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NATURAL HAZARDS IN SAO VICENTE (CABO VERDE)

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Abstract
São Vicente island (República de Cabo Verde) lies within the Sahelian zone and faces a number of natural hazards, of which the most significant ones are erosion and gully formation, desertification and flash flooding hazards. Based on examples, we set out to examine the main factors involved in the development of these natural hazards from a regional point of view, while simultaneously assessing the importance of anthropic action as a structural factor. The investigation of Lazareto's gullies (located to the west of Mindelo) aimed to determine the main factors of the gullies formation. It also sought to demonstrate that the gullies' formation is a reliable indicator of the high rates of erosion on a regional scale. The approach to the desertification hazards was based on farmers' perception related to the evolution of agricultural production, strategies to mitigate drought and desertification issues, consequences and future prospects based on a set of interviews conducted in Ribeira da Vinha. Finally, the intense rainfall event that occurred on August 26, 2008 was analysed to identify the main vulnerability factors of the city in light of the flash flood hazard.

Keywords: São Vicente (Cape Verde), risks, vulnerability, flash flooding, gullies formation

INTRODUCTION

São Vicente faces a number of natural hazards, particularly erosion and gully formation, desertification and flash flooding hazards (PANA, 2004). As the archipelago of Cabo Verde lies within the Sahelian zone, it is in a region at high hazard of erosion with serious consequences for the productive capacity of the soil. The steepness of many slopes, the poor vegetation cover, the irregular and concentrated precipitation are the most important factors for explaining how erosive processes are manifested.

In rural areas, degradation of the soil is certainly one of the more restrictive phenomena for occupation of the territory and rural development due to the reduction of useful agricultural space (Costa, 1996). Besides the climate, agricultural-forestry-pastoral over-exploitation also helps to accentuate the erosion hazard. In these conditions, run-off is particularly effective, making use of the slopes with little or no vegetation cover, the absence or thinness of the soil and presence of thick surface formations, creating a relief marked by furrows and gullies. Drought and desertification are other serious concerns induced by lifestyles based on agriculture and/or livestock and which may also be linked to urban growth, which generates major environmental and social consequences that are hard to quantify and assess (SEPA, 2000a; Ferreira et al., 2013).

Damage caused by drought is generally resolved with short term palliative interventions, even though they need to be repeated periodically over the years. Desertification has more severe origins, connected to erosive processes that contribute towards the loss of humidity in the soil, which reduces its availability for vegetation, even in years with more rainfall.

The only incontestable proof of desertification for a given area would come from experimental fields, in which all the factors which influence production, except environmental factors, have remained constant for a period of time of never less than a decade, so that it would cover dry years and rainy years (Warren and Maizels, 1992). Although the quantification and strict definition of the areas subject to the process of desertification are difficult to define in Cabo Verde, numerous areas have suffered severe damage with the natural loss of productivity and environmental recovery processes should be undertaken in São Vicente (SEPA, 2000a).

There are many methods of assessing the soil's loss of capacity and the levels of desertification and they take different approaches (Hare et al., 1992), which are influenced by the concept itself, but which, generally, in more advanced states include gullies. In the initial states the signs are more subtle and easier to correct. Therefore, the assessment methods include signs indicating a disturbance in the balance of the ecosystem on the one hand, and, on the other hand, indicators of the levels of severity and recovery (Warren and Maizels, 1992).

On land lacking any protection strategies the rain erosion hazard is high in the sub-humid fringes, due to the greater frequency of concentrated rainfall in the wetter areas. In contrast, wind erosion constitutes the greatest hazard in the drier areas of Cabo Verde because the surfaces in these more arid areas are poorly compacted.

However, very often the processes combine and so in São Vicente we frequently find signs of water and wind erosion in different morphoclimatic contexts. Stony soil is common in arid spaces and results from the combination of wind and rainwater runoff erosion, leading to the formation of ground surfaces similar to those in deserts. Gullies often form on sub-humid slopes and in the areas at the bottom of the slopes, which makes it practically impossible to use them for agriculture.

The soils are generally of fine texture with low permeability, with poor infiltration capacity. When precipitation occurs, and because of the low infiltration capacity, the runoff helps to reduce the water that could be made available for vegetation. The way the landscape evolves and the role of erosion in the productive capacity of the soil will therefore largely depend on anthropic action. This should take into consideration the vulnerability of the ecosystems of the dry lands, particularly where vegetation is sparse as it offers practically no protection to the soil against the runoff.

In urban areas, rapid construction increases the flash flooding hazard and is one of the most important factors in increasing vulnerability (Monteiro, 2007; Andrade and Silva, 2017). The aim of this investigation was to understand the main factors involved in the development of the erosion hazard and gully formation, together with the dangers of desertification and flash flooding, from a regional point of view. It also set out to assess the importance of vulnerability as a structural factor in the overall dimension of the hazards.

The gullies of Lazareto, to the west of Mindelo, were therefore assessed so as to understand the factors influencing their origination. Furthermore, the work showed that gully formation is a reliable indicator of high rates of erosion on a regional scale. The approach to the desertification hazards was based on farmers' perception related to the evolution of agricultural production, strategies implemented to mitigate the desertification hazard and the consequences of falling productivity on farms in. Finally, the episode of intense rainfall that occurred on August 26, 2008 was studied in order to identify the main factors and the vulnerability of the city in the face of the flash flooding hazard.

STUDY AREA

Located in the Atlantic Ocean, with latitude situated between parallel 17°12' and 14°48' north and longitude which extends from 22°44' to 25°22' west of Greenwich, the archipelago is composed of ten islands and eight minor islets arrayed in a west-facing horseshoe formation. The islands are traditionally divided into the Barlavento (windward) group that includes the islands of Santo Antão, São Vicente, Santa Luzia, São Nicolau, Sal, and Boa Vista, and the Sotavento (leeward) group, comprising Maio, Santiago, Fogo, and Brava.

From a structural point of view, the archipelago is located in a continental interpolate situation (Enrst and Buchan, 2003), whose genesis would be related to a hotspot mechanism (mantle plumes); a ridged connection of the basement rocks can be seen between the archipelagos of Cabo Verde and the Canary Islands

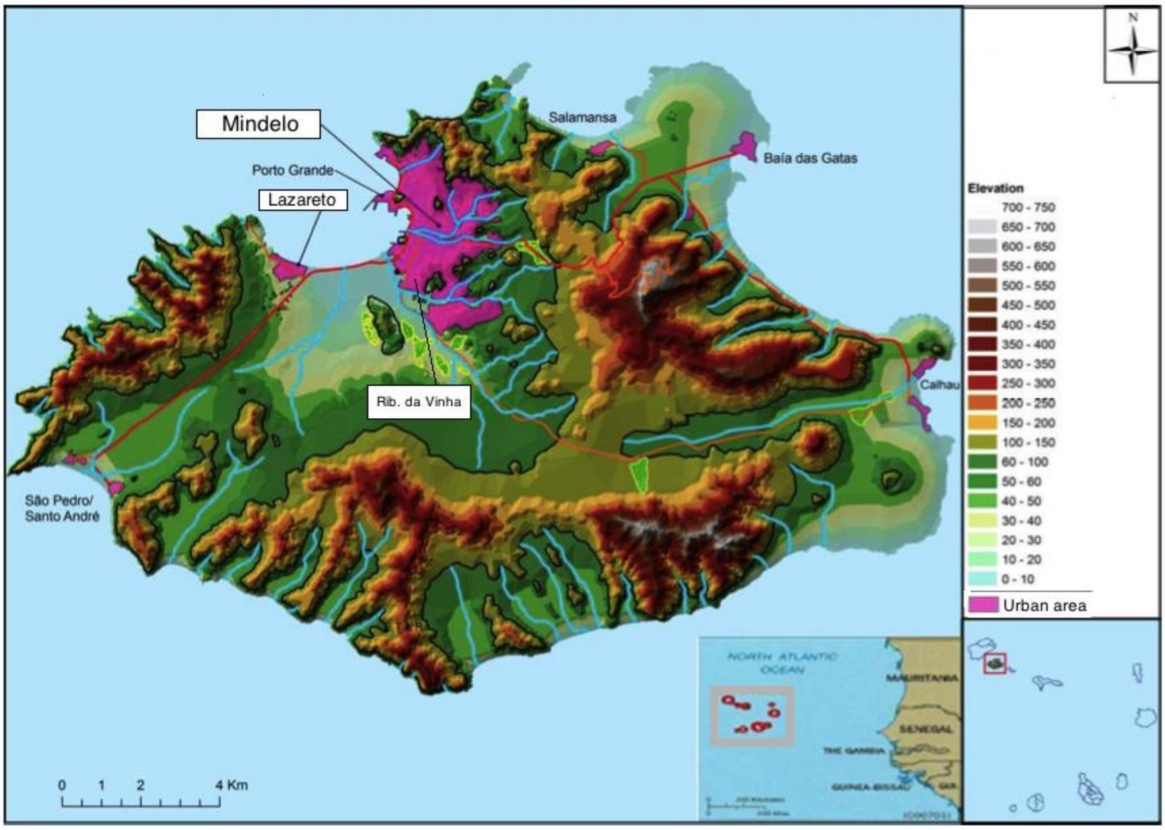

Fig. 1 São Vicente and its location in the archipelago of Cape Verde. Source: Adapted from Andrade and Silva (2017)

(Patriat and Labails, 2006; Holm et al., 2008). The Cabo Verde islands would have originated from the fragmentation of an ancient subcontinental mantle, when forming an oceanic mantle during the opening of the Atlantic Ocean (O'Reilly et al., 2009). The hotspot type activity would have begun around 19 to 22 million years ago and resulted in an uplift crustal area in which the archipelago is implanted (Plesner et al., 2002), with volcanic activity still a feature today. The tectonic activity is highlighted with the presence of inter-Atlantic transforming rift faults, important lifting processes and a main regional alignment in a NW-SE direction, and NNE-SSW tectonic structures (Victória, 2013).

São Vicente has a diversified morphology reaching altitudes of 744 meters in Monte Verde and 395 meters in Monte Topona. The city of Mindelo is surrounded by slopes that correspond to what remains of the volcano that originated the island and serves as a limit to the city (Fig. 1).

The archipelago of Cabo Verde falls within the so-called Sahel climatic belt, with an arid and semiarid climate. Rain is scant and highly variable. In general, rain falls in the form of showers, at times in heavy downpours that can reach values equal to or above monthly mean values. The rainy season runs from August to October, and can sometimes start in July, associated with the intertropical convergence zone, when this is further north (Amaral, 1964; Ferreira, 1983). However, the archipelago lies on the fringe of the main convective intensity, which explains the high variability of precipitation over the years. In the dry season, the islands are under an anticyclonic influence, with winds blowing from the northeast – the trade winds. Between December and June three types of weather are frequent: (i) "wintering" (December to March); (ii) "dry weather"; and (iii) the "westerly winds" (Amaral, 1964).

The average monthly temperature varies from 22 ºC in January and February to 27 ºC in August and September. These last two months are also the months where the precipitation values are higher. Rainfall events occur with great intensity. The average annual precipitation is 51 mm. According to the Thornthwaite climatic classification São Vicente has an arid climate.

METHODOLOGY

Analysis of three different hazards required different methodological approaches. For land cover determination downloaded satellite images from LANDSAT 8 were used with the Raster Calculator function available in the QuantumGIS 2.2 Valmiera software. Two maps (NIR and SWIR composition) with a supervised classification and natural composition using the Pan-Sharpening methodology were generated. This methodology allowed a higher resolution images which were then used to the definition of the land use areas.

Gullies located to the west of Mindelo were assessed in the field to ascertain the influencing factors. Twenty-two samples of soil sediments were randomly collected from the area where the gullies have formed. Both surface and depth sampling were used, taking advantage of the gullies' lateral walls to determine granulometric parameters. The Wentworth scale was used for particle size analysis. The fine fraction corresponds to the sum of the elements of less than 0.063mm in size (silt-clay fraction). Summing the different fractions we obtained a final weight which, when subtracted from the initial weight, results in the loss by analysis, thus allowing possible errors to be controlled throughout the process. The cumulative curves resulted from the sum obtained for each fraction in relation to the weight sieved, being made up from the thicker elements (2mm). Measurements were subsequently taken that describe the granulometry of sediments with central tendency (median Mdø, mean Mø, graphic mean Mz and trend), dispersion (calibration σ), asymmetry (Ski) and angularity of the curve (kurtosis).

The approach to the desertification hazards was based on farmers' perception analysis of productivity and strategies to mitigate the potential loss of the soil's productive capacity. In this order, 12 actions were held for farmers in Ribeira da Vinha. Regarding the observer's participation, it was a "non-participant observation", given that we were to remain outside the reality being studied, without interfering or becoming involved in the situation, i.e., it is the community that experienced the situation that will provide us with the information. In terms of the number of observers, it was a team observation, which we have also called "shared", given that it was conducted by both authors of this paper. It was a "field observation" because it was done at the location of the phenomenon. This classification is also supported in the ideas of Lessard-Hébert et al. (2005) in which the authors refer to "participated observation". This is because the facts are presented based on the information from the observed subjects, although the latent phenomena have been taken into account by us as observers of the phenomenon. Thus, there was a face-to-face relationship in the quest to rebuild the inhabitants' everyday life. In brief, this research was based on three pillars: direct observation of the phenomenon (interviews with the involved individuals); field survey; own perception based on a combination of the collected information. There were semi-directed individual interviews, given there were some pre-determined questions: (i) how farmers perceive the trend in agricultural production; (ii) what measures have been taken to mitigate the problems related to the decline in agricultural production; (iii) the farmers' future prospects. A logbook was written, recording our perceptions of the events, according to a reference table planned ahead of the trip and the field work.

Lastly, observation of the manifestation of the flash flooding hazard in the city of Mindelo on 26 August 2008 helped to identify the spatial location of the events that occurred and, therefore, to estimate the area, the most susceptible to its occurrence. It also helped us to gain a better understanding of the manifestation of the process and, in this way, to better estimate the consequences in the event of the repetition of similar situations. The rainfall amounts on that day and on the days prior to the event, and also the synoptic descriptions were kindly provided by the National Meteorology and Geophysics Institute of Cabo Verde.

RESULTS AND DISCUSSION

Erosion hazard and gullies formation - the example of the gullies of Lazareto (NW of São Vicente)

Periods of intense and concentrated precipitation contribute towards the significant loss of soil and generate powerful torrents due to the steep slopes that are filled with small materials, as a result of the poor vegetation cover (Fig. 2), which lend particularly active dynamics to the water courses. It is a common sight in São Vicente to see these streams reaching the sea loaded with solids, giving the water a yellowish-red tonality, principally near the outflow of the streams (Fig. 3).

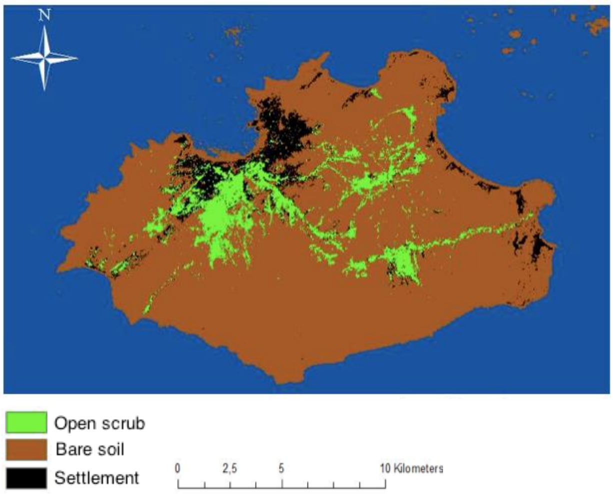

Fig. 2 São Vicente land use map based on LANDSAT 8 image

We can frequently observe gullies that are generally associated with problems of erosion, especially, when they affect areas of cultivation of high economic value. Unlike other processes associated to erosion by water like, for example, the rill formation, gullies imply much greater effort of control and erosive correction. In fact, studies developed to mitigate and prevent the effects of erosion attribute severe and often permanent damage to the land due to the action of creating gullies (Desta and Adugna, 2012). Even without affecting areas of cultivation, the gullies in the area of Lazareto, in NW São Vicente, confirm the importance of erosive processes, as they develop in the area at the foot of the slopes, situated to the east of the edge of the crater that borders the island to the northwest (Fig. 4).

Fig. 3 Terminal sector of a stream on Laginha beach. Note the orange tonality and the materials deposited at the outflow of the stream

The deepening and development of the network of gullies essentially depends on the presence of colluvium. In general, colluviums are very heterogeneous varying in size from over a metre to just centimetres with a varied degree of rolling, containing highly rolled blocks and others less so, while the basis is fundamentally formed by coarse sand. They can be more than 3 meters deep, comprising basaltic, conglomeratic material, of pebbles and rocks of black to dark grey in colour that are generally

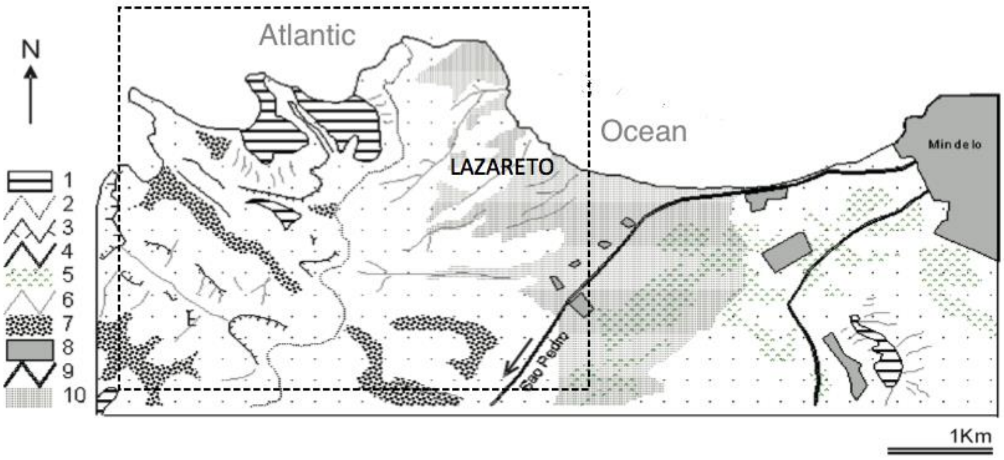

Fig. 4 Lazareto gullies location. Morphological features with land use information based on 2004 aerial photographs with field verification (extracted from Martins and Rebelo, 2009). 1 – Siliceous structural plateau; 2 – siliceous concave slope; 3 – escarpment; 4 – deep groove; 5 – vegetation; 6 – gullies; 7 - alluvial ejection cone; 8 – settlement; 9 – road; 10 –deep soils with open scrub.

well conserved (W1). The rocks generally have a disorganised disposition, especially the larger ones. Occasionally we observe interwoven stratification. The larger rocks are over one meter in diameter, with a great deal of heterogeneity regarding the degree of rolling, some with rounded edges, indicating that they were transported and subsequently deposited. Usually occupy a higher position to wind-blown deposit from the stratigraphic point of view (Fig. 5).

Wind-blown deposits correspond to conglomeratic sand dunes from the Quaternary period (Romariz and Serralheiro, 1967; Pereira, 2010), fundamentally made up from well calibrated sand which, in some sectors, can be over 30 meters deep. They are quite well stratified. Sand predominates (sample trend = 0.5mm) containing bioclasts, mineroclasts and lithoclasts of clear basalt, yellowish to beige in colour.

Figure 6 shows the curves and graphic illustration of some granulometric descriptive measurements obtained from the mean of the samples collected from the colluvium (Fig. 6A) and from the wind-blown sands deposit (Fig. 6B).

Colluvium occupies a higher position generally comprising sandstone and brownish clay/silt deposits, with a basaltic structure. They include sand and small rocks of a basaltic nature, sub-rolled and sub-angular not exceeding 5 cm in diameter. The volume of colluvium, the presence of wind-blown sand and the network of gullies are a reliable indicator of the high rates of erosion on a regional scale. The presence of very deep, recessed gullies, some of which are over 3 meters deep, also suggests a process of densification and recessing associated to each rainy season, confirming the concentrated surface runoff as the main agent of erosion, in particular, in movable materials which, given the absence or scarcity of vegetation together with the weakness of the soil (fine texture and low permeability), has a high intensity of mobilization of detritus.

Fig. 5 Typical profile where we see colluvium and lower down wind-blown deposit. The box of the camera surrounded by the circle serves as a scale

The desertification hazard

Although agriculture occupies only 9,6% of the surface of the country, this activity represents one of the most important sectors of primary production in the archipelago's socioeconomic development. In the years with the best agricultural results, almost always in line with the quantity and spatial and temporal distribution of the rains, significant changes in macroeconomic

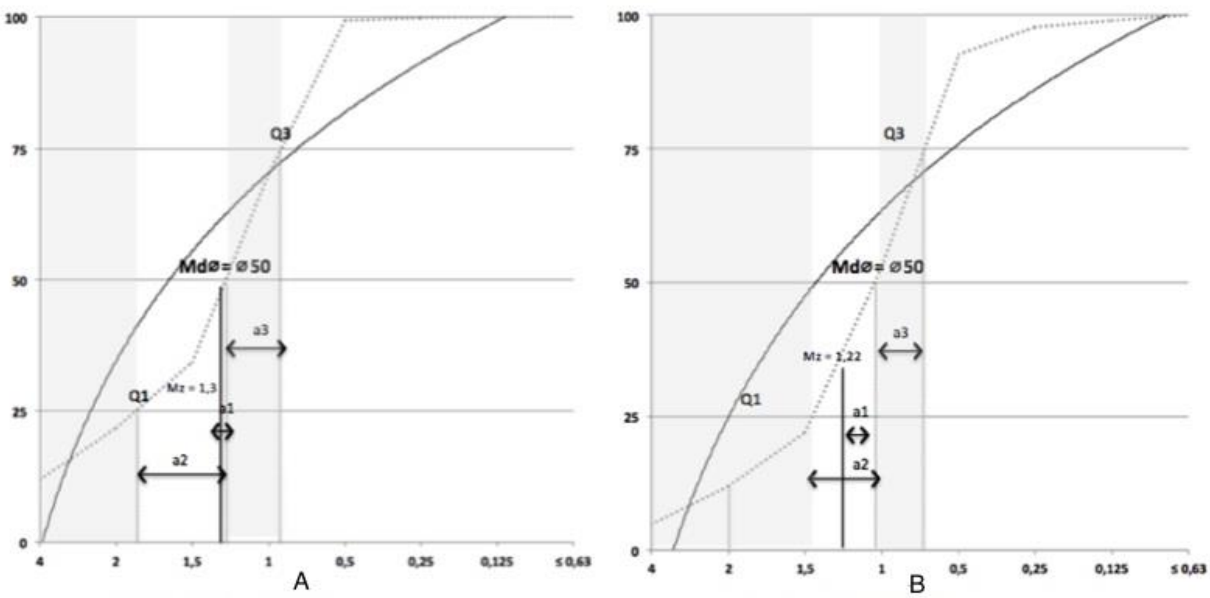

Fig. 6 Granulometric curves and graphic illustration of some descriptive measurements of these curves for the deposits: colluvium (A) and wind-blown (B) (Mdø: median, Mz: graphic mean, a1: distance between Mdø and Mz, a2: distance between Q1 and Mdø, a3: Mdø and Q3, Ski: asymmetry, Kg: angularity of the curve (kurtosis))

indicators are recorded, both in inflation and in the purchasing power of consumers, arising from the reduction in market prices (SEPA, 2000b and 2000c). On a national level, dry farming is predominant, and is used in over 75% of farms. Irrigation farming represents only 17% of farms and agroforestry is below 2%. However, the island of São Vicente does not reflect this distribution. The number of dryland farms does not exceed 6%. The farms are mainly irrigated farms and are concentrated around the Vinha streams, to the west of Mindelo.

Based on the interviews, irrigation systems that use shallow water wells are at hazard of the salinization hazard, resulting in a drop in production and the consequent abandonment of farms. In these cases, several farmers immediately moved to the urban centres or considered emigrating in the hope of improving their living conditions. However, irrigation using water from the ETAR (water treatment plant) of Vinha had a significant impact on the medium and long term prospects. The use of water from the ETAR helps to increase the agricultural production of vegetables. Currently, more than 40% farms now obtain their water from the ETAR.

Poor management of water from the ETAR and the investment needed to make the irrigation system more efficient are the major concerns mentioned by the farmers. The investments made are high, at times requiring loans, which puts some investors off. The water distribution technique is generally drip irrigation, involving setting out piping to transport the water, which implies enormous investments, both at the outset and *a posteriori*, in maintenance. This method is used by the majority of the farmers. It consists of releasing water at frequent intervals at strategic points located close to the roots. It also allows the water supply to be adjusted to the soil's absorption capacity and to the seasonal needs of the crops. All the farmers unanimously reported that, based on this irrigation system, production is more regular and has been increasing.

The interviews led to the recognition that the farms affected by desertification are reflected in the decrease in agricultural profitability, as well as in the consequences associated with migration.

Investigation also shows that abandoning farmland did not resolve the problem of desertification since these problems remain in most farms, especially those which are not investing in irrigation systems. The use of water from the Vinha ETAR was positive as an alternative, although it requires investment, which is a serious obstacle for a good number of the interviewed farmers. The absence of the government is a concern for the farmers interviewed.

The flash flooding hazard – the example of that occurred on 26 August 2008, in Mindelo

The city of Mindelo is surrounded by slopes that correspond to what remains of the volcano that originated the island of São Vicente and that forms the city limits. Rapid urban growth which on average is higher than the growth of the archipelago's population (Fig. 7), has meant that the construction of dwellings and thoroughfares now occupy areas that often correspond to small stream beds that are dry for most of the year, at times for years, but which rapidly fill up when there is more intense and concentrated rain (Rebelo, 1999).

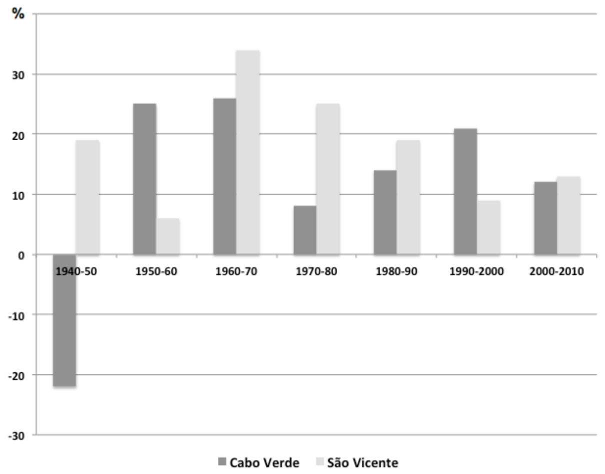

Fig. 7 Comparative analysis of the growth of the population in the island of São Vicente and in Cabo Verde, by decade, between 1940 and 2010. Data source: INE-CV.

This process of urban growth, devoid of planning, is one of the most important factors in the increase in vulnerability to the flash flooding hazard. Besides dwellings, many of the avenues and streets are badly affected by flash flooding, as is the case of the Rua do Côco, which leads to the central hospital of Mindelo, Baptista de Sousa.

There are countless examples of clandestine constructions that occupy areas subject both to flash flooding and mud flows. It then becomes very interesting to observe the large channels that cross the city and which, although of varying sizes, were built with the same objective, of leading the rainwater to the sea, but are frequently occupied by dwellings or even truncated by avenues and roundabouts.

In the case of Mindelo there are therefore factors related with the actions of humans that accelerate and exacerbate the consequences of physical processes.

The flash flooding on 26 August 2008 caused enormous material loss. Rainfall amounts in the form of showers were over 35mm (Fig. 8). This was an episode of rainfall associated with two cells of low pressure, with greater incidence in the region south of Cabo Verde, which led to the development of convective cloud formation namely cumulonimbus (Cb). Levels of humidity of over 85% were recorded in the whole of Western Africa and strong nuclei of vorticity and well defined cyclonic circulation. There was also a tropical wave on the east Atlantic (precisely southwest of the archipelago), moving in a north-easterly direction, and the positioning of the intertropical convergence zone (ITCZ) along an alignment defined by the coordinates 07°N52°W/9°N34°W/16°N25°W and with disperse convection in its central axis (information obtained from the National Meteorology and Geophysics Institute of Cabo Verde).

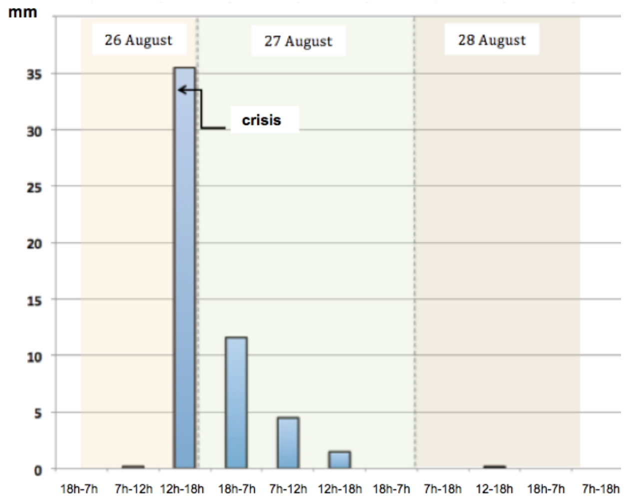

Fig. 8 Precipitation distribution (mm), in different intervals, in the weather station of the city of Mindelo, on 26 and 27 August 2008. Data source: INMG-CV

Although the precipitation resulting from this meteorological situation may have been a major factor in triggering the whole process, it cannot be the only explanation for what happened. In fact, slopes and soils with poor infiltration capacity, together with the morphological characteristics of the city and, above all, the significant increase in the constructed surface area which, in turn, increases the impermeable area, mean that more water remains on the surface and increases the speed of the river water, namely when full, thereby making the runoff process more violent. From the point of view of preventing this hazard, measures have to be taken that delay the runoff's response to intense rain, increasing the time of concentration and, therefore, reducing the velocity of the surface runoff.

However, the disorganised growth of the city contributed towards the destruction of important drainage channels, built with the intention of channelling the surface waters and also increasing the drainage speed, so it would reach the sea more quickly. Therefore, although the process or physical phenomenon has remained practically unchanged an inadequate response strategy significantly increases the hazard consequences.

In order to mitigate the effects of flash flooding hazard, in December 2010, the Town Hall of São Vicente carried out some torrential correction works, one of the main ones being the construction of dikes in the upper reaches of the water courses and drainage channels in the Rua do Côco and near Praça Estrela (Fig. 9). While these works are considered to be effective in hazard mitigation, rainfall crises continue to occur in various areas of the city of Mindelo, as was the case of the flash flooding in September 2013 (Fig. 10).

The losses were only material, but they showed that the drainage system is still insufficient. On the other hand, for the same intensity of rain we see that the flash flooding hazards have unfortunately increased.

Fig. 9 Torrential correction works near Praça Estrela in December 2010

Fig. 10 The flooding of the Rua do Côco in September 2013

CONCLUSION

As the archipelago of Cabo Verde is inside the Sahelian zone, it is in a space of high erosion hazard with serious consequences for the productive capacity of the soil. Periods of intense and concentrated precipitation play a part in significant loss of soil and generate powerful torrents as a result of the poor vegetation cover. The network of Lazaretto gullies is a reliable indicator of the high rates of erosion on a regional scale. The presence of very deep, recessed gullies, some of which are over 3 meters deep, also suggests a process of densification and recessing associated with each rainy season, confirming concentrated surface runoff as the main erosion agent, particularly with respect to movable materials.

The interviews led to a recognition that the farms affected by desertification are reflected in both the fall in agricultural profitability and the consequences associated with migration. Our research also shows that the abandonment of agricultural fields did not solve the problem of desertification since most farms still suffer this problem, especially those which are not investing in irrigation systems. The use of the water from the Vinha

ETAR was positive as an alternative, although it requires investment, and this is a serious obstacle for many of the farmers we interviewed. Most farmers feel there is too little government support.

Disorganized urban growth is responsible for the increased flash flooding hazard through the destruction of important drainage channels that were built with the intention of channelling the surface waters and also increasing drainage speed, so the flow would reach the sea more quickly.

In climatic zones subject to intense erosive processes and where the ecosystems' response to anthropic interventions is very sensitive, as is the case of the island of São Vicente, action in the territory should be cautious. In fact, the growing abandonment of agricultural-pastoral activities will not resolve the problems, quite to the contrary, as the abandonment of agricultural areas and the consequent rural exodus may increase the vulnerability of the urban areas, in particular, in the larger cities, as is the case of the city of Mindelo.

Acknowledgements

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