers have the same structure. Each polygon is informed through:

- A synthetic risk attribute (text) gathering all information related to the different hazards;
- The local maximum risk level, whatever the hazard;
- Several attributes (one for each hazard) presenting the corresponding risk level expressed through text (L, M, H);
- Several attributes (one for each hazard) presenting the corresponding risk level expressed through integer (0-null, 1-Low, 2- Moderate, 3-High).

6. Vulnerability mapping

The identification of risk areas and characterization of the types of hazards most common in each area was based on a series of methodologies and phases. The process was initiated with a field visit aimed at collecting preliminary information to identify stakeholders and themes to be included in the survey by questionnaire to be conducted in the selected neighbourhoods.

The objectives of this first visit are to:

1. Collect historical information on past natural disasters, vulnerable areas within the neighbourhoods selected for the study, and how the communities have dealt with these disasters;
2. Identify stakeholders, such as institutions, organizations, or people that are involved in mitigation of natural hazards. These groups could either benefit from, stand to lose or be indifferent to different mitigation and adaptation measures. This completes the stakeholder identification presented in section 4.2.

In order to collect the above-mentioned information, four participatory methods are to be used:

1. Transect walks in the selected neighbourhoods of the study. This activity entails walking through the neighbourhoods and listing their characteristics covering the following aspects: soil, geomorphology, access, housing, services, environmental vulnerabilities and adaptation measures. This provides an idea of how people live, the problems they face, and the coping mechanisms they have developed;
2. Semi-structured interviews, where open-ended questions are asked in relation to historical events that involved natural disasters and climate change, relevant stakeholders, stakeholder's responsibilities, and the preventive and mitigation measures used in the event of a natural disaster. These interviews can be conducted with institutions such as INGC and the Municipal Government where the study is being conducted. The institutions are also to be consulted on the best approach for transferring knowledge to the selected neighbourhoods;
3. Community mapping, where people are asked to draw their neighbourhood and include the access roads, services such as schools and health centres, and boreholes and wells. Additionally, they are asked to identify the areas that are vulnerable to floods, erosion, etc. The other exercise is a histogram, where community members are asked to make a timeline for the natural disasters and calamities that have occurred in their neighbourhoods, beginning with their earliest memory. They are also asked about the history of their neighbourhood, such as when it was established, what the composition of the inhabitants is, how the neighbourhood is structured both administratively and physically, and what are the main problems that they face;
4. Transfer of knowledge collected in the neighbourhoods, consists of an informal explanation of the study that includes study objectives, activities and the outputs to be produced from this study. This is done prior to initiating the participatory exercises.

On the basis of these methodologies and stages, it is possible to ascertain what historical events have occurred in the neighbourhoods of the study in relation to natural hazards and climate change, and what adaptation measures are being applied by the communities themselves. More specifically, it is possible to identify the major themes related with vulnerability to natural hazards.

7. Natural hazard assessment and mapping

7.1. DATA COLLECTION

7.1.1. Possible difficulties

Rainfall data are paramount for this kind of study, but they can be lacking in some region. It should be noted that rainfall measures can strongly vary from one station to the other. If the closest weather station is far from the study zone, rainfall data may be over- or underestimated.

Local sea-level records, like rainfall data, can be lacking for extreme weather events.

Accurate maps of the cities are not always available. The urbanism services of Municipios or the Provincial agency for urbanism and land planning may not be able to provide recent and accurate maps (even in sheet format).

The same remark applies to topographical (altitude) database.

It is really difficult to deal with urban planning without map, and it is also difficult to imagine how accurate and relevant planning can be done without any map support.

7.1.2. Comprehensive inventory of relevant data

The data necessary to carry out the study are obtained from public organizations in Mozambique (Maputo) and locally from the representatives of the Governor of the province, from the Provincial Delegations of INGC, the technical services of the Municipalities and various public agencies.

The following data are important for the study and must be collected.

Population characteristics

- City users: permanent inhabitants, visitors, etc.
- Demographic density: global population and population of the neighbourhoods; variability (daily, weekly, seasonal);
- Social characteristics: age groups, socio-economic classes, local population (and tourists?);
- Human flows and mobility (daily, weekly, seasonal);
- Population-growth rate: proportion of immigrants, of tourists; trends for the future.

Urban space

- Urban site topography: maps of towns and cities;
- Urban size and territorial organization;
- Environmental features and resources;
- Local meteorological data;
- Water resources and raw material resources;
- Natural sites of interest and natural heritage (forests, lakes, beaches, etc.);
- Public buildings;
- Main infrastructure elements, roads network;
- Lifelines and water reservoirs;

- Urban growth and trends;
- Historical expansion (especially in the past 30 years);
- Identified open areas for urban expansion (main perspectives for the future);
- Main disturbances due to past disasters if known and localized.

Activities and employment

- Economic activity data: agriculture, fishery, industry, trading, services, tourism, and transportation;
- Public activity data: sanitation, social and emergency employments;
- List and localization of cultural activities, leisure and information: entertainment, cultural heritage, religious centres, publishing, media, associations, sports, etc.
- List of administrations: territorial, welfare, judicial;
- Description of disturbances to these activities due to past disasters.

Urban functions and services

- Social functions: health, education, social services;
- Housing: permanent legal settlements, illegal settlements;
- Supply and sanitation: water and energy distribution, sewage, waste-disposal management;
- Transportation;
- Communication: telecommunications, institutional information;
- Safety: emergency resources (defence, relief, shelters, hospitals, etc.);
- Main difficulties/failures of these functions observed during past disasters;
- Description of Institutional organization: territorial and other institutions;
- Description of decision-making processes;
- List of the urban stakeholders: key players involved in a city's development, government officials (mayor and municipal council, prefect or governor), community representatives, teachers, citizens associations and NGOs, business leaders;
- Draft assessment of social cohesion, local culture and history;
- Perception of the existence at a local scale (city) of the culture and memory of risks and vulnerability to natural hazards.

Basic data

- Aerial photographs (old and recent);
- Geo-referenced high-resolution recent remote-sensing images;
- Land-use/land-cover maps;
- Digital Elevation Model (DEM) with the best available resolution (especially for the coastal zone);
- Local topographical maps (1:25,000 scale or more accurate);
- Marine charts of the coasts;
- Local tide characteristics (tidal recordings, if available);
- Soil maps with their related parameters;

- Regional hydrogeology (maps, structures, irrigation, resources, etc.);
- Hydrometric and/or piezometric data for water-resource protection, catchment areas;
- Meteorological maps of present rainfall or IDF curves;
- Data on local floods, discharge of rivers (if available) for different return periods (10, 50 and 100 years).

Other data:

- Information on historical disasters (floods, coastal flooding and erosion) affecting the study area;
- Relevant regional studies led by the INGC/MICOA on the impact of climate change on meteorological events;
- Database on tropical-cyclone activity in Mozambique (historical and future trends in connection with climate change trends).

The following list gives **central or local public agencies** providing relevant physical data to be consulted:

- National Meteorological Institute (INAM);
- National Institute for Hydrology and Navigation (INAHINA);
- National Institute for Disaster Management (INGC) – National and local levels;
- National Institute for Maps and Remote Sensing (CENACARTA);
- Ministry for Coordination of Environmental Affairs;
- Ministry of Agriculture;
- Fundo de Investimento e Património de Abastecimento de Água (Water Supply Investment and Asset Fund) (FIPAG);
- Electricity company;
- National Roads of Mozambique Directorate (ANE).

Depending on the quantity and quality of acquired data, it is possible to purchase a digital elevation model (DEM) and very high resolution (VHR) satellite images in order to dispose of a topographic background for the different mapping purposes, and to have the possibility of carrying out urban and morphological analyses (using VHR images like aerial photos).

7.1.3. Historical data analysis

Historical data analysis consists in:

- (i) Making an inventory of extreme climatic events such as cyclones and extreme rainfall events;
- (ii) Describing natural hazards and giving their typology and characteristics;
- (iii) Describing and studying local climatic parameters;
- (iv) If possible, studying a recent and representative extreme event in detail.

7.2. SOIL EROSION HAZARD MAPPING

Erosion mapping with MESALES (Modèle d'Evaluation Spatiale de l'ALéa Erosion des Sols – Regional Modelling of Soil Erosion Risk) allows mapping hazard levels at a global scale,

discriminating between high- and low-level areas. This mapping is qualitative and is completed by quantifying linear erosion and runoff, using the STREAM model (Sealing and Transfer by Runoff and Erosion related to Agricultural Management).

7.2.1. MESALES model (Erosion)

MESALES has been described in detail in the following scientific publications:

- Le Bissonnais Y., C. Montier, M. Jamagne, J. Daroussin, D. King (2002). Mapping erosion risk for cultivated soil in France. *Catena*, 46, 207-220.
- Le Bissonnais Y., J. Daroussin, M. Jamagne, J.J. Lambert, C. Le Bas, D. King, O.Cerdan, J. Léonard, L.M. Bresson, R. Jones (2005). Pan-European soil crusting and erodibility assessment from the European Soil Geographical Database, using pedotransfer rules. *Advances in Environmental Modelling and Monitoring*, 2 (1) 1-15.

The goal of using MESALES was to develop and apply a methodology based on present knowledge and available data for the assessment of soil erosion risk at a national scale. Land cover and crust formation on cultivated soils were considered as key factors influencing runoff and erosion risk. A soil geographical database has been created, and a model of erosion risk was developed using a GIS. MESALES uses the best available information layers at national scale:

- (i) Land-cover database at regional 1:250,000 scale (source: Landsat images);
- (ii) The Soil Geographical Data Base of FAO at 1:1,000,000 scale (source: FAO);
- (iii) A 90 x 90 m cell resolution digital elevation model (source: SRTM); and
- (iv) Around 30 years of daily meteorological data at local resolution (source: Maxixe rainfall station).

The MESALES modelling approach can accommodate a heterogeneous data resolution and quality. However, errors and uncertainty associated to the results are much more dependent on the resolution and quality of the input data than on the model itself. The methodology presented here allows generating a single homogeneous map of erosion risk at the regional scale. The decision-tree-type model considers different types of erosion depending on land use. The production of seasonal maps shows the importance of seasonal effects on erosion. The aggregation according to different spatial units allows adapting the results to the needs of different users. Finally, the model is easy to modify in terms of the rules and to update with new data.

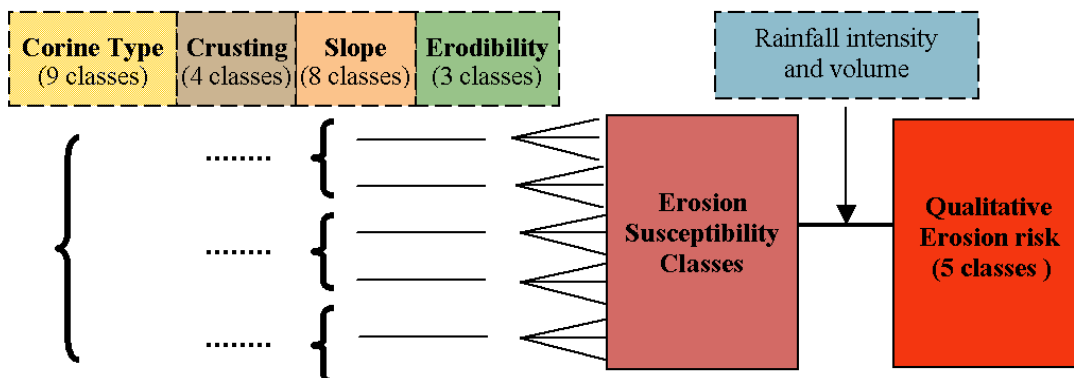


Figure 27: MESALES methodology

7.2.2. MESALES input

Land use parameters: Original land-cover classes were reclassified into 9 classes, each corresponding to a specific behaviour towards soil erosion: arable land, permanent crops, heterogeneous cultivated land, grassland, forest, degraded areas (after fire, land clearing or overgrazing), bare land without vegetation (rocks, glaciers and beaches), water and wetlands, and urban areas.

Soil parameters: Soil crusting and soil erodibility parameters are derived from soil names (third level FAO legend), soil dominant and secondary surface textural class, parent material class (third level), using chained pedotransfer rules (Bouma and Van Lanen, 1986; Daroussin and King, 1996).

Relief parameters: MESALES on Maxixe uses the SRTM digital elevation model (DEM) with a cell resolution of 90 x 90 m. The DEM determines the basic cell resolution for all other information layers. A finer DEM would clearly lead to a better assessment of slopes. The average slope within each cell (in percentage) has been calculated from the greatest elevation difference between the cell and its 8 neighbours, using the Arc/Info "slope" function. Slopes were classified into 8 classes, the limits of which are defined according to field experience or values to be found in the literature. Class limits are adjusted in order to take into account the smoothing effect in slope assessment due to the coarse cell resolution of the DEM. Slope classes used in this study are the following:

0-1% >1-2% >2-5% >5-10% >10-15% >15-30% >30-75% >75%

Climate: Rain is the main factor for water erosion and its erosive effect is related to its amount and intensity. Hence, an attempt was made to combine both parameters for characterizing erosivity for each season. Basic climate data were provided by the Maxixe rainfall station as daily meteorological data for the past 30 years. Mean monthly rainfall was calculated for each cell. These values were reclassified into five classes for each season (rainy season from December to March, dry season from July to October and intermediate seasons for remaining months).

7.2.3. Erosion-hazard mapping with MESALES

A "decision-tree" type model was constructed, combining logical-operation parameters. A specific decision tree was built for each of the six first land-use classes corresponding to cultivated land or land with natural vegetation, thereby accounting for the various erosion types defined above. Erosion risk was not considered in this study for the three remaining classes (bare land, water, and urban areas). Parameters were ranked and weighted using present knowledge of the different erosion types. Each combination of parameters was ranked from 1 to 5, indicating the relative soil erosion risk (Figure 29). Parameters on sensitivity to erosion from land-use, soil type and morphology were combined with the climatic erosivity for each season, thus providing an overall seasonal erosion risk.

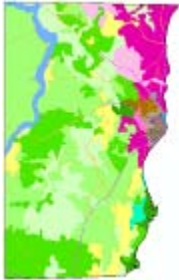


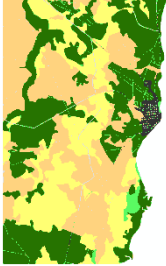
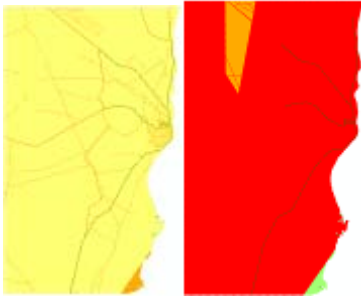
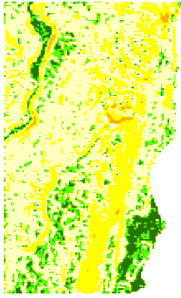
LAND-USE	SOILS	SLOPES
 <p data-bbox="177 658 488 689">Land-use from Landsat</p>	 <p data-bbox="667 658 919 689">Soil map from FAO</p>	 <p data-bbox="1187 658 1350 689">DEM SRTM</p>
 <p data-bbox="188 1055 472 1122">Reclassification of land-use (10 classes)</p>	 <p data-bbox="501 1055 1082 1151">Crusting map (left) and erodibility map (right) (5 classes)</p>	 <p data-bbox="1102 1055 1437 1151">Reclassification of slopes (8 classes)</p>

Figure 28: Reclassification of MESALES parameters

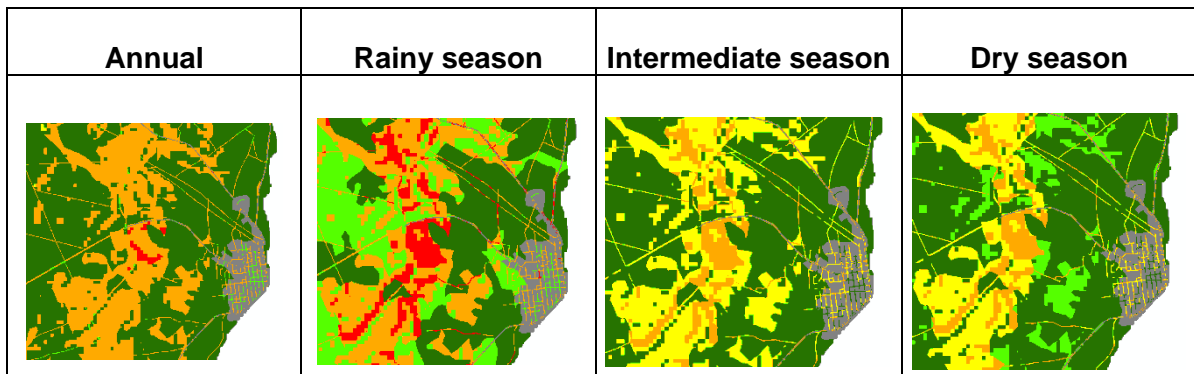


Figure 29: MESALES erosion hazard mapping

7.3. RUNOFF AND FLOODING HAZARD MAPPING

7.3.1. STREAM model (run-off and linear erosion)

The STREAM model (Sealing and Transfer by Runoff and Erosion related to Agricultural Management) was created in the late 1990s following a critical analysis of various modelling approaches (Cerdan et al., 2001). It stemmed from the conjunction of three phenomena:

- 1) Demonstration of the importance of surface degradation of soil structure as a determining factor in soil erosion;
- 2) Development of digital technology (GIS) enabling both the description of a model's fluxes and the quantitative spatialization of input variables (King et al., 1998);
- 3) Availability of new remote sensing data.

STREAM modelling consists of characterizing the main parameters influencing runoff and infiltration in the studied context. This characterization is based on the synthesis of laboratory and field experiments carried out on catchments. Four main factors are taken into account as the parameters that embrace most of the processes: surface-state degradation, surface roughness, crop cover, and moisture content.

STREAM considers the aforementioned parameters as homogeneous at the field scale if the soil characteristics are homogeneous. By combining the identified parameters, the aim is to characterize each field by an infiltration capacity for a given rainfall event.

Calculation of the potential infiltrated water height is done in any point for a given rain. The potentially infiltrated water depth for all the pixels and for a given rain is calculated by the following equation:

$$\text{Infiltration / runoff balance} = R - IR - (IC \times t)$$

where R is the rainfall amount in mm; IR the amount of rainfall needed to reach soil saturation in mm; IC the infiltration capacity class in mm; and t the duration of the rainfall in minutes. The result is an infiltration/runoff balance value that indicates whether the corresponding pixel will generate runoff if the balance value is positive, or, on the contrary, if it will infiltrate a potential upstream runoff in addition to the rainfall, if the balance value is negative.

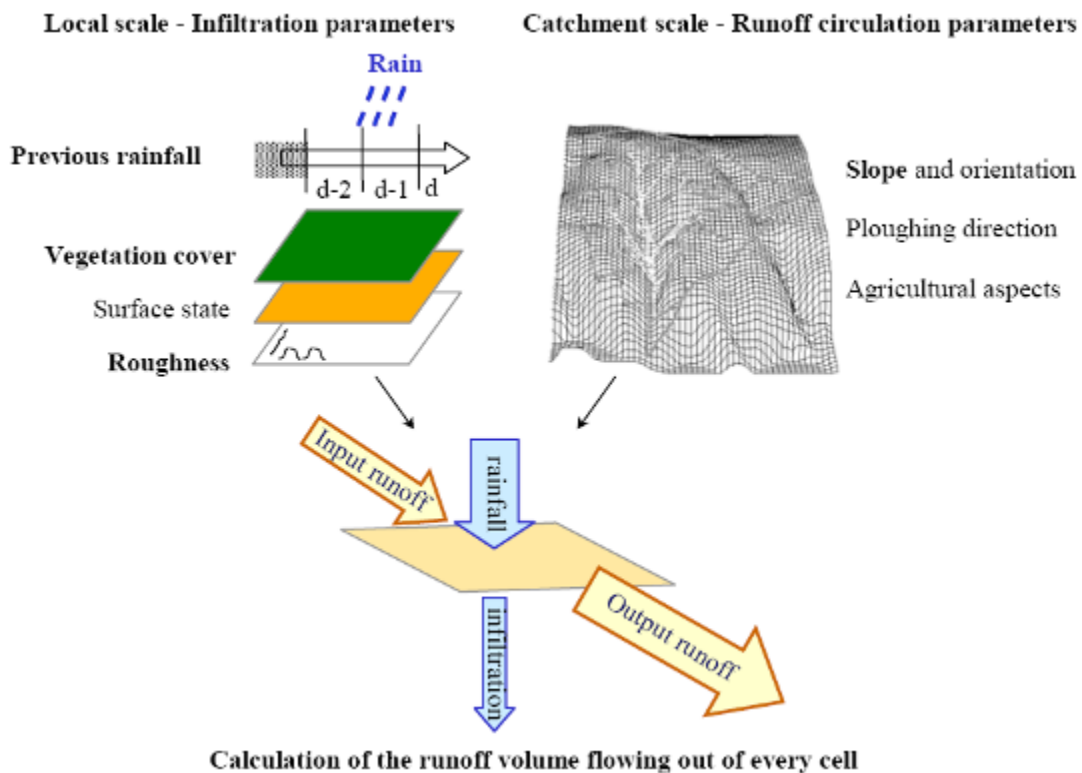


Figure 30: STREAM Model

7.3.2. STREAM input

Soil-surface crusting influences both the runoff rate and soil erodibility. The processes influencing surface crusting have been well studied, but their dynamic nature and their high spatial and temporal variability make quantitative modelling complex.

Roughness is a dynamic property that influences numerous processes on the soil surface, such as infiltration, temporary storage capacity, reflectance, deposition or detachment of particles, etc. It evolves rapidly under the influence of climatic agents and soil roughness (Zobeck and Onstad, 1987). In addition to its use for characterizing the temporary storage capacity of excess water on the soil surface (Mitchell and Jones, 1978), its second major influence is on the runoff direction which, however, is rarely taken into account even though many authors know the insufficiency of only topographic criteria (Fullen and Reed, 1987; King and Le Bissonnais, 1992; Auzet et al., 1993; Souchère et al., 1998).

In Maxixe, the Digital Elevation Model was resized in order to have a 5-m cell, corresponding to the width of gullies.

Crop cover: good ground cover is an essential part of the majority of soil conservation programmes (Houghton and Charman, 1986). Vegetation protects soil against surface erosion in various ways. The interception of rainfall by the plant has two main consequences, the major one being that it breaks the erosive power of the rain, especially in a cultivated context where the drops have little impact. It also decreases the volume of water reaching the soil surface.

Soil permeability depends on crop cover and soil input. It must be defined for the different soil and land-use classes observed in the field. Land-use maps were taken from MESALES modelling. Because of the strong soil homogeneity of the Maxixe catchment, land-use cover is on this site the only parameter. For the 19 land-use classes, soil permeability is proposed, based on bibliographic data:

- 60 mm/h: dispersed homes with a high tree density (5), dispersed homes with a medium tree density (6), forest (13), forest along river (19);
- 50mm/h: coastal areas (1), coastal areas without trees (2), coastal grassland (3), fields with a high tree density (8), fields with a medium tree density (9), fields with a low tree density (10);
- 40 mm/h: dispersed homes with a low tree density (7), quite dense habitations with a high density of trees (18);
- 30 mm/h: fields with rare trees (11), grassland with rare trees (12);
- 10 mm/h: sandy track sides (16);
- 5mm/hour: densely built-up areas (4), sandy tracks (15);
- 3 mm/h: very densely built-up areas (14);
- 0 mm/h: paved roads (17).

Except for built-up areas, the permeability of arenosols is important, ranging from 25 to 250 m/h (Report of Consultec & Salomon, September 2009).

Rain simulations: the STREAM model requires unique values or gridded rainfall for a particular event. Previous rain (just before the studied event) and duration of the rain are also required.

7.3.3. STREAM output: runoff circulation network and linear erosion

The STREAM model uses the methodology defined by Souchère et al. (1998) for calculating the flow network. Between fields, roads and tracks are considered as both impermeable and smooth,

maintaining the behaviour of a usual topographic runoff model derived from a Digital Elevation Model (DEM) towards water flow movement, i.e. the flow is directed toward the lowest adjacent cell. Ditches or back furrows impose their direction on the surface flow. Within cultivated plots including the dead furrows, a discriminant function enables deciding whether flow direction will be imposed by the standard down-slope method.

The last step is calculation of the accumulated flow for each pixel of a catchment by combining the modified runoff circulation network and the runoff vs. infiltration value. For flow-accumulation processing, a FORTRAN program was written and incorporated into ARC/INFO, enabling pixels to infiltrate all or part of the upstream runoff in addition to the rainfall amount.

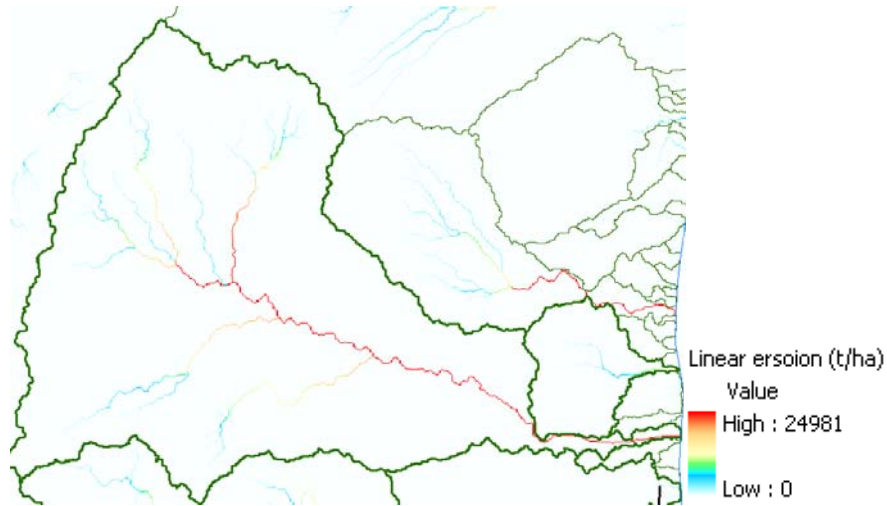


Figure 31: Mapping of linear erosion with STREAM for the 2008 rainy event

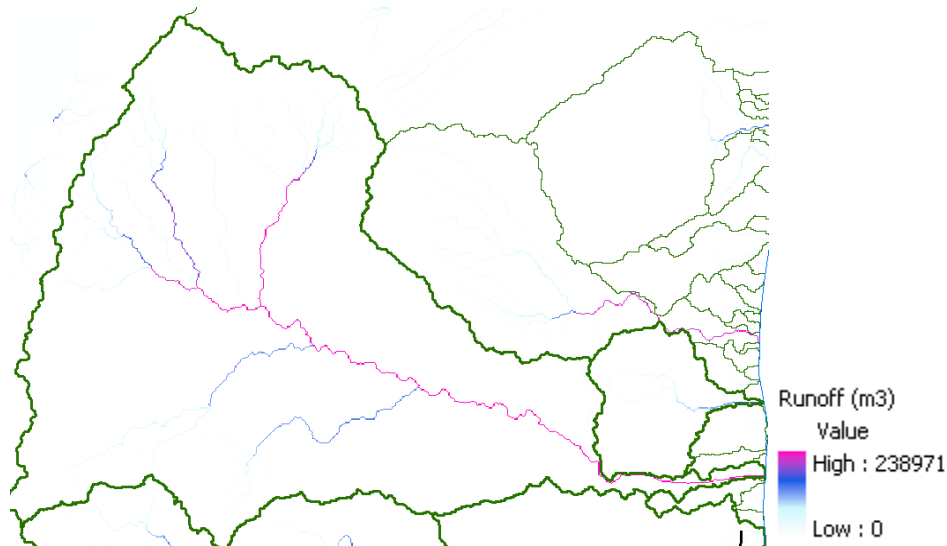


Figure 32: Mapping of runoff with STREAM for the 2008 rainy event

7.4. COASTAL FLOODING HAZARD MAPPING

7.4.1. An under-estimated hazard

The phenomenon of coastal flooding (main inundation) could affect low-lying areas near the sea. It is common to find homes (“*barracas*”) backing onto the beach at a height that is extremely close to the high-water spring-tide level. They are separated from the sea by a thin strip of sand that, under normal conditions, protects the land from flooding by the sea.

7.4.2. Hazard-mapping method

The coastal flooding hazard mapping method could not be based on direct observations or on the gathering of historic data, as this information was lacking.

The mapping proposed here is based in part on perceptions gleaned from visits to low-lying coastal zones (land notes located via GPS positioning) and on the high-resolution Digital Elevation Model (DEM) acquired for this study. Reference sea levels (normal and extreme levels) were used and compared with elevation data for known areas using the DEM.

The proposed mapping (limits to hazard zones) is the result of an approximate demarcation based on the altimetry provided by the DEM for each pixel (5 x 5 m), taking local topography into account. In addition, the zoning limits will merely have an indicative value, and cannot be given any absolute and definitive value.

Normal reference levels for the sea

Reference sea levels related to astronomic tides (excluding storm surges or falling levels resulting from atmospheric effects and waves on the shore) are given in relation to the local hydrographic zero and terrestrial zero (Datum).

Extreme sea levels taken into account

Extreme sea levels have been studied in some Mozambique ports. The study “Ciclones e da Subida do Nível Médio das Águas do Mar: INGC Alterações Climáticas Relatório” provides, for three ports, the characteristic values of maximum sea levels for the study periods of 1, 10, 100 and 1000 years, compared with the average local sea level. Data for the highest astronomical tides (MAMA) were also provided.

The difference in maximum heights at the highest astronomical high tide (MAMA) gives a surge value for each return period. If the studied urban area is near Maputo, Beira or Nacala, the extreme sea levels calculated in these ports could be used from previous studies (see 2.1.5).

Hazard mapping

The limits of the DEM and its accuracy at all points must always be kept in mind, as well as the complexity of coastal flooding phenomena (see level, wave action) also caused by sudden beach erosion during a storm. The demarcation of hazard areas and their qualification into low, medium or high hazard levels, can only be approached using a simplified method based on the elevation of the land with respect to the sea level reached during heavy cyclone or storms events.

The DEM can then be used with thresholds, for example 1 m, 2 m and 3 m. These thresholds are in relation with characteristic sea water levels. Then three areas can be demarcated corresponding to areas having an elevation between 0 and 1 m (zone A), 1 and 2 m (zone B), and 2 and 3 m (Zone C). For each area, an assumption is made: in zone A, land is at an average height of +0.5 m; +1.5 m in zone B, and +2.5 m in zone C.

Zone A (elevation less than 1 m, average of 0.5 m) has a height such that at any tide (spring or neap tide) the land is located below the high-tide mark. This land is damp and difficult to drain. It is

not regularly flooded when located inland (basin, depression cut off from the sea by higher land), or on the edge of the sea and artificially protected by low earth levees. In the event of a 10-yearly surge (for example +2.1 m), land in zone A can be on average under 1.5 m of water (2 m at most). Zone A is categorized as having a high hazard level.

For zone B (between 1 m and 2 m, average of 1.5 m elevation), the land is on average safe from the highest annual tides (for example a MAMA¹³ of +1.6 m). However, it is totally flooded in the event of a 10-yearly surge when the sea level can reach 2.1 m. Land is then under an average of 0.5 m of water (between 0 and 1 m across the zone). Zone B is categorized as having a medium hazard level.

Zone C (land between 2 and 3 m in height – 2.5 m on average) is only flooded by surges occurring less than once every 10 years. If one considers that the extreme sea level reaches 2.6 m for a 100-year return period, this zone will be partially flooded by the sea, with depths of at most around 0.6 m in the lowest areas. Zone C is categorized as having a low hazard level.

This demarcation (and its corresponding threshold values) is based upon MAMA (*Maré astronomica mas alta*), upon extreme storm surges (with reference to a return period) and, if necessary, upon the effect of swells and run-up.

7.5. COASTAL CLIFF HAZARD MAPPING

7.5.1. Geotechnical properties and instability of coastal cliffs

Marine erosion, during geological times, is at the origin of the existence of coastal cliffs. These generally present a height of a few metres near the shore, where they can be subvertical, but can reach more than 10 to 15 m in elevation with a slope between 30° and 45°.

Material properties

Important parameters concerning material properties are grainsize distribution, clay content and hydraulic conductivity. These parameters allow describing the behaviour of soils under heavy rain and their variations of water content.

Water is a key factor in slope stability: a sudden increase in water content may modify mechanical parameters such as friction angle and cohesion.

Instabilities and erosion phenomena

During heavy rains or storms, natural slopes or cliffs may be subject to two kinds of phenomena:

- A loss of mechanical resistance due to an increase in water content, which leads to a lower stability and may result in landslides or collapse;
- Strong erosion by running water, leading to the formation of gullies that may extend more or less rapidly, depending on the mechanical properties of the soil.

Cliffs located close to the sea can also be eroded by sea water during high tides and storm surges or under wave action.

¹³ MAMA = *Maré astronomica mas alta* (highest astronomical tide level)

7.5.2. Hazard mapping

Concerning hazard mapping, it has been considered that landslides and gullies may occur everywhere within the slope, and may significantly affect a strip of land in both upstream and downstream directions from the cliff.

When gullies form, materials are excavated uphill and transported downhill. The influence zone of a gully is considered to be proportional to the height of the cliff, which is estimated from DEM. The size of a gully can be once to twice the height of the cliff.

For that reason:

- A **very high hazard level** is affected to the main slope;
- A **high hazard level** is affected to both downstream and upstream strips over a width equivalent to the cliff height;
- A **moderate hazard level** is assumed next to the upstream directed high-hazard level strip; its width again is equivalent to the cliff height.

8. Risk assessment and mapping

8.1. DEFINITIONS

Risk assessment is performed by:

- Identifying and analysing a potential phenomenon: **hazard** is the probability that the phenomenon occurs with a given intensity and a given return period;
- Assessing the expected damage to the elements at risk is obtained by combining exposure and fragility values.

Risk, strictly speaking, is then the combination of hazard and vulnerability values.

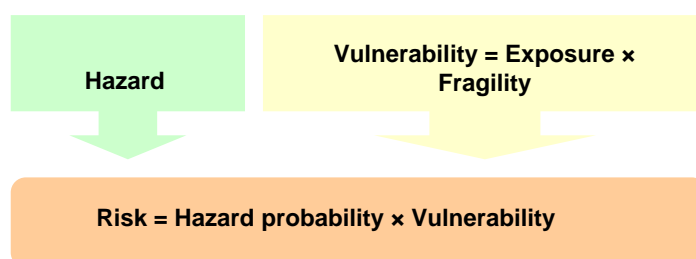


Figure 33: Hazard vs. risk

8.2. RISK-MAPPING PROCESS

This task aims at analysing and qualifying the risks induced by the various previously estimated hazards (flooding, coastal erosion and inundation, and gully erosion) for identified exposed elements. The categories identified in this study are the following:

- Unconstructed sectors;
- Urbanized sectors:
 - o Wooden huts,
 - o Masonry houses,
 - o Concrete buildings,
 - o Water-supply facilities,
 - o Electricity-supply facilities,
 - o Drainage and waste-water sewerage systems;
- Road infrastructures:
 - o Unpaved roads,
 - o Asphalted roads.

To derive the various risk maps, hazards are combined with the elements at risk according to their vulnerability. This distinction allows in particular highlighting those zones where precarious housing is significantly exposed since it is, as previously mentioned, the most vulnerable to the various hazards.

Grading of the hazards has been described in Chapter 6. Four hazard levels are generally considered: no hazard, and low, moderate and high hazard levels. The combinations between hazard and elements at risk carried out by crossed matrices are given in Tables 10 to 12.

Table 10: Matrix of risk gradation generated by coastal flooding and in-shore depressions filled by excessive runoff

	No Hazard	Low Hazard	Moderate Hazard	High Hazard
Precarious houses	No Risk	Moderate	High	High
Masonry houses	No Risk	Moderate	High	High
Concrete houses	No Risk	Moderate	Moderate	High
Unpaved roads	No Risk	Low	Moderate	Moderate
Asphalted roads	No Risk	Low	Low	Moderate

Table 11: Matrix of risk gradation generated by coastal cliff hazard

	No Hazard	Moderate Hazard	High Hazard	Very High Hazard
Precarious houses	No Risk	High	High	High
Masonry houses	No Risk	Moderate	High	High
Concrete houses	No Risk	Moderate	High	High
Unpaved roads	No Risk	Moderate	High	High
Asphalted roads	No Risk	Moderate	High	High

Table 12: Matrix of risk gradation generated by thalweg and street flooding

	No Hazard	Low Hazard	Moderate Hazard	High Hazard
Precarious houses	No Risk	Moderate	High	High
Masonry houses	No Risk	Moderate	Moderate	High
Concrete houses	No Risk	Low	Moderate	High
Unpaved roads	No Risk	High	High	High
Asphalted roads	No Risk	Moderate	High	High

Moreover, composite risk maps are derived in order to consolidate the possibilities of damage for the different typologies of elements at risk. Therefore, a specific GIS cover has been designed for each category.

9. Urban options and adaptation measures for increasing overall resilience

Resistance and resilience, or the development of human capacity for minimizing the impacts of exposure to natural hazards and their consequences through coping strategies, seems to be the best way out. Resilience results from a combination of interventions in which adequate urban development planning occupies a prominent position.

In the long term, this will translate into settlements that were properly designed from the onset. Other subsidiary measures for arriving at a suitable urban land-use planning, include public and private investments in facilities that improve the capacity of preventing and managing floods in general, and for responding to emergency situations. Such facilities include drainage, embankments, protection walls, refilling of eroded areas, provision of public and private water supply, sanitation facilities, etc.

9.1. GOALS AND OBJECTIVES

The impact of catastrophic events may be assessed at two different levels. The first one is related to impacts on distinct human persons or at the family level. A second level, of social dimension, refers to the destruction of infrastructure as well as to the disturbance of local or even regional economies.

It must be reminded that risk corresponds to a combination of hazard (i.e. the likelihood that a catastrophic event of given intensity will occur within a given time-period/geographic space) and vulnerability, which expresses the pre-disposition of elements at risk to be affected, damaged or destroyed by the event. Therefore, risk mitigation has to be considered through two main axes:

- Decreasing the vulnerability (fragility) in threatened sectors;
- Reducing the hazard where and when possible.

These two objectives can be reached by taking measures that cover two aspects:

- Protection of goods and persons: for instance by developing suitable works aiming at reducing the hazard;
- Prevention: defining rules for town- and land-use planning that take environmental constraints into account as early as possible, in order to adapt compensatory measures on urban development and to inform the population. Prevention will be approached hereafter by:
 - o Reduction of the vulnerability through integrated urban planning: this should deal with existing and foreseen elements at risk when considering a given hazard intensity;
 - o Non-increasing or reduction of the hazard caused by urbanization: this should deal with future vulnerabilities throughout the hazard control, since this latter varies over time according to urbanization.

To reach these goals, priority is to be given to the participation of stakeholders identified during a diagnostic phase. This participation is needed in order to identify the critical factors and vulnerable areas.

Participants may be representatives from State or local municipal and provincial government.

9.2. REGULATORY FRAMEWORK

9.2.1. Baseline conditions, policies, plans, laws and regulations

The development and adoption of structured responses to natural hazards and the vulnerability of human settlements do not happen in isolation. It is important that those who are involved in such processes be aware of the wider picture in which their interventions are and/or should be integrated.

During the study, we compiled the issues defining the context in which urban vulnerability should be considered as well as the existing and relevant legal and regulatory tools.

Natural disasters are phenomena that capture global attention and have become a cause for concern to most Governments. They are likely to be aggravated by climate change and will directly affect human settlements that often are already quite vulnerable. The solutions for mitigating the effects of natural hazards have been discussed both at international and national levels.

At the international level, a series of conventions such as the United Nations Convention on Biological Diversity, The Convention for the Protection, Management and Development of the Marine and Coastal Environment of Eastern Africa, the African Convention on the Conservation of Nature and Natural Resources, and other conventions adhered to by Mozambique for the SADC region play a significant role in environmental protection.

Mozambique has long defined itself as a country prone to natural hazards, mainly as recurrent and cyclic floods and droughts. The contents of the Constitution and of other laws, policies, strategies, and regulations pertaining to the management of natural hazards and spatial planning are a clear reflection of this view. After approval of the second Constitution in 1990 and after the Rio Conference on Sustainable Development in 1992, significant developments have taken place in the realm of environmental management, the use of natural resources, and land-use planning. This progress was based on three fundamental pillars:

- a) Adherence to international environmental protection and conservation instruments, namely the international conventions and regional protocols on environment;
- b) Approval of several acts of legislation that have a direct or indirect effect on the protection and conservation of the environment, including laws, decrees and numerous ministerial executive orders; and
- c) Creation of specific public organs dealing with environmental issues or broadening the mandate of existing ones, so as to cover additional environmental responsibilities. This includes the establishment of INGC itself as well as the Ministry for the Coordination of Environmental Affairs (MICOA).

The main environmental legislation is very recent, but even more so is the legislation related to physical planning. The Law and Regulation on Physical Planning were approved in 2007/2008 in recognition of the difficulties created by unplanned occupation of space, especially in urban centres. It is worth noting that the Government has always had environmental and territorial management on their agenda. The main development strategy documents of Mozambique, such as the second version of the Poverty Reduction Strategy of Mozambique (PARPA II-2006-2009/2010) and the Environmental Strategy for Sustainable Development (EADS – 2007), have incorporated issues related to spatial planning as one of their priorities.

Considering the relative institutional weaknesses that characterize Mozambique, it is obvious that the implementation of this recent legislation requires time and consolidation. The establishment of laws and regulations alone will not make a difference if institutional strengthening is not tackled and put into practice.

The challenges brought about by the climate-change component just exacerbate existing problems in relation to the efficient use of spaces, thus justifying quite complex interventions as the study proposes.

The main guiding documents for environmental and territorial planning and management, and more specifically for natural disaster management, were grouped into the following categories: (i) General instruments; (ii) Instruments with specific characteristics related to vulnerability; (iii) Strategic instruments; (iv) Specific territorial planning instruments; and (v) Related regional and international conventions. A summary of each category and main instruments is presented below. More details can be found in the project paper on "Laws and Norms".

9.2.2. General instruments

The Territorial Planning Policy, Law and Regulation – The Territorial Planning Law (LOT) 19/2007 provides the legal framework for the Spatial Planning Policy so that the following essential goals may be attained: sustainable and rational use of natural resources; preservation of the environment; promotion of social cohesion; valuing of the diverse potential of each region; promotion of citizens' quality of life; balance between the quality of life in rural and urban areas; improvement of housing and urban infrastructure, and the security of populations vulnerable to natural or human provoked disasters.

The Environmental Law does not specifically address the issue of human settlements, but Article 14 forbids the existence of housing or other infrastructures that, due to their size or location, may have a negative impact on the environment, specifically in coastal zones, areas affected by erosion, wet lands, or other environmentally protected and ecologically sensitive areas.

The Environmental Sector Strategic Plan for the period 2005-2015, defines the mission, vision, guiding principles and priority actions of the environmental sector, stating Mozambique's environmental priorities as being:

- (i) Sanitation and hygiene in relation to water and space;
- (ii) Spatial planning;
- (iii) Land degradation (erosion, loss of fertile lands, soil salinity);
- (iv) Natural resource management (flora, fauna, water, including brush fires);
- (v) Legal and institutional aspects (legislation, conventions, capacity building, environmental education);
- (vi) Pollution (water and air); and
- (vii) Natural and environmental disasters (drought, floods, and desertification).

9.2.3. Specific regulatory instruments in relation to vulnerability

The main regulatory instruments regarding the management of natural disasters are:

- Natural Disaster Management Policy;
- Master Plan for the Prevention and Mitigation of Natural Disasters (PDPMCN);
- National Action Programme for Climatic Change Adaptation (NAAP),
- National Plan for Natural Disasters Management, the Contingency Plans, and the Manual entitled: *“Learn to live with Floods: Manual of Recommendations for the Reduction of Vulnerabilities in Informal Settlements Susceptible to Floods.”*

9.2.4. Strategic regulatory instruments

The approval of LOT and its respective regulations as well as the introduction of the decentralized Planning and Finance methodology have contributed to the development of strategic and master plans for districts, towns and cities, as well as their respective territorial planning instruments. Under this framework, the towns of Inhambane and Maxixe have begun the process of creating their own urban planning instruments.

9.2.5. Specific territorial planning instruments

As part of LOT guidance and regulation, the towns of Inhambane and Maxixe have their own Structure Plans¹⁴ produced in different periods. In 1991, a Structure Plan covering both towns was prepared. In 1997, a Structure Plan for the town of Inhambane was started but not finished, having been interrupted at the appraisal stage through lack of financial resources. In 2008, a Structure Plan was produced for the town of Maxixe.

These Structure Plans are general documents, which for both cases establish general rules and parameters for the use of urban land. In the case of Maxixe, after production of the Plan, a partial urbanization plan was implemented in the neighbourhoods of Rumbana and Chambone with the objective of their reorganization. This exercise excluded the Rumbana neighbourhood as it was considered unsuitable for the development of human settlement and was eventually classified as a protected area due to the coastline of Inhambane Bay.

The Structure Plan for Inhambane focused on the reorganization of the neighbourhoods that were spontaneously occupied, strengthening services and infrastructures deemed weak. The Structure Plan was intended to provide vitality to these neighbourhoods by increasing inter and intra mobility in the neighbourhoods, as well as in the allotting of spaces for the development of social equipment.

9.2.6. Related regional and international conventions

Mozambique has been adhering to several international instruments that determine the need to be pro-active in the realm of environmental conservation and protection. The country's Constitution states that the norms of international law have the same value in the internal judicial order as the constitutional norms. Such requirements assume the character of a Law if they are ratified and emanate from the Parliament, and become decrees when they are ratified and emanate from the Government.

Additionally, Article 18 point N° 1 of the Constitution states that “validly approved and ratified international treaties and conventions are part of the Mozambican Judiciary Order after their official publication and while internationally binding the Mozambican State.”

Mozambique has signed many conventions and protocols as part of its adherence to the efforts made at a global level to promote the sustainable use and management of natural resources. Among the international instruments signed, the ones that are pro-active in the protection of the environment are the:

- United Nations Convention on Biological Diversity,

¹⁴ In article 10 from the Spatial Planning Law, the Structure Plan is defined as the instrument that establishes the spatial organization of a municipal or settlement unit, the parameters and norms for its utilization, keeping in mind the actual land use, the existent and future infrastructure elements and social equipment, and its integration in the spatial structure of the region.

- Convention for Co-Operation in the Protection and Development of the Marine and Coastal Environment of the West and Central African Region,
- African Convention on the Conservation of Nature and Natural Resources,
- Protocol on Wildlife Conservation and Law Enforcement in the SADC, and
- Mozambique's commitment as a State in the International Union for the Conservation of Nature and Natural Resources (IUCN) and Climate Change Actions Post-Copenhagen.

Under the last commitment mentioned above, it is worth noting that the Institute for the Management of Natural Disasters (INGC) commissioned specific studies to be carried out in Mozambique concerning the impact of climate change on the occurrence of natural disasters.

Reports INGC 2008 and 2009 note several challenges that are being faced in the management of natural disasters in urban environments as a result of climate change. In general the challenges and questions that have to be answered are:

- What contingency and mitigation plans are necessary to deal with the heavy rains and flooding attributed to extreme climate change and how to better predict such events?
- How are these changes going to affect the resettlement programs aimed at guaranteeing safety, and water and food security for the poor?
- How can the new transport infrastructure be optimized for reducing dependency on fossil fuels and their impact on climate change?
- What new patterns are necessary for taking climate change into consideration and for protecting people and infrastructures?
- How can urbanization be sustainable and contribute to reducing poverty through the development of new environmentally friendly markets?

9.3. RELEVANT TECHNICAL OPTIONS AND SOLUTIONS

It is important to determine if the proposed options are relevant. Relevant options should be technically feasible, while helping to mitigate hazard effects in the long term with minimal secondary impact. Technical feasibility deals with how effective a selected option is. A long-term solution is one that solves the problem and not only the symptom. An option that creates secondary impacts thus becomes ineffective and part of another problem.

Technical options differ from hazard to hazard. As such, a distinct evaluation of options should be carried out for each hazard. The relevant technical options will be the result of an in-depth analysis of the risks of a selected area, as well as of the available materials, resources (both human and financial), and technologies.

In the case of Inhambane and Maxixe, the following hazards were identified and technical options suggested:

N/O	Area of intervention	Hazard	Activity	Responsible for implementation	Priority
1	Maxixe	Erosion	Set up gabions (wire of 2.4 mm, mesh 8 x 10 cm) of 5 meters long and 1.5 m height on a series of 5 in breaks of 500 m on top of Reno Type mattresses (on thalwegs 103, 105, 106 and 110) in a total length of 14,000 meters.	City Council	High
2		Flooding	Construction of drainage ditches	City Council	Medium
3		Flooding	Excavation of gutters	City Council	Medium
4		Flooding	Excavation of a collection system and reservoirs to store water in the construction areas (houses and socio-economic infrastructures) Chambone neighbourhood 1 and 5.	Each Citizen	Medium
5		Flooding	Excavation of a temporary barrier basin between 5,000 and 10,000 m ³ for rain waters and their respective control mechanisms	City Council	Medium
6		Flooding	Excavation of drainage ditch along the roads of Maxixe and Chicucue and on the way to the hospital.	City Council	High
7		Flooding	Revision of the Urbanization plan for the Expansion area.	City Council	High
8	Inhambane	Coastal erosion and flooding	Landmark an area of risk below 2.6 meters.	City Council	High
9		Flooding	Remove the houses that are located on a height below 2.6 meters.	City Council	Medium
10		Flooding	Designing of a Detailed Plan	City Council	High
11		Flooding	Dumping area of 1.00 m of gravel in a surface of 2.500 m ² in a marked area that is bordered to the north by Av. Do Trabalho and to the south by Av. Patrice Lomumba and Moçambique.	City Council	Medium
12		Flooding	Construction of a drainage system along the dumping area bordered to the north by Av. Do Trabalho and to the south by Av. Patrice Lomumba and Moçambique.	City Council	Medium
13		Flooding	Set up pumping equipment (Φ200 to Φ400) on blocks 2 and 4 and the respective absorbing pipes for dirty waters (2,000 m).	INGC	High
14		Flooding	Construct a drainage system between Rua 20 de Setembro and the old railway that is 4 to 5 m deep passing through Eduardo Mondlane towards the sea.	City Council	High
15		Flooding	Design a partial plan for use change.	City Council	High
16		Flooding	Remove the houses located at the heights, 4 to 4,0 meters Q4 and 2.5 from Block 2.	City Council	Low
17		Flooding	Create a dumping area at the Q2 for the passing of the drainage pipes.	City Council	Medium
18		Flooding	Create a dumping area with gravel in an area of 8 ha behind Av. Eduardo Mondlane.	City Council	Low
19		Flooding	Design the Detailed Plan.	City Council	High

Table 13: Technical options for Inhambane and Maxixe

9.4. PARTICIPATORY IDENTIFICATION OF ADAPTATION ACTIONS

In order to identify zones vulnerable to intense rains and the critical factors to be considered in relation to mitigation, the participation of parties identified during the diagnostic phase was ensured. These parties were recognized as key figures in the mitigation of natural disasters in the two towns covered by this study. In this way, representatives of local authorities, such as the municipal and provincial governments, participated.

In this pilot study at the neighbourhood level, in both Inhambane and Maxixe, the Neighbourhood Secretaries and Heads of Quarters¹⁵ represented the local authorities, and at the municipal level, the Heads of Urbanization and Planning participated. In addition, the Representative of the State and the Head of the Department of Edifications from the Provincial Directorate of Public Works and Habitation were also involved in identification of the mitigation measures.

During the phase of mapping of natural risks and hazards and identification of adaptation measures, the representatives of the State and the municipalities presented an appraisal of different preventive and relief measures that have been carried out and/or implemented in the event of natural disasters. The Neighbourhood Secretaries and Heads of Quarters identified all the areas in their neighbourhood that they considered to be critically vulnerable to natural hazards, and proposed measures for increasing the resilience of the people that are living within areas vulnerable to flooding and extreme hazards.

Diagnosis of the terrain morphology and analysis of the climatic variables, carried out throughout the study, led to the production of strategies aimed at increasing the resilience of the communities in the event of natural adversities and hazards. This analysis was based on combining information on the subject with current local practices. In addition, bibliographic references regarding similar situations and outcomes were consulted. Thus, vulnerable areas and specific mitigation measures were identified for each study area.

9.4.1. Principles of risk mitigation using physical measures

Urban planners can limit the damages generated by natural events thanks to a better knowledge of the risk and its transcription into town-planning schemes. The consequences of events in the most vulnerable sectors can thus be limited by a better space management. The main measures imply:

- Prohibiting construction in the most dangerous sectors;
- Avoiding spaces likely to be affected by a high or very high hazard level;
- Authorizing construction in certain sectors, but within specific limits.

The approach has to be conducted at a sufficiently large scale in order to take into account the whole phenomenon.

In the case of flood risk, the catchment basin scale is ideal (downstream flow results from upstream runoff).

Preferential flows and sectors of runoff protection must first be identified and mapped as hazard maps. Urban planning may for example consider those elements, in order to propose an adequate urban organization against flood risk.

¹⁵ Neighbourhoods in Mozambique are generally divided into quarters. Therefore each neighbourhood is headed by a Secretary and below these, each Quarter within the neighbourhood has a Head/Leader.

The urban system may be organized into two complementary hydraulic systems:

- A “**minor system**” that consists in a sewer system for evacuating rainwater up to a certain return period with minor and limited overflowing. In this case, the flow is often hidden from the inhabitants as it generally remains underground;
- A “**major system**” formed by streets, roads and parks that evacuate overflowing rainwater from the rarer events. The major system must be designed for reducing the vulnerability. Obstacles to flow and sectors with significant stakes are thus to be banned from this system. In urban zones, parks, uncultivated thalwegs, nature reserves, playgrounds, etc. are to be privileged for the major system development.

This organization in two systems aims at accompanying the risk management in a continuous and progressive way, but it is not possible to ensure total protection against all types of heavy rain events. For the majority of rains, the current sewer system will be sufficient, but for exceptional and more intense rains this will be exceeded. It is then necessary to channel the generated overflow into the major system in order to limit its consequences.

The switch from the minor to the major system actually depends on the failure period of the pluvial sewer works. It is generally accepted that this should correspond to a mean return period of about 10 to 20 years.

Urban planning thus has to manage both runoff on newly developed sectors (with an objective of not increasing the downstream hazard), and flow in the city in the case of storm-sewer network overload or failure. In other words, hydrological (streaming) and hydraulic (flow in streets) prescriptions have to be considered as a whole for the urban planning implementation.

9.4.2. Middle- or long-term measures for reducing vulnerability

Land-space organization

Risk management implies a management of the urban space. The urban system consists in a minor and a major system.

In the **major system**, the use of green spaces has to be privileged. Urban planning also has to choose between urban projects and developments that favour infiltration or retention following the sector capabilities. Furthermore, the public road and street networks will have to respect the following considerations:

- The secondary public road network should be perpendicular to the natural slope;
- The main public road network should be parallel to the natural slope to collect rainwaters;
- The main public road network should pass, if possible, through parks, nature reserves or playgrounds, to slow down flow and to collect excess rainwater.

Major system layout

The major system layout consists in flooding the least vulnerable sectors in case of an exceptional event and in reducing the floods in the most sensitive and exposed sectors.

Use of the public road network

The existing public road network may be used as flow-way for overflow from the storm-sewer system. But, to reach this objective, it must be designed so as to be able to evacuate certain flow-rates, while ensuring the effective protection of surrounding elements at risk such as dwellings.

Low points in roads must be able to evacuate surplus water. Sidewalks must be heightened by several tens of centimetres with regard to the traffic lane. The water heights should not be too significant in order not to compromise personal safety.

Use of public space

Free areas near thalwegs may be located in green spaces. Such areas can be flooded during important rainy events. Similarly, when designing the layout of several houses in an urban programme, certain areas should be reserved as green space, which can serve as a playground but also as a retention zone for runoff water.

Building location

Planning of the urban space has to allow for flood risk management during exceptional events such as 100-year return-period floods. Beyond this 100-year return-period flood notion and in order to decrease overall vulnerability, the layout of building space density has to be adapted to the hazards and risks prevailing in each sector:

- Houses located within thalwegs have to be avoided (forbidden);
- Houses located near thalwegs, but outside the areas of maximum hazard, might be authorized with specific prescriptions.

Location of strategic buildings

Strategic buildings are those that have an operational role in case of emergencies (Ministry, Civil Protection, disaster and emergency services, police, fire brigades, hospitals, communication centres, electric transformers, water reservoirs, etc.). These buildings as well as those of public access (schools, churches, commercial centres ...) have to be located in areas protected from flooding or, if this is not possible, should be protected by dykes, walls, etc.

Urban land-use planning may reserve the less exposed sectors for strategic and public-access buildings, which in any case should not be built within or near thalwegs with a significant hazard.

9.4.3. Middle- or long-term measures for not increasing hazard**Urban flooding risk in new urban development areas**

For any new urban layout, a site diagnosis has to be first made for identifying upstream runoff characteristics. Then, at an early stage of the project, adequate hydraulic compensation measures must be included within the layout. Moreover, as this new scheme will likely (i) reduce the infiltration capability of the site, (ii) divert the course of flows, and (iii) modify the catchment basin area, the urban planner has to make sure that the leak flow-rate remains acceptable as far as its impact on the downstream hazard is concerned. Some recommendations can be made for inclusion in town-planning regulations:

- Design thresholds of buildings with a certain elevation;
- Recommend a ratio for impervious surfaces;
- Establish a leak flow-rate that is not to be exceeded for a reference event;
- Maintain new layouts at a certain distance from thalwegs.

Compensatory measures for reducing runoff

Compensatory measures for not increasing downstream runoff consist in collection, retention and infiltration techniques. Such measures are various and mostly depend on site constraints:

- Technical (hydraulic, topographic) constraints;
- Socio-economic constraints, such as the cost of implementing the scheme or land tax.

The main compensatory measures that are possible in the study area are:

- Stocking roofs: a certain quantity of the rain is stored in the roofs of houses;

- Wells or tanks: wells are depressions covered with porous materials. Tanks can be arranged at the bottom of gutters to partly collect rainwater;
- Retention basins: the water is collected and forwarded to a basin and then evacuated as regulated exit-flow.

This last measure is applicable to significant building programmes or industrial sites and/or at the scale of a catchment basin. The first two measures concern especially individual plots. It must be emphasized that all compensatory measures ask for regular maintenance in order to maintain their optimal capabilities.

The dysfunctional effects of hydraulic works or the impact of events with long return periods have to be analysed for (i) preventing an increase of the hazard in a downstream direction, and (ii) ensuring the control of excessive runoff.

9.5. IMPLEMENTATION MECHANISMS FOR INCREASING RESILIENCE

There is sufficient evidence to the effect that rainfall levels and flood occurrences due to worldwide rising sea levels are worsening. Undoubtedly, this will also affect the study area and, for this reason, appropriate measures need to be taken for increasing the capacity of people living in these risk areas to survive and overcome adversities whenever extreme natural events occur.

Experience also shows that although people may be forced to abandon their homes when flooding occurs, and although there is also destruction and disruption to infrastructures such as roads, water and electricity supply, and sanitation, many houses in risk areas have managed to endure. Floods lasting from several days to weeks or months always tend to subside, with the beleaguered land returning to normality. As a result, most of the people affected by these situations feel tempted to rebuild their lives on the original sites (Few R, 2003).

The incapacity of both local authorities and those affected by disasters to abandon the troubled areas once and for all, has led to the need for reflection on measures for families living in areas prone to flooding, to defend themselves and to coexist with extreme natural adversities.

In short, a combination of political, cultural, socio-economic (mainly the need to live closer to social amenities) and other factors explains why relocation and resettlement is hardly ever a valid option. Resistance and resilience, which in other words mean the development of human capacity to minimize the impact of disasters through coping strategies and mechanisms, seem to be the best way out. This should result from a combination of interventions in which adequate urban development planning occupies a prominent position. In the long term, this will translate into properly planned settlements from the onset. Other subsidiary measures to a suitable urban land-use planning include public and private investments in facilities that improve the capacity for preventing and managing floods in general, and for responding to emergency situations such as drainage, embankments, protection walls, refilling eroded areas, provision of public and private water supply and sanitation facilities, etc.

9.5.1. Municipality actions

The municipalities should take up an essential role in managing the occupation of urban land. Such control should include the participation of the inhabitants of the exposed areas themselves. Thus, the following measures are foreseen:

- Formulate Urbanization Master Plans and Detailed Plans, aiming at re-organizing areas of spontaneous and disorderly occupation;
- Include maps on Conditioning Factors for Urban Soil Use in the different urban territorial planning instruments (Structural Plans, Urbanization Master Plans and Detailed Plans),

containing an identification of those areas exposed to flooding, erosion and others with fragile ecosystems which make the development of human settlements unfeasible;

- Include measures to be adopted for the development of human settlements in areas prone to flooding, erosion, cyclones or other natural weather phenomena in the Urbanization Master Plans, and particularly in their regulations. Such measures should indicate soil occupation indexes in addition to absorption indexes;
- Demarcate the land located in areas at risk on maps and on the ground, with three hazard levels (high, moderate and low);
- Identify new areas for housing expansion.

The municipality's leadership in the rehabilitation or construction of infrastructure included in its urbanization plans should provide for the inclusion of areas exposed to flooding and erosion, and as such should:

- Establish programs for identifying critical areas within a global context of the City;
- Develop programs for opening drainage ditches and other systems to control rainwater, taking into account community participation.

9.5.2. Role of local structures

The participation of local structures during the period prior to and during the occurrence of extreme events is essential, particularly to guide the first responses to natural disasters. Such coordination should aim at:

- Identifying exposed areas prior to the occurrence of events;
- Conduct a census of the families at risk;
- Monitor the implementation of mitigation measures foreseen for specific areas;
- Establish or interest community-based organizations in matters relating to the reduction of impact of natural disasters;
- Establish committees or mutual assistance groups to provide response in cases of first-hand intervention.

9.5.3. Role of State institutions and representatives

The State representatives should be solely responsible for coordinating actions to mitigate the impact of natural disasters, with the INGC providing methodological and logistical guidance. The responses could include:

- Constant awareness-raising actions to discourage the occupation of exposed areas;
- Health education actions to improve the response in case of floods; structure logistical means as alternatives to latrines (mobile or ecological latrines) during flood periods.

9.6. PARTICIPATORY FORMULATION OF PRELIMINARY ADAPTATION ACTION PLAN

Any measures decided on for reducing the impact of natural disasters must always consider the target group. According to the social survey underpinning this study, most people living in exposed areas have insufficient resources to improve their life.

Because of the need to inhabit areas close to the economic and social services offered by urban centres, most people prefer to occupy apparently free areas such as areas close to the margins of drainage ditches, low-lying and coastal areas, among others, even though they know there is a history of flooding.

Measures to mitigate the impacts of floods may occur at two specific times, during and after disaster, and may take the form of structural and non-structural measures.

Non-structural measures do not aim at preventing floods, but rather at reducing their impact on assets in the short and long terms.

At a macro level, these measures include a formal warning system and programmes for monitoring soil use in areas prone to flooding. They also include establishing specific regulations for building in these areas and safety plans.

At a micro level, attention focuses on non-structural measures for reducing vulnerability based on actions carried out in, and by, the affected community itself, by reproducing plans and solutions previously used in other situations.

Another route that can be explored is to mobilize and organize community-based organizations into networks for initial assistance when natural disasters affect an area, namely by providing temporary shelters and basic food.

10. Recommended safeguards

Both Mozambican and World Bank legislation and regulations require that safeguard assessments and feasibility studies be conducted prior to the implementation of physical interventions. This would apply to the series of solutions and adaptations measures considered suitable and proposed in this study, in particular environmental assessments (EA) in order to provide environmental license to the interventions. The EA process is discussed in this chapter as a way of providing general indications of the issues and modus operandi that would need to be considered in the environmental licensing of the interventions likely to be selected.

Mozambique has developed comprehensive regulations to cover the EIA process, which are included in the Regulation of the Process of Environmental Impact Assessment¹⁶. The regulations are in line with the world's environmental and social management best-practices, including World Bank recommendations and procedures. They would take precedence for interventions to be adopted as part of this study.

There are three main specific objectives of any EA exercise:

- *Scoping of the proposed developments in terms of their potential impact on the natural and social receiving environment, indicating both its beneficial outcomes and adverse effects, This initial screening is needed to determine the scope of the Environmental Impact Assessment (EIA) required prior to approval of the interventions. If the investment is likely to have significant adverse environmental impacts that are sensitive, diverse, or unprecedented (a Category A), the EIA will be more stringent than if the investment has impacts which are less adverse, site-specific, mostly reversible and where adequate mitigation measures can be designed (Category B). For investments with multiple sub-projects, this screening is often done in the form of a checklist of potential impacts included in standard Environmental and Social Management Frameworks (ESMFs).*
- *The actual Environmental Impact Assessment (EIA), which assesses the potential impacts of the investment in detail and evaluates alternatives.*
- *Proposal of measures to be taken in order to avoid, mitigate and/or eliminate adverse effects both at the planning, design and installation stages, and during operation and eventual decommissioning of the project. This is generally done in the form of an Environmental Management Plan (EMP), which is normally an intrinsic part of the EIA.*

It should be stressed that the Scoping Exercise, EIA and the Environmental Management Plan (EMP), are components of particular importance in any EIA process.

EIA Scoping

Scoping primarily explores fundamental issues and identifies any potentially significant positive and negative environmental as well as social impacts associated with the proposed development, helping to determine the scope of the Environmental Impact Assessment. This involves correspondence and liaison with key Interested and Affected Parties (I&APs) such as central, provincial and local authorities and other relevant project stakeholders.

Environmental and Social Impact Assessment (EIA)

Based on the findings of the scoping process the EIA makes a detailed description of the project's receiving natural and socioeconomic environment. The descriptions form the baseline for the

¹⁶ Decree 45/2004 of September 29, 2004 and Decree 42/2008 of November 04, 2008

impact evaluation. The assessment of effects includes direct and indirect, secondary and cumulative, short and long-term effects as well as permanent and temporary and negative and positive effects of the proposed project and is done for the design, construction, operation and, where applicable, the decommissioning phases of the project.

Environmental Management Plan (EMP)

In terms of Regulation of the Process of Environmental Impact Assessment, an EMP should be prepared as part of the EIA process. The EMP “should include the monitoring of the impacts, prevention plans as well as accident contingencies”.

In an EMP, various mitigation measures are organized into a well-formulated plan, which serves as a guide for the construction and operational phases of a development. An effective EMP is usually a practical document, which precisely sets out both the goals and actions required in mitigation.

More Specific Aspects about the Mozambican Context

Once the decision to go ahead with a certain intervention, the EIA Process comprises the following main phases:

Pre-assessment Application: This involves preparing the pre-assessment application following the form specified in Decree 45/2004. The pre-assessment application is aimed at providing sufficient information about the project for the environmental regulatory authority, the Ministry for the Coordination of Environmental Affairs (MICOA), to categorize it. This assessment determines, or confirms (based on the category into which the activity falls) the type of assessment required for licensing.

There are three possible categories under which a project can be expected to fall, namely

- (i) Category A for projects that should be subjected to a full EIA exercise, which starts with the preparation of an Environmental Pre-feasibility and Scoping Study (EPDA) and the Terms of Reference of the EIA (see below). The kinds of projects that fall into Category A are:
 - Dams and weirs;
 - Re(settlement) and urban development;
 - Infrastructures (transport, sanitation, industry);
 - Energy and extraction of minerals (gas, coal, oil);
 - Waste management and disposal of toxic and hazardous material;
 - Energy (transmission lines and power plants);
 - Forestry (clearing more than 50 ha); and,
 - Agriculture (parceling of more than 350 ha and 1000 ha of grazing land, aquaculture, etc.)
- (ii) Category B for simpler projects for which focus should only be on the preparation of an environmental management plan (EMP) as part of a Simplified EIA Study. The kind of projects that fall under this category are:
 - All the activities that don't fall under category A or C; and,
 - Activities that don't significantly affect the environment, or that have short term impacts, duration, etc.;
- (iii) Category C for projects that are exempted from undergoing any EIA process due to their simplicity and acknowledgment of the fact that they will not have any significant environmental and/or social impacts. The projects that fall under this category are:
 - Irrigation schemes between 50.100 ha;

- Hotels, homes, etc. in cities or towns;
- Pavilion for animals (1000-1500 animals);
- Clearing/transformation of natural areas between 100-200 ha without grazing; and
- Horticultural and fruit conservation industries.

Environmental Pre-feasibility and Scoping Study (EPDA) - If a project is classified as a Category A there is a need to prepare an EPDA (EIA Scoping). EIA scoping involves a series of activities that can be divided into three broad categories, namely:

1. Garnering input from Interested and Affected Parties (I&APs) on:

- Study of possible alternatives that may come to light during the course of the study
- Identification of significant issues to be addressed
- Identification of possible mitigating measures
- Determination of specific guidelines for the impact assessment

2. Obtaining and/or developing input from project proponents, designers, engineers and financiers on:

- Detailed design specifications
- Design alternatives
- Timing
- Method of implementation and operational controls
- Decommissioning details

3. Obtaining input from environmental specialists on:

- Specific knowledge of the site
- Preliminary investigations conducted

The scoping report details the scope of further work to be carried out during the subsequent phases of the EIA process as well as the areas of study (natural and socioeconomic environments), time frames, methods and reporting requirements.

Terms of Reference for Environmental Impact Assessment (TOR) - Based on articles 10 and 11 of the Environmental Impact Assessment Process Regulation there is a need to develop TORs for environmental studies, if a project is classified under Category A. The TORs have to be approved by MICOA before the environmental impact assessment can proceed.

Environmental Impact Assessment (EIA) and Environmental Management Plan Studies (EMP) – An environmental and social impact evaluation for the proposed project is required if an intervention is classified under Category A.

It under the EIA phase as such that a detailed description of the project's receiving natural and socioeconomic environment is made. The description forms the baseline for the impact evaluation. The assessment of effects includes direct and indirect, secondary and cumulative, short and long-term effects as well as permanent and temporary and negative and positive effects of the proposed project and is done for the design, construction, operation and, where applicable, the decommissioning phases of the project. As part of the environment and social assessment process, an Environmental Impact Report that includes a general Environmental Management Plan (EMP), should also be prepared. As detailed above the EMP includes measures to avoid, reduce or compensate for significant adverse impacts or enhance positive impacts.

EIA Regulation also require that the Draft EPDA/TOR and the Draft EIA/EMP Report be debated in public meetings in relevant places for the project to give an open opportunity for all project interested and affected parties (I&APs) to present their concerns and suggestions for these to be considered in project enhancement.

Given their relatively reduced magnitude and complexity, most of the proposed adaptation options listed under this study would fall under Category B, requiring (i) only the preparation of an EMP as part of Simplified EIA Studies (Category B). Some, however, may require a full EIA and EMP (Category A), and a few (such as early warning system, and creation of community awareness or disaster preparedness groups) would likely fall under Category C, i.e. be exempted from the need to undergo an EIA process and be automatically licensed from the environmental and social point of view (Category C).

Resettlement

Certain interventions might require people to be resettled. The Regulation of the Environmental Impact Assessment Process, which governs the EIA process in Mozambique, says very little about resettlement, except that in its Annex I, point 1. Infrastructures, line a) it states that “under environmental licensing, all interventions requiring people to be resettled will be considered as Category A Activities”.

Mozambique legislation guiding involuntary resettlement is spread over a series of legal documents dealing with land, general rights, compensation, etc. To counteract potential inconsistencies derived from using laws and regulations that are not always easy to harmonize, most of the resettlement procedures undertaken to date by development initiatives in Mozambique have basically followed the OP 4.30 /OP 4.12 of the World Bank on Involuntary Resettlement, which is endorsed by the government. The policy covers the involuntary taking of land, as well as restriction of access to means of livelihood, as explained below. This would be valid to the proposed adaptation options to be considered as part of this study.

Involuntary resettlement has a significant impact on a person, family, group or community that is forcibly removed because of decisions made by agents outside the group. Resettled people are those affected by the loss of infrastructure, housing of varied types, sources of employment and/or livelihoods. Under the WB OP 4.12 resettlement is not restricted to its usual meaning – i.e. “physical displacement.” Depending on the cases, a resettlement action may include (i) loss of land or physical structures on the land, including business, (ii) the physical movement, and (iii) the economic rehabilitation of affected persons (APs) in order to improve (or at least restore) the levels of income or life prevailing before the action causing the resettlement has taken place.

International, regional and national practice that is embraced by the Government of Mozambique in general, indicates that, whenever possible, resettlement should be avoided and/or minimized. In other words, when resettlement is inevitable, it is necessary to develop a Resettlement Action Plan (RAP) to ensure that the affected people are resettled and compensated adequately and equitably. Similarly, the affected people and the authorities that represent them should receive clear and timely information about the possible alternatives of compensation in order to choose the alternatives that best suit their needs. Therefore, the resettlement process must be participatory.

However, before this is done a “Resettlement Policy Framework (RPF)” would be prepared as an instrument to be used throughout the RAP implementation. The RPF will be publicly disclosed in impacted areas to set out the resettlement and compensation policy, organizational arrangements and design criteria to be applied to meet the needs of the people who may be affected by the program. The Resettlement Action Plans (RAPs)” would be prepared consistent with the provisions of this RPF. If several RAPs are to be carried out in the urban areas, it would be advantageous to have an RSF that can be used for all the RAPs.

These principles would apply to the proposed measures under this study if they are to have resettlement implications. Additional and relevant principles include:

- People affected both directly and indirectly by project development are compensated as part of the project.
- Resettlement covers physical displacement and economic impacts causing the loss of, or loss of access to, any assets growing on or permanently attached to the land, such as shelters, buildings and crops and, to the impact causing loss of, or access to, an economic resource base or local communities' means of livelihood.
- If the impacts include the need for physical relocation, measures must be taken to ensure that the affected people are provided with assistance (such as moving allowances) during relocation and be provided with residential housing, or housing sites, or, as required, agricultural sites for which a combination of productive potential, location advantages, and other factors are at least equivalent to the advantages of the old site.
- Losses may be total or partial. Local laws and regulations have adopted what the majority of donor policies emphasize to the effect that the absence of legal title to use and benefit of land does not limit rights to compensation. Preference should be given to land-based resettlement strategies for displaced people whose livelihoods are land-based. If sufficient alternative land is not available, non-land-based options built around opportunities for employment or self-employment should be provided in addition to cash compensation for land and other assets lost. The lack of adequate land must be demonstrated and documented.
- The need to involve people affected by the project in the planning and implementation of interventions that result from these policies is stressed. Resettlement planning includes:
 - early screening,
 - scoping of key issues,
 - the choice of resettlement instrument, and
 - the information required to prepare the resettlement activity.

The scope and level of detail of the resettlement instruments vary with the magnitude and complexity of the resettlement.

In its turn World Bank OP 4.12 recognize that involuntary resettlement can give rise to significant disturbance and risk of increased vulnerability for affected people caused by physical displacement or disruptions to their livelihood systems and income sources.

Specifically, OP 4.12 contains the following main principles and provisions:

- Involuntary resettlement should be avoided where feasible or minimized;
- Resettlement activities should be regarded as sustainable development programs with meaningful consultation with affected people in program planning and implementation;
- Affected people should be compensated for lost assets and assisted in their efforts to improve/restore their standards of living;
- Resettlement covers relocation/loss of shelter; loss of assets/access to assets; and loss of income sources or livelihood means (whether or not affected persons must physically relocate);
- A formal resettlement plan or resettlement policy framework is required to address project associated resettlement impacts. According to OP 4.12 a resettlement plan should describe the following:
 - The project, potential impacts and measures taken to avoid or minimize resettlement;
 - Socioeconomic studies carried out to identify who is affected and nature of effects; information on vulnerable groups; local livelihood and land-tenure systems and social and cultural characteristics of affected populations; etc;
 - Applicable legal framework with which the land acquisition and resettlement process should comply, and any gaps between national laws and OP 4.12;
 - Affected persons and eligibility for compensation and other resettlement assistance,

- including cut-off dates;
- o Methodologies to value losses and compensation at replacement cost;
- o Resettlement measures and support to be provided to project-affected people;
- o Resettlement sites including their identification, suitability, resettlement procedures, influx risks and institutional and legal considerations;
- o Plans to provide any necessary housing, infrastructure and social services;
- o Community consultation and participation during resettlement planning and implementation;
- o Measures to mitigate impacts of resettlement on host communities;
- o Grievance mechanisms and procedures;
- o The organizational framework for implementing resettlement;
- o Resettlement implementation schedule;
- o Resettlement costs and budget;
- o Monitoring and evaluation of resettlement implementation (internal and external).

Simplified RAP

Local legislation as well as the World Bank guidelines (WB OP 4.12), specify that when the people being affected are less than 200 a simplified resettlement plan becomes acceptable. A simplified resettlement plan describes the activities and actions of the project undertaken to minimize the resettlement and / or compensation, it also provides an officially certified inventory of persons affected by the project, an inventory of assets and their evaluation and, if necessary, a complementary socioeconomic research that describes the dynamics of local life that will facilitate the understanding of the measures being taken to restore standards of living which are equal or superior to what those people and families affected had before the project caused their new condition. The plan describes in detail the compensation and other forms of support including the right of participation of affected people in alternative activities for development of livelihoods. The plan also identifies institutional responsibility for implementation as well as systems and procedures for submission and channelling of complaints and grievances as well as arrangements for implementation and monitoring an also and implementation schedule and budget.

Simplified RAP would also apply to most of the proposed adaptation options listed under this study.

CONCLUSION

The objective of the safeguard measures matrix is to propose precautionary measure to prevent or reduce the impact of the proposed activities within the Adaptation Plan. The proposed safe guard measures were produced based on the intersection of the following variables:

- Review and territorial analysis of the different impacts;
- Estimation of the magnitude of the different impacts projected by the extreme events;
- Evaluation of the success and sustainability of the current local experiences and solutions; and,
- Local adaptation of successful international experiences/measures.

The final safeguard measures matrix considers the sustainability of the measures to be carried out from the construction, economic, social and environmental perspective. In this manner, solutions that had a strong negative interaction with the environment were discarded. These negative impacts were exemplified by large movements of land that would be necessary in embankment operations in areas with low quotas. Interventions with vast technological complexities and with consequently high costs were also discarded because the intervening institutions would not be able to bear these exorbitant costs.

11. Estimation of costs

11.1. MAIN INPUTS AND COMPONENTS OF THE PROCESS

The objective of this task is to produce a proposal with cost components that are as detailed as possible and which will allow INGC to secure the funds for investment for the Adaptation Plan. The estimation of costs includes four categories, which are described in detail below:

- **Special Infrastructure Costs:** information for these types of costs include the items (such as the length of a drainage tube, amount of embankment, etc.), their respective amounts and unit prices (e.g. USD/ml or USD/m³). The estimations of these items were equated based on current costs in the market for the material required for each activity.
- **Monitoring and Evaluation Costs:** these can be calculated at a reasonable margin, such as 1 percent of the total cost of the project.
- **Contingency Costs:** a 10 percent contingency of the base costs as a preliminary figure is deemed appropriate given the time lag between the project preliminary design and inventory census and project construction design, when costs will be updated. In addition, if some material for the special infrastructure is unavailable on-site, this fund will allow for its acquisition off-site.
- **Implementation Management Cost:** this can be set for 2-4 percent.

This plan favours urgent actions aimed at reducing the magnitude of the problems, advancing slowly to more secure measures, some of which are more technically complex and thus incur elevated financial costs.

It is important to note that the estimation of costs is a budget for the required actions to be implemented, but it does not include miscellaneous costs that might be incurred due to extenuating circumstances. These miscellaneous costs could include transportation because depending on where the project is being implemented, the material necessary to implement some of the measures indicated in the adaptation plan may not be available. This therefore requires additional funding in order to bring the material to where it is needed. For example, the Adaption Plan for the City of Inhambane includes the acquisition of 220,000 m³ of embankment which will be difficult to find. Therefore, transportation costs would be incurred, but could be taken from the contingency fund.

11.2. COST PER INPUT COMPONENT/SUBCOMPONENT

Below is a sample budget with cost estimates, including costs per input component and subcomponent. Prices should be estimated from local suppliers, as available.

N/O	Area of intervention		Activity	Quantity	Unit	Unit Cost	Total Cost US\$	Responsible for implementation	Priority
	City	Neighbourhood							
1	Maxixe	Chambone Mazambanine	Set up gabions (wire mesh 2.4 mm, 8x10cm), 5 m long, 1.5 m tall in series of 5 in 500 m breaks on Reno Type mattresses (on thalwegs 103,105,106 and 110) for a total length of 14,000 m	28	Un	2,800	78,400	City council	High
2			Excavating of drainage ditches	6 500	ml	150	975,000	City Council	Medium
3			Construction of culverts	13	Un	2,500	32,500	City Council	Medium
4			Building of a collection system and reservoirs to store water from construction sites (houses and social and economic infrastructures) Chambone neighbourhood 1 and 5.	n	Un	Variable	Variable	Every citizen	Medium
5			Excavating of a temporary barrier basin for 5,000 to 10,000 m ³ of rainwater and respective control mechanisms.	1	Un		150,000	City Council	Medium
6			Excavating of drainage ditches along the roads in Maxixe and Chicuque and on the way to the hospital.	10	Km	150	1,500	City Council	High
7			Revision of the urbanization plan of the expansion area.	1	Un	30,000	30,000	City Council	High
8	Inhambane	Chalambe Liberdade	Marking of the area that is prone to risks below 2.6 meters	7	Ha	10,000	70,000	City Council	High
10			Designing of a detailed plan.	1	Un	50,000	50 000	City Council	High
11			Build a drainage system along the dumping area which is bordered to the north by Av. do Trabalho and to the south by Patrice Lumumba and Moçambique.	600	ml	1	90,	City Council	Medium

N/O	Area of intervention		Activity	Quantity	Unit	Unit Cost	Total Cost US\$	Responsible for implementation	Timeframe
	City	Neighbourhood							
12			Set up pumping equipment (Φ200 to Φ400) in blocks 2 and 4 and the respective absorbing pipes for dirty waters (2,000 m).	2	Un	10,000	20,000	INGC	High
13			Build a drainage system between Rua 20 de Setembro and the old railway with 4 to 5 m depth passing by Eduardo Mondlane on the way to the sea.	600	ml	150	90,000	City Council	High
14			Design a partial plan to change uses.	1	Un	30,000	30,000	City Council	High
16			Dump area in Q2 for drainage pipe passage.	15,000	m ³	30	450,000	City Council	Medium
18			Design a Detailed Plan.	1	Un	30,000	30,000	City Council	High
SUB TOTAL							2,097,400		
Monitoring and evaluation costs (1%)							20,974		
Contingency costs (10%)							209,740		
Implementation and management costs (3%)							62,922		
TOTAL COSTS							2,391,036		

Table 14: Sample budget for estimation of costs

12. Conclusions and recommendations

The best approach to prepare cities facing present and future climate variability in coping with natural hazards, is to increase the resilience of the population as a whole, and to adopt adaptation measures and specific urban options.

All city stakeholders, including individuals and residents, their local and community leaders, city and municipal authorities, technical and management government departments, etc. should be aware of the potential hazards. They should be able to acquire specific knowledge and skills for adequately establishing and implementing resilience and adaptation measures. Capacity building is required for this to happen.

Using the specific cases of Inhambane and Maxixe, this manual was developed as part of the capacity-building process. It was designed as a reproducible methodology for increasing overall resilience in highly vulnerable areas, in full consultation with the exposed populations.

People and particularly adults learn by applying an approach, which involves both training and providing practical experience. This would be carried out for all identified stakeholders including the ultimate beneficiaries, i.e. the residents in different areas of the cities which are exposed to natural hazards.

Capacity is translated into staff having the appropriate knowledge, skills, attitudes and ability to do what is required in a given context. Inseparable from capacity are the appropriate conditions and resources for enabling staff to carry out such tasks. These include the financial, human and time resources made available by different organizations and for the task at hand.

In parallel with the project/programme cycle, this manual covers a series of stages that should be considered for developing adequate and sustainable responses to present and future climate variability. These stages were dealt with in a participatory manner, allowing relevant stakeholders to see and experience how the process should be conducted. This is in line with a maximum participation of the exposed populations in the target townships and of other relevant local (and national) stakeholders in all phases of the process. The stages covered problem identification, planning and costing. Implementation, monitoring and evaluation stages should follow as needed, always bearing in mind that *“all relevant stakeholders should be actively involved in joint analysis and action plans”*.

More specifically, obtaining an understanding of the broader context in which resilience and adaptation should be shaped, took a significant part in the entire exercise in the form of:

- (i) Characterization of the climate and climate change in Mozambique and the intervention areas, and reviewing present and future trends including expected scenarios;
- (ii) Characterization of the specific socio-economic context in which the interventions were expected to occur, as well as the assessment and mapping of climate, climate change and natural hazards including the identification of relevant stakeholders.

Adequate technologies and methods were used for covering this initial stage, which ranged from primary and secondary data collection and processing to the use of IT/GIS and other technical resources. The whole exercise was conducted in such a way as to make it understandable and easily copied by the identified people and institutions in other similar contexts, even if those contexts would be marked by limited human and technical resources when compared to those that were available in this particular case.

The issues of the context and the strengths and weaknesses identified were then translated into options and adaptation measures for increasing resilience. Several possibilities based on the existing legal and regulatory framework at national, regional and international levels were explored, which then led to identification of the available technical options and solutions.

Based on the aforementioned elements, a plan of action was formed in a participatory manner. It considers the general principles to be followed and the specific measures to be taken for counteracting climate variability and extreme natural hazards in a urban setting.

The various elements of the plan, i.e. its components and subcomponents distributed over a defined time horizon, underwent a process of resource allocation to ensure that defined interventions have the necessary means to be implemented.

There are reasons to believe that, after being involved in the process, the different stakeholders will have acquired the right attitude, knowledge and skills for implementing the various aspects of the plan, and/or to embark on and even play a leading role in similar exercises in the future. This is particularly relevant for government staff at central and provincial levels, who are expected to inspire and lead similar exercises in other cities of the country and/or Inhambane province.

The final review of this manual will certainly identify areas in need of modification, or those that should be given further particular attention.

For the learning to be consolidated, it will be very important that those who participated in this exercise be used as resource persons in the implementation, monitoring and evaluation of future developments, but more importantly that, as far as possible, they be given the opportunity to refine what was done and to replicate it in similar contexts. *It is a well-known fact that when learning is not applied (without delay) it is lost and translated into wasted time and resources.* People and institutions also need opportunities to reflect after they have applied what they learned in training, in order to embed this learning and to continually improve it.

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Appendix 1:

IDF curves extracted from “*Regulamento dos sistemas publicos de Distribuicao de Agua e Drenagem de Agua Residuais*” 2003 – Anexo 11

Terça-feira, 1 de Julho de 2003

I SÉRIE — Número 26



BOLETIM DA REPÚBLICA

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SUPLEMENTO

IMPrensa NACIONAL DE MOÇAMBIQUE

AVISO

A matéria a publicar no «Boletim da República» deve ser remetida em cópia devidamente autenticada, uma por cada assunto, donde conste, além das indicações necessárias para esse efeito, o averbamento seguinte, assinado e autenticado: Para publicação no «Boletim da República».

Regulamento dos Sistemas Públicos de Distribuição de Água e de Drenagem de Águas Residuais

Título I - Disposições técnicas da distribuição pública de água

CAPÍTULO I

Generalidades

ARTIGO 1

Objecto e campo de aplicação

1. O presente Título tem por objecto definir as condições técnicas a que devem obedecer os sistemas de distribuição pública

ANEXO 11 - CURVAS INTENSIDADE-DURAÇÃO-FREQUÊNCIA DA PRECIPITAÇÃO

Passos a adoptar para o cálculo da intensidade de precipitação de projecto:

1. Localização da área de estudo no mapa e identificação da região pluviométrica.
2. Cálculo da intensidade da precipitação para a duração e período de retorno escolhidos com base nas curvas I-D-F de Maputo.
3. Afectação do valor obtido pelo factor multiplicativo correspondente à região pluviométrica em causa.

Expressão analítica das curvas I-D-F para Maputo:

$$I(\text{mm/h}) = a \times t(\text{min})^b$$

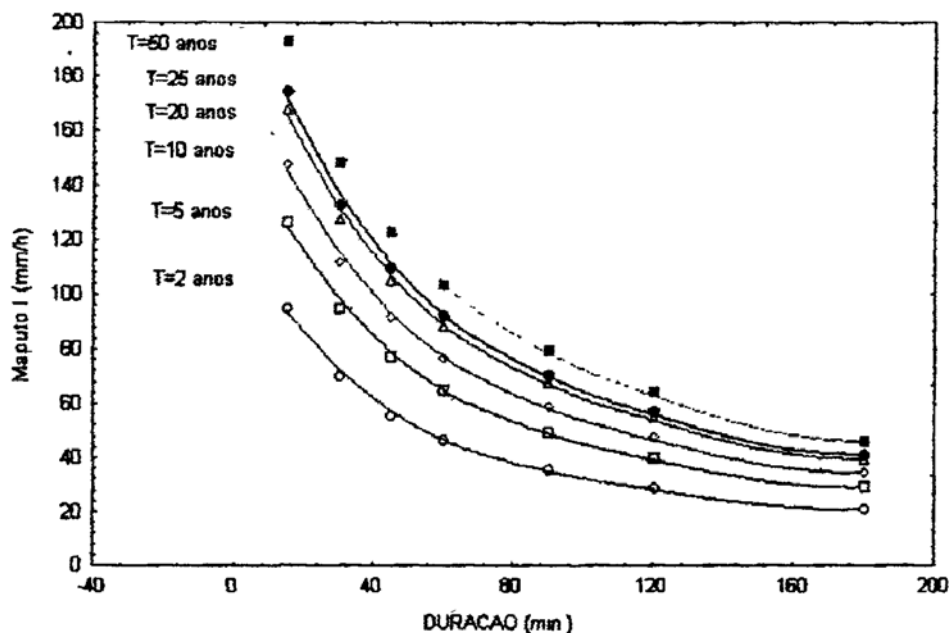
em que:

- T - período de retorno (anos);
- I - intensidade da precipitação (mm/h);
- a, b - parâmetros adimensionais;
- t - duração (min);

sendo a e b obtidos pela tabela seguinte:

T(anos)	2	5	10	20	25	50
a	534.0468	694.504	797.3841	896.5751	930.8815	1026.694
b	-0.6075	-0.59383	-0.5869	-0.58197	-0.58119	-0.57749

Expressão gráfica das curvas I-D-F para Maputo



Appendix 2: Stakeholder Analysis Interview Guide

Example (from Inhambane/Maxixe Study)

1. Identification of the Stakeholder
2. Stakeholder Activity

Objectives of the project

The INGC hired the consortium BRGM (French company) and AustralCOWI (Mozambican company) to conduct a study to requalify vulnerable areas in the cities of Inhambane and Maxixe. This is a pilot study that aims to develop and test a methodology that can later be replicated in other areas vulnerable to natural hazards. In the city of Inhambane the study will primarily be conducted in the neighbourhoods of Liberdade 3 and Chalambe 2. In the city of Maxixe the study will be conducted in the neighbourhoods of Chambone 1, 5, and 6 and Mazambanine.

Part of the study involves identifying all interested parties that are affected by issues related to natural hazards in these cities and in particular in these neighbourhoods. These parties include the communities, but also social, commercial, governmental, non-governmental and other institutions. These entities were identified based on preliminary conversation with the municipal authorities and the INGC in each of the cities, as well as based on the community leaders in each neighbourhood.

Vulnerability and Reasons for Vulnerability:

3. What type of natural hazards occurred in the city in the last 5 years?
4. What type of natural hazards/adversities occurred particularly in the chosen neighbourhoods (Liberdade 3, Chalambe 2 - Inhambane; Chambone 1, 5, and 6, and Mazambanine - Maxixe)?
5. Why do you think that these adversities occur in these neighbourhoods (climate change, population density, etc.)?

Problems that the vulnerabilities cause:

6. How do the natural hazards normally affect the city (houses, commerce, institutions, etc.): large impacts, problems brought on to the city, urban planning management of the city?
7. How do the natural hazards/adversities normally affect your activities?

How to deal with the vulnerability (adaptation measures):

8. What do you do to deal with the natural hazards/adversities (prevention and mitigation)?
9. What institutions, individuals, entities or members of the community do you normally receive aid from in the event of a natural hazard/adversity?
10. How do you normally support/provide aid to the affected members/institutions of your community?
11. How are the natural hazards/adversities normally dealt with in the city?
12. What institutions/people are involved and how? What do they do?
13. What other measures should be taken to prevent these kinds of events?
14. Who should intervene and how?

15. What else could be done to reduce the effects of natural hazards/adversities in the neighbourhoods and City being studied?

FGD (Venn Diagram/Force Field Analysis) – Institutions and groups that are associated with the theme – who should have more responsibility in relation to the management of natural hazards/adversities (actual situation and ideal).

Appendix 3: Questionnaire for Households

Questionnaire N°	_ _ _ _ (to be filled in by supervisor)		
Interviewer	_ _ _		
City	01 Inhambane 02 Maxixe	neighbourhood	01 Liberdade 3 02 Chalambe 2 03 Chambone 04 Mazambanine
Quarter	_ _ _		
Date	_ _ _ / _ _ _ / _ _ _		
Start time	_ _ _ : _ _ _		
<p>Good morning (good afternoon), My name is____ I am an interviewer for AustralCOWI Lda., a consulting firm that conducts research in Mozambique. At the moment we are conducting a study about disasters in the vulnerable areas of Inhambane and Maxixe. We will spend some time in your community speaking with various people. You were chosen, from your community, to speak a little bit about your household, livelihood and how you protect yourself from natural disasters. All the information collected is private and confidential. It will only be used for the purposes of this study, without any reference to your name or any member of your family.</p>			
Interviewee Identification			
1. Name of Interviewee:			

2. Degree of Relation with the head of the household:			
01 Head of household (If 01, pass to question 5)			
02 Wife/Husband of head of household			
03 Son/Daughter			
04 Other relation			
05 No relation			
3. Sex of Interviewee:			
01 Man			
02 Woman			

4.	Age of Interviewee: _ _ 99 Unknown
Section A: INFORMATION ABOUT THE HEAD OF THE HOUSEHOLD	
5.	Name of the head of the household: _____
6.	What name does the head of the household most commonly go by? _____
7.	Sex of the head of the household: 01 Man 02 Woman
8.	What is the age of the head of the household? _ _ 99 Unknown
9.	Marital status of the head of the household: 01 Single 02 Married (Church, civil, traditional/nikah/lobolo or mixed) 04 Separated/Divorced 05 Widow(er) (wife/husband died)
10.	Main occupation of the head of the household? 01 Government employee 02 Private sector employee 03 Farmer 04 Fisherman 05 Owner of an informal business 06 Occasional/seasonal work 07 Student 08 Retired 09 Unemployed/housewife
11.	What is the level of education of the head of the household? 01 None 02 Literate (Knows how to read and write his/her name) 03 Primary School 1 st Level 04 Primary School 2 nd Level 05 Secondary/ Basic 06 Technical/vocational school 07 University level
Section B: HOUSEHOLD CHARACTERISTICS	
12.	How many members are there in the household? (<i>People that eat from or contribute to the same pot, although they do not live in the house. Not forgetting to include the interviewee's children</i>) _ _
13.	What religion is most practiced in the family? 01 Catholicism 02 Islam 03 Other Christian 04 None 08 Other (specify) _____
14.	Does the head of the household speak Portuguese? 01 Yes 02 No
15.	How many adults (including the head) in the household DO NOT speak Portuguese? _ _ If 00 pass to question 18
16.	What are the ages of the adults (including the head) in the household that DO NOT speak Portuguese? (how many people are there in each category) _ _ 18 years – 24 years _ _ 25 years – 34 years _ _ 35 years – 44 years _ _ 45 years – 64 years _ _ 65 years or more

17.	What is the sex of the adults that DO NOT <u>speak</u> Portuguese? (how many people are in there in each category)
__ __	Men
__ __	Women
SECTION C: ACCESS TO SERVICES	
18.	How old are the members of the household? (how many people are there in each of the following categories)
__ __	Less than 6 years
__ __	6 years – 14 years (If 00 pass to question 20)
__ __	15 years – 64 years
__ __	65 years or more
19.	How many children between the ages of 6 and 14 are NOT studying?
__ __	
20.	How long does it take, for those that <u>ARE</u> studying, to get to the school furthest away, if they walk?
01	No one studies
02	Less than 5 minutes
03	5 minutes to half an hour
04	More than half an hour
	If 01 pass to question 22
21.	How do those who <u>ARE</u> studying, go to the school furthest away?
01	They walk
02	They cycle
03	They catch a ride
04	They take public transportation
08	Other (specify) _____
22.	What is the highest level of education reached in the household?
01	None
02	Literate (Knows how to read and write his/her name)
03	Primary School 1 st Level
04	Primary School 2 nd Level
05	Secondary/Basic
06	Medium
07	Superior
23.	How many people in the household get sick in the last month?
__ __	
	If 00 go to question 26
24.	What were the diseases they suffered from? (indicate the three main ones)

25. Did they go to the Health Center to get treated? (iv) Yes No
26. How long does it take to the closest Health Center, if they walk? 01 Less than 5 minutes 02 5 minutes to half an hour 03 More than half an hour
27. How do they get to the closest Health Center? 01 They walk 02 They cycle 03 They catch a ride 04 They take public transportation 08 Other (specify) _____
28. How far from the household's home is the market where they purchase their groceries, if they walk? 01 Less than 5 minutes 02 5 minutes to half an hour 03 More than half an hour
29. How do they get to the market? 01 They walk 02 They cycle 03 They catch a ride 04 They take public transportation 08 Other (specify) _____
30. How is waste normally disposed of in your neighbourhood ?(Chose one) 01 A hole is made and waste is thrown in 02 Waste is burned 03 It is used as fertilizer for farming and gardening 04 There is a garbage collection system from the municipality 05 There is a garbage sight/dump in the neighbourhood where everyone throws away their garbage 08 Other (specify) _____
31. When it rains in your neighbourhood, are there pathways/ditches where the water drains? 01 Yes 02 Yes, but it does not work 03 No If 03 pass to question 35
32. Are these drainage pathways/ditches permanent? 01 Yes 02 No 03 They are made when it rains
33. Who dug these pathways/ditches? 01 Residents of the neighbourhood 02 Municipal government 03 ANE (National Road Authority) 08 Other (specify) _____
34. Who performs the maintenance of these pathways/ditches in your neighbourhood ? 01 No one 02 Residents of the neighbourhood 03 Municipality 08 Other (specify) _____
35. Has any member of the household paid any taxes this past year? 01 Yes 02 No If 02 pass to question 37
36. Did you pay any of the following taxes in the past year?(read the options) Personal tax (City Council) 01 yes 02 no Income tax 01 yes 02 no Bicycle tax 01 yes 02 no Commercial tax 01 yes 02 no Bank/market tax 01 yes 02 no Garbage tax 01 yes 02 no Car tax 01 yes 02 no

SECTION D: SOCIO-ECONOMIC STATUS OF THE HOUSEHOLD																													
37.	How many members of the household have employment with a regular salary or retirement benefits? _ _ _ IF 00 pass to question 39																												
38.	What is the total amount received from salaries and pension payment of all members of the household that receive them? <table border="0"> <tr> <td>< 1.000 MT</td> <td>1.001 MT to 2.500 MT</td> <td>2.501 MT to 5.000 MT</td> <td>5.001 MT to 7.500 MT</td> </tr> <tr> <td>7.501 MT to 10.000 MT</td> <td>10.000 MT to 12.500 MT</td> <td>12.501 MT to 15.000 MT</td> <td>> 15.000 MT</td> </tr> </table>	< 1.000 MT	1.001 MT to 2.500 MT	2.501 MT to 5.000 MT	5.001 MT to 7.500 MT	7.501 MT to 10.000 MT	10.000 MT to 12.500 MT	12.501 MT to 15.000 MT	> 15.000 MT																				
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7.501 MT to 10.000 MT	10.000 MT to 12.500 MT	12.501 MT to 15.000 MT	> 15.000 MT																										
39.	What other income activities are undertaken by the household and how much was earned last month? _ _ _ (fill in if no other activity is undertaken) 99 None <table border="0"> <tr> <td>Renting out a house</td> <td> _ _ _ _ _ _ _ </td> </tr> <tr> <td>Craft work</td> <td> _ _ _ _ _ _ _ </td> </tr> <tr> <td>Traditional Medicine</td> <td> _ _ _ _ _ _ _ </td> </tr> <tr> <td>Producing coal/firewood</td> <td> _ _ _ _ _ _ _ </td> </tr> <tr> <td>Making/selling drinks</td> <td> _ _ _ _ _ _ _ </td> </tr> <tr> <td>Store</td> <td> _ _ _ _ _ _ _ </td> </tr> <tr> <td>Stall</td> <td> _ _ _ _ _ _ _ </td> </tr> <tr> <td>Street vendor/peddler</td> <td> _ _ _ _ _ _ _ </td> </tr> <tr> <td>Construction</td> <td> _ _ _ _ _ _ _ </td> </tr> <tr> <td>Carpentry</td> <td> _ _ _ _ _ _ _ </td> </tr> <tr> <td>Locksmith</td> <td> _ _ _ _ _ _ _ </td> </tr> <tr> <td>Electrician</td> <td> _ _ _ _ _ _ _ </td> </tr> <tr> <td>"Ganho ganho"</td> <td> _ _ _ _ _ _ _ </td> </tr> <tr> <td>Other _____ </td> <td> _ _ _ _ _ _ _ </td> </tr> </table>	Renting out a house	_ _ _ _ _ _ _	Craft work	_ _ _ _ _ _ _	Traditional Medicine	_ _ _ _ _ _ _	Producing coal/firewood	_ _ _ _ _ _ _	Making/selling drinks	_ _ _ _ _ _ _	Store	_ _ _ _ _ _ _	Stall	_ _ _ _ _ _ _	Street vendor/peddler	_ _ _ _ _ _ _	Construction	_ _ _ _ _ _ _	Carpentry	_ _ _ _ _ _ _	Locksmith	_ _ _ _ _ _ _	Electrician	_ _ _ _ _ _ _	"Ganho ganho"	_ _ _ _ _ _ _	Other _____	_ _ _ _ _ _ _
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Other _____	_ _ _ _ _ _ _																												
40.	In the last month, how much money was received from people outside the household? (<i>do not include members of the household that do not live in the house</i>) _ _ _ _ _ _ _																												
41.	What is the total amount received from salaries and pension payment of all members of the household that receive them? <table border="0"> <tr> <td>< 1.000 MT</td> <td>1.001 MT to 2.500 MT</td> <td>2.501 MT to 5.000 MT</td> <td>5.001 MT to 7.500 MT</td> </tr> <tr> <td>7.501 MT to 10.000 MT</td> <td>10.000 MT to 12.500 MT</td> <td>12.501 MT to 15.000 MT</td> <td>> 15.000 MT</td> </tr> </table>	< 1.000 MT	1.001 MT to 2.500 MT	2.501 MT to 5.000 MT	5.001 MT to 7.500 MT	7.501 MT to 10.000 MT	10.000 MT to 12.500 MT	12.501 MT to 15.000 MT	> 15.000 MT																				
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50. Does the family fish? 01 Yes 02 No If 02 pass go to question 53
51. How do you use the fish? 01 To sell 02 for Consumption If 02 pass to question 53
52. How much was collected from the last sale? _ _ _ _ · _ _ _ _
SECTION E: HOUSING CHARACTERISTICS
53. Does the land where the household resides belong to any member of the household? 01 Yes 02 No If 02 pass to question 56

54. How was the land acquired? 01 Bought it 02 Inherited it 03 Occupied it 04 It was donated/given
55. Do you possess an official document (e.g.: DUAT) to prove ownership of the land? 01 Yes 02 No
56. Does the house where the household resides belong to any member of the household? 01 Yes 02 No If 02 pass to question 59
57. How was acquired the house where the household resides? 01 Bought it 02 Inherited it 03 Occupied it 04 It was donated/given 05 Constructed it
58. Do you possess a property title for the house? 01 Yes 02 No
59. What material is the roof of the house made of? 01 Straw/vegetation 02 Zinc sheets 03 Shingles 04 Lusalite 08 Other (specify) _____
60. What material are the walls of the house made of? 01 Reeds 02 Cement blocks 03 Zinc sheets 08 Other (specify) _____
61. How many divisions does the house have? (in how many parts is it divided) __ __
62. How many annexes does the garden have? __ __

63. Does the house have electricity? (includes generators) 01 Yes 02 No If 01 pass to question 65
64. What source of energy is used to illuminate the house? 01 Wood 02 Gas 03 Flashlights 04 Candles 08 Other (specify) _____
65. What source of energy is used for cooking? 01 Wood 02 Gas 03 Charcoal 04 Electricity 08 Other (specify) _____
66. If you use wood to cook, where do you get it? 01 Does not use wood 02 Buy it in the market 03 Gather it in the mangrove swamp 04 Gather it in the machamba 05 Buy it from an informal vendor/peddler 08 Other (specify) _____
67. Does the house have running water? 01 Yes 02 No If 01 pass to question 69
68. Where do you fetch water the water to use at home? 01 Well 02 Cistern 03 Public Fountain 04 Neighbour's tap 08 Other (specify) _____
69. What sanitation system does the household have at home? 01 Simple latrine 02 Latrine with a bathroom 03 Bathroom inside the house with an independent septic tank 04 Bathroom inside the house with a septic tank connected to the city sanitation system 08 Other (specify) _____
SECTION F: MIGRATION PATTERNS
70. Was the head of household born in this city? 01 Yes 02 No If 01 pass to question 74
71. What year did you move to this city? _ _ _ _
72. For what reason did you move to this city? 01 Work 02 Studies 03 Marriage 04 Reunite with family 05 War 08 Other (specify) _____
73. When you moved to this city to come to this neighbourhood first? 01 Yes 02 No
74. Why did you choose to live in this neighbourhood? 01 There was land available 02 Access to public services (schools, hospitals, market, etc.) 03 War 04 Family 08 Other (specify) _____

<p>75. Since you moved to this for the first time, have you always lived here?</p> <p>01 Yes 02 No</p> <p>If 01 pass to question 79</p>
<p>76. Where did you go?</p> <p>01 Another neighbourhood in the city</p> <p>02 Another place in the same province</p> <p>03 Another place out of the province</p> <p>04 Out of the country</p>
<p>77. Why did you move to that place?</p> <p>01 To look for new work opportunities</p> <p>02 Because you were resettles due to floods</p> <p>08 Other (specify) _____ </p>
<p>78. Why did you return to this neighbourhood?</p> <p>01 Because you didn't find the opportunities you were looking for in the place where you went</p> <p>02 Because the place where you went didn't have good living conditions</p> <p>08 Other (specify) _____ </p>
<p>SECTION G: SOCIAL NETWORKS</p>
<p>79. What was the last conflict that your household had to resolve of which you sought the intervention from people outside of the household? (<i>consider the household in accordance with our concept of the household</i>)</p> <p> __ __ </p> <p> _____ </p> <p>99 None</p> <p>If 99 pass to question 81</p>
<p>80. Who do you seek to resolve this problem?</p> <p>01 Head of the neighbourhood /Quarter 02 Traditional leader</p> <p>03 Religious authority 04 Police 05 Community tribunal</p> <p>06 Relatives outside of the household 07 Friends/neighbours</p> <p>98 Other (specify) _____ </p>

<p>81. What is the most common source of conflict in the community and that requires the intervention of an authority to resolve?</p> <p>01 Inebriation 02 Adultery 03 Robberies 04 Land conflict 05 Water conflict 08 Other (specify) _____ 99 None</p> <p>If 99 pass to question 83</p>
<p>82. Who do the community members normally turn to resolve this problem?</p> <p>01 Head of the neighbourhood/Quarter 02 Traditional leader 03 Religious authority 04 Police 05 Community tribunal 08 Other (specify) _____ </p>
<p>SECTION H: NATURAL HAZARDS AND ADAPTATION MEASURES</p>
<p>83. In what period of the year does it rain most?</p> <p>From month __ __ to month __ __ </p>
<p>84. During that period, how do the rains affect your neighbourhood? (<i>more than one answer, don't read the options</i>)</p> <p>01 It doesn't normally affect the community 02 The water runs uncontrollably through the neighbourhood 03 The water that runs creates holes 04 The water that runs brings waste 05 The water enters the houses 06 Many houses fall 07 Some houses fall 98 Other (specify) _____ </p>
<p>85. How did the last rains affect your house? (<i>more than one answer, don't read the options</i>)</p> <p>01 They didn't affect your home (If 01 pass to question 87) 02 The water entered your home 03 The water entered your garden and created holes 04 The water brought waste 05 The water partially destroyed your house 06 The water completely destroyed your house 07 The water destroyed your latrine 98 Other (specify _____)</p>

<p>86. What did you do or want to do in the future to protect your house against what happened, so that it does not happen again? <i>(more than one answer, don't read the options)</i></p> <p>01 Didn't do anything</p> <p>02 Placed zinc sheets on the roof so that water wouldn't enter the home</p> <p>03 Lifted the terrain with trash and sand so that the water wouldn't enter the home</p> <p>04 Lifted the house with cement blocks so that water wouldn't enter the home</p> <p>05 Made a ditch to divert the water away from the house</p> <p>08 Other (specify _____)</p>
<p>87. In what period of the year do the high tides normally occur?</p> <p>In the months of __ __ , __ __ , __ __ , __ __ </p> <p>97 High tides don't exist in this neighbourhood</p> <p>If 97 pass to question 91</p>
<p>88. During this period, how do the high tides affect your neighbourhood? <i>(more than one answer, don't read the options)</i></p> <p>01 They don't normally affect the community</p> <p>02 The roads become flooded</p> <p>03 The water enters the houses and stores</p> <p>04 The children became sick</p> <p>08 Other (specify) _____ </p>
<p>89. How did the last high tides affect your home? <i>(more than one answer, don't read the options)</i></p> <p>01 They didn't affect your home (If 01 pass to question 91)</p> <p>02 The water entered your home and destroyed some items</p> <p>03 The water entered your home and destroyed many items</p> <p>04 The water brought trash</p> <p>05 The destroyed your latrine</p> <p>06 The children became sick</p> <p>08 Other (specify) _____ </p>
<p>90. What did you do or want to do in the future to protect your house against what happened, so that it does not happen again? <i>(more than one answer, don't read the options)</i></p> <p>01 Didn't do anything</p> <p>02 Built a barrier with cement blocks so that the water wouldn't enter the garden</p> <p>03 Lifted the land with trash and sand so that the water wouldn't enter the garden</p> <p>04 Lifted the house with cement blocks so that water wouldn't enter the house</p> <p>08 Other (specify) _____ </p>

<p>91. What other natural hazards have occurred in the last 5 years in your neighbourhood? <i>(more than one answer, don't read the options)</i></p> <p>01 Natural hazards don't occur (If 01 pass to question 94)</p> <p>02 Strong winds/cyclones</p> <p>03 Floods</p> <p>04 Fire</p> <p>08 Other (specify) _____ </p>
<p>92. How the community was affected by this/these natural hazard(s)?</p> <p>Strong winds/cyclones _____</p> <p>Floods _____</p> <p>Fires _____</p> <p>Others _____</p>
<p>93. How was your home affected by this natural hazard(s)?</p> <p>01 The water partially destroyed your house</p> <p>02 The water completely destroyed your house</p> <p>03 Nothing happened</p> <p>08 Other (specify) _____ </p>
<p>94. When other natural hazards occur (heavy rains, strong winds, high tides, floods, etc.) what people/institutions normally provide aid/support to the affected people in your community? <i>(more than one answer, don't read options)</i></p> <p>01 INGC (National Institute for Calamity Management)</p> <p>02 Municipal Government</p> <p>03 NGOs</p> <p>04 Churches/mosque</p> <p>05 Friends and family</p> <p>08 Other (specify) _____ </p>
<p>95. Who helped you the last time your house was affected by a natural calamity (heavy rains, strong winds, high tides, floods, etc.)?</p> <p>01 Was never affected by a natural hazard (If 01 pass to question 97)</p> <p>02 INGC (National Institute for Calamity Management)</p> <p>03 Municipal government</p> <p>04 NGOs</p> <p>05 Church/mosque</p> <p>06 Friends and family</p> <p>07 Nobody helped (If 07 pass to question 97)</p> <p>98 Other (specify) _____ </p>



<p>96. In what way did they help? <i>(more than one answer, don't read the options)</i></p> <p>01 Resettled your family in another place</p> <p>02 Provided them with tents</p> <p>03 Provided them with food</p> <p>04 Provided them with money</p> <p>08 Other (specify) _____ </p>
<p>97. What can be done to reduce the vulnerability of your neighbourhood in relation to heavy rains?</p> <p>_____</p> <p>_____</p>
<p>98. What can be done to reduce the vulnerability of your neighbourhood to high tides?</p> <p>_____</p> <p>_____</p>
<p>99. What can be done to reduce the vulnerability of your neighbourhood in relation to other natural hazards?</p> <p>In relation to strong winds _____</p> <p>In relation to floods _____</p> <p>In relation to fires _____</p> <p>Another hazard (specify) _____</p>
<p>100. If you had the option, would you like to leave your neighbourhood and move to another?</p> <p>01 Yes</p> <p>02 No</p> <p>If 02 pass to question 103</p>
<p>101. Where would you like to move to?</p> <p>01 Another zone within the same neighbourhood</p> <p>02 Another neighbourhood (specify) _____ </p> <p>03 Other (specify) _____ </p>
<p>102. Why would you like to move from your neighbourhood?</p> <p>_____</p>

103. Why would you NOT like to move from your neighbourhood?		
<hr/> <hr/>		
104. In your opinion, do you agree/disagree that the following affirmations apply to your city: <i>(read options)</i>		
Rains don't happened during the same period as before	01 Agree	02 Disagree
The rains are stronger than they were before	01 Agree	02 Disagree
The winds are stronger now than they were in the past	01 Agree	02 Disagree
Now there are winds and in the past they didn't exist	01 Agree	02 Disagree
105. Is there something else that is happening with the environment that didn't happen before?		
<hr/> <hr/>		

End Time | __ | __ | : | __ | __ |


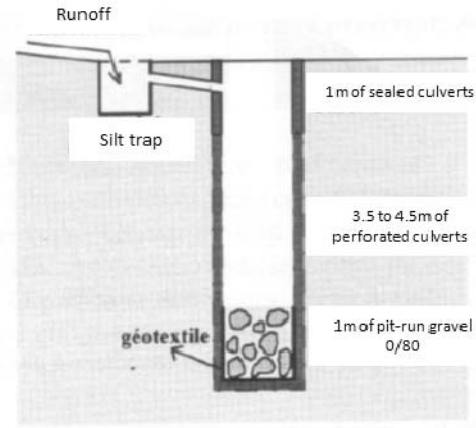
Appendix 4 : Standard solutions

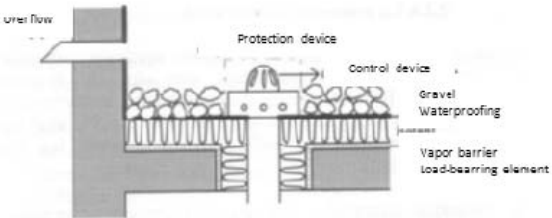

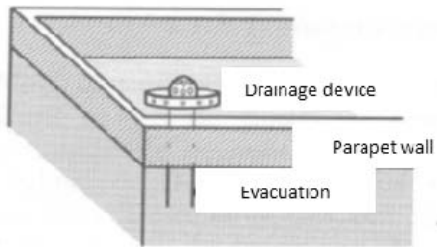
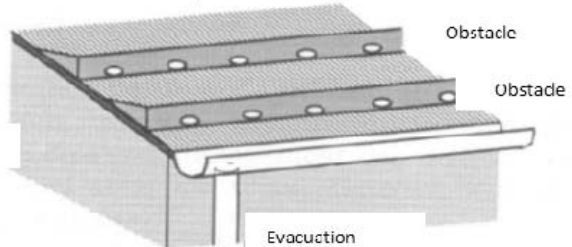
- ✓ **SEW : rainwater sewerage system**
- ✓ **FL : Flow of runoff water**
- ✓ **MR : Managing runoff**
- ✓ **SP : Shore Protection**



SEW1		Area of application: The rainwater sewerage system	
Maintenance of the rainwater sewerage system			
Objective: Reduction of overflow onto public roads			
Applicable to: <input checked="" type="checkbox"/> The existing layout <input checked="" type="checkbox"/> The future layout	Priority: <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No		<input type="checkbox"/> Upstream area <input checked="" type="checkbox"/> Downstream area
<p><i>Description:</i></p> <p>The maintenance of the different primary collectors and secondary canalisations must be regular in order to avoid the overflow of runoff water onto public roads. Runoff water is highly charged with sediments and carries along with it numerous wastes from illicit dumping. This material and waste usually end up in water collection structures upstream of protective grids. If these materials are not removed before heavy rain, the water collection facilities are obstructed and part of the runoff overflows onto the road.</p>			
<p><i>Photos:</i></p> <div style="display: flex; justify-content: space-around; align-items: flex-start;"> <div style="text-align: center;"> <p style="color: blue;"><i>Downstream</i></p>  <p style="color: blue;"><i>Upstream</i></p> <p>(IMG_0210)</p> </div> <div style="text-align: center;"> <p style="color: blue;"><i>Upstream</i></p>  <p style="color: blue;"><i>Downstream</i></p> <p>(IMG_0187)</p> </div> </div> <p style="text-align: center;">Maintenance of ditches and gully gratings</p>			



SEW2		Area of application: The rainwater sewerage system	
Integrated design of the urban rainwater sewerage system			
Objective: Reduction and non aggravation of the risk of runoff			
Applicable to:	Priority:		
<input checked="" type="checkbox"/> The existing layout	<input checked="" type="checkbox"/> Yes		<input type="checkbox"/> Upstream area
<input checked="" type="checkbox"/> The future layout	<input type="checkbox"/> No		<input checked="" type="checkbox"/> Downstream area
<p><i>Description:</i></p> <p>The integrated design of a rainwater sewerage system necessitates:</p> <ul style="list-style-type: none"> - Taking into account all of the catchment areas situated upstream of the area in question. - Reducing the runoff flow rates and volumes by alternative infiltration and storage techniques (storage roofs, storage tanks, etc.). - Ensuring the bottoms of talwegs are clear of obstacles and allow the free flow of water. - Only authorising overflows for fairly long return periods (T>10 years). - Controlling overflows in the urban fabric by favouring the least vulnerable areas (parks, sports fields, etc.). - Managing the organisation of built structures within the areas at risk so as to reduce vulnerability. <p>The integration of these recommendations can take place as of the land use planning stage through better land development of the surroundings of talwegs and by taking into account the physical location of sewerage and runoff facilities (impounding reservoirs for example).</p> <p>Integrated design thus necessitates knowledge of the risks by the public authorities and clear information in the areas at risk for waterside residents and users. The objective is to plan for and manage rain water runoff areas in the event where the capacity of the sewerage system is exceeded.</p>			

SEW3	Area of application: The rainwater sewerage system		
Infiltration and storage Basins			
Main goal : runoff control an flow reduction			
Suitable to :	priority :	Suitable to :	
<input checked="" type="checkbox"/> existing landcover	<input checked="" type="checkbox"/> yes	<input checked="" type="checkbox"/> Maxixe	<input checked="" type="checkbox"/> upstream area
<input checked="" type="checkbox"/> futur landcover	<input type="checkbox"/> no	<input type="checkbox"/> Inhambane	<input checked="" type="checkbox"/> downstream area
<p><i>Description :</i></p> <p>Retention ponds store temporarily some of the runoff volume. The amount stored depends on the surface area and depth. It is about 5 000 to 10 000 m3 on the study area.</p> <p>Water is collected, stored in the basin and finally discharged with controlled flow. Basins can be supplied for example by drains located across the road.</p> <p>The dry ponds will be used very rarely because they will intervene in case of failure of the existing sewerage network. These basins can thus serve another purpose at other times: sports, green space ...</p> <p>Retention ponds should be placed along the main talweg. They mark the flow area for overflow and they are a way to reinstate the vision of water and flooding in the urban area.</p> <p>Maintenance should be relatively frequent (at least annual after each rainy season).</p>			
(Source : dhn.ihr.uiowa.edu)			

MR1	Area of application: Managing runoff		
Wells and storage tanks			
Objective: Reduction and non aggravation of the risk of runoff			
Applicable to:	Priority:		
<input checked="" type="checkbox"/> The existing layout	<input checked="" type="checkbox"/> Yes	<input checked="" type="checkbox"/> Upstream area	
<input checked="" type="checkbox"/> The future layout	<input type="checkbox"/> No	<input type="checkbox"/> Downstream area	
<p><i>Description:</i></p> <p>Diffusion wells favour the infiltration of rain water thanks to holes made in the ground.</p> <p>Storage tanks make it possible to store part of the runoff water before it is used for another purpose (watering gardens, cleaning roads, etc.).</p> <p>In both cases, the objective is to limit runoff downstream. Wells can be dug to drain areas ranging from several tens of square metres (case of roofs for example) to several thousand square metres (parking lots, roadways). Storage tanks are especially suited to the plot of land and housing unit scale.</p> <p>The general principle is the collection of rainwater runoff generated by impermeable surfaces and to channel it through gravity towards the wells. A decantation inspection chamber needs to be provided to trap floating objects and sediments. The wells must be closed off. Drainage can take place through infiltration into the ground in the case of buried wells or by gravity in the case of tanks.</p> <p>The major disadvantage of this type of technique is the regular maintenance that is required in order to prevent clogging.</p> <p>Diffusion wells must not be sunk in areas subject to medium or high risk of landslide (summits of hillsides, slopes, loose terrain, etc.).</p>			
<p><i>Schematic diagram:</i></p> <div style="display: flex; justify-content: space-around; align-items: flex-start;">   </div>			

MR2	Area of application: Managing runoff		
Rooftop Storage			
Objective: Reduction and non aggravation of the risk of runoff as early as possible			
Applicable to: <input checked="" type="checkbox"/> The existing layout <input checked="" type="checkbox"/> The future layout	Priority: <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No		<input checked="" type="checkbox"/> Upstream area <input type="checkbox"/> Downstream area
<p><i>Description:</i></p> <p>Storage roofs intercept rain and store it in a provisional manner before it runs off. The principle consists in only retaining a certain height of water by means of a small wall surrounding the roof. The rate of outflow into drainpipes is regulated by means of a small opening and an overflow device in order to avoid overloading the roof.</p> <p>The advantage of this technique stems from the fact that it can be integrated easily into the urban landscape (from a real estate and aesthetics viewpoint), it is easy to put in place and it has proven efficiency.</p> <p><i>Schematic diagram:</i></p>			
			
<p>Flat roof</p> 	<p>Low slope roof</p> 		

MR3		Area of application: Managing runoff	
The development of vegetation cover			
Objective: Reduction and non aggravation of the risk of runoff through better infiltration			
Applicable to: <input checked="" type="checkbox"/> The existing layout <input checked="" type="checkbox"/> The future layout	Priority: <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No		<input checked="" type="checkbox"/> Upstream area <input type="checkbox"/> Downstream area
<p><i>Description:</i></p> <p>The development of vegetation cover involves:</p> <ul style="list-style-type: none"> - The replanting of trees in rural areas - The creation of green spaces, parks and grassy strips in urban areas <p>The development of vegetation cover has an influence on runoff through better infiltration of rain water. Reforesting operations also contribute to halting the erosion of soils and improving the stability of the most highly sloping catchment areas.</p> <p>The development of vegetation cover can also be accompanied by alternative techniques for managing runoff water: banks, small crests in gabions at the heads of ravines, depressions in green spaces so as to increase storage capacities, etc.</p>			
<p><i>Photos:</i></p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;">  <p>Urban area with sparse vegetation (IMG_0043)</p> </div> <div style="text-align: center;">  <p>Rural area with tree cover (108_IMG0554)</p> </div> </div>			

MR4		Area of application: Managing runoff	
Maintenance of thalwegs			
Objective: Reduction of the risk of runoff			
Applicable to: <input checked="" type="checkbox"/> The existing layout <input checked="" type="checkbox"/> The future layout	Priority: <input checked="" type="checkbox"/> Yes <input type="checkbox"/> No		<input checked="" type="checkbox"/> Upstream area <input checked="" type="checkbox"/> Downstream area
<p><i>Description:</i></p> <p>Maintenance consists in restoring the talweg to its full hydraulic efficiency. Maintenance is thus essential to avoid the formation of log jams and overflows. In addition, the maintenance of thalwegs makes it possible to clean them of any household rubbish and waste that has an impact on the pollution of the receiving body of water. Finally, maintenance contributes to the improvement of the landscape and ecological aspects.</p> <p>Maintenance essentially consists in the following tasks:</p> <ul style="list-style-type: none"> - Cleaning out deposits and wastes - Weed cutting - Clearing of undergrowth and removal of trees. 			
<p><i>Photos:</i></p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;">  <p><i>Deposits/wastes and thalweg (IMG_0187)</i></p> </div> <div style="text-align: center;">  <p><i>Vegetation and culvert (IMG_0125)</i></p> </div> </div>			

MR5

Area of application:
Managing runoff

TREATMENT OF MEDIUM-SIZED GULLIES

1. First improve **infiltration on the catchment**, before planning a stable channel that can evacuate the peak flows that occur every ten years (or even less frequently).
2. Treat the gullies gradually (5-10 years) on the whole watershed. Biological fixation gully will consolidate the sides and bottom once they have been stabilized by various types of sill
3. Position sills carefully, according to the objective. If the purpose is simply that of raising the gully bottom so that the sides achieve the natural equilibrium, a key narrow section should be chosen where a number of light sills can rest on solid sides.
4. The spacing of the sills depends on the slope of the land. The downstream spillway must be on a level with the base of the sill above, according to the on-site equilibrium bed slope (1 to 10%). Initially, the spacing can be doubled, with intermediate sills being built when the first generation is filled with sediment.
5. Hydrostatic pressure should be offset by providing drainage for the sills in the form of grids, baffles, or loose stones.
6. The sills must be anchored in the bottom and sides of the gully by a foundation trench to avoid piping and circumvention (sand and gravel filter)
7. The wings of the sill should keep the watercourse centered along the axis of the gully. Reinforce the spillway with large flat stones with or without cement (resist the tearing force of the sand, gravel and stones that tumble down gully bottoms at considerable speed)
8. The energy of the water as it falls from the spillway must be broken by a cushion (riprapping, gabion, metal grid + tufts of grass) to avoid piping under or actual overturning of the sill.
9. Livestock must be kept away from the treated section, for they would quickly destroy sills and degrade plant cover.
10. Mechanical treatment is not complete until the source of the sediment has been tamed, and the gully heads and sides stabilized. Vegetation should then establish itself naturally if the equilibrium profile has been reached, although nature can be assisted by quickly covering the sediment with grass and fixing it with ecologically appropriate, productive trees. Simply managing sediment must be followed by getting the most out of the system thus treated.

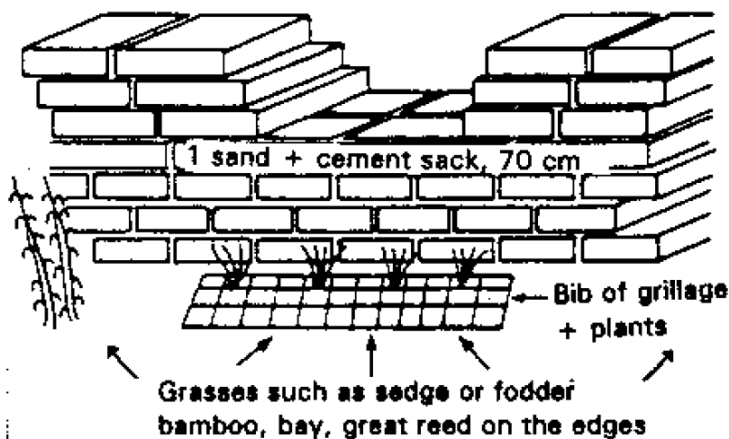
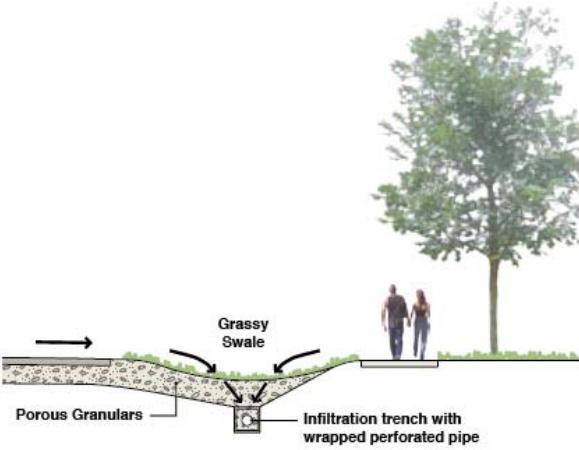
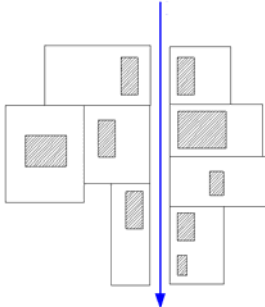
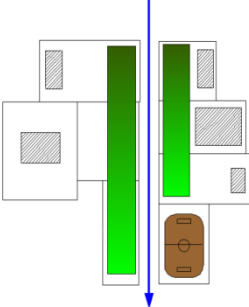



Figure : sills constructed of bags filled with local earth -spillway reinforced by sacks and sand mixed with cement

Source : FAO, Lilin and Koohafkan 1987

MR6	Area of application: Managing runoff		
Laying out flow areas into green areas			
Main goal : protecting elements at risk and floodplain enhancement			
Suitable to : <input type="checkbox"/> existing landcover <input checked="" type="checkbox"/> futur landcover	priority : <input type="checkbox"/> yes <input checked="" type="checkbox"/> no	Suitable to : <input checked="" type="checkbox"/> Maxixe <input type="checkbox"/> Inhambane	<input type="checkbox"/> upstream area <input checked="" type="checkbox"/> downstream area
<p>The enhancement of flow zones aims at reducing the vulnerability of flooded areas in relevant socio-economic neighbourhoods.</p> <p>The axes of urban runoff are planned in areas where uses are compatible with flood risk:</p> <ul style="list-style-type: none"> - parks and gardens - sports field - footpath - "green corridor" <p>The green corridor takes the concept of a green path (parks, gardens, playgrounds) along the drainage channels. These swales take place in the talwegs but also routes used by runoff in case of exceeding the capacity of the storm pies.</p> <p>The idea of "green corridor" thus contributes to the enhancement of the flooding areas and to a communication on the risk.</p> <p>Necessary accommodations are implemented in a longer-term plan and require concerted efforts with local residents.</p>			
			
(Figure : Source : ottawa.ca)			
BEFORE		AFTER	
			

FL1		Area of application: Flow of runoff water	
Limiting obstacles that cut across the flow			
Objective: Reduction of the water height			
Applicable to: <input checked="" type="checkbox"/> The existing layout <input checked="" type="checkbox"/> The future layout	Priority: <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No		<input type="checkbox"/> Upstream area <input checked="" type="checkbox"/> Downstream area
<p><i>Description:</i></p> <p>Obstacles situated in the area of flow increase the height of water in line with the obstacle and can also cause a wave if ruptured. The technique thus consists in eliminating or reorganising obstacles that cut across the flow of the water current. These obstacles can be walls, fences, dykes, miscellaneous constructions, etc.</p>			
<p><i>Favour the orientation of constructions along the axis of flow rather than at right angles to it:</i></p> <div style="text-align: center;"> <p>AXIS OF FLOW</p> <p>NO YES</p> </div>			

FL2		Area of application: Flow of runoff water	
Construction of linear infrastructures that are hydraulically transparent			
Objective: Constructing structures and developments that have zero impact in the event of flooding			
Applicable to: <input type="checkbox"/> The existing layout <input checked="" type="checkbox"/> The future layout	Priority: <input type="checkbox"/> Yes <input checked="" type="checkbox"/> No		<input type="checkbox"/> Upstream area <input checked="" type="checkbox"/> Downstream area
<p><i>Description:</i></p> <p>The linear infrastructures that will be created (roads) and which cross a talweg must be hydraulically transparent, in other words the layout must have zero impact on flow in the event of flooding.</p> <p>A sufficiently wide section of structure and discharge structures thus need to be provided in any new linear type infrastructure.</p>			
<p><i>Upstream</i></p>  <p style="text-align: right;"><i>Downstream</i> (59_PS_DSCN0246)</p>			

SP1	Area of application: SHORE PROTECTION
Conventional Rubble Mound Breakwater	
<p>A breakwater protects a defined area against sea and wave attacks. Once the plan layout has been chosen (in the whole area submitted to sea attack and in accordance to accepted damage levels) the main dimensions of the cross-section can be estimated.</p> <p>This solution fits to the Inhambane area where a new protection against extreme sea level is sought.</p> <p>The choice of the dimensions depends on elements at risk and sea condition (2.6 to 3.6m at Inhambane and Maxixe). The crest is protected by the armour layer. The toe protection is needed to maintain stability of the slope.</p>	
	<p>Crest freeboard, R_c (m)</p> <p>Crest width, B (m)</p> <p>Slope angle, α (deg)</p> <p>Armour layer thickness, t_a (m)</p> <p>underlayer thickness, t_u (m)</p> <p>seaward toe level, h_t (m)</p> <p>leeward berm or shoulder level, h_k (m)</p> <p>toe width, B_t (m)</p> <p>shoulder width, S_s, S_l (m)</p>
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>1 Conventional rubble mound</p> <p>2 Conventional rubble mound with crown wall</p> <p>3 Berm breakwater</p> <p>4 Low-crested (submerged) breakwater</p> </div> <div style="width: 45%;"> <p>5a Caisson type on rock foundation</p> <p>5b Vertically composite breakwater</p> <p>6 Horizontally composite breakwater</p> </div> </div>	<p><i>Typical cross-sections of various types of rubble mound breakwater</i></p> <p>1 – most frequent mound</p> <p>2 – the crown wall allows circulation and maintenance</p> <p>3 – during extreme storm, stones move up and down, absorbing a part of the energy of the wave</p> <p>4 – (out of interest for Inhambane or Maxixe protection)</p>
<p>5 & 6 – breakwater designed for port protection (adapted for north Inhambane protection)</p>	
<p>Source : <i>Rock manual, chapter 6 – CIRIA, CUR, CETMEF</i></p>	

Loose Rock, Blocks, Asphalt or Grass Dike revetments

Loose Rock

Loose rock on dikes is traditionally applied below mean water level for accessibility and aesthetics reasons. However examples show dikes where rock is applied up to the crest of the dike.

Placed Blocks

Placed blocks offer better strength. They are placed with skill and care.

Asphalt

An asphalt revetment can protect strongly against severe wave attack (which is not the case at Inhambane and Maxixe).

Grass

A grass revetment (or other vegetation) can be an attractive solution from an economical point of view when wave attack does not play an important role (<0,5m). For the lower parts of the revetment, another has to be applied because grass does not support permanent water.

Rigid structures

Seawalls made of concrete or masonry offers the best solution against heavy loads, with little space required and low maintenance.

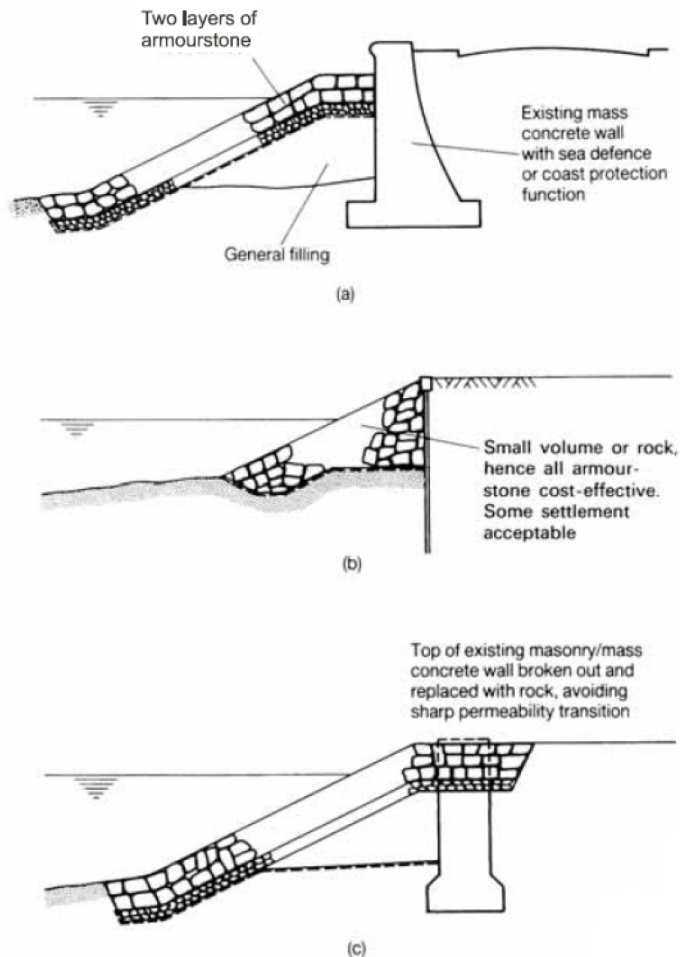


Figure : forms of sea wall protection

Source : introduction to bed, bank and shore protection, Gerrit J. Schiereck, 2004

Rock manual, chapter 6 – CIRIA, CUR, CETMEF



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