

The Effects of Aeolian Sand on Infrastructure in Walvis Bay



Abstract

When a natural hazard interferes with the human society, the society becomes vulnerable and a natural disaster might occur. There are two kinds of natural disasters, catastrophic and pervasive. Dune migration is a type of pervasive natural disaster and sand and dust storms might be catastrophic disasters if sand encroaches into human settlements, damaging buildings and infrastructure. Using previous research and primary data consisting of semi-structured interviews and field observations, a study has been made of how sand encroachment affects the infrastructure in Walvis Bay, a coastal industrial town of western Namibia. In this study, we report on a correlation between sand encroachment and future industrial and economic development of the town, based on the fact that Walvis Bay is vulnerable to what we refer to as aeolian sand. The existence of such a relationship is based on the results of interviews with different actors within the infrastructure network, decision making agencies and researchers, as well as field observations, studies of maps and aerial photos, a small discourse analysis on the local media and studies of local weather data. The results are partially contradictory, but indicate that the vulnerability of Walvis Bay due to aeolian sand might increase within the near future.

Keywords

Walvis Bay, aeolian sand, vulnerability, geomorphology, hazard, sand encroachment, dune migration, infrastructure, transportation network, Namibia

Abbreviations

ANT – Actor Network Theory

EIA – Environmental Impact Assessment

ITCZ – The Intertropical Convergence Zone

GCM – Global Climate Model

GIS – Geographic Information Systems

NDRM – Natural Disaster Risk Management

SADC – Southern African Development Community

SEA – Strategic Environmental Assessment

WBCG – Walvis Bay Corridor Group

Table of contents

1. Introduction.....	1
1.1 Aim and problem at issue.....	1
1.2 Delimitations.....	1
Aerial delimitation.....	1
Time delimitation.....	2
1.3 Central concepts and terminology.....	2
1.4 Methodology – Choices of approaches, methods and sources.....	3
Actor Network Theory.....	3
Studying of previous research.....	3
Semi-structured interviews.....	3
Field observations.....	4
GPS mapping.....	4
Study of maps and aerial photos.....	4
Study of weather data.....	4
Discourse analysis on media.....	4
1.5 Criticism of methods and sources.....	5
2. Theoretical background.....	6
2.1 Vulnerability of society and geomorphological hazards.....	6
2.2 Disaster prevention.....	7
2.3 Aeolian sand.....	8
Defining sand encroachment and dune migration.....	8
Defining sand and dust storms.....	10
The effects of aeolian sand on infrastructure on a global level.....	10
Preventing and controlling aeolian sand.....	10
2.4 Climate change, effects on aeolian sand.....	11
3. Case study.....	12
3.1 Area description.....	12
Absolute and relative location.....	12
3.2 Physical geography of the Walvis Bay area.....	12
Climate.....	12
Dune areas and type of dunes.....	13
Kuseb River and its delta.....	13
3.3 The town of Walvis Bay.....	14
Infrastructure in Walvis Bay.....	14
3.4 Previous research on the study area.....	15
3.5 Natural disaster risk management in Namibia.....	16
3.6 Results of interviews.....	17
The effects of aeolian sand on the railway network.....	17

The effects of aeolian sand on the airport.....	17
The effects of aeolian sand on the port of Walvis Bay.....	17
The effects of aeolian sand on roads.....	18
The effects of aeolian sand on the expansion of Walvis Bay.....	21
Municipal responsibilities, David Uusho.na.....	21
A researcher’s perspective, interview with Mary Seely.....	22
3.7 Results of field observations.....	22
3.8 GPS mapping.....	25
3.9 Study of maps and aerial photos.....	28
3.10 Study of weather data.....	28
3.11 The depiction of aeolian sand in media.....	30
4. Discussion.....	31
5. Conclusion.....	34
List of Sources.....	36
Appendix.....	40
Summary.....	41

Figures:

Figure 1. Delimited study area of Walvis Bay. Modified from Google Maps.....	2
Figure 2. The ingredients of natural disasters.....	7
Figure 3. Barchan dune dimensions.....	9
Figure 4. Transverse dunes	9
Figure 5. Kuiseb River Delta after the diversion 1962.....	14
Figure 6. Sand removal after a sand storm.....	19
Figure 7. Sand on the streets of Meersig.....	23
Figure 8. Prevention methods, green belts and fencing south of Meersig.....	23
Figure 9. Sand overtaking fences south of Meersig	24
Figure 10. Barchan dune formation south of Meersig	24
Figure 11. Mechanical excavation of sand dunes along the C14 road.....	25
Figure 12. Sand encroachment on the C14 road.....	25
Figure 13. Map of the dune area south of Meersig.....	26
Figure 14. Map of the dune area south of the C14 road closest to Walvis Bay.....	27
Figure 15. Map of the dune area south of the C14 road closest to the airport.....	27
Figure 16. Median precipitation per year.....	28
Figure 17. Average annual temperature	29
Figure 18. Average annual wind speed.....	29
Figure 19. Average annual wind direction, 2003-2008 in percentage.....	30
Figure 20. Photos on the derailment.....	30
Figure 21. The progression of aeolian sand in Walvis Bay.....	31
Figure 22. Actor Network for Walvis Bay in relation to aeolian sand.....	32

Tables:

Table 1. Sand management budget for roads by the Municipality of Walvis Bay in Namibian Dollars.....	20
Table 2. Sand management budget for town and townlands by the Municipality of Walvis Bay in Namibian Dollars.....	20
Table 3. Different prevention methods on aeolian sand.....	33

1 Introduction

Human societies tend to inhabit milieus which are prone to noticeable or unnoticeable geomorphological hazards (Bryant, 2005). Places such as coastal zones are prone to coastal erosion or floods, however they offer certain benefits, for example fishing and transportation opportunities. When people populate areas which are prone to geomorphological hazards, adaption is necessary (Alcántara-Ayala, 2002).

The town of Walvis Bay is situated in a desert environment consisting of sand dunes with constant winds blowing from one direction. It is also an important industrial junction in Namibia and for the SADC, South African Development Community, region. According to Goudie (2010a) dune migration and sand encroachment are geomorphological hazards since migrating dunes may block railway lines, and encroach on to runways and roads. Due to global warming, the dunes near Walvis Bay might reactivate and dust storms may occur more frequently, increasing the degree of vulnerability. The adaption and prevention methods will therefore be of greater importance (ibid).

1.1 Aim and problem at issue

Due to Walvis Bay's industrial and economic importance to Namibia, the aim of this essay is to investigate how the infrastructure of Walvis Bay is affected by aeolian sand in relation to its relative location. Our focus is on dune migration and sand encroachment, on different scales and over time. We have also sought to map the dunes in areas which might be possible threats to the infrastructure. Our question at issue is:

How is the infrastructure of Walvis Bay affected by aeolian sand?

In order to answer our question at issue, we have conducted additional sub questions, which are:

- How has Walvis Bay adapted to aeolian sand on a day-to-day basis, and will the adaptation remain sufficient in the future?
- What are the prevention methods to dune migration and encroachment?
- Who is responsible for managing the sand within and outside the town borders?
- How will the infrastructure be affected by aeolian sand in the future?
- What changes have taken place within the area during the last 50 years up until today?
- How are the effects of aeolian sand displayed in the local media?

1.2 Delimitations

Areal delimitation



Figure 1. Delimited study area of Walvis Bay. Modified from Google Maps (Bovin & Jonsson, 2010)

We have delimited our study area to the town of Walvis Bay including parts of the C14 road and the airport, see Figure 1. This is suitable for our essay since we cover all the different actors within the infrastructure. By including the C14 road, we also cover sand management on different scales, both municipal within the town borders and national outside of the town borders. In addition, we have included the dune area south of Meersig since Le Roux (1974) stated that these dunes threatened the town in the 1970s.

Time delimitation

The time delimitation of this essay ranges from 1944 to 2100 and covers a time span of 156 years. This is appropriate since we are able to study aerial photos of the Walvis Bay area from 1944 up till today. The future reference of 2100 is based on the effects of climate change in Namibia stated in the National Policy for Disaster Risk Management in Namibia (2009). In addition, scenarios of the GCMs for the mega-Kalahari, illustrate that there will be a reactivation of all dunes located from South Africa in the south to Angola in the north by 2099 (Goudie, 2010b).

1.3 Central concepts and terminology

Aeolian sand – refers in this essay to sand carried by wind which causes sand encroachment and form sand dunes when accumulated

Infrastructure – refers to the transportation network consisting of airports, roads, railway and ports

Long-term prevention methods – sustainable solutions ranging from five years and onwards

Short-term prevention methods – ranging from a day-to-day basis up to five years

1.4 Methodology - choice of approaches, methods and sources

Actor Network Theory

The following paragraphs are based on the work of Bosco (2006) who states that the Actor Network Theory, ANT, started to be used in the 1980s and has its origins in sociology studies of science and technology. The principle is that principle that knowledge, agents, institutions, organizations and the society are all results of the effects of relationships within heterogeneous networks, consisting of both humans and non-humans. Researchers use the theory in order to understand the general patterns amongst constructions of the social, by tracking associations which are heterogeneous amongst things. It is first when human and non-human actors have the capacity to act and become related to each other, that the effects of the network can be analyzed and understood. Still, ANT sees a difference between humans and non-humans by claiming that “humans and non-humans are treated symmetrically in our descriptions of the world, especially with regard to the agency of non-humans, an agency which may or may not have been designed or inscribed by human actors” (Bosco, 2006, p. 137).

Since a network is built upon the actions of actors and their relations to each other it is not a fixed system but is always changing. All the actors involved contribute to circulations and flows. Since it deals with the elusive, and encourage thinking of space, place and scale, we believe that ANT is the most appropriate theory of science to understand the complexity of the global world we live in today.

ANT is used in our study to survey the rate of vulnerability of society due to aeolian sand since there are a lot of actors, both human and non-human, affected by the phenomenon. According to Alcántara-Ayala (2002), vulnerability arises when human societies and natural hazards coincide. By implementing an actor network approach to our study, we are able to break down what we call societies to smaller pieces, study them individually, and then put them back together to see how they correlate. Then we can draw conclusions on how the infrastructure is affected by aeolian sand and whether it should be considered as vulnerable to the phenomenon or not.

Study of previous research

To provide background information to our subject, we have studied previous research on geomorphological hazards, vulnerability and the effects of aeolian sand on societies globally. There is a variety of literature on the matters of geomorphological hazards and vulnerability, but regarding aeolian sand in particular we have mostly relied on scientific articles. In addition, there have been many studies on our study area. However, most studies discuss barchan dunes and their movement and not their impact on the society. Such research is dealt with in the beginning of our case study, in order to function as a link to how the infrastructure is affected at the present time and in the future.

Semi-structured interviews

In order to obtain information from actors and other informants within, and associated to the Walvis Bay infrastructure network, we have implemented semi-structured interviews. Apart from the different actors within the infrastructure network, we sought to obtain a researcher’s perspective on the effects of aeolian sand, thus we interviewed Dr. Mary K. Seely. She is an associate of the Desert Research Foundation in Namibia and a former desert researcher, who was the director of Gobabeb Research Station for 26 years. Most of her research was on the recharging of the Kuiseb River aquifer and the physiology of beetles in Gobabeb. However, she has been very active in other subjects and has written a number of books on the Namib Desert.

In order to facilitate semi-structured interviews, we composed a few main questions in advance which were adapted for the different actors, see Appendix. Depending on the answers, we could add follow-up questions, which then led to an open dialogue. The informants we interviewed were as follows:

- Booysen, Dirk F., Manager for Walvis Bay and Regional Airports, 10.11.2010, Walvis Bay
- Eiman, Tim, Coordinator EMS / QMS – Namport, 10.11.2010, Walvis Bay
- Gelderbloem, Elzevir W., Project Engineer, Project Manager, Deputy Port Engineer – Namport, 15.11.2010, Walvis Bay
- Hitula, Hilia, City Town Planner - Walvis Bay Municipality, 14.11.2010, Walvis Bay
- Louw, Adri, Roads and Building Control - Walvis Bay Municipality, 8.11.2010, Walvis Bay
- Road inspector, Road's Authority, 12.11.2010, Swakopmund
- Seely, Mary, Desert Research Foundation Associate, 24.11.2010, Windhoek
- Schommarz, Horst, Divisional Manager Maintenance – Road's Authority, 24.11.2010, Windhoek
- Train inspector, Transnamib, 9.11.2010, Walvis Bay

In addition we attended a lecture by David Ushona at the Offices of the Department of Water, Waste and Environmental management at the Municipality of Walvis Bay, 8.11.2010.

Field observations

To be able to study the daily situation in Walvis Bay we carried out field observations. We took notes and photographs of different areas in Walvis Bay during three days, and studied the dune areas south of Meersig, along the C14 road towards the airport, see Figure 1, as well as the effects of sand on roads, streets and railway lines. In addition we observed the different prevention methods being used within and outside the town borders.

GPS mapping

During our GPS mapping we used a Garmin 60 GPS. In the field, we chose to map three different areas: the dune area south of Meersig, the dune area along the C14 road closest to the town and the dune area along the C14 road closest to the airport, see Figure 1. Our primary data consists of coordinate points taken on top of larger dunes located closest to roads and streets, as well as points on the different prevention structures. The data was used in mapping of sand dunes in relation to housing and infrastructure.

Study of maps and aerial photos

By studying maps and aerial photos of the Walvis Bay area we were able to investigate changes in land-use and land-cover over time. We were able to study aerial photos from 1944, 1976 and 1997 at Stockholm University, and from 2008 using Google Earth. We also studied two topographic maps from 1983 and 2003 collected at the Geological Survey Center in Windhoek, as well as a map of dunes in Walvis Bay from 1977 produced by the municipality of Walvis Bay.

Study of weather data

To investigate if there is a correlation between changes in weather and dune activity, we obtained weather data from the Meteorological Service Center in Windhoek, ranging from 1994 to 2010. The data originates from the Walvis Bay airport and is relevant for our study since it includes precipitation, wind speed and temperature. The data is measured on a monthly basis, except for wind speed and wind direction which is measured on a daily basis. Wind direction data has been collected from Windfinder, a website which provides global wind reports.

Discourse analysis on media

In order to gain media's perspective on the matter of aeolian sand we have performed a minor discourse analysis of the local newspaper in Walvis Bay. At the library of Walvis Bay we were able to

study two year's articles of The Namib Times from 2008 and 2009. This gave us an indication on how the issue of aeolian sand is depicted in the local media.

1.5 Criticism of methods and sources

Well known researchers such as Goudie and Alcántara-Ayala write about global phenomena such as climate change. Some researchers present the effects of climate change as crucial, while others claim the opposite. Even though we refer to researchers such as Goudie, we are aware of the contradictory theories on climate change. In addition, previous research on the study area has mainly been performed by foreign researchers who have been in Walvis Bay for a short period of time. Due to an outsider's perspective, this may affect the view of aeolian sand for the society. This is the case for our study as well, turning the essay into our perception of the situation, which may or may not correspond to the reality. Articles dealing with dune activity and vulnerability in Walvis Bay tend to be a bit outdated, and we therefore rely much on primary data from informants.

According to Brockington and Sullivan (2003) interviewing embraces different forms, including open conversations, semi-structured discussions on certain topics or strict and structured questionnaires. However, all forms of interviews face challenges and potential problems. When interviewing, Brockington and Sullivan argues that recording information may be difficult. Writing while people are speaking may be frowned upon and transcribing tape recordings takes time. Since we were two interviewers, one was able to take notes while the other one was writing. However, this might be problematic since the setting of conversation is made by the one interviewing and not the person taking notes. This could result in misinterpretation of information, which in a tape recording would be the exact meanings of the informant. On the other hand, transcribing of recordings takes much longer than note taking and since time was limited for us, we chose to take notes. Another critical aspect to our interviews is the role of informants. For instance, some informants might have limited their information due to their occupation. In addition, the information might be limited because of our occupation. It is therefore important to introduce ourselves and our essay. Woodhouse (2007, p. 173) claims that, "One of the most important elements establishing an investigator's identity is the way in which she or he is introduced to informants".

A critical aspect to our field observations is that we are the ones interpreting the surroundings, and can only claim our observations based on earlier experience and knowledge from three terms of undergraduate geography studies. Another aspect is the perspective of time, since landscapes change both naturally and due to human activity. The situation observed now may therefore differ in the future.

The GPS mapping might differ from reality since the GPS device has an error margin of +-4 meters, which could cause some errors in mapping of the dunes. Furthermore, the GPS measurement points may change over time due to changes in landscape. Therefore it will not be possible to iterate the study with the same outcome. However, our main objective was to map the dune situation at the present time.

The aerial photos were all photographed at different height, making the analysis difficult since we did an ocular study and did not digitalize the photos. The latest aerial photo which is possible to analyze is from 2008, and the latest map is from 2003. Therefore we do not have contemporary information.

Since we were only able to obtain weather data from the early 1990s, it is difficult to observe a change over time. Wind direction is only available from 2003-2008. In addition, some months lack data. Therefore, we chose to exclude those years when creating diagrams. We argue that it is preferable to exclude years lacking data rather than including deceptive data.

Due to lack of time, we could only analyze two years of articles in The Namib Times. If we would study articles further back in time, our result might have been different. In addition, had we analyzed a national newspaper, our result might have differed. However, since the Namib Times was the only newspaper available at the Walvis Bay library, we had to delimit our analysis to that particular archive. In addition, there were no authors to be found of the different articles, which have aggravated the ability to examine the reliability of the articles.

2 Theoretical background

2.1 Vulnerability of society and geomorphological hazards

According to Wisner et al. (2004, p. 11) the term vulnerability is defined as being exposed to damage or injury, “By vulnerability we mean the characteristics of a person or group and their situation that influence their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (an extreme natural event or process)”. The idea is that depending on situation, people, or groups of people, are exposed to different risks. Alcántara-Ayala (2002, p. 119) defines vulnerability as, “The propensity of an endangered element to any kind of natural hazard to suffer different degrees of loss or amount of damage depending on its particular social, economic, cultural, and political weaknesses”, see Figure 2. Mutual for these definitions is that an object, whether it is human beings, roads or buildings, becomes vulnerable when exposed to natural hazards. Rosenfeld (2004, p. 423) notes that, “A significant practical contribution of geomorphology is the identification of stable landforms and sites with a low probability of catastrophic or progressive involvement with natural or man-induced processes adverse to human occupation or use. Hazards exist when landscape developing processes conflict with human activity, often with catastrophic results”. Goudie (2010c, p. 1) stresses that geomorphological events can cause the lives of humans and damage property. Catastrophic geomorphological events such as hurricanes or earthquakes, gain attention since the effects are of great magnitude, both financially and in numbers of casualties. However, there are also slower and pervasive geomorphological events which consequences affect the human welfare. Different environments are exposed to different natural hazards, and desert areas for example, are exposed to wind erosion and deflation of surfaces as well as dust storm generation, dune migration and encroachment (ibid).

According to Bryant (2005), humans choose to live in risk-areas since they tend to offer certain benefits. For example, volcanic ash produces beneficial nutritious soils, however, the effects of a volcanic eruption might be devastating. Natural hazards threaten human society and are capable of damaging both physical and social spaces. Alcántara-Ayala (2002) notes that hazardous events are not only damaging at the moment of impact, but also in a long-term perspective due to its associated consequences. When society and/or infrastructure is exposed to natural hazards, the hazards become natural disasters. Alcántara-Ayala (2002, p. 121) states that, “The degree of their impact in space and time is a function of the exposure to and the magnitude of the natural phenomena (natural vulnerability) and the human vulnerability of the threatened entity”.

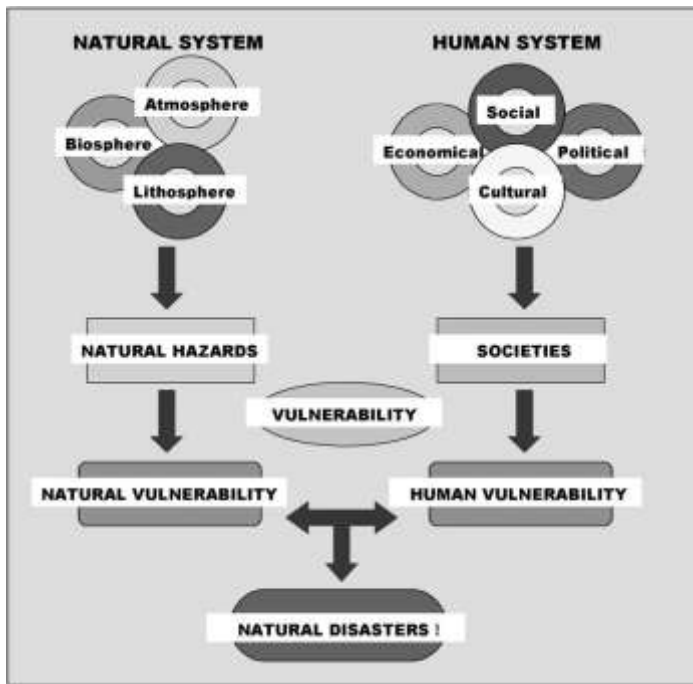


Figure 2. The ingredients of natural disasters (Alcántara-Ayala, 2002)

To prevent natural disasters, Alcántara-Ayala (2002) claims that an attempt to provide risk assessments and management framework, interacted with the work of geomorphologists is needed. Goudie (2010c, p. 1) notes the role of geomorphologists in hazard research as, “[...] mapping of hazard-prone areas; constructing the history of occurrence of past hazardous events; establishing their frequency and magnitude; predicting the occurrence and location of future events; monitoring geomorphological change; and using knowledge of the dynamics of geomorphological processes to advise on appropriate mitigation strategies”.

2.2 Disaster prevention

As mentioned above, vulnerability and risk assessments are of importance in order to prevent natural disasters. Van Westen (2010) notes that the impacts of hazardous events cannot be ignored and the concepts of disaster risk management has to be included into spatial planning by producing environmental impact assessments (EIA) and strategic environmental assessments (SEA). The estimated loss due to a hazardous natural occurring requires a spatial analysis since apparatus of risk assessment differ in space and time. One valuable geographical tool is geographic information systems (GIS), which handles spatial data. With the help of GIS, geographers are for instance able to map hazardous areas as well as perform modeling, two helpful functions in producing risk and vulnerability assessments (ibid).

The following paragraph are based on Länsstyrelsen i Stockholms län (2010, Internet), The Stockholm County Board, a risk and vulnerability assessment is a combined analysis of two different analyzes; a risk analysis which aims to identify risks and consequences, and a vulnerability analysis which seeks to identify objects and factors that can be protected against certain threats, for example natural hazards. There is no standard template for a risk and vulnerability assessment but they identify some central strategies:

- To map what is worthy of protection
- To identify which risks, threats and unwanted incidents may exist, and in which way they can damage what is worthy of protection

- To map the ability to withstand and manage the threats
- To propose measures that reduce risk and vulnerability, both prevention and damage reduction
- To investigate the effects of the proposed measures
- To evaluate current and improved management capability against possible impacts to produce a benefit-cost calculation as a basis in prioritizing different measures

Adapting human society to its environments and natural hazards faces its challenges and prevention methods differ depending on location (Alcántara-Ayala, 2002). Hufschmidt and Glade (2010, p. 239) stresses that protecting the environment and society with the help of engineering structures is mostly important in risk-areas. However, building structures has a given lifetime and if not maintained, they might fail in the future. For instance, if snow avalanche fences are not maintained, the snow would accumulate more than under natural conditions. The consequences of failing the maintenance of prevention structures might worsen the natural hazard causing the nature to fight back (ibid).

To sum up, there are two main general disaster prevention methods, the risk and vulnerability assessment and protective structural engineering. However, it is important to note that depending on location and the natural hazard, different adaption methods are necessary (Alcántara-Ayala & Goudie, 2010).

2.3 Aeolian sand

Defining sand encroachment and dune migration

A sand dune is a hill of sand formed by the wind, at a place where there is a source of loose sand and a constant lack of vegetation (Strahler & Strahler, 1994). It can be changed by the wind only when there is no vegetation to keep the sand in place, and different types of dunes behave differently when they are exposed to strong winds. The most important factors to how dunes are shaped and how they migrate are the direction of wind, speed of the wind and the grain size of the sand (ibid). According to Yao et al. (2007), sand dunes overall can be divided into three main groups: migrating dunes, elongating dunes and accumulating dunes. It is called a migrating dune when the whole dune advances without change in shape and size, an elongating dune when the dune extends as the length increases over time, and an accumulating dune when the dune shows no elongation or net advance. Barchans and transverse dunes represent migrating dunes (Yao et al.). Christopherson (2009) defines a barchanoid ridge dune (a barchan) as a dune ridge that is usually wavy and asymmetrical. It is aligned transverse to effective winds and looks like connected crescents in rows, having open areas between them, see Figure 3. Christopherson furthermore claims that a transverse dune differs from a barchan in the way that a transverse dune only has one slip face, and results from relatively ineffective wind and abundant sand supply see Figure 4. How the two types of dunes move in relation to the wind direction is showed in Figures 3 and 4.

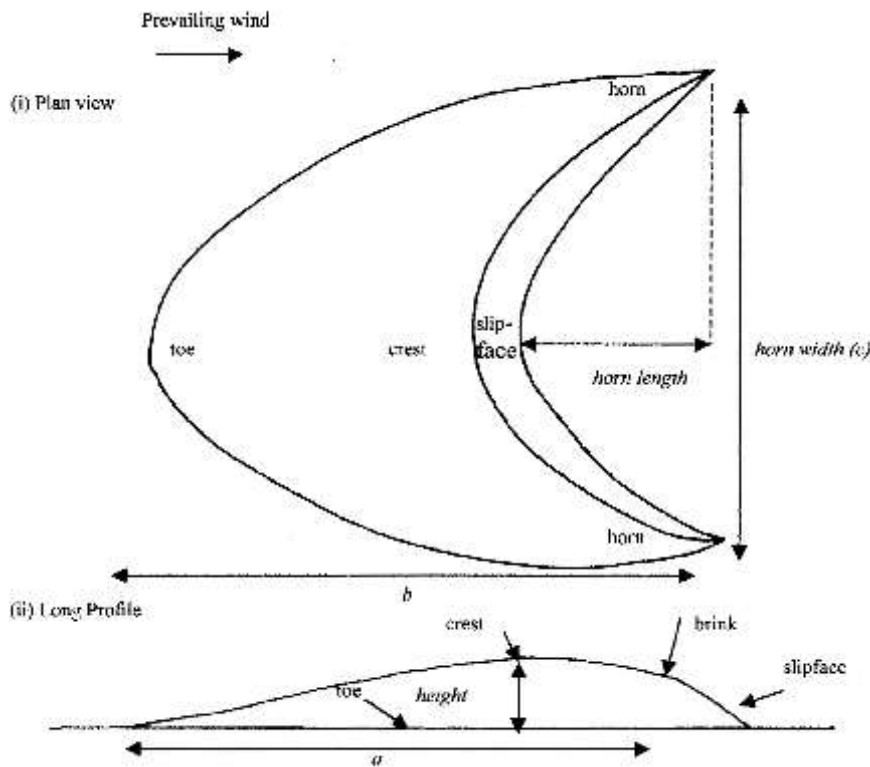


Figure 3. Barchan dune dimensions (Barnes, 1999)

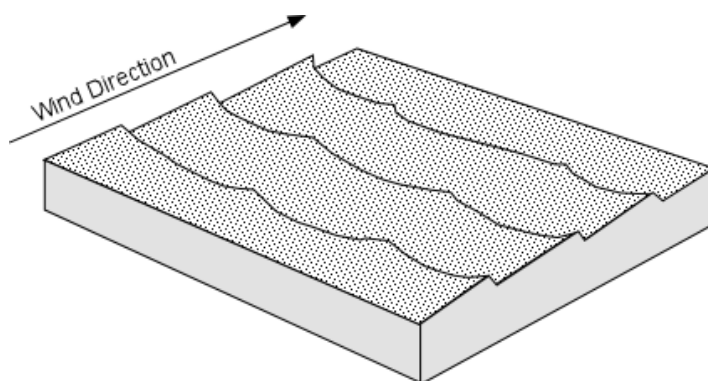


Figure 4. Transverse dunes (earthsci 2010, Internet)

Several studies on dune migration and sand encroachment have been carried out in different places of the world. Common for these areas is that they are classified as arid environments, which according to The Köppen Climate Classification System means that they receive precipitation less than $\frac{1}{2}$ the natural moisture demand (Christopherson, 2009). On the northern Alxa Plateau, Inner Mongolia, China, the conditions are in many ways similar to the ones on the west coast of Namibia. The desert consists of great sand dunes and sand sheets and the dunes are mainly barchans or transverse dunes (Yao et al., 2007). The area is therefore characterized by mobile sand and the populations living downwind is considered as being under a significant threat because of this (Yao et al). Misak and Draz (1997) provide a study on sand drift control of selected coastal and desert dunes in Egypt and state that “Sand encroachment causes hazards to farmlands, highways, population centers and other infrastructures” (ibid: p. 17). In their study they define three levels of dune migration: Severe dune migration, which is migration over 15 meters per year, moderate dune migration, which is 5-15 meters per year, and slight dune migration, which is less than 5 meters per year.

Defining sand and dust storms

In arid and semiarid regions, dust storms are a common natural recurrent (Orlovsky et al., 2005). The following paragraph is based on the work by Whittow (2000), in which he explains that the dust is brought up by strong, turbulent winds, which makes the dust form a cloud that behaves like a rapidly moving cold front. The dust cloud can elevate to several thousand meters high and can carry up to a hundred million tons of dust for up to 4000 kilometers. A sand storm differs from a dust storm in that the particles transported are greater in size, and therefore do not ascend to such a great height. In addition, sand cannot be transported such great distances as dust.

According to Xu (2005) human activity must be taken into consideration while studying the phenomenon of sand and dust storms. Land cover change by different types of land-use may lead to land degradation of the loose and fine materials that occur in arid environments. When aeolian erosion is enhanced, it results in a higher frequency of sand and dust storms. This generates a mechanism of positive feedback that “may accelerate the process of land degradation or desertification [...] Therefore, a study of the relationship between sand-dust storms and land degradation is of importance not only in theory but also in the practice of sand-dust storm control” (Xu, 2005, p. 280).

Longjun (2001) divides sand storms into strong sand storms and very strong sand storms. He states that “*Strong sandstorms* occur under conditions where wind speed is over (or equal to) 20 m/s and visibility is less than 200 m and *Very strong sandstorms (black wind)* occur when wind speed is over (or equal to) 25 m/s and visibility is less than 50 m” (Longjun, 2001, p. 216). His opinion is that over the last few years, sandstorms over large areas occur with increasing frequency, extent and scope.

The effects of aeolian sand on infrastructure on a global level

Berte (2010) highlights the power of migrating dunes, as he states that they can bury villages, roads, oases, crops, market gardens, irrigation channels and dams, thus causing major material and socioeconomic damage. In Iraq, there have been programs launched to halt the encroachment of sand dunes and to reduce the frequency of sand and dust storms. This is mainly because aeolian sand affects the infrastructure, including highways, main roads and feeder roads, railways and irrigation projects (Al Farajii, 2001). The sand often buries stretches of roads and channels, hindering traffic flow and increasing maintenance costs. The volume of sand that was needed to be removed from roads in Iraq in one year reached 180 000 cubic meters in the year 2000, with high costs as a consequence. Sections of the track within the railway system are frequently getting covered by sand, hindering train movement and causing accidents (ibid).

In the past 50 years, the need for more effective measures of sand control has become more important due to urban development and economic growth (Dong, 2004). In the Taklimakan Desert of China, aeolian sand was not seen as a possible threat to the society until petroleum reserves were explored and developed, and the place became an important industrial junction for the country. When the need for modern infrastructure became important, so did an establishment of aeolian sand control system. Blown sand can cause damage to roads in different ways, such as encroachment of moving dunes and roadside slip erosion. When the place became of economic interest, so did the interest of minimizing such damages (ibid).

Preventing and controlling aeolian sand

In his chapter on dune migration and encroachment, Goudie (2010a, p. 200-201) identifies four main techniques which are used in order to contain aeolian sand:

1. Endorse the deposition of drifting sand by devices such as ditches, barriers, and fences, and vegetation belts.
2. Enhance the transportation of sand by aerodynamic streamlining and surface treatments.

3. Reduce the sand supply through surface treatments (e.g. water spraying, chemical stabilizers, mulches), fences and vegetation strips.
4. Deflect the moving sand by using fences, barriers and tree belts.

When controlling mobile sand dunes, the main techniques are:

1. Sand dune removal by mechanical excavation and transportation to new location.
2. The dissipation of encroaching dunes by disrupting its aerodynamic profile by reshaping, trenching, or surface treating.
3. Dune immobilization using surface strips, fences, etc.

According to Goudie (2010a), these diverse techniques are not very successful, and the best adaptation would be to site and design engineering structures in order to allow the sand free movement. In addition, one alternative is mapping different dune types in order to observe their direction and mobility. Then it would be possible to arrange structures outside of risk-areas. Goudie (2010a, p. 201) notes that, "Avoidance may be better than defence".

In the Taklamakan desert, effective measurements such as checkerboards, fences, and netting were structured to protect dune encroachment on a major highway. In addition, studies in northwest Nigeria have shown that shelterbelts were the best solution. There has also been some success using chemical stabilizers and geotextiles. However, some devices are expensive and prohibited (Goudie, 2010a). A study by Qui et al. (2004) shows that the straw checkerboard technique decreases the sand flux intensity by as much as 95%, preventing wind erosion and causing sand to deposit. The straw checkerboard technique is made out of wheat, rice, reeds or other plants, and then positioned in a checkerboard pattern. Half of the straws are exposed, and the other buried in the sand. The technique is widely used in China and has several advantages, both in dune fixation as well as being environmentally friendly, not causing pollution. Qui et al. (2004, p. 463) note that, "On the whole, the straw checkerboard can be regarded as a very effective technique that can be widely used for sand dune fixation around the world". Another technique which is used in order to combat sand encroachment is by halting or slowing the sand movement (Berte, 2010). This is carried out by erecting fences which results in a buildup of sand, an artificial dune. According to Berte there can be two different types of artificial dunes. The artificial dune types are dependent on the positioning of fences in relation to wind direction. The first type is known as stop or check dunes. Stop or check dunes appear when a fence is erected directly across the course of the prevailing wind. According to Berte, this is the most common method in order of preventing dune encroachment. The second type, deflection or diversion dunes are made by deflecting moving sand in another direction of the prevailing wind. This is done by erecting fences at an angle of 120 to 140 degrees in relation to the wind direction. Berte claims that this method is not widely used since the solution mainly diverts the sand in another direction which could lead to encroachment in other areas, affecting settlements, crops or infrastructure.

There is a wide array of techniques in order to prevent aeolian sand from encroaching human society (Goudie, 2010a). It is important to observe rates of dune mobility, dune types and size in order to provide different methods. However, numerous techniques have met mixed success, and can be either costly or unattractive. These diverse prevention methods might also face challenges in the future since a warmer world will likely increase dune activity (ibid).

2.4 Climate change and the effects on aeolian sand

Goudie (2010b, p. 245) states that, "It is likely that global climate will change substantially in coming decades (IPCC, 2007) and will have a series of impacts on the operation of geomorphological hazards as a result of changes in temperatures, precipitation amounts and intensities, and soil moisture conditions". Some environments are more prone than others to react to climate change and these are

known as ‘geomorphological hotspots’. These hotspots will change crucially when thresholds are crossed, for example glaciers and ice caps will melt, dune and dust activity may change, and the permafrost will thin and retreat (ibid).

If climate change would cause soil moisture levels to decline due to changes in precipitation and/or temperature, Goudie (2010b) notes that there is a possibility that dust storm activity may increase in a warmer world. A study made in Xinjiang, China, shows an increase in desertification and the amount of dust storms in the past 50 years. This seems to be closely related to the increase in temperature, which directly has led to a decrease in humidity, making the aridity more serious (Wei et al., 2005). Wei et al. also stress that desertification is closely related to changes in the ecological environment due to human activity. Al Farajii (2001) claims that the worst aspect of desertification is the formation of shifting dunes, because of its effect on drainage and irrigation infrastructure, and the severe sand and dust storms which increase in frequency. Furthermore, Kassas (1995) stresses the difference between drought and desertification by stating that drought is a natural hazard and desertification is a degradation of land resources. The ongoing desertification is a result of natural and human factors combined (Wei et al., 2005). Dust storms are both a process that accelerates desertification and the result of desertification developed to a certain degree (Wei et al.).

On the matter of sand dune activity, Goudie (2010b) states that dune landforms are highly vulnerable to climate change. This is mainly because of the crucial relationship between vegetation cover and sand movement. For instance, Goudie (2010b, p. 252) notes that, “Some areas, such as the south west Kalahari (Stokes *et al.*, 1997) or portions of the High Plains of the USA (Gaylord, 1990) may have been especially prone to changes in precipitation and/or wind velocity because of their location in climatic zones that are close to a climatic threshold between dune stability and activity”. Detailed scenarios for dune migration due to global warming have been developed for the Kalahari in southern Africa. According to Goudie (2010b) much of the Kalahari is currently stable and vegetated. However, GCMs suggest that by 2099, the dune fields from South Africa to the south of Zambia and Angola to the north will be reactivated. Nevertheless, it is important to note that the methods and models used in order to estimate dune field mobility are still flawed and more research is needed (ibid).

Future climate change will have a direct impact on geomorphological hazards, whether there will be changes in frequency, distribution or intensity (Goudie, 2010b). At the same time, human population is both increasing and urbanizing. An increasing severity in natural hazards will therefore have a growing impact, making the human society more vulnerable to its environs (ibid).

3 Case study

3.1 Area Description

Absolute and relative location

Walvis Bay has an absolute location of 22°56'54.71"S and 14°30'31.53"E (Google Earth 2010, Internet). The town has a relative location in the coastal parts of the Namib Desert neighboring the Atlantic Ocean. It is the capital of the Erongo Region and is situated west of Windhoek, the capital of Namibia.

3.2 Physical geography of the Walvis Bay area

Climate

The Namib Desert covers more than 94 000 square kilometers of land and has an average annual rainfall of less than 50 millimeters per year, with the coastal zone receiving less than 15 millimeters

(Stoppato and Bini, 2003). The average annual rainfall varies depending on the position of measuring, and from year to year. Therefore it is often better to measure rainfall in terms of median than in average (Mendelsohn et al. 2009). The Namib Sand Sea, or as Jacobson et al. (1995) calls them, the High Wandering Dunes are secluded from the rest of the desert by The Great Escarpment, running south from South Africa and along Namibia's west coast. According to Mendelsohn et al. (2009) the reasons why the Namib sand sea is located on the west side of the Escarpment are of climatic and oceanographic manners. The heart of this complex climatic system that has created the sand sea over millions of years is named The Benguela Current. It carries cold water north from the South Atlantic Ocean and is driven by the South Atlantic Anticyclone. The cyclone consists of strong cold winds that stop moist warm air coming from the north by the ITCZ to reach the West Coast (ibid). According to the New Era website (2010, Internet) this phenomenon creates the coastal fog which is characteristic for Walvis Bay, bringing in frequent moisture to the coastal area, moderating the heat. The foggy zone of the coast brings salty air inland from the ocean, and the fog precipitation is more than 200 % of the annual average rainfall (ibid).

According to the windfinder website (2008, Internet) the wind measured at Walvis Bay Airport comes, most frequently, from west, west southwest, west northwest and southwest. The average wind speed measured at Walvis Bay Airport over the year is 8 knots. This gives the effect, according to the weather station's own definition, of "Leaves and smaller twigs in constant motion" (windfinder 2008, Internet). However, during the winter months, the wind direction often changes into easterly often stronger winds, increasing the risk of great dust storms travelling from the inland (New Era 2010, Internet).

Dune areas and type of dunes

It is possible to recognize two major types of dunes in the area closest to Walvis Bay, transverse dunes and barchans. These two types are of different character regarding formation, the way they move and their ability to move at all, as explained in chapter 2.3.1, see Figure 3 and 4. Because of the strong, salty south westerly winds from the Atlantic Ocean, the dunes are devoid of plants (Mendelsohn et al., 2009). The following paragraph is based on the work of Goudie in Seely and Pallett (2008) who states that barchans are the most common dunes in the Walvis Bay area. They have a crescent shape and move individually with the two horns facing the direction of the movement. Barchans have steep slopes, vary in size, and can grow quickly if the sand supply is great. Around Walvis Bay they have an average moving rate of 12.4-14.6 meters per year and their height is usually around eight meters.

Kuiseb River and its delta

The Kuiseb River stops the northward march of the main dune field (Mendelsohn et al, 2009), working as a barrier to the aeolian transport of sand, see Figure 5. North of the Kuiseb River bed the landscape changes dramatically, the majority of the sand being replaced by igneous and stony gray metamorphic rock (Stoppato and Bini, 2003). The Kuiseb River does not carry surface water all year round, but only during the rainy season. Instead, fresh water is mainly extracted from its alluvial aquifer (New Era 2010, Internet).

Walvis Bay has been vulnerable to floods of the Kuiseb River due to the town's location on the delta. In the prevention of future floods, trenching took place around Walvis Bay to divert floodwater in the 1960s, making it almost impossible for the run-off water to reach the ocean Logan (1960).



Figure 5. Kuiseb River Delta after the diversion 1962 (Jacobson et al., 1995)

3.3 The town of Walvis Bay

According to Dobson (2010) Walvis Bay is the only deepwater harbor situated between Lüderitz and Angola. The location of Walvis Bay has therefore been of great strategic importance for Namibia. Based on the New Era website (2010, Internet), Walvis Bay has a population of 43700 inhabitants, making the town one of the most urbanized places in Namibia. The town is also a major economic driver for the Erongo region which is mainly due to the port of Walvis Bay (ibid).

Infrastructure of Walvis Bay

The following paragraph is based on the Namport handbook (2010) which states that the Namibian Ports Authority, known as Namport, is a state-owned corporation which manages and maintains the ports of Namibia. According to the Namport handbook, the port of Walvis Bay offers the shortest route to and from the SADC region, as well as the European and American regions. The port is also one of Africa's most efficient and best equipped, and has a capacity to handle more than five million tons of cargo per annum. In addition, the port is linked to Namibia's air, rail and road network which suits transportation services to landlocked countries in southern Africa. These services are available through the Walvis Bay Corridor Group, WBCG, a company coordinating international trade with the SADC region.

Another main actor is the Walvis Bay International Airport, located 12 km east of the town (Namport handbook, 2010). The airport serves both private and commercial markets, offering daily flights with Air Namibia and the South African Express Airways. The destinations are mainly Windhoek, Lüderitz, Oranjemund, Cape Town and Johannesburg (ibid).

The rail and road network in Walvis Bay and Namibia is linked to the SADC region's hinterland (Namport handbook, 2010). The road network in Namibia is divided into national and municipal management, where the national roads are maintained by the Road's Authority (Road's Authority 2010, Internet). Based on the Road's Authority website, the expansion of the road transport network has contributed to the economic growth in Namibia as well as in the SADC region. The primary purpose of the Road's Authority is, "To manage the national road network so that it is safe and efficient" (Road's Authority 2010, Internet). In Walvis Bay, the road network is both national and municipal. The national roads maintained by the Road's Authority are the B2 road, heading north to Swakopmund, the C14 road, heading east towards the airport, and the D1984 road behind Dune 7 north to Swakopmund, see Figure 1. On a municipal level, roads and streets within the town are maintained by the municipal section of Roads and Building Control (Municipality of Walvis Bay 2010, Internet).

The railway network of Namibia and Walvis Bay is owned and maintained by the private company Transnamib. On the Transnamib website (2010, Internet) they state that "Specialising in the transportation bulk and containerized freight, TransNamib is the premier transport operator in Namibia. It utilizes a combination of rail and road transport to deliver its services" (Transnamib 2010, Internet). In Walvis Bay, the Transnamib railway station is located near the harbor and the railway runs east through the town, inland along the C14 road towards the airport, turning north towards Swakopmund at Dune 7, see Figure 1.

3.4 Previous studies on the study area

According to Le Roux (1974), the dune area south of the town border, between the lagoon to the west and the southern arm of the Kuiseb River to the south and east, is threatening the town of Walvis Bay, see Figure 5. That is due to the constant south-westerly winds, building up fast north-easterly moving barchans. To protect the town from sand encroachment, dune barriers with the aid of poles were built during the 50s to 70s, conducted by the Department of Forestry (ibid). All houses in Walvis Bay which were built before the turn of the century 1800-1900 were built on piles, which protected them from shifting sand (Stengel, 1961). Those structures disappeared sometimes before the 60s, when new housing was built, made them more vulnerable to shifting sand (ibid). It is possible to note that small individual dunes make day by day progresses whilst migrating through the town (Logan, 1960). But by the implementation of 14 kilometers of artificial dunes along the southern town borders, the issue of aeolian sand within the town borders was reduced for some time in the beginning of the 60s (Stengel, 1961). Thirty years later, Slattery (1990, p. 5) states that the occurrence of barchans in the Kuiseb River delta "is of sufficient density to present a continuous hazard to the inhabitants of the region".

According to an anonymous source¹, the irregular flows in the Kuiseb River have always stopped sand dunes south of the delta from moving northwards and by that protected Walvis Bay from major sand encroachment. But due to the diversion of the river and the building of dams in the 60s floods appear less frequent, which has led to an increase in the amount of sand that can be carried northwards towards Walvis Bay, see Figure 5. An unsustainable outtake of fresh water from the river and an over-exploitation of the delta have also led to a decrease in floods, breaching the river's role as a sand-breaker. The loss of vegetation due to the decreased amount of water reaching the ocean has also increased the amount of sand being able to move northwards. If unsustainable outtake of water continues, and the dams are not to be opened, there is a risk that the Kuiseb's role as a sand-break barrier might be breached. Stengel (1961) argues that floods only occur during years with heavy rains, whilst sand encroach the town regularly every year, turning shifting sand into the greater issue of the two.

¹ In order to protect our reference, this source will remain anonymous. Contact authors if necessary.

Barnes (1999) points out the importance of the grain size for the movement of dunes, with the following paragraph based on her work from 1999. The grain size of the dunes within the Kuiseb is coarse to medium sand, which is a more poorly sorted material than observed in dune areas in the rest of the world. The dunes proximity to their sand source could be the explanation to the coarseness sorting of the material, since the material has been transported over a smaller distance. Therefore, it has not been exposed to erosive aeolian processes and has not been reduced in size. For that reason, the grain size of the inland linear dunes is often smaller than the coastal dunes and, in addition, the material is well sorted.

Observations show that dunes south of Walvis Bay have moved as coherent bodies from 1961 to 1999, and without any control measures, with the speed the dunes are moving at today, the southern suburb of Walvis Bay will be covered in sand within 30 years (Barnes, 1999). Previous studies have shown an average migration rate of 13.5 meters per year between 1961 and 1988 (Barnes, 1999). However, aerial photos show that there has been a marked increase in dune movement during those years (Slattery, 1990). Between 1976 and 1988 the dunes moved 10-20% faster than between 1961 and 1976 (Barnes, 1999). In 1988, the measurement of barchans' movement within the Kuiseb River delta was compiled during a field programme, which resulted in a linear relationship between dune movement and height of the dune (Slattery, 1990), hence some studies show that increasing dune height decreases the rate of movement (Barnes, 1999). Furthermore, rate of movement is negatively correlated to dune area (Barnes).

Studies on average annual wind direction indicates a change to more south-southeasterly winds between 1976 and 1988 and since 1997, more south-southwesterly before and between those periods, making the dunes change direction of movement within those periods (Barnes, 1999). Similar observations have been carried out for the coastal region of South Africa (ibid).

3.5 Natural Disaster Risk Management in Namibia

The following paragraph is based on the state report National Policy for Disaster Risk Management in Namibia (2009). In Namibia, the government is responsible for disaster risk management and the NDRM policy aims to, "Minimise the loss of human life, property and damage to the environment from hazards of natural, technological and ecological origin" (p. 2). The report states that the policy has improved capacity for early warning, tracking, monitoring and distributes information on different phenomenon causing disaster events. The Namibian NDRM identifies hazards such as floods, drought and desertification as interrupting human development. Furthermore, the policy reports that in Namibia, disasters have had two reasons (National Policy for Disaster Risk Management in Namibia, 2009, p. 44), firstly, "the degree of exposure of people, infrastructure and economic activities to a physical event or hazard", and secondly, "the vulnerability of those exposed to the hazard or shock". In addition, the report notes that there is a need for awareness of hazard characteristics and their relation to the environment. The policy states that hazard mapping is of great importance in the NDRM in planning and activities.

On the matter of climate change, Namibia is a minor contributor of greenhouse emissions (National Policy for Disaster Risk Management in Namibia, 2009). However, the country is one of the world's most vulnerable countries to the effects of climate change. The predicted effects of climate change in Namibia includes a temperature increase in 2-6 degrees Celsius by 2100 and an increase in rainfall of 30 mm per year in some areas, and a decrease of 200 mm lower than the present rainfall average in other areas (ibid).

3.6 Results of interviews

The effects of aeolian sand on the railway network

According to a train inspector at the Transnamib railway station in Walvis Bay (2010, Informant), aeolian sand is a great problem for the railway network. At present time Transnamib handles 95% of goods, with most transported to Windhoek. When sand encroaches on the railway, the traffic may be delayed by four or five hours, resulting in economic consequences for the company. According to the train inspector it is the employees of Transnamib who are responsible for the maintenance and clearing of sand on the tracks. Since dunes might migrate onto the tracks, both man power and machinery is necessary when removing sand.

The effects of aeolian sand on the airport

The following paragraphs are based on an interview with the Regional Manager of the Walvis Bay Airport, Booysen (2010, Informant). The Walvis Bay airport is owned by the Namib Airport Company and hosts mainly passenger flights. Today, 86% of the flights are international and 14% domestic. However, the airport anticipates handling more cargo transports in the future, managing a mix of passenger flights and cargo flights.

According to Booysen (2010, Informant), the impact of aeolian sand on the airport itself is not major. Since the airport is constructed without obstructions on the runways the sand is not able to deposit and cause build-ups. However, due to strong winds, heavy dust may encroach onto runways, and the airport staff has to sweep the dust with machinery. On the matter of air traffic, Booysen claims that sand storms may cause delays due to decreased visibility. Sand storms are not very common, however there is a risk when the strong east wind blows. In addition to decreased visibility, aeolian sand might also affect the airplane engines. These effects are not costly for the airport itself since their purpose is to provide landing areas for the airplanes. Furthermore, the C14 road towards the airport is often affected by sand encroachment and since it is a national road, it is the Road's Authority who is responsible for maintenance.

The airport is expanding and reconstruction of the terminal will begin in 2011 and aims to be finished by 2012. Booysen (2010, Informant) states that the airport is expanding since the whole Erongo region, and particularly Walvis Bay is expanding. During construction the matter of aeolian sand will be taken into consideration. As mentioned above, a goal for the airport is to handle more cargo flights and one particular goal is to increase the fish export. The fish would then be transported from Walvis Bay to the airport on the C14 road. Even though this would lead to more traffic, Booysen argues that the road will not become more vulnerable since the Road's Authority would continue with their regular maintenance.

The effects of aeolian sand on the port of Walvis Bay

According to Eiman (2010, Informant), a coordinator at Namport, Namport is a privately owned authority that stands on its own but operates under the government. The port is of great importance for Walvis Bay and the economic growth for Namibia. Eiman claims that aeolian sand does not affect the port itself, but on days with strong winds, sand storms may cause decrease visibility. Gelderbloem (2010, Informant), a deputy port engineer, states that aeolian sand is a hazard for the town of Walvis Bay. Since the sand constantly blows onto roads and buildings within the port area, the sand has to be managed. The sand is then swept away on a routine basis. Even though Namport spends a lot of money on the sweeping process, it is the salt which aeolian sand transports that is considered as the main problem in the port. Since aeolian sand deposits on steel constructions, the sulfides in the salt are degrading the constructions, making them rust. Therefore, Namport have constructed buildings in concrete with salt resistant paint. This has led to an expensive maintenance of structures within the port area. Gelderbloem argues that the engineers need to use a durable concrete mix during construction in order to stop sand from degrading the material. The concrete mix is expensive, but

necessary. In addition, Namport has also started changing all window frames from wood to aluminum since the sand is getting through the wooden frames into the buildings.

Outside of the port area, Gelderbloem (2010, Informant) states that the Walvis Bay municipality is responsible for maintenance of streets within the town, and the Road's Authority outside of the town borders. Since the transportation of goods from the port is mainly on roads, a good communication between the actors within the road network is of great importance. The reason as to why most of the goods are transported by trucks and not train is that the railway is in bad condition. However, Namport is lobbying a renovation of the tracks in order to transport goods by train. Gelderbloem states that the whole infrastructure network has to be well maintained and connected in order to expand the industrial sector in Walvis Bay. This is especially important since both the port and the airport are expanding. Namport has plans of bringing larger vessels in the future (Eiman 2010, Informant), and Gelderbloem (2010, Informant) claims that Namport's expansion is supported by the Namibian government since the goal is to make Walvis Bay Namibia's primary industrial town. Today, the capacity of the roads is enough to transport cargo from the port. Still, the B2 road to Windhoek from Walvis Bay via Swakopmund is currently being upgraded. However, the Namport authority would rather use the district road, D1984, behind Dune 7, see Figure 1, since Walvis Bay is expanding accommodation along the coast. The current heavy traffic on the B2 road will not be suitable nor attractive along the coast and therefore Namport is lobbying to get D1984 paved. This will directly lead to more traffic on the C14 road which according to Gelderbloem is vulnerable to sand encroachment.

Since the port of Walvis Bay is currently expanding, more roads within the port area are being paved. This will add another four hectares of land usable for transportation. On the other hand, this results in an additional four hectares where sand needs to be swept away. However, Gelderbloem (2010, Informant) does not consider the port to be vulnerable to aeolian sand since prevention methods are used when expanding.

The effects of aeolian sand on roads

According to a road inspector at Road's Authority (2010, Informant) in Swakopmund, the C14 road between Walvis Bay and the airport is the most exposed road to aeolian sand, see Figure 1. It is a stretch of 7 km from the town and eastwards which is the most problematic, and when there are strong south westerly winds the road can be covered in sand within 30 minutes. Therefore, the inspector stresses that it is only safe to drive at about 20 kilometers per hour, since the layer of sand can get up 150 millimeters thick, which presents a serious accident risk for drivers. If a lot of sand is blown onto the road, it can form dunes which have to be removed by a bulldozer. The bulldozer gathers up the sand and dumps it on the northern side of the railway, see Figure 11. Since the C14 road is national, the responsibility for maintaining it is with the Road's Authority office in Swakopmund. However, the inspector points out that there is a contractor who maintains the road on a daily basis, stationed in Walvis Bay. Only if there are strong winds, and a lot of sand encroaches onto the road, the road inspector from Swakopmund will need to assist. The road inspector has been working at the authority for about six years, and he insists that the C14 road has been a daily problem ever since, but he is not able to tell whether there has been a change in the amount of aeolian sand over the years. The Road's Authority does not use prevention methods such as fencing or planting green belts, since they argue that it is a short term solution that might cause greater problems in the future. When enough sand has gathered up on the south side of the fence it will eventually blow over the ridge and on to the road anyway, the inspector stresses. Instead, he argues that stabilizing the dunes is a better prevention method in the long run, but that is very expensive. However, if you compare the costs of removing the sand over a longer period of time, he stresses that stabilizing the dunes is the most economic solution to the problem.

According to Louw (2010, Informant), the road and building engineer at the Walvis Bay Municipality, the diversion of the Kuiseb River in the 1960s to protect the town from flooding, has turned the former green area in the outflow of the Kuiseb into a dune belt. Since the ground is no longer damp and

cannot bind the sand, the dunes start to encroach onto the road, and Louw's opinion is that the problem needs to be solved within five years or so if the dunes are not to continue to emerge. The solution would have to be to let the water in the Kuiseb reach the sea again and a decision needs to be taken soon. According to Louw, it is the diversion of the Kuiseb River that is the reason behind the formation of new dunes in the area, not the ongoing climate change. To consolidate that argument, he refers to the case of the town's waste water, which some years ago was dumped east of the town border and south of the C14 road. Later this was forbidden since it led to problems with mosquitoes and today the waste water is led in pipelines and dumped further to the east. This has now led to an increase in vegetation growth within that area which now binds the sand. However, Louw has been working with the management of aeolian sand for twenty years, but since the amount of sand that is removed has not been measured on a regular basis, he finds it hard to tell whether there has been an increase in the amount of aeolian sand.

For the municipality of Walvis Bay, the dunes south of Meersig are the most problematic, according to Louw (2010, Informant). In 1977 the dunes were mapped, which made the municipality take the decision of flattening the dunes by the use of machineries, and to put coal on top to stop the migration of the dunes. When the coal mine was shut down, coal was replaced by gravel. In the following 30 years, no more flattening was needed to be done, but in recent years new barchans have formed and the sand is migrating again and encroaching on the town. South westerly winds pick up the sand and carry it into the town of Walvis Bay, and therefore other prevention methods besides flattening needs to be used. The municipality puts up fences 50-60 meters out of the range of houses to stop the sand from encroaching. The last 15-20 years, they have also started to plant vegetation for the same purpose, so called Green Belts. Louw points out that almost all visible vegetation within the borders of Walvis Bay is either planted or moved there from other places. The sand that still manages to get into the town, which is a great amount according to Louw, needs to be moved away by tractors and bulldozers. Louw has five teams, with 20 people in total, who work with sand treatment and the physical removal of sand on a daily basis.



Figure 6. Sand removal after a sand storm (Louw, 2010)

Whether aeolian sand is considered a serious problem or not for Walvis Bay is always a matter of definition and a question of what is acceptable, according to Louw (2010, Informant). The people of Walvis Bay might think that a 30 millimeter layer of sand on the streets is acceptable, but Louw's teams should not accept more than zero millimeters. Whether the town is vulnerable to aeolian sand is also a matter of definition and changes with how the sand is managed, Louw argues. Three years ago the town expanded to the south, an area where there is no vegetation and the dunes are directly to the south. Within a few years the society will have adapted to the situation, the planted green belts will have grown and the dunes will have been flattened and stabilized, making the vulnerability progress in cycles, Louw argues.

More and more money is being spent on landscaping in town which is good for the sand management, and there is a land development project going on today within the municipality, but the streets are always difficult to manage since it is impossible to put up fences or green belts on the streets, Louw (2010, Informant) stresses.

Within the town borders, the municipality has the whole responsibility for sand management, which is costly. Louw (2010, Informant) stresses that aeolian sand should be of national concern, given the industrial and economic importance of Walvis Bay for the country, but lack of communication between the different levels of governance complicates the management. Also the road inspector at Road's Authority (2010, Informant) agrees upon this, stressing that lack of communication between actors is their biggest concern regarding sand management.

There has been a risk and vulnerability assessment done regarding flooding of the Kuiseb River but none on aeolian sand, nor has there been a mapping of the dunes done recently. Instead, the municipality relies on everyday observations and according to Louw (2010, Informant) they do not cooperate with researchers regarding this manner. Even though there are written and accepted theories about how to handle aeolian sand, there is no global cooperation regarding the issue. Instead, all the work is being done on a local level, Louw stresses.

Table 1. Sand management budget for roads by the Municipality of Walvis Bay in Namibian Dollars (Louw 2010, Informant)

General Expenses	Budget 2010	Actual 2010	Budget 2011
Sand Removal – Green Belt	0	2 556	0
Sand Removal – Streets	2 396 000	2 100 211	2 500 000
Total	2 396 000	2 102 767	2 500 000

Table 2. Sand management budget for town and townlands by the Municipality of Walvis Bay in Namibian Dollars (Louw 2010, Informant)

General Expenses	Budget 2010	Actual 2010	Budget 2011
Control of Sand Ingress	600 000	320 400	620 000
Dune Stabilization	600 000	607 362	660 000
Green Belt	320 000	262 471	350 000
Sand Removal – Green Belt	400 000	177 308	400 000
Repairs	-	-	-
Fences	300 000	182 189	330 000
Total	2 220 000	1 549 730	2 360 000

In order to acquire information on the effects of aeolian sand on a national level, we interviewed Schommarz (2010, Informant), the Divisional Manager of Maintenance at Road's Authority in Windhoek. Schommarz identifies Lüderitz and Walvis Bay as areas which are prone to be affected by aeolian sand. In Walvis Bay, the B2 road and the C14 road are the ones most affected by encroaching sand. Additionally, Schommarz states that Transnamib is affected by encroaching sand. However, the maintenance of aeolian sand is easier in Walvis Bay than in Lüderitz since the wind is always blowing in the same direction. In Lüderitz, sand dunes may encroach national roads over a night, while the Road's Authority is able to observe dune migration in Walvis Bay. Nevertheless, Schommarz claims that aeolian sand is a temporary problem with temporary solutions. The matter in Walvis Bay is currently maintained by locally situated contractors. According to Schommarz, sand removal costs “a few dollars”, and methods such as dune stabilization are simply “working for time being, until nature

takes over". Currently, there is no surveillance of dune migration and the maintenance is a daily process. However, Schommarz argues that one solution to the problem is lifting the roads on gravel in the same way as the railway line parallel to the C14 road. This would decrease the speed of aeolian sand and prevent build-ups. This adaption is mainly considered for the C14 road and the D1984 road. Since the Road's Authority has plans to surface the D1984 they are able to lift it up at the same time.

According to Schommarz (2010, Informant) the Road's Authority cooperates with municipalities and major actors within the infrastructure network. The main objective is to follow certain standard rules and regulations. However, Schommarz argues that he has an old road network to maintain and if the port were to expand, he would need more funding. The question is then if Namibia can afford a larger and modern road network. If a town was to expand beyond town borders, Schommarz claims that the Road's Authority prefers to keep the national road network as one grid. Therefore, national roads can remain within municipal borders, but no municipal roads within the national road grid. Even if national roads would be situated within municipal borders it is the Road's Authority responsibility to maintain those roads. Currently, Road's Authority has four regional offices with engineers and contractors spread out in Namibia. There are no priorities for offices situated in areas which are exposed to aeolian sand and every regional office receives the same maintenance budget. Nevertheless, Schommarz claims that the Road's Authority faces more challenges than the municipalities since the Road's Authority have few contractors covering larger areas.

The effects of aeolian sand on the expansion of Walvis Bay

According to Hitula (2010, Informant), the town planner of Walvis Bay, the municipality has several expansion plans for the town. There are plans of constructing a heavy industrial area east of Dune 7, and a light industrial area south of Narraville, see Figure 1. Since the plan is to make Walvis Bay Namibia's main industrial town, the city town planners are developing the C14 road. They also plan to connect the C14 road to Swakopmund. An expansion of Walvis Bay is needed since the town has a high population influx of economic immigrants. Nevertheless, Hitula claims that expanding in the desert is problematic. Since the wind is constantly blowing, the town planners' face challenges with aeolian sand and they have to construct rapidly. At the moment the municipality is considering how to remove the sand and to keep it away. According to Hitula the areas which are most prone to dune and sand encroachment are Kuisebmond, south of Meersig and the C14 road. The C14 road can be covered by sand over a day. The maintenance of the dunes and aeolian sand is costly, and the town planners are therefore considering how to adapt to the sand. One way is to construct the roads in curved structures. Furthermore Hitula states that if Walvis Bay would expand east of Dune 7, the maintenance of the C14 road would be sorted out once the expansion is finished. However, when town lands expand beyond municipal borders, there is a degradation of roads in which a national road becomes a municipal street.

In addition, Hitula (2010, Informant) claims that there is a conflict of interest when Walvis Bay plans to expand. On one hand, the town of Walvis Bay wants to expand and needs to move into the dunes, on the other hand there are interests in conserving the dune environment. Hitula states that one solution might be the "compact city concept" which would make Walvis Bay dense. However, densification faces its own challenges due to cultural reasons. People do not feel as if they own land when living in apartments. Nevertheless, Hitula states that in the end they "can only work with the land they got".

Municipal responsibilities, David Uushona

David Uushona is one of the managers of the Department of Water, Waste and Environmental management at the Municipality of Walvis Bay. Uushona (2010, Informant) discusses the Walvis Bay Local Agenda 21, which is a whitepaper about environmental management that is to be fulfilled by 2015. It consists of four headlines:

1. Environmental Policies and Strategies in Walvis Bay Municipality

2. Walvis Bay Coastal Area
3. Environmental Funds and Tariffs
4. LA21 Micro Projects in Walvis Bay

Uushona (2010, Informant) stresses that within the Local Agenda, there are action plans for the lagoon, the bay and the harbor. The action plans consist of investigations on how to stop those areas from silting up, since such a happening would be a major problem for the town. Because of that, aeolian sand is an everyday issue for Walvis Bay. Still, in the action plan there is no headline about sand management in general, and none on how it should be handled on land, Uushona argues. Therefore, the office of environmental management does not work with issues regarding aeolian sand and its effects on infrastructure and development. However, Ushona highlights the importance of sustainable development in such a sensitive environment as the sand sea where Walvis Bay is located, but there are many challenges to management activities. He argues that there are resource constraints, low awareness levels amongst the people, migration and urbanization which lead to major expansion of the town and possible conflicts/duplicating efforts within the different actors. Then there is the issue of climate change and desertification, which is not taken into consideration while expanding different human activities within the area according to Uushona. The UN wants to link wind data and the amount of aeolian sand in the area, but there are not enough financial resources to fulfill such requirements on a local scale, Uushona argues.

A researcher's perspective, interview with Mary Seely

According to Seely (2010, Informant) sand encroachment is a natural phenomenon and not a problem per se. However, it is a process that Namibia has to adapt to. Even though the Erongo region, and the town of Walvis Bay, is the most affected area of sand encroachment, Seely believes that the phenomenon affects Namibia on a national level. Communication of actors is therefore of great importance. However, Seely claims that communication between actors is a main problem in the whole of Namibia, and reasonably in Walvis Bay as well. For instance, a lot of money is being spent on monitoring and maintenance of roads instead of long term solutions such as constructing a road behind the dunes.

On the matter of dune migration, Seely (2010, Informant) states that the Barchans in the Walvis Bay area, especially around the C14 road, can move very quickly on windy days. When sand encroaches on the road, Seely claims that situation could be managed in a more effective way. For instance, if one would clear a larger dune area south of the town, one could maintain that area instead of maintaining the issue on a daily basis. It would be less costly to prepare for hazards than coping with them. In addition, Seely states that there used to be a green area 50 years ago along the C14 road. Today, the vegetation is gone and the dunes have taken over. The main reason for an increased dune activity, is because the Kuiseb River no longer flows through Kuisebmond. However, if the water would be able to runoff in the Atlantic Ocean, the risk of floods would increase, Seely argues.

3.7 Result of field observations

In field, we were able to observe the effects of aeolian sand on a daily basis. First, we studied the dune area south of Meersig. When we walked to Meersig, we noticed how sand was spread out on streets within the Walvis Bay town borders, see Figure 7. We also observed a marked difference between main streets and smaller streets with less traffic, the main streets being cleared from sand while the smaller ones were not. In the housing areas, there was a lot of planted vegetation which was regularly irrigated. The further south of the town we went, the more vegetation seemed to be planted.

Once in the dune area south of Meersig, we observed fencing and green belts, two prevention methods used in order to halt dune migration, see Figure 8.



Figure 7. Sand on the streets of Meersig. Photo by Mattias Bovin (2010)



Figure 8. Green belts and fencing south of Meersig. Photo by Mattias Bovin (2010)

Some fences had caused build-ups of sand, see Figure 9, and some had been shattered. In addition, the dunes situated closest to the housing in Meersig had been flattened or covered by gravel. However, in between the stabilized dunes we noticed how new, small Barchan dunes had formed, see Figure 10. We were also able to find dumped sand consisting of mixed material behind the fences. This sand was probably excavated in order to build new housing.



Figure 9. Sand overtaking fences south of Meersig. Photo by Mattias Bovin (2010)



Figure 10. Barchan dune formation south of Meersig. Photo by Mattias Bovin (2010)

Along the C14 road we were able to observe how sand was maintained by mechanic excavation, see Figure 11. The dunes situated parallel of the C14 roads were at some places located 100 meters from the road and at other places 5-10 meters from the road. At one place, we noticed how sand encroached on the road, see Figure 12. In addition, we observed how sand had caused build-ups onto the railway line, some meters north of the C14 road. Distinct from the C14 road, the railway line had been lifted for approximately 1,5 meters of gravel. Unlike the area south of Meersig, no dunes along the C14 road had been treated or stabilized.



Figure 11. Mechanical excavation of sand dunes along the C14 road. Photo by Mattias Bovin (2010)



Figure 12. Sand encroachment on the C14 road. Photo by Mattias Bovin (2010)

3.8 Results of GPS mapping

The following maps are the result of GPS mapping in three different areas in Walvis Bay.

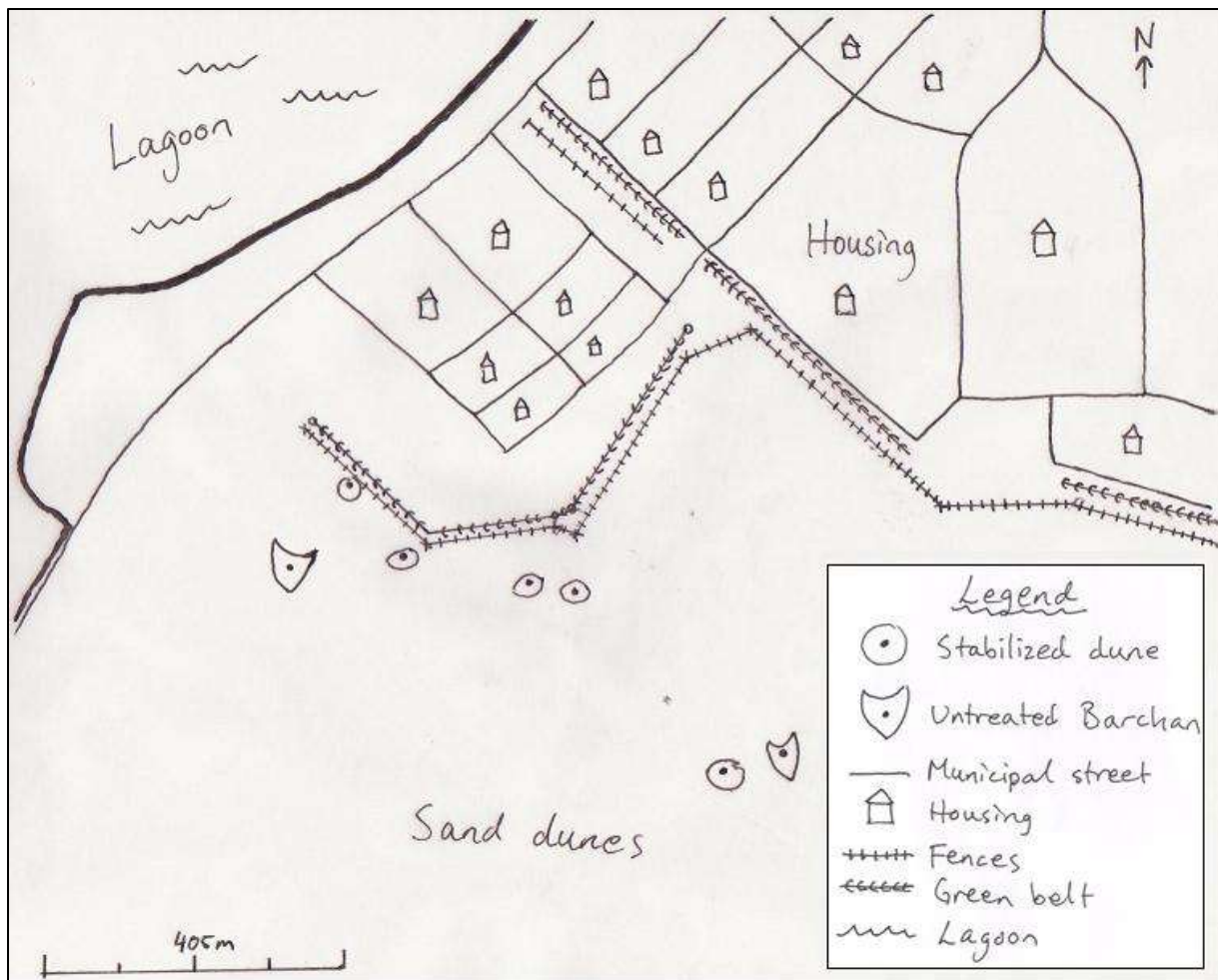


Figure 13. Map of the dune area south of Meersig (Bovin & Jonsson, 2010)

Figure 13 is a mapping of the area south of Meersig, see Figure 1. The map presents stabilized dunes, new barchans dune formations and different prevention methods.

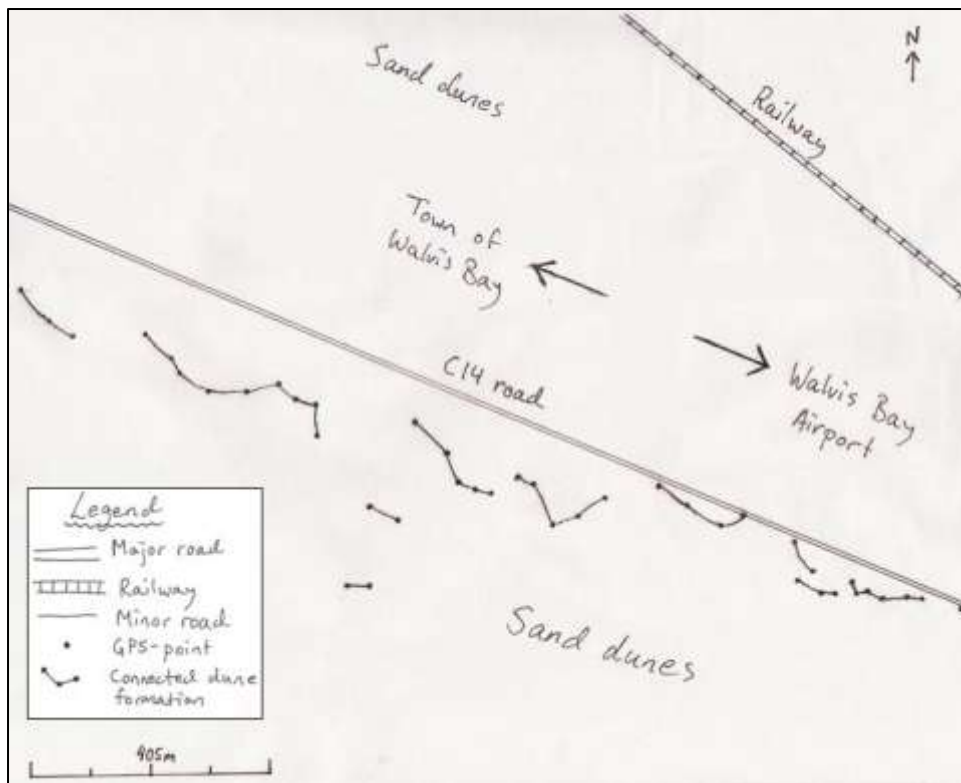


Figure 14. Map of the dune area south of the C14 road closest to Walvis Bay (Bovin & Jonsson, 2010)

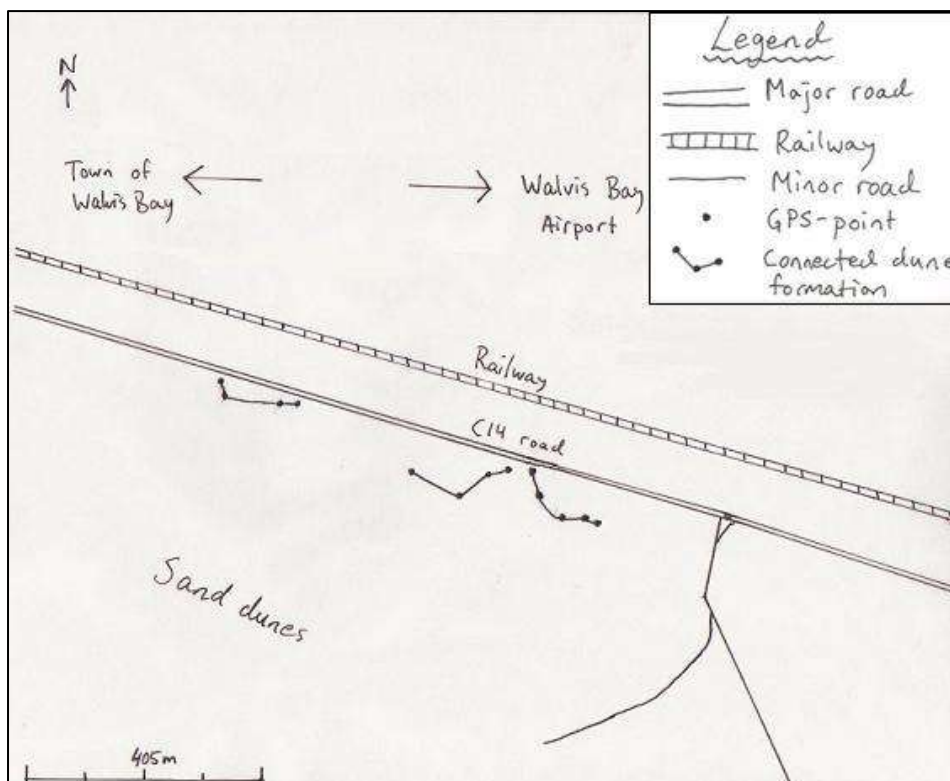


Figure 15. Map of the dune area south of the C14 road closest to the airport (Bovin & Jonsson, 2010)

Figure 14 displays an area of the C14 road closest to Walvis Bay, and Figure 15 show an area closest to Dune 7, see Figure 1. The maps present the position of sand dunes situated next to the road.

3.9 Study of maps and aerial photos

In the map from 1981 (2214CD &DC WALVISBAAI 1st edition, 1981), land cover south of the C14 road is characterized as consisting of trees and bush. The map from 2003 (2214 Walvis Bay 3rd edition, 2003) classifies the same area as consisting of shifting sand dunes. The vegetation cover is still visible in the aerial photo taken in 1976, but not as much in 1997. In the satellite image in Google Earth from 2008 (2010, Internet), there is still some vegetation, but there are mostly sand dunes.

Furthermore, the aerial photo taken 1944, displays the area today known as Meersig, which was not built in the 1940s, consisting of wetlands. In 1976 and 1997 Meersig has been constructed and there are no signs of wetlands. Based on the municipal map from 1977 (Louw 2010, Informant) depicting sand dunes in Walvis Bay, all the dunes closest to the town have been stabilized. The sand dunes south of the C14 road have not.

3.10 Study of weather data

The results of collected weather data are presented in the diagrams below. The diagrams are compilations of monthly measurements displayed in years. The years with no piles lack data. Precipitation is presented in median since there are great fluctuations in rain between the dry and wet seasons. Presenting in average would therefore be deceptive. Temperature and wind data are displayed in annual average.

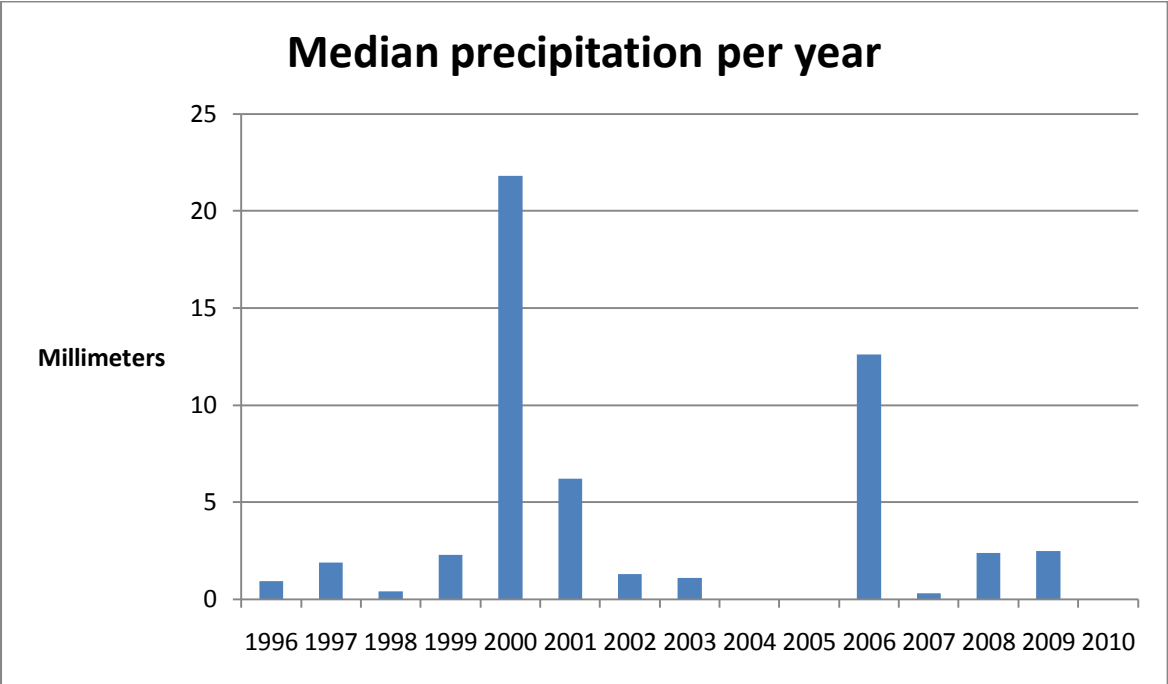


Figure 16. Median precipitation per year, compiled of monthly measurements (Bovin & Jonsson, 2010)

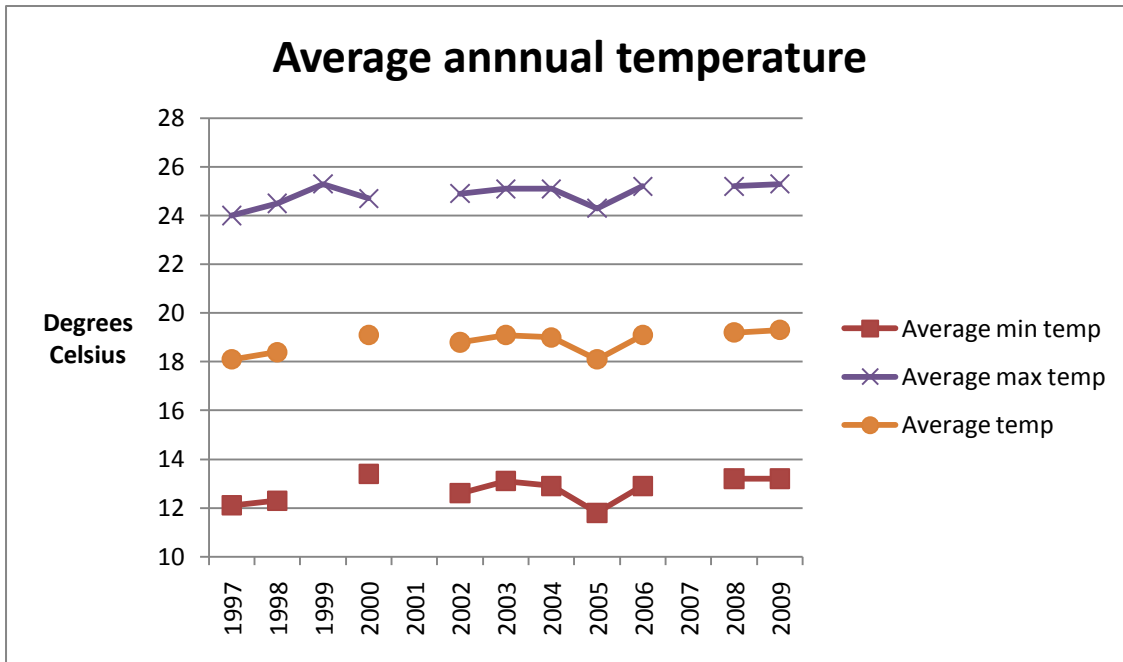


Figure 17. Average annual temperature (Bovin & Jonsson, 2010)

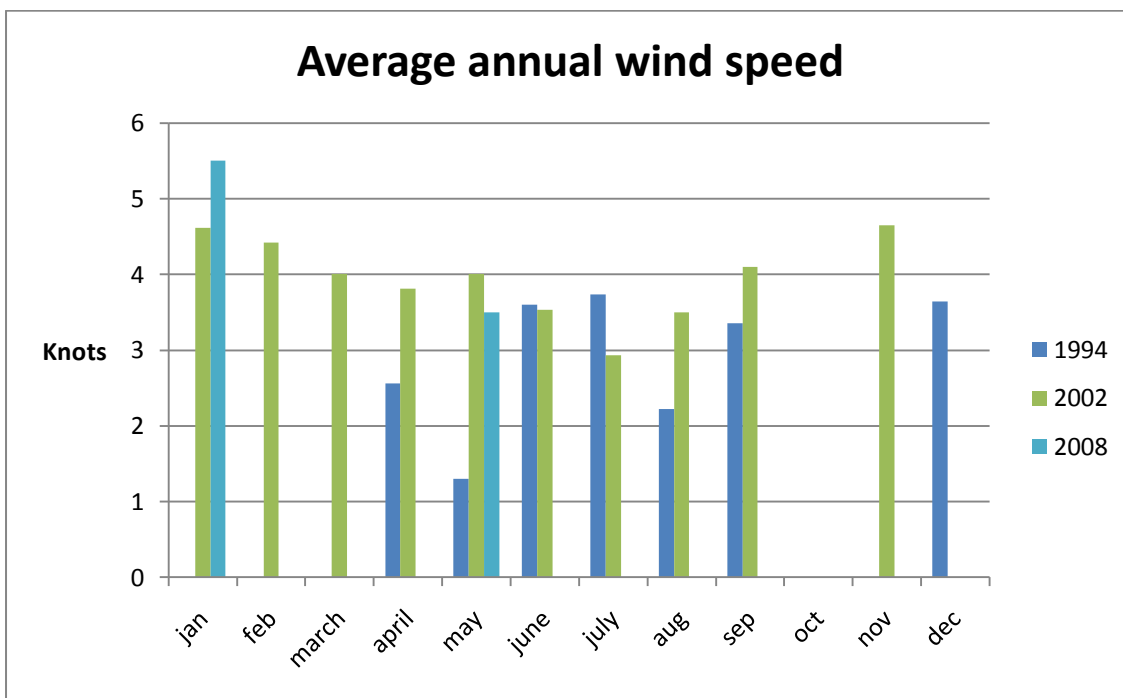


Figure 18. Average annual wind speed (Bovin & Jonsson, 2010)

The years 1994, 2002 and 2008 were chosen since those years encompass the most collected data.

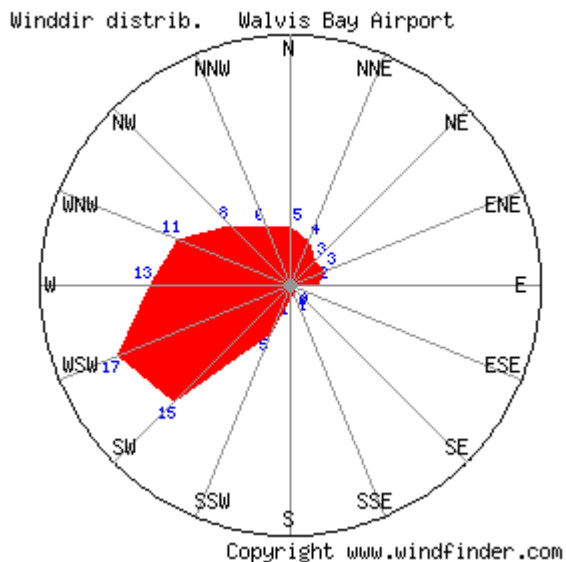


Figure 19. Average annual wind direction, 2003-2008 in percentage. Statistics based on observations taken between 8/2003 - 11/2010 daily, where the marked area shows wind direction. For example, 15 % of the wind came from SW between 2003 and 2008 (windfinder 2008, Internet)

3.11 The depiction of sand in media

In 2008, sand encroachment was mentioned on one occasion, on the 18th of January. The headline states, “Meersig residents say it's not just the holes in the streets, but sand is also their concern” (Namib Times, 2008). In addition, the Namib Times posts traffic hints every month regarding poor visibility due to fog and sand.

During 2009, sand encroachment was noted at three occasions. On the 8th of September, an article reported a man who has been troubled by aeolian sand. The affected man states that the sand is not being cleared away from the streets and the houses by the municipality (Namib Times, 2009a). Another article from the 11th of September headlines, “Sand causes third derailment in weeks” (Namib Times, 2009b), see Figure 20. According to the reporting, the sand has caused a derailment of a freight train on the railway line between Walvis Bay and Dune 7. Due to extreme windy conditions the sand was able to accumulate rapidly, covering the entire track. The derailment cut Walvis Bay’s railway link to Swakopmund and the rest of the country for one day. Furthermore, an article from the 13th of October reports that Dune 7 has buried benches and other structures (Namib Times, 2009c).



Figure 20. Photos on the derailment (The Namib Times, 2009b)

4 Discussion

Goudie (2010c) classifies dune migration and sand encroachment as a geomorphological hazard. In addition, Alcántara-Ayala (2002) notes that societies become vulnerable when they are exposed to natural hazards, see Figure 2. Based on the latter, and that Walvis Bay is a great industrial junction for the whole of Namibia, situated in a harsh arid environment, we claim that the town is vulnerable to aeolian sand.

Based on our interviews, we argue that the airport, the port, the railway, and the roads are all affected by aeolian sand. However, some actors seem to be more affected than others. In order to decide on the best solution to the matter of aeolian sand, we claim that an investigation supported by researchers, engineers, the municipality, the state, and actors within the infrastructure is needed. This argument is based on the Actor Network model for Walvis Bay in relation to aeolian sand, see Figure 21, illustrating the complexity of the issue.

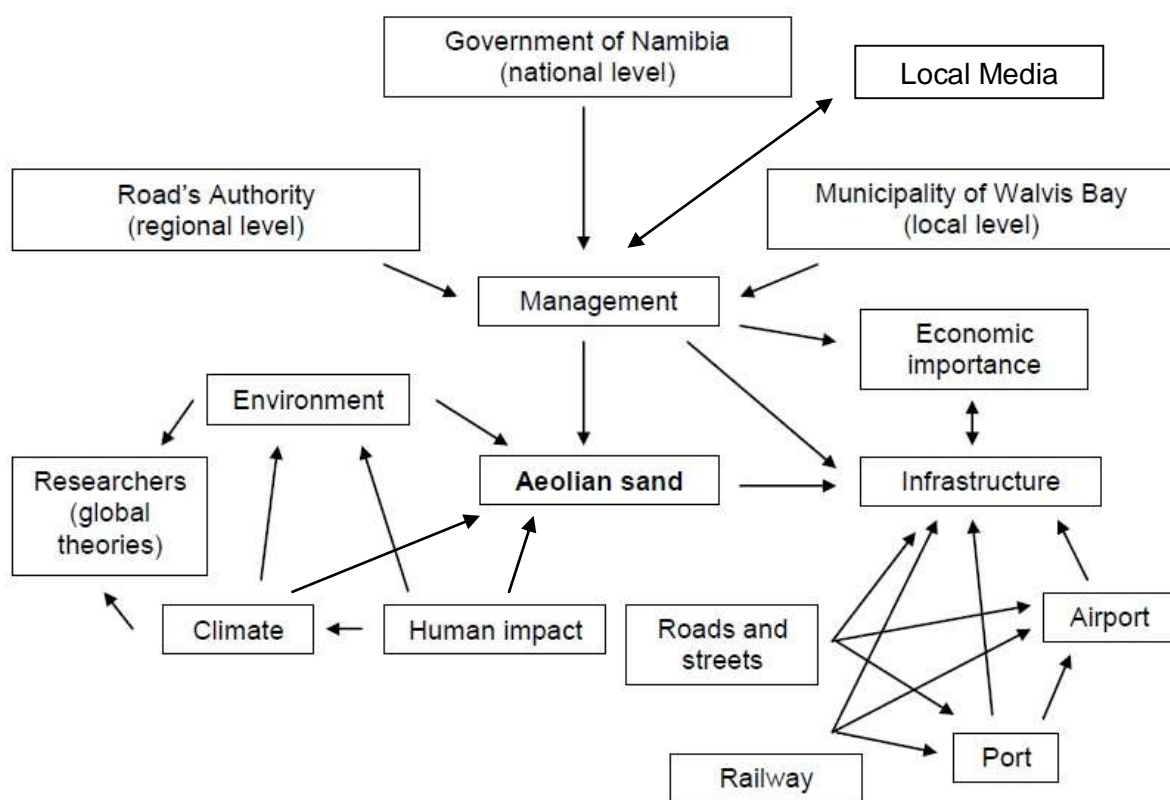


Figure 21. Actor Network for Walvis Bay in relation to aeolian sand (Bovin & Jonsson, 2010)

We claim that the roads and the railway are the most vulnerable actors since they are connected into the wider Walvis Bay infrastructure network, see Figure 21. The port and the airport are dependent on the roads and the railway to transport their cargo, and transportation of goods is an important part of the economic society of Walvis Bay. But as the model shows, the roads and the railway are not dependent on the port and the airport. As mentioned in chapter 3.7, Walvis Bay Municipality plan to build a heavy industrial area east of Dune 7, and both the port and the airport is expanding at present time. We believe that this will result in heavier traffic on roads and rails and the C14 road in particular, see Figure 1. According to Alcántara-Ayala (2002), the more dependent humans are of places, the more vulnerable they become to natural hazards. Increased traffic on the C14 road will therefore make it more vulnerable to aeolian sand, increasing the vulnerability of the whole infrastructure network in Walvis Bay.

Even though sand and dust storms reduce visibility, which might cause derailments and car accidents, the effects of aeolian sand on infrastructure in Walvis Bay seem to be mostly of economic concern. On the other hand, sand management creates jobs for the local inhabitants, which stimulates the economic society of Walvis Bay, as shown in Figure 21.

We argue that communication and cooperation is of great importance in order to prevent the effects of aeolian sand. Currently, it seems that each different actor maintains the problem on a daily basis based on their own funding. As mentioned in chapter 3.7, most actors state that there is a lack of communication between actors. Measures are being taken on a regional and a municipal level in order to prevent aeolian sand from interacting with the infrastructure. However, during our field observations, we observed sand encroachment on national roads, municipal streets and railway lines, see Figure 12, fences overtaken by sand, see Figure 9, and new dune formations amongst the stabilized dunes south of Meersig, see Figure 10. Therefore, we reason that if the different actors would cooperate with each other, aeolian sand could be maintained in a more sufficient way.

As Seely (2010, Informant) states, preparing for hazards is less costly than coping with them. Therefore we believe that a joint budget for the main affected actors within the infrastructure could be useful in order to achieve more sufficient and long-term solutions. The question is then if a joint budget is possible to achieve? We argue that it would be realistic if the matter of aeolian sand is handled on a higher political level. If the state of Namibia would act as an umbrella organization, it would be easier to link the different actors and make sure that the funding is used properly. It could therefore be useful in order to provide long-term solutions. On the other hand, decision-making at a high bureaucratic level generally takes time, and since the matter of aeolian sand is a daily progress in Walvis Bay, quick decisions are often necessary. Therefore we argue that a redistribution of the responsibility of sand management could be sufficient, dividing decision-making at different political levels as displayed in Figure 21.

The current progression of aeolian sand in Walvis Bay can be represented in Figure 22. Aeolian sand will have an impact on the infrastructure followed by direct and indirect effects, for instance sand encroachment and economic costs. The town of Walvis Bay will then adapt to the effects, and for example erect fencing, planting green belts or flatten dune areas. Due to dune flattening or sand removal in the streets, the progression will be stabilized until the cycle starts over again. In our mapping of the dune area south of Meersig, see Figure 13, we note that most of the dunes have been stabilized with gravel. As mentioned in chapter 3.7.4, this has halted dune migration in the area. However, we observed new barchans forming in between the stabilized ones, which might support the theory presented in chapter 3.4, that the migration rate has increased.

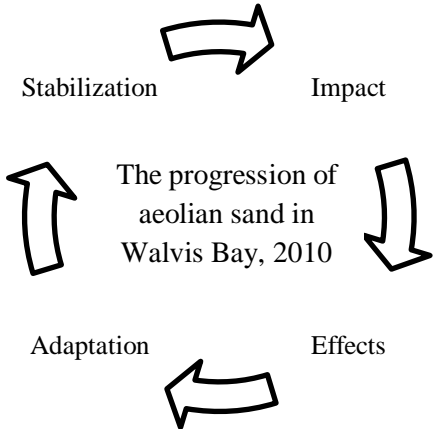


Figure 22. The progression of aeolian sand in Walvis Bay (Bovin & Jonsson, 2010)

As presented in Figure 21, humans impact on the natural environment and the diversion of the Kuiseb River exemplifies this, see Chapter 3.4. Since the river no longer floods, vegetation cannot grow to the

same extent, and dunes can form and migrate without restraint. Therefore we argue that the dune area south of C14, see Figure 14 and 15, is the result of anthropological impact. However, on one hand Walvis Bay had to divert the Kuiseb River in order to protect the town from floods. On the other hand sand dunes have started to migrate and affect the town and infrastructure to a greater extent, which we observed during our field observations. The question is then, which geomorphological hazard causes the most damage and economical loss for the society? We believe that floods cause greater damage at direct impact. However, aeolian sand affects the town regularly and all year round with a level of moderate dune migration, see chapters 2.3.1 and 3.4. Louw (2010, Informant) claims that the only solution to the continuous increasing amount of dune formations is to open up the dams and allow the water in Kuiseb River to run again. Nevertheless, we argue that the latter would not be a sustainable solution for the town.

Instead, we argue that the most sufficient solution would be to design and site structures in order to allow aeolian sand to move freely. As Stengel (1961) stresses, all housing built before the 1900s were built on piles so that the sand would be able to move under the buildings. Schommarz (2010, Informant) argues that the best solution for preventing sand encroachment on the C14 road would be to lift the road on gravel as it has been done with the railway line. However, in field we observed sand build-ups on the slope side of the railway and sand had been able to encroach on the tracks. Therefore, lifting on gravel is not a long-term solution. Instead, we argue that lifting the road on poles, similar as to bridges crossing ephemeral rivers, would result in free movement of dunes and therefore could be a more efficient solution. Nevertheless, constructing bridge structures is expensive, and the question is if such an investment is possible with the current management? Since Walvis Bay is an important economic town in Namibia, we believe that the impacts on infrastructure should be of national concern. Therefore, we argue that a redistribution of the sand management responsibility, as discussed above, would make it easier to finance such a construction. On the other hand, one prevention method that has proven to be sufficient in dune fixation globally is the straw checkerboard method. This method is not costly, does not pollute the environment and could be suited for the current situation in Walvis Bay. We have conducted a table on different prevention methods, shown in table 3. The table shows which methods we consider to be long-term and short-term solutions and which methods that are being used today.

Table 3. Different prevention methods on aeolian sand (Bovin & Jonsson, 2010)

	Short-term	Long-term	Currently used
Green belt		X	X
Fences	X		X
Sweeping	X		X
Stabilizing dunes		X	X
Netting		X	
Re-diversion of Kuiseb River		X	
Straw Checkerboards		X	
Lifting on gravel	X		X
Lifting on poles		X	
Collective management	X	X	
Risk and vulnerability assessment	X	X	

As presented in Table 3, collective management and risk and vulnerability assessments provide indirect long-term and short-term solutions on the matter of aeolian sand. Therefore, we highlight the importance of these prevention methods. For instance, with the help of researchers, risk and vulnerability assessments provide future predictions due to climate change. Since previous research stress that climate change will increase the effects of aeolian sand due to increasing temperatures, decreasing soils moistures and desertification, we wanted to investigate if climate change and sand

activity correlate by studying weather data. However, the data turned out to be defective and we were not able to observe such a correlation. In addition, the weather data in Walvis Bay was not recorded until 1994. This might be one of the reasons why Uushona (2010, Informant) claims that the effects of climate change is not taken into consideration while expanding human activities in Walvis Bay and the reason why a risk and vulnerability assessment has not been done. Still, as mentioned in chapter 3.5, Namibia is one of the world's most vulnerable countries to climate change.

The question is, how can researches produce GCMs and predict future climate when weather data is not complete? On one hand, researchers claim that desert environments are prone to climate change. On the other hand, the local media and our informants do not seem as concerned, and do not believe that aeolian sand is correlated to climate change or desertification. Media's role in the Walvis Bay actor network is presented in Figure 21. As mentioned in chapter 3.11 media presents how the sand is managed, but the management is also affected by what is written in media. What is depicted in media effects what people perceive, so if media does not report of climate change or the occurrence of desertification, people might not think of it as an ongoing matter. On the other hand, the diversion of the Kuiseb River led to an increase in dune activity. Therefore we argue that it should be classified as a type of desertification since desertification is defined as land degradation due to human impact on the environment.

Whether or not climate change will continue to increase dune activity, we claim that the industrial expansion of Walvis Bay makes the infrastructure vulnerable to aeolian sand. On the other hand, actors in Walvis Bay argue that vulnerability is a matter of definition and is based on people's state of mind. Hitula (2010, Informant) claims that aeolian sand is an issue for the town, but that Walvis Bay is situated in a desert environment and the people living and working there "can only work with the land they got".

5 Conclusion

Our question at issue is: How is the infrastructure in Walvis Bay affected by aeolian sand? Based on our findings, we have found that:

- Sand encroachment is the common effect of aeolian sand, which causes:
 1. Delays, e.g. transport and trade
 2. Accidents such as derailments and car accidents
 3. Economic loss due to daily and long-term maintenance
- Roads and railway lines are the most affected, however,
 1. The port suffers from degradation of structures and buildings due to the salt which is brought in with aeolian sand.
- The different actors are dependent on each other, leading to a chain reaction if one actor is affected, therefore
 1. It effects the whole economic system in Walvis Bay, as explained in the actor-network theory (see Figure 21), however
 2. There is no cooperation between the different actors or the political levels today.
- There has been an increase in aeolian sand activity in the last 50 years due to the diversion of the Kuiseb River.
- Future predictions state that dune mobility and sand storm activity may increase with climate change, still
 1. Actors within the Walvis Bay infrastructure claims that aeolian sand is an issue which should be maintained on a daily basis, but it is apparent that the phenomenon can be maintained in a more effective way.

- Currently, aeolian sand is depicted as a day-to-day issue in media, which reports only about standalone accidents or when sand encroaches on housing within the town. It has not focused on the issue as a cumulative basis with which its readers should be increasingly concerned.

List of Sources

Literature

- Al Farajii, 2001: Combating desertification and sand storms in Iraq. In, *Global alarm: Dust and sand storms from the world's dry lands*, United Nations, eds. Yang Youlin, Victor R. Squires, and Lu Qi, pp. 203-215.
- Alcántara-Ayala, Irasema, 2002: Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. *Geomorphology*, Vol. 47, pp. 107-124.
- Alcántara-Ayala, Irasema, 2010: Geomorphology and disaster prevention. In, *Geomorphological Hazards and Disaster Prevention*, eds. Irasema Alcántara-Ayala and Andrew S. Goudie. Published by Cambridge University Press. Copyright Cambridge University Press 2010.
- Alcántara-Ayala Irasema & Goudie Andrew S., 2010: *Geomorphological Hazards and Disaster Prevention*, Published by Cambridge University Press. Copyright Cambridge University Press 2010.
- Barnes, Jessica, 1999: *Barchan dune morphology, migration and management on the Kuiseb River Delta, Namibia*, Oxford University.
- Benito, Gerardo & Hudson, Paul F., 2010: Flood hazards: the context of fluvial geomorphology. In, *Geomorphological Hazards and Disaster Prevention*, eds. Irasema Alcántara-Ayala and Andrew S. Goudie. Published by Cambridge University Press. Copyright Cambridge University Press 2010.
- Berte, Charles Jaques, 2010: Fighting sand encroachment – lessons from Mauritania. *FAO Forestry Paper*, No 158.
- Brockington, D. & S. Sullivan, 2003: Qualitative Research. In, *Development Fieldwork. A Practical Guide*, eds. Scheyzens, R. & Storey, D, Sage, London.
- Bosco, Fernando J., 2006: Actor Network Theory, Networks, and Relational Approaches in Human Geography. In, *Approaches to Human Geography*, eds. Stuart Aitken and Gill Valentine, SAGE Publications Ltd, London.
- Bryant, Edward, 2005: *Natural Hazards*. 2nd Edition. BPA Print Group. Australia.
- Christopherson, W. Robert, 2009: *Geosystems – An Introduction to Physical Geography*. Pearson Education International.
- Dictionary of Physical Geography*, Whittow, B. John, “Dust Storm” pp. 152, “Sand Storm” pp. 461, 2000, Second Edition. Penguin Reference.
- Dobson, Sue, 2010: *Thomas Cook traveler guides: Namibia*. Thomas Cook Publishing.
- Dong, Chen, He, Han, Wang, 2004: Controlling blown sand along the highway crossing the Taklimakan Desert. *Journal of Arid Environments*, Vol 57, pp. 329–344.
- Goudie, Andrew, 2008: Barchan dunes in the Namib and on Mars. In, *Namib Secrets of a desert uncovered*, eds. Mary Seely and John Pallett, Venture publications.
- Goudie, Andrew, 2010a: Dune migration and encroachment. In, *Geomorphological Hazards and Disaster Prevention*, eds. Irasema Alcántara-Ayala and Andrew S. Goudie. Published by Cambridge University Press. Copyright Cambridge University Press 2010.

- Goudie, Andrew, 2010b: Geomorphological hazards and global climate change. In, *Geomorphological Hazards and Disaster Prevention*, eds. Irasema Alcántara-Ayala and Andrew S. Goudie. Published by Cambridge University Press. Copyright Cambridge University Press 2010.
- Goudie, Andrew, 2010c: Introduction. In, *Geomorphological Hazards and Disaster Prevention*, eds. Irasema Alcántara-Ayala and Andrew S. Goudie. Published by Cambridge University Press. Copyright Cambridge University Press 2010.
- Huschmidt, Gabi & Glade, Thomas, 2010: Vulnerability analysis in geomorphic risk assessment. In, *Geomorphological Hazards and Disaster Prevention*, eds. Irasema Alcántara-Ayala and Andrew S. Goudie. Published by Cambridge University Press. Copyright Cambridge University Press 2010.
- Jacobsson, Peter J., Jacobsson, Kathryn M., Seely, Mary K., 1995: *Ephemeral Rivers and their Catchments*. Desert Research Foundation of Namibia.
- Kassas, M, 1995: Desertification: A general review. *Journal of arid environments*, No. 30, pp. 115-128.
- Le Roux, P.J., 1974: Drift Sand Reclamation of Walvis Bay, South West Africa. *International Journal of Biometeorology*, Vol. 18, No. 2, pp. 121-127.
- Logan, Richard F., 1960: The Central Namib Desert South West Africa. *Foreign Field Research Program. Report*, No. 9. National Academy of Sciences – National Research Council Washington, D.C.
- Longjun, Ci, 2001: Disasters of strong sandstorms over large areas and the spread of land desertification in China. In, *Global alarm: Dust and sand storms from the world's dry lands*, United Nations, eds. Yang Youlin, Victor R. Squires, and Lu Qi, pp. 215-226.
- Mendelsohn, John, Roberts, Carole, Jarvis, Alice & Robertson, Tony, 2009: *Atlas of Namibia*. Sunbirds Publishers Ltd. Cape Town, South Africa.
- Misak, R.F & Draz, M.Y, 1997: Sand drift control of selected coastal and desert dunes in Egypt: case studies. *Journal of Arid Environments*, No. 35, pp. 17-28.
- Namport handbook, *Namport Walvis Bay*, 2010
- National Policy for Risk Disaster Management in Namibia. *Republic of Namibia*, 2009
- Orlovsky, L, Orlovsky, N, Durdyevb, A., 2005: Dust storms in Turkmenistan. *Journal of Arid Environments*, Vol. 60, pp. 83–97
- Qiu, Guo Yu, Lee, In-Bok, Shimizu, Hideyuki, Gao, Yong, & Ding, Guodong, 2004: Principles of sand dune fixation with straw checkerboard technology and its effects on the environment. *Journal of Arid Environments*, Vol. 56, pp. 449-464.
- Encyclopedia of Geomorphology. Volume 1*, Rosenfeld, Charles L., “Geomorphological Hazard” pp. 423. Edited by A.S. Goudie, 2004. Routledge Ltd.
- Slattery, M. C., 1990: Barchan migration on the Kuiseb River Delta, Namibia, *South African Geographical Journal*, Vol. 72, No. 1, pp. 5-10.
- Stengel, H, W., 1961: Protection for the town of Walvis Bay, *Der Kreis*, Vol. 4, No. 11-12, pp. 347-352.

Stoppato, C. Marco and Bini, Alfredo, 2003: *Deserts*. Firefly books Ltd.

Strahler, Alan & Strahler, Arthur, 1994: *Introducing physical geography*. John Wiley & Sons INC.

Xu, Jiongxin 2005: Sand-dust storms in and around the Ordos Plateau of China as influenced by land use change and desertification. *Catena*, Vol. 65, pp. 279 – 284.

Yao, Z.Y, Wang, T, Han, Z.W, Zhang, W.M, Zhao, A.G, 2007: Migration of sand dunes on the northern Alxa Plateau, Inner Mongolia, China. *Journal of Arid Environments*, No. 70, pp. 80-93.

Youlin, Yang, Squires, R. Victor and Qi Lu, 2001: *Global Alarm: Dust and sandstorms from the worlds dry lands, United Nations*.

Van Westen, Cees J., 2010: GIS for the assessment of risk. In, *Geomorphological Hazards and Disaster Prevention*, eds. Irasema Alcántara-Ayala and Andrew S. Goudie. Published by Cambridge University Press. Copyright Cambridge University Press 2010.

Wei, Zhou, Shi, Abe & Kai, 2005: Climatic and environmental changes in the source areas of dust storms in Xinjiang, China, during the last 50 years. *Water, Air, and Soil Pollution: Focus*, Vol. 5, pp. 207–216.

Wisner, Ben, Blaikie, Piers, Cannon, Terry, and Davis, Ian, 2004: *At Risk: Natural hazards, people's vulnerability and disasters*. 2nd Edition. Routledge.

Woodhouse, P., 2007: People as informants. In, *Research Skills for Policy and Development. How to find out fast*, eds. Thomas, A. & G. Mohan, Sage, London.

Internet

Eartsci, 2010: Desert and winds

URL: <http://earthsci.org/education/teacher/basicgeol/windes/windes.html#TransverseDunes>
(20.12.2010)

Google Earth, 7.12.2010, Visningshöjd 3.18. Bilddatum 12 mars 2008. Satellitbilder: DigitalGlobe 2010, TerraMetris 2010, Google 2010, Europa Technologies 2010.

Länsstyrelsen i Stockholms län, 2010: Risk- och sårbarhetsanalyser i Stockholms län.

URL: <http://www2.lansstyrelsen.se/stockholm/Sv/manniska-och-samhalle/krisberedskap/risker-i-lanet/rsa/Pages/default.aspx> (21.12.2010)

New Era, 2010: Elections 2010: Erongo regional profile.

URL: <http://www.newera.com.na/article.php?articleid=14109> (7.12.2010)

Road's Authority, 2010: About us.

URL: http://www.ra.org.na/index.php?option=com_content&view=article&id=2&Itemid=3
(21.12.2010)

Transnamib, 2010: Who We Are.

URL: <http://www.transnamib.com.na/Who%20we%20are.htm> (21.12.2010)

Walvis Bay Municipality, 2010: Roads and Building Control.

URL: <http://www.walvisbaycc.org.na/administration.htm> (21.12.2010)

Windfinder, 2008: Walvis Bay airport

URL: http://www.windfinder.com/windstats/windstatistic_walvis_bay_airport.htm (21.12.2010)

Informants

Booyesen, Dirk F., Manager for Walvis Bay and Regional Airports, 10.11.2010, Walvis Bay

Eiman, Tim, Coordinator EMS / QMS – Namport, 10.11.2010, Walvis Bay

Gelderbloem, Elzevir W., Project Engineer, Project Manager, Deputy Port Engineer – Namport, 15.11.2010, Walvis Bay

Hitula, Hilia, City Town Planner - Walvis Bay Municipality, 14.11.2010, Walvis Bay

Louw, Adri, Roads and Building Control - Walvis Bay Municipality, 8.11.2010, Walvis Bay

Road inspector, Road's Authority, 12.11.2010, Swakopmund

Seely, Mary, Desert Research Foundation Associate, 24.11.2010, Windhoek

Schommarz, Horst, Divisional Manager Maintenance – Road's Authority, 24.11.2010, Windhoek

Train inspector, Transnamib, 9.11.2010, Walvis Bay

Uushona, David, Offices of the department of water, waste and environmental management at the Municipality of Walvis Bay, 8.11.2010, Walvis Bay

Other sources

2214CD & DC WALVISBAAI 1st edition, 1981. Geological Survey Center, Windhoek.

2214 Walvis Bay 3rd edition, 2003. Geological Survey Center, Windhoek.

Front cover, Road's Authority, Swakopmund, 2010.

Namib Times, 2008: Meersig inwoners sê dit is nie net die gate in die strate nie, maar sand ook wat hulk we, 28th January.

Namib Times, 2009a: Sand is not being cleared, 8th September.

Namib Times, 2009b: Sand causes third derailment in weeks, 11th September.

Namib Times, 2009c: Die geriewe is die verantwoordelikheid van die Ministerie van Omgewing en Toerisme, 13th October.

Appendix

Frame for semi-structured interviews with actors within the infrastructure network

1. Could you tell us about your job, what do you do?
2. Interesting for our study, is the environs of sand. Is blown sand a problem for Walvis Bay [...]? How is it a problem?
 - a. Economic costs
 - b. Transportation – goods and people
 - c. Cancelling of traffic
 - d. Change over time
3. Is there an adaption to the matter of blown sand? Is it taken into consideration in railway planning and infrastructure in general?
 - a. Change over time
 - b. What prevention methods are being used?
4. Who is responsible for managing the sand? The actor, The Municipality of Walvis Bay or the State?

Frame for semi-structured interviews with a roads and building engineer responsible for sand management at the Walvis Bay Municipality

1. How is the infrastructure in Walvis Bay affected by aeolian sand?
2. How do you manage the sand? What are your prevention and adaption methods?
3. Has there been a change in sand encroachment over time? Why/Why not?
4. Is the municipality responsible for sand management on all levels? Is the state somehow responsible?

Frame for semi-structured interviews with the town planner at the Walvis Bay Municipality

1. What are the expansion plans for Walvis Bay?
2. How will sand movement be taken into consideration while expanding Walvis Bay?
3. Will there be any challenges regarding the sand and the expansion?
4. Is it mainly housing or industry that will be built within the near future?
5. How will the expansion affect the economic growth of Namibia?
6. Do you cooperate with actors within the infrastructure network while planning for expansion?

Frame for semi-structured interviews with a desert researcher at DRFN

1. Is aeolian sand problematic on a national level? Why/why not?
2. Who handles the problem? How is it handled?
3. How is the communication between the local, regional and national?
4. Is there any regional priority due to the management of aeolian sand?
5. Have you seen a change over time? Is the matter of aeolian sand in Namibia increasing? Why/why not?
6. Do you know if aeolian sand is taken into consideration while planning for expansion and economic growth?
7. Would you say that Namibia is vulnerable to aeolian sand on a national level?

Summary

The Effects of Aeolian Sand on Infrastructure in Walvis Bay

By: Caroline Jonsson & Mattias Bovin

Human societies tend to inhabit milieus which are prone to noticeable or unnoticeable geomorphological hazards. Places such as coastal zones are prone to coastal erosion or floods, however they offer certain benefits, for example fishing and transportation opportunities. When people populate areas prone to geomorphological hazards, adaptation is necessary.

The town of Walvis Bay is situated in a desert environment consisting of sand dunes with constant winds blowing from one direction. It is also an important industrial junction in Namibia and for the SADC region. Dune migration and sand encroachment are geomorphological hazards since migrating dunes may block railway lines, and encroach on to runways and roads. Due to global warming, the dunes near Walvis Bay might reactivate and dust storms may occur more frequently, increasing the degree of vulnerability. The adaption and prevention methods will therefore be of greater importance.

Due to Walvis Bay's industrial and economic importance to Namibia, the aim of this essay is to investigate how the infrastructure of Walvis Bay is affected by aeolian sand in relation to its relative location. Our focus is on dune migration and sand encroachment, on different scales and over time. We have also sought to map the dunes in areas which might be possible threats to the infrastructure. Our question at issue is: How is the infrastructure of Walvis Bay affected by aeolian sand?

Based on the results of our field work, we argue that the infrastructure in Walvis Bay is affected by aeolian sand. Sand encroachment is the common effect and causes delays, accidents and economic loss. It is apparent that the actors within the infrastructure have adapted to aeolian sand, with some prevention methods proving more adequate than others. The municipality has erected fences, planted green belts and stabilized sand dunes in order to halt dune migration. When sand encroaches on the roads, the port, the airport, or the railway, the sand is swept away on a routine basis.

We have found that there has been a change in aeolian sand activity in the last 50 years which is due to the diversion of the Kuiseb River. The river was diverted in order to prevent the town from floods. However, this increased the dune mobility and future predictions state that dune mobility and sand storm activity may increase with climate change. This should be of great concern since the town of Walvis Bay is expanding and aims to remain Namibia's central industrial junction. We have also found that the roads and the railway are the most affected and are the most vulnerable actors, since they are connected into the wider Walvis Bay infrastructure network. The port and the airport are dependent on the roads and the railway in order to transport their cargo. However, the roads and the railway are not dependent on the port and airport.