Sand dune movement and its impact on human activities in the North Western coast region of Libya

An analysis of the sediment characteristics of sand dunes, and their movement using satellite images, and the effects of encroachment on farms assessed by a questionnaire survey

Thesis submitted for the degree of Doctor of Philosophy (PhD)

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Abstract

Sand movement is one of the many environmental problems facing humans in the dry and semi-dry areas of the world. This study has investigated the observed changes in sand dune coverage compared to predictions, and has also assessed the impact of sand movement on human activity in the north western coastal region of Libya. The study used three methods. The first was a statistical model proposed by Bagnold, which correlates wind shear velocity with particle size, in order to predict likely sand movement. It was found that 60% of sand grains within the study area have a diameter of less than 0.25 mm, making them liable to be moved by the wind speeds recorded, particularly from March until September, and mostly in a northerly direction. The sand in the western part of the study area had a greater predicted rate of sand transport compared with the sand in the eastern part, which was related to its origin. The second method involved the analysis of satellite images for four different years; from 1986 to 2003. The land cover in the study area was found to have changed over this time. Sand dune area cover had increased, and there were other changes particularly a decline in forest. The third method was the use of a questionnaire (the respondents being land owners), which showed that there was notable loss of crop production (by about a quarter) due to sand movement, and that land owners mostly used afforestation to help control the sand movement in the region. The observed sand movement did not match the predictions based solely on sand grain size and wind speed, and climatic analyses showed no convincing trends which could explain increased sand movement except perhaps an increase in wind gusts. The thesis concludes that the overriding determinant in greater sand movement over the period studied was the loss of forest from the area due to human impacts, which farmers are having to compensate for by planting trees locally to reduce sand movement.

Keywords: Encroachment, Sand dune, Farming, Impacts, Spatial analysis, Misurata, Almurgib, Tajoura.

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1 CHAPTER ONE: Introduction

1.1 Introduction:

The phenomenon of wind-blown sediments is closely linked with the geographical distribution of a dry or semi-arid climate. About 37% of the surface of the globe (equivalent to 50 million km^2) has a dry or semi-arid climate, and a large proportion of that area is affected by wind activity (Darraz, 1995). Wind-blown sediments are not limited only to desert areas, since there is sediment sand in other regions such as the shores of the seas and oceans, and on the banks of rivers (Ayad, 1995). The origin of these sediments is often due to marked environmental and climatic changes, which happened in earlier times, often especially in the Holocene (Tawadros, 2001). The origin of wind-blown sediments in Libya has been established to have been in the post Holocene (Al Emsalati, 1995).

Sand dunes cover vast areas of the world, some constitute a major threat to cities, villages and road networks, farms, water sources and irrigation and pasture (Darraz,1995). Despite efforts to reduce their movement, studies indicate that movement of the dunes is continuing (Ayad, 1995; Goldsmith and Gertner, 1990).

Most studies on sand dune encroachment have found that the largest proportion of sand dunes is located in semi-arid, arid and severe drought areas all over the world (Herrmann, 2002; Mastronuzzi and Sans, 2002; Wang *et al*., 2004). In 1995, according to studies of desertification, the semi-arid areas covered 18.3 million km2, arid area occupied 22.4 million km^2, and severe drought areas represented about 6.64 million km^2 (Ayad, 1995).

Studies of all areas covered by sand dunes in the world show that the problem of encroachment is strongly connected with the movement of sand dunes (Nhal, 1989, p35). This problem is widespread around the North African desert, especially in areas which are close to natural resources and human activity.

Most North African states face severe problems resulting from the encroachment of sand dunes, the movement of which constitute the final stages of desertification (Hegazi *et al.,* 2005). Dunes threaten agricultural land, natural pastures and economic and social installations in the area (Al Kataly, 1988). Libya, for instance, has been affected by this phenomenon. The total of land in the NW of Libya which has been covered with sand during 1952 is over 250 thousand hectares, much of which has previously been one of the most fertile agricultural areas in this region (Abd Elgawad, 1997). As a result, the city of Tripoli was exposed to the encroachment of sand dunes in the first quarter of the twentieth century (Almasoudi, 1984). Transport is threatened by these phenomena along the Libyan coast (Libyan Agricultural Ministry, 1973), and it has also been stated that the entire western region of Libya was suffering from the migration of sand dunes (Abo Lugma, 1996, p.65). Similarly Tunisia is also exposed to the encroachment of sand dunes, where about 800 thousand hectares of agricultural land have been covered (FAO, 2007). Dunes have also encroached on more than

5000 palm farms in the south of Morocco, leading to a reduction of agricultural production of between 55-80% (FAO, 2007).

Taking Libya as a specific example of sand dune movement reveals two contributing sets of factors: the first is human factors (such as bad exploitation of the soil, and removing vegetation for different purposes); and the second set of factors are those relating to the environment such as climate change, the fluctuation in rainfall and severe winds; both of these sets of factors make this phenomenon of sand movement more likely. Sand dunes cover vast tracts of the territory of Libya. The bulk of this territory falls within the dry area, however large amounts of sand are also located along the coast, which are near to and threaten living areas, transportation and agricultural development projects (see Figures 1.1 and 1.2). The estimated area covered by sand along the Libyan coast from the Tunisian borders in the West to Ejdbiya city in the East is about 370 thousand hectares (Al Emsalati, 1995).

Figure 1.1 Illustration of the problem of shifting sand near to farms and buildings, specifically between latitude 32° 27′ N to 32° 28′ N, and longitude 14° 35′ E to 14° 36′ East (Source: Google Earth, 2003).

Figure 1.2 A further illustration of sand dunes, specifically between latitude 32° 30′ N to 32° 31′ N, and longitude 14° 27′ E to 14° 28′ East (Source: Google Earth, 2003).

Using control methods to prevent sand dune movement in Libya was started in 1913, when a committee of specialist researchers was commissioned by the Ministry of Italian Colonies to study and evaluate the economic and environmental situation in the north western region of Libya (Aljadedie, 1992, p.41). This commission noted that the movement of sand dunes within the region ranged between 15 - 20 m/year, and it recommended implementing an urgent plan to afforest the whole of the region (Darraz, 1995). The purpose of this plan was to reduce the sand movement and to assist the reclamation of agricultural land.

In the late seventies and early eighties of the twentieth century the Libyan state adopted a comprehensive development plan, including a five-year plan for reforestation and planting of wind barriers on extensive areas of sand dune (Ministry of Agriculture in Libya, 1986). Reforestation plans have been successfully implemented in the entire target area, and thus forest coverage spread significantly (Aljadedie, 1992, p.48).

In more recent years there has been less attention of local administrations in Libya towards protection of current forest and reforestation processes. Moreover, there has been considerable expansion of urban development and agricultural land in the entire region as a result of natural population growth and planned farming development. Over this period, most forests have been exposed to removal or fires, which have led to a great deterioration of the extent of forested areas. These forests were those which helped in the past to stabilise the sand dunes in the region, as noted in reports issued by the Libyan Agricultural Ministry (2002), and as illustrated in Figure 1.3.

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Figure 1.3 Shows a great deterioration and shrinking of the area of Al Garapoli forest, through it being exposed to removal or fires, within the western part of the study area (Photo by the researcher, October, 2008)

The present project has been developed in the light of these problems of contraction of vegetation cover and the emergence of mobile sand dunes in the whole region. The area dunes for this study has small groups of dunes which have spread and are near to roads and within the flat agricultural land in the study area, as shown in Figures 1.4 and 1.5. Further details of this study area are given in chapter 3.

Figure 1.4 Photographs showing the current status of the vegetation on sand dunes within the western part from the study area, namely, A. North Algaweah region, B. Al Ataya region, C. Alwady Alsharqy region, D. Alwady Alqarby region. The photographs also show the emergence of mobile sand dunes with reduced vegetation cover, this being the last stage of deterioration within the local environment. Photos by the researcher (October, 2008)

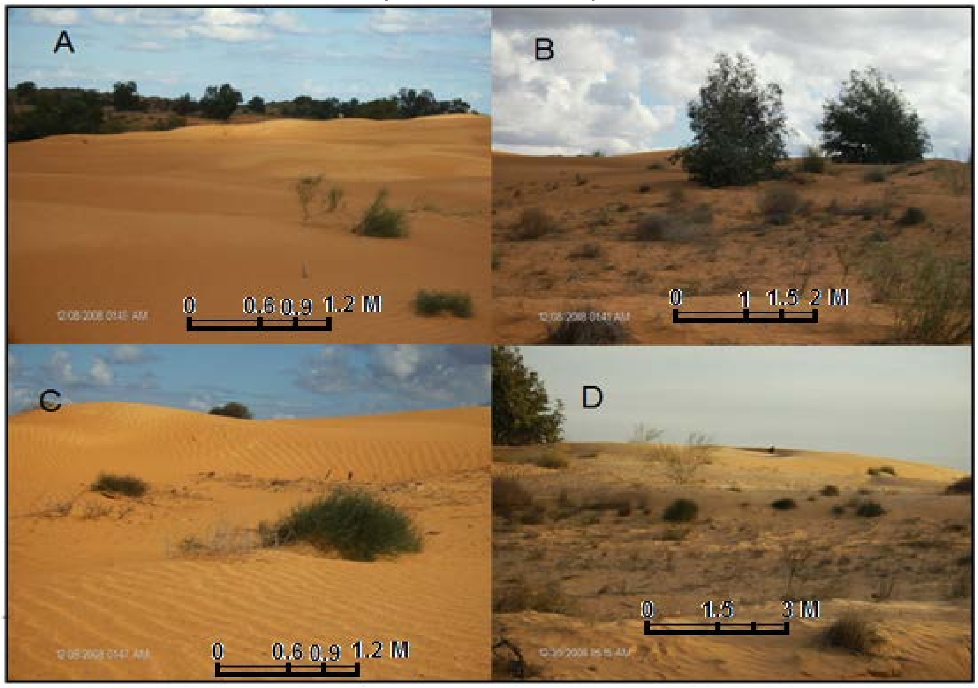
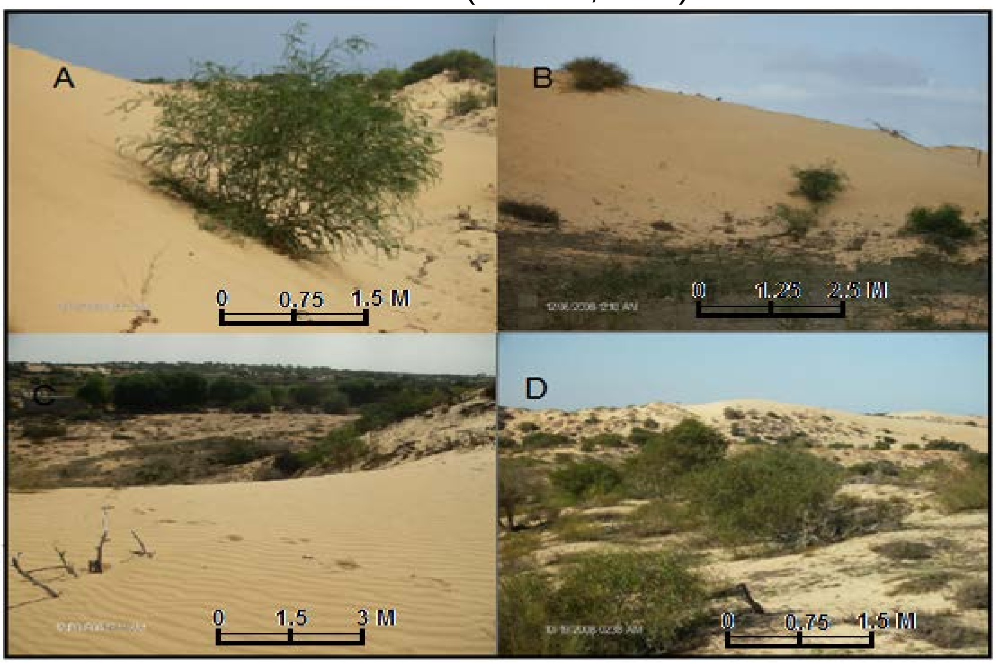
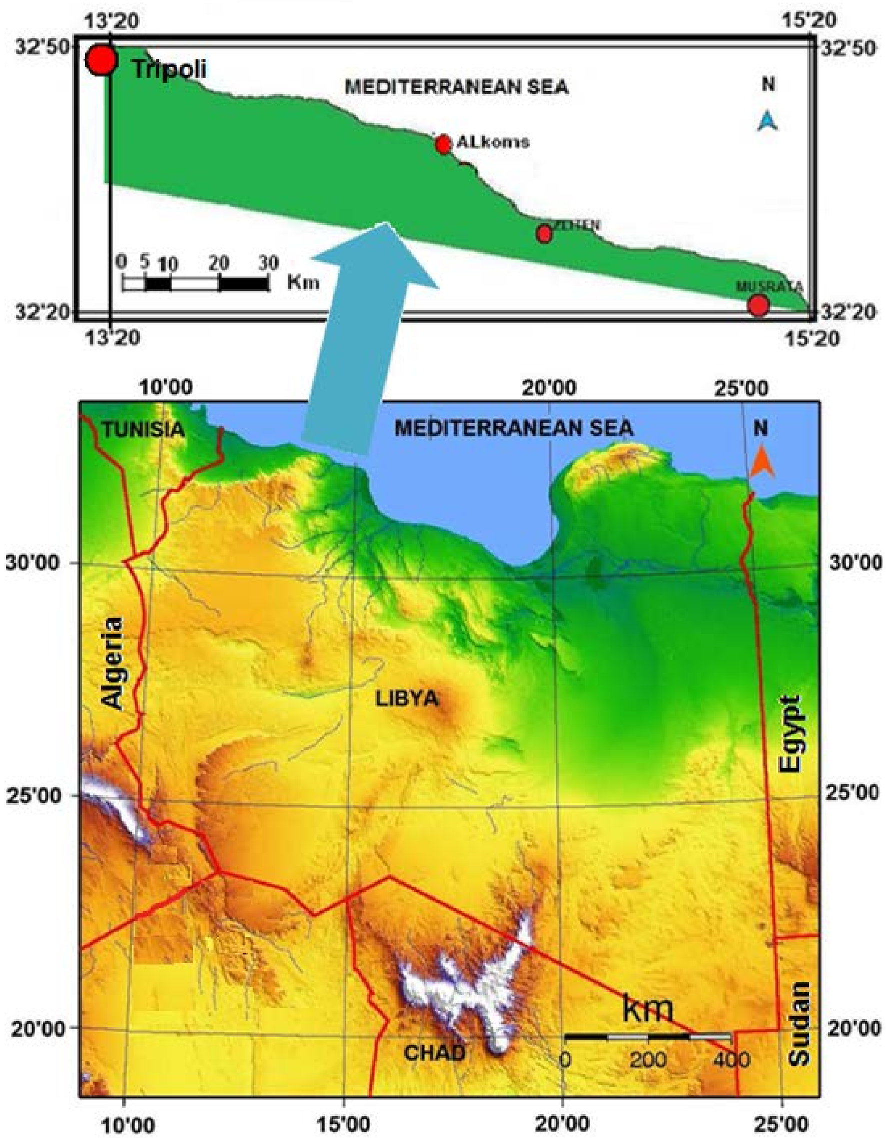


Figure 1.5 Photographs showing the current status of the vegetation on sand dunes within the Eastern part from the study area, namely, A. Azdo region, B. Aldafniya region, C. Zeriq region, D. Abourwia region, which also show the beginnings of a reduced vegetation cover on the sand dunes. Photos by the researcher (October, 2008)



The area studied in this research lies between latitude **32**° 18′ to 32° 50′ north and longitude 1**3°** 20′ to **15**° 13′ east. This area includes the coastal region from the city of Tripoli in the west up to Tawerghaa in the east, the Mediterranean Sea in the north and the Plateau series in the South (Figure 1.6). The estimated length of this area is about 180 km West-East and its width (North-South) is between 8-20 km depending on coastal topology (the degree of coastline sinuosity).

Figure 1.6 Map showing the location of the study area and its relationship to Libya as a whole



As this chapter has highlighted, there are considerable problems with sand movement in this region of Libya. There is sand dune creep on to agricultural land (Figure 1.7) and onto roads (Figure 1.8), causing damage to crops and obstructing traffic. Also the existence of sand dunes hampers development plans for land reclamation and constructing buildings (Figures 1. 9).

Figure 1.7 Photograph showing the encroaching of sand on agricultural land in the study area, which also shows the seasonal crops which were affected (Legume) as a result of the sand movement. (Photo by the researcher, October, 2008).

To study the phenomenon of sand movement in this region it is intended that this project will include an estimation of the rates of sand movement and the actual changes in amount of sand coverage of the land, in addition to establishing the effects of the sand dune movement on human activities and the perception of local people of the likely extent of the damage, according to the present circumstances.

Figure 1.8 Picture showing the creep of sand dunes and their coverage over a large part of the road, taken from the western part of the study area, namely, the Wadi Alrabiha region (Picture by the researcher, October, 2008).

Figure 1.9 Photograph showing the spread of sand dunes and their proximity to houses, as shown in the upper right side of the picture, a picture taken from the Eastern part of the study area, namely, Azdo region.(Photo by the researcher, October, 2008).

1.2 Research aims:

1. To quantify the extent and dynamics of sand dunes, including the estimation of movement potential and changes in sand dune coverage in NW Libya.
2. To investigate the impact of sand dune movement on human activity.

1.3 Research objectives:

1. To determine the sand particle size distribution of sand dunes across the region and evaluate their potential for movement through wind action. This will test the hypothesis that sand dunes in different locations will vary in how prone they are to such movement.
2. To test the hypothesis that sand dune coverage and that of other land use has been consistent over time. Satellite images from different time periods will be used to quantify any change in coverage of' sand dunes over time, in relation to other land use changes in the areas considered.
3. To assess whether the predicted movement patterns due to wind transport actually match observed changes. This will indicate the main controlling factor(s) governing such movement.
4. To test the expectation that sand dune movement has had a substantial impact on local farmers, through use of a questionnaire survey, and to explore their strategies for coping with sand dune movement.

1.4 Contribution and originality:

This is the first study to investigate the status of the impact of sand movement on human activities in NW Libya. It makes a contribution by providing an insight into the extent of the problem and the present status of sand dune dynamics in the region and assessing the solutions for controlling sand dune movement to protect agricultural land, road links and buildings, according to local environmental conditions. The project will also contribute in presenting essential new data and information which can serve as a basis for future development plans (land reclamation, implementation of buildings and other infrastructure) of the region.

The thesis begins with a literature review in chapter 2, and a description of the study area in chapter 3 and then is organised into three chapters for analysing results and discussing them, with detailed description of the methods used indicated in each chapter. The fourth chapter predicts rates of sand movement by using the predictive equation of Bagnold, to achieve objective 1. Chapter five analyzes the changes in the actual extent of coverage of the sand dunes area by using satellite images for the region taken in different years, and this part is consistent with achievement of objective 2. Chapter six analyzes the results of the impacts of sand dune movement on farming by using a questionnaire, this chapter relates to achieving objective 4. Chapter seven draws the various lines of information together in a general discussion, including seeking to achieve objective 3, though it is broader than just this objective, and concludes with recommendations and suggestions for further work.

2 CHAPTER TWO: Literature Review

2.1 Introduction

A loss of speed of wind, suddenly or gradually, results in the deposition of sediment and other materials to create geomorphologic phenomena, where the most important of these phenomena resulting from wind are sand dunes (Nordstrom, 2000, p.148).

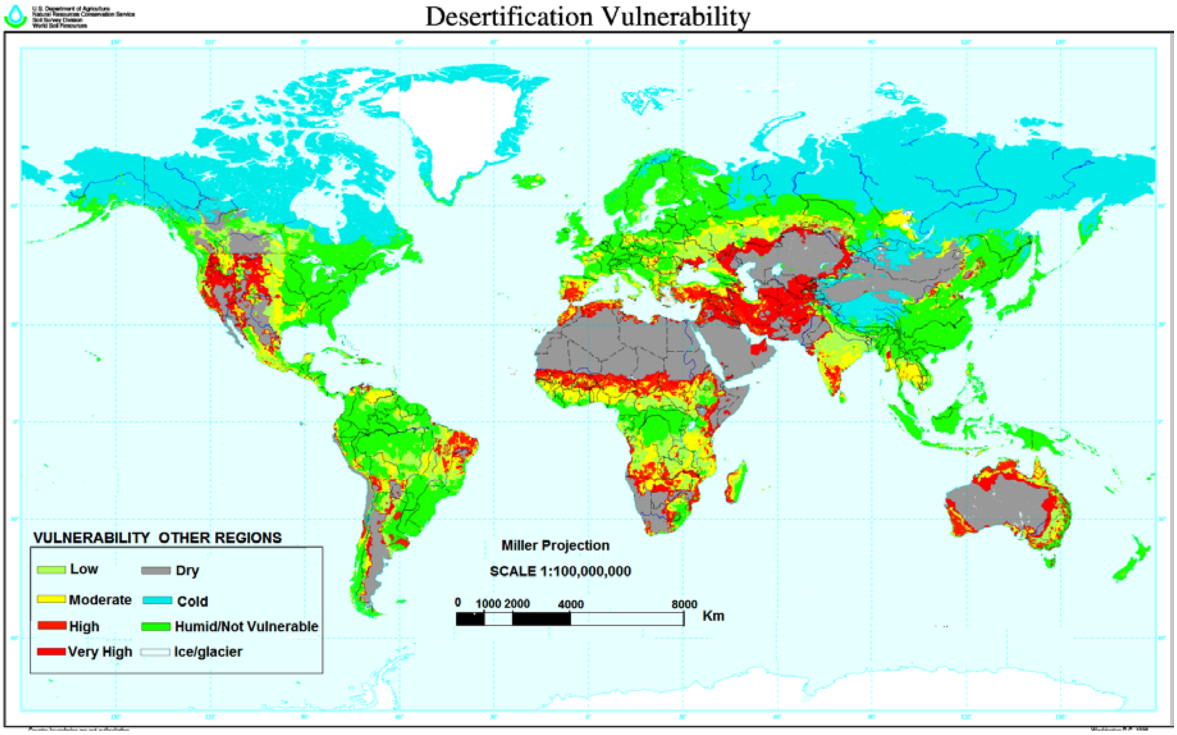
Sand dunes are formed by a group of sand particles; dunes are different in their sizes, from those 100s of kilometres long and over 200m high, as is the case in some parts of the great Sahara desert in Africa and Colorado desert in North America, to the sand hills which are given the name dune and which vary in height from a few cm to tens of meters (Saliem, 1991, p.104). Sand dunes form according to a set of factors namely wind speed and direction, volume of sand available, and the topography (Sherman and Hotta, 1990). The catalyst for the beginning of dune growth may be an exposed barrier or an obstruction in the wind flow (Nhal, 1989, p.58).

Moreover, when the sand dunes accumulate with natural form the wind-flow works again to transport sand grains and they are deposited in other places. These grains mostly have a diameter of between 0.2 -0.3 mm. However, the total variation in the size of grains is considerable, between 0.1-2 mm **(**Saliem, 1991, p.61).

Sand dune phenomena have been concentrated in areas of predominantly dry climate, including North Africa where this phenomenon has emerged largely through the role of climate in those regions (see Figure 2.1). Most North African countries are characterized as having a dry climate; these circumstances may increase the negative impacts of sand dune movement (Al Haram, 1995). Many studies have indicated that the droughts which currently dominate most of the northern parts of the Sahara Desert were preceded by periods of rain and humidity (Al Haram, 1995; Almakasbie, 2001; Ben Mahmod, 1995, p.71). This change to drier conditions has led to an increase in erosion processes for the modern sediment, including the current sand accumulations (Al Emsalati, 1995). The geological evolutions of land and fluctuations in levels of the Mediterranean Sea during the Holocene have contributed to extensive sand dunes, which are currently extending in those regions of the world (Gawdah, 1998, p.41).

The movement of sand dunes represents a direct threat to population and sites of economic activities. The natural environment adjacent to desert areas has tended to be lost due to the development of population centres in those regions (Almasoudi, 1984). This has lead to strenuous efforts in many countries to resist the negative effects of this environmental phenomenon, and despite continuing efforts, there are many technical problems, so there has been a reduction in the stability of dunes leading to their expansion both at the local and regional level (Aljadedie, 1992, p.58).

Figure 2.1 Area of desertification vulnerability together with dry land areas in the world



Source: Soil map and soil climate map (USDA-NRCS, 1998).

2.2 General principles of what controls sand movement

Crustal rocks are exposed constantly to many chemical and mechanical changes. This is due to erosion and fragmentation of many rocks, resulting in the formation of several types of soils (Moussa, 1986, p.49). These changes are occurring in the rocks due either to the weathering process (humidity, temperature), for example by rains, rivers, seas and oceans, or due to erosion processes (winds). The movement of sediment begins from the moment of separation from the original rock, and it may continue indefinitely. However it often stabilizes to become large sediments after the movement ceases, such as in sand dunes (Musharraf, 1987, p.95).

There are five causes for the movement of sediments: water, air, ice, gravity and animals, according to Twenhofel (1950), who has summarized the transport modes as follows:

A) Transportation by air and water:

The sediments are transported by air and water by creep and suspension, where this process is done by turbid currents or disturbances of water on low viscosity (Davidson-Arnott and Law, 1990).

B) Transport by gravity and crawl of ice:

The sediments are transported by this method, in the form of large blocks or small particles, where they resemble the movement of the flow of the sediment chips in fluids (Nordstrom, 2000, p.134).

C) Transport by movement of animals:

The sediments in such a case are moved directly or indirectly by the movement of animals. The best example of this process is the grazing of animals on mountain slopes, and rabbits can be one of the causes of sand moving. The reason for this role of rabbits is because they can remove the plants which protect the soil from erosion, and also directly disturb the sand particles and break surface crusts which hold the material in place (Sherman and Hotta, 1990).

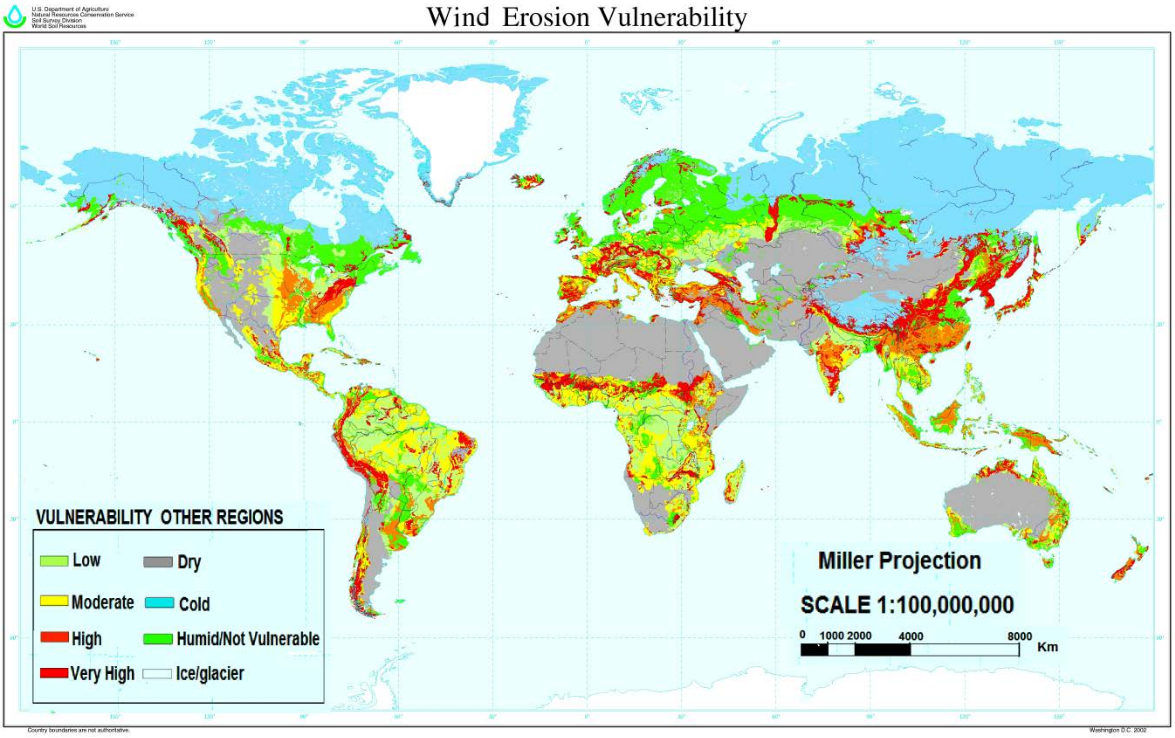
2.2.1 Wind is the key factor of erosion

Wind erosion is most severe within arid and semi-arid areas particularly during drought times. Such as, in the Great Plains within North America, during drought years where according to some studies the estimated loss of soil due to wind erosion is 6100 times greater than in wet years (Wiggs *et al*., 1996). Furthermore, modern agricultural operations, deforestation, overgrazing and suburban sprawl are amongst the important human activities that have an effect on stimulating erosion (Ritchie and Penland, 1990).

Despite erosion being a natural process, in recent years human activities have increased the normal rate of erosion which are occurring globally by between 10-40 times as much as previously (Goldsmith and Gertner, 1990). Active erosion processes caused many problems in different regions of the world (see figure 2.2), as is the case in desertification, land degradation and decreases in agricultural productivity, sedimentation of waterways, and loss of upper soil layers (Godone, 2011, p.145). Both types of water and wind erosion are the main cause of land degradation, where they are responsible for 84% of degraded acreage within the world (Pye and Tsoar, 2009, p.131).

Erosion by wind is of two potential kinds: deflation, this process occurs when the wind picks up and carries away loose particles; and abrasion, which is when the bottom surfaces are exposed to striking by airborne particles carried by wind.

Figure 2.2 Illustration about the regions which have wind erosion variability in the world



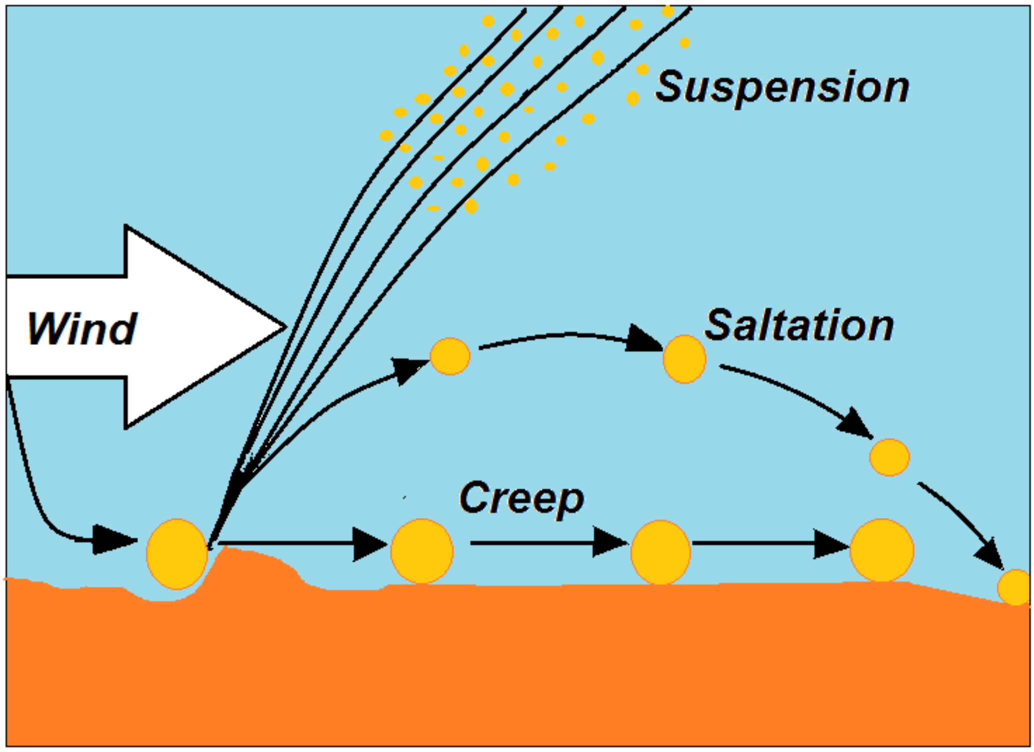
***Source**:* Soil map and soil climate map (USDA-NRCS, 1998).

2.2.2 Methods of transport of sand grains

Transport of sediment by wind is different from the transport of sediment by other factors, because the wind movement occurs at different heights, and consequently the processes of transfer and deposition of sediments by wind often occurs differently at different heights (Bauer *et al.,* 1990). Also, strength work of wind has similarity with strength work of water in sediment transport, because the sediments are moving in different directions (Sherman and Hotta, 1990).

The transfer by wind of deposits is directly linked to wind speeds, where sand grains and sometimes particles of gravel size are moving through creep, while the particles of mud, silt and other particles of dust are moving by suspension in the air, and this happens particularly when the wind speeds are high. Bagnold (1973) and Goldsmith and Gertner, (1990), studying the nature of the movement of sediments by wind, noted that there are three types of movements: saltation, suspension and creep, see Figure 2.3.

Figure 2.3 Methods of transport of sand grains, according to Bagnold (1973)



Source: Bagnold, (1973), (adapted by researcher).

Deflation is divided into three categories: suspension, which is responsible for (30-40%) of wind erosion; saltation is responsible for the majority (50-70%) of wind erosion; and surface creep is responsible for (5-25%) of wind erosion (Horikawa *et al*., 1984). These are discussed further in the next section.

2.2.2.1 Suspension

The particles of sediment (silt, clay, dust) which are smaller than 0.2 mm in size move with winds through suspension. The materials of very small sizes are mostly suspended in the air and usually are not found near to the Earth's surface. They probably remain hanging in the currents of surface air over long distances before falling on the Earth's surface (Robertson-Rintoul, 1990). This is evident particularly during the start of dust storms where the small particles are suspended with strong currents of surface wind to move up into the air. When fine sediments are carried in the air they remain suspended in the air for several hours or for several weeks (Sherman and Hotta, 1990). This is due to the fact that the descent velocity of these grains is less than the speed of ascending air currents. The upper parts of sand storms consist mostly of dust, where the dust rises into the air to a height of hundreds of meters, according to Wang *et al*. (2003b). For example, in 1930 Colorado State in the USA was exposed to sand storms, which impacted on the Atlantic Ocean through the transfer of large quantities of sand (Goldsmith and Gertner, 1990).

2.2.2.2 Saltation

According to laboratory experiments by Bagnold (1941) on the nature of the sand moving by wind, most sand grains are mobile through wind on an irregular track, which is not very high above the surface of the Earth. This process was named saltation. Most of the sand grains of about 0.2 mm size are moved by saltation in air (Lancaster, 1995, p.67). Because the air currents are turbulent and move in an ascending form, sand grains saltate with each batch of air. Sedimentation distances are commensurate with the wind speed and the size of mobile grains (Cook *et al*., 1993); these authors said that saltation depends on a wind speed of not less than 16 kilometres per hour (Bauer, *et al.,* 1990). The movement of the sand grains consists of a sudden rise and fall.

2.2.2.3 Surface creep

When the air currents are not sufficient to cause impact saltation of sand grains, the particles begin to crawl on the surface (Lancaster, 1995, p.74). Their movement progresses in slow motion sporadically in the general wind direction, and the size of sand grains which move through this creeping range between 0.5-2 mm (Livingstone *et al.,* 2007). An increase in the rate of wind speed does not increase the speed of the movement of sand creep, but if the wind speed increases strongly, some quantities of extra sand enter the movement.

Bagnold (1941) noted that most sand movement is by creep method, which he estimated as being six times as frequent as the movement of sand grains by other methods. The process of encroaching sand dunes happens under the influence of winds and under the influence of gravity, when the sand grains roll over to the top of the dune by wind until they reach the summit slopes and then, under the influence of gravity, they move down in the direction opposite of the dune crest, parallel the air stream (Sherman and Hotta, 1990).

2.2.3 Key factors which control sand movement

There are a variety of factors which control sand movement; also they are very essential for dune composition through to have access to their supply, which can be identified as follows:

2.2.3.1 Availability of sand

The formation of sand dunes takes place if there is a sufficient quantity of sand, in an area where there are rivers and torrential rains as a source for sediments. For example, sand dune systems in Arizona USA had resulted from the sediments of rivers coming from the moist interior areas (Singhvi and Porat, 2008), as were sand dunes on the northern coast of the Sinai Peninsula and Gaza Strip, according to Saliem (1991, p.84). These latter dunes are linked with silt sediments which have originated from the river Nile, and have been pushed by currents from the southern part of the Mediterranean to the east. Sand dune formation may also occur when the coastline retreats, which can lead to the formation of sand dunes by a new process, mainly from the erosion of old sand dunes (Sherman and Hotta, 1990).

2.2.3.2 Moisture

It is well known that marine sediments are usually saturated with water. The water increases the cohesion of particles and their ability to resist being blown by the wind (Belly, 1964, p.73). Sands typically contain a percentage of moisture ranging between 2 and 3% (Belly, 1964, p.94), needing high-speed winds to move them. This article also demonstrated that the movement of sand in humid coastal areas needed greater wind shear strength, by comparison with the shear strength in dry-areas, because the damp sand was heavier. The growth of the sand dunes in humid coastal tropics may be currently at a standstill (Asal, 1997, p.56), as was the case in the east coast of the Malay Peninsula, where it was found that the high humidity rates impeded the movement of sand dunes. Through field observations, Bauer *et al*., (2004) found that the strong onshore winds in the temperate regions act to dry the surface of the sandy beaches, which facilitate the process of moving sand in such beaches, so that coastal sand dunes are still actively developing in those regions.

2.2.3.3 Wind speed, wind direction and continuity

The presence of high winds (not less than 4.5 m/s according to Bagnold, 1973, p.103) in sand dune areas is essential to the process of moving the existing sand in these areas; so the largest sand dunes in temperate regions are found along the coasts where they are influenced by on-shore winds. These winds largely disappear in areas of the equatorial coast, particularly in those areas which experience a tropical climate with calm air. As noted by Pandey *et al*., (2008), strong winds rarely occur in the humid tropics compared to drier areas. Tropical storms are often accompanied by torrential rains, which saturate sandy surfaces (Saliem, 1991, p.119). Moreover, continues wind has an influential role in increase of sand movement. Wind speed rates which are capable of carrying particles and remain constant for long periods of time, as is the case in a full day or for several days, can directly contribute to growth of new dunes. Also, the direction of wind has an important role in direction of sand movement, particularly in the formation of different types of dunes.

2.2.3.4 Vegetation cover

Vegetation cover is one of the important methods which controls effective erosion, because the vegetation protects the upper layer of the soil, also it slows wind speed and it may be trap for any moving particles. Whether dead or alive, vegetation cover can impede sand movement and thus new dunes are formed. Further, vegetation cover can act as an interface between the atmosphere and the soil, because it most often works to increase the permeability of the soil to rainwater, thus limiting the process of runoff and decreasing wind erosion, through roots of the plants which bind the soil together with other roots, to forming a more solid mass against both processes of water and wind erosion (Pye and Tsoar, 2009, p.158). On the other hand, the density of vegetation on slope areas contributes greatly to stability of sediment movement within those areas, where the ability of the plant life growing on slopes will promote the stability on the slopes through the relationship between the plant species and complex combination of the type of soil (Thomas, 2011).

2.2.4 Characteristics of sand grain form

Many studies have been made of the form of sand grains and its link with the local sedimentation environment. From these studies, Asal (1997) has indicated several characteristics which distinguish between the form of sand grains from rivers and those from coastal areas, particularly the sphericity of the grains. This study focused on samples of igneous rocks from flint and quartz (Chert), where it is difficult to measure the form of sand crystals from three axes. Therefore, the forms of sand crystals are identified by the coefficient of sphericity (Musharraf, 1987, p.194).

Many studies (such as Howari *et al*., 2007; Lancaster *et al*., 2002; Muhs *et al*., 2003) have indicated that balling and roundness in the sediments increase with distance from the original source. As noted by Syvitski (2003), through experiments which he conducted in the laboratory on samples of gravel and sand, there are several methods (wind and water) to complete the deposition process of sediments.

The changes in erosion of grains along the rivers and coasts can be classified in form, such as in the case of continuity sculpture; those tests which were conducted by Warrick *et al.* (2009) have confirmed that wind erosion is more effective in achieving the roundness of grains than water sculpture across the same distance, but there are some indications that chemical solvents have an important role in processing the roundness of grains. This was confirmed by Wanke and Wanke (2007), who concluded that the best roundness in sand grains is created by the combined effect of sculpture at the same time as the deposition of silica on the surface of grains.

It is understood that the roundness of sand grains is achieved during transition and movement. The transport of grains over long distances can increase the roundness, but the roundness of grains differs from one rock type to another according to the quality of rock; for example, igneous rocks are not affected by the moving process because of the characteristics of the rocks (rigidity, size). For this reason, the characteristic of roundness cannot be used as an indicator of the presence of ancient waterways (Syvitski, 2003). The results of previous studies involving field work and laboratory tests have shown that the roundness of sand occurs through a very slow process (Jafari *et al*., 2010). Wang *et al.,* (*2003a*) also found through experiments that wind erosion is the most influential factor on the roundness of sand grains.

2.3 Basic conditions which control sand dune formation

Sand dunes are the most complex terrestrial form of sediment due to the complex processes involved in their formation (Embabi *et al.,* 1992). Such as an overlap between the types, with some ambiguity about the conditions of their formation, furthermore a complex process of sand movement by wind which is involving several modalities of grain movement and which happen more or less in the same time (Bagnold, 1941, p.148).

There is a set of terms which relate directly to the formation of sand dunes, in accordance with the differing conditions between the various regions in the world. Many studies have showed that there is a relationship between the important characteristics for formation of dunes and the local environment of dunes. (e.g. Wang *et al.,* 2002; Muhs *et al*., 2003; Wang and Zheng, 2004; White *et al*., 2007; Etyemezian *et al*., 2007). These criteria relate to the environment in which where there are sand dunes, where the researchers have sought to identify the basic conditions for formation of sand dunes.

These conditions centred about sand supplies, wind speed and their directions, and the vegetation cover.

2.3.1 Sand dune processes that affect morphology

Sand dunes vary in form and size; they also differ in terms of movement and stability. These differences have resulted in multiple classifications and divisions that have been developed to study the dunes. The classification of Bagnold was one of the first and the best of these classifications, with his researches having been collected in one book ("The physics of blown sand and desert dunes", Bagnold, 1941). The book contains the results of all of the laboratory tests which he conducted, and their accurate reliable results have been and still are used by other researchers. Despite other classifications more recently, based on different perspectives, all of these studies had indicated that there is a set of primary factors which are directly affect the process of sand dune formation. These factors are as follows:

2.3.1.1 The Winds

The role of wind on sand movement is firstly due to erosion and the dissociation of grains, followed by the process of friction for grains, which become small in size, leading to an easy movement horizontally (Lancaster, 1995, p.98). There are three methods of wind action, namely sculpture, transport and sedimentation.

2.3.1.2 Sculpture

The process of erosion is accomplished by strong air currents and friction at the surface (Cook *et al*., 1993), the surface wind speed erodes components of the Earth's crust by deflation through the removal of loose particle of rocks by the strong eddy of wind and by scraping, where the winds play the lead role as an erosion agent through saltation or creep of the surface material.

2.3.1.3 Transportation

Sand grains and dust are moved in the air by the winds to other places for deposition (Livingstone and Warren, 1996, p.109). Where the ability of winds to transfer sediment is dependent on wind speed, strong winds can move gravel and sand a limited distance, whereas it can transfer the fine particles of clay long distances (Gawdah, 1997, p.85). The movement of sediment by wind is different from the method of being transported by water. Because winds are less dense than the density of water, they are less able to transport large sizes of sediment (Gawdah, 1998, p.104). Also, winds are not confined to certain channels; they spread out over large spaces.

2.3.1.4 Sedimentation

Sedimentation on dry land is correlated with general movement of wind, as the sediment transport process is brought about by wind movement (Musharraf, 1987, p.76). Therefore there is a correlation between wind speed and the size of sand grains, according to Bagnold (1973), who linked the size of grains of sand with the wind speeds necessary to carry them, as shown in Table 2.1.

Table 2-1 Correlation between wind speed and the size of sand grains according to tests by Bagnold (1973, p. 114)

Diameter of sand grains	The speed required to transport the sand grains
0.25 mm	From 4.5 to 6.7 metres per second
0.50 mm	From 6.7 to 8.9 metres per second
1.10 mm	From 8.9 to11.4 metres per second
1.50 mm	From 11.4 to 13 metres per second

2.4 Types of sand dunes and how their formation is controlled by wind and sand supply systems

Sand dunes are formed by strong wind-blow, plenty of sand, and obstacles or barriers which act to reduce the wind speed, in order to cause the sedimentation process. Heavier particles of sand are deposed first in front of an obstacle, therefore a dune has started to be formed, while the lighter particles then settle above the dune and then start to slip to the other side of dune (called the slip face). Dunes may continue to grow for a long time depending on the wind - blow and sediment supply (Cooke *et al*, .1993). The direction and velocity of wind are the main factors involved in the formation of many types of dunes. There are three main types of dune formations which are the most common in the world, besides a few other dune formations which are rare. The major types of dune formations are as follows:

A) Crescent dunes: This group is the most common dune in different regions of the world, this type of dune is caused by wind which blows from one direction.

B) Linear dune: This type of dune is longer than others and it often contains a prominent ridge, also it the most common in the coastal dunes and depends on two nearly opposing directions of wind and their continuation.

C) The star dune: This group of dunes extend out from the centre of the dune towards different directions, according to wind directions, this type may be formed by multidirectional winds.

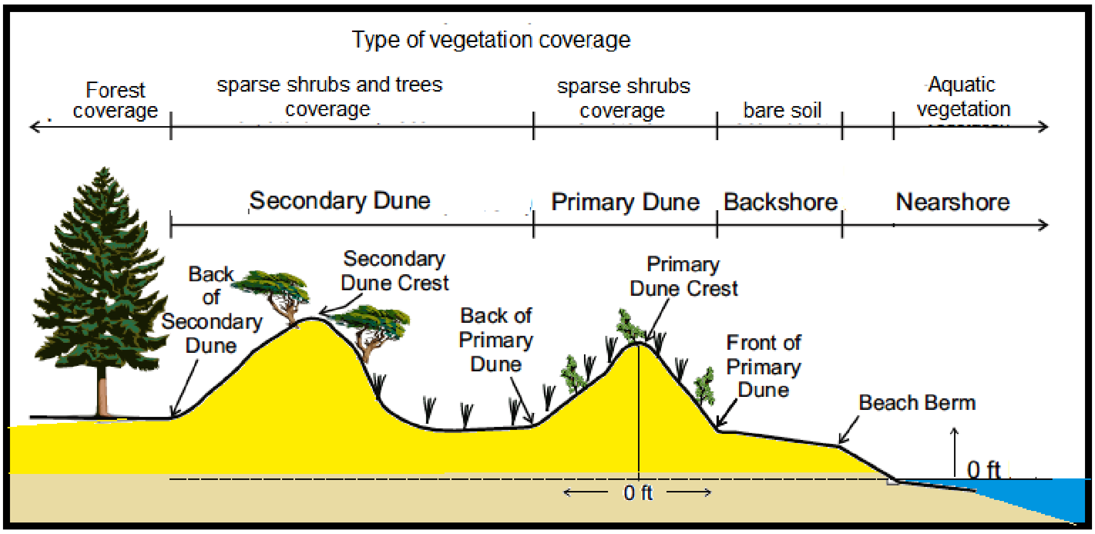
The remaining types of non-common sand formations are identified as reverse, parabolic and the dome. Wang *et al*. (2002) have noted three types of sand dunes existing in the Taklimakan Desert including compound, linear and crescent chains. As well as the compounds, crescent and linear dunes are divided into three forms: simple, compound, and complex dunes, the simple dune usually including one type of dune, whereas the compound dunes are formed from more than one type of dune while complex dunes include several groups of dune, from different types. The multiplicity of sand dune types does not necessarily mean a major difference in the form or type of dune, for example, the simple dune is similar to a linear dune; mostly the different names are due to the divisions which are established by the different researchers of those dunes.

Also, sand dunes are divided based on whether they are mobile or stable sand dunes; the stability of the sand dunes is temporary or sometimes constant, the constant form results from natural causes, such as the proliferation of plant life, or mechanical reasons such as spraying of oil or other substances. One of the main reasons for the movement of sand dunes is attributed to a sequence of periods of drought within those regions which has had covered sand, which is usually accompanied by an increase in wind speed, and with a decrease in vegetation (Al Kataly, 1988). Furthermore, climate is one of the important natural factors affecting all living organisms and natural activities within their environment. It also impacts on some geomorphological phenomena. For example, wind performs an important role in the movement of sand grains from one place to another; it also is the main factor in the formation of sand dunes and erosion processes in general, where sand movement requires speeds of not less than 16 km/ hour (Asal, 1997, p.112). Often, high wind speed is associated with areas of sand availability. Wind speed is affected by various elements of climate, such as the air pressure, where an increased difference in pressure means a greater increase in wind speed; pressure is also affected by temperature. An increase of relative humidity in the air stream increases the critical speed required to move the sand.

Moreover, sand dunes have been divided into primary and secondary dunes. The primary dunes are produced directly from aeolian processes on the beach, where sand supply derives primarily from the beach. Further, vegetation plays a major role in the development of this type of dune by hindering the speed and direction of wind. Also primary dunes are significantly affected by wave action (as both a constructional and erosional force) (Davies, 1980, p.96). The primary dune are the first dune which located directly adjacent to the beaches, with having an elevation equal to the mean flood level for the area, see Figure 2.4.

Primary dunes can be further divided into free dunes (with few plants and of limited importance), and transverse ridges and oblique dunes which have further vegetation cover. These types of dunes are noted within different regions of the world (Livingstone *et al*., 2007). Free dunes are distributed in two patterns (Yao *et al*., 2007). The first extends along the desert coasts, as in the coasts of California, Peru, Namibia, or Morocco on the Atlantic Ocean and the south - western coasts of Australia, where the moisture needed for plant growth is not available.

Figure 2.4 Schematic illustration of the formation and composition of primary and secondary dunes.



Source: Davies, (1980), (adapted by researcher).

The second pattern of free dunes is linked to the humid coasts, best represented by the west coast of the United States. This type of free dune is found in parts of the present study area. This pattern is formed on beaches due to the wind velocity, and the presence of vegetation such as usually appears in wetland areas (Lambin and Helmut, 2006, p.116). The growth of these dunes is common in the humid temperate regions, where the strong winds help the accumulation of large quantities of sand and the humidity encourages the existence of vegetation which increases the accumulation of sand and its stabilization (Dong *et al*., 2003a). Such dunes are widespread in the world, as in the Picardy Coast and Vendee in France, and the plateaus of sand on the shores of the Seychelles (Nunn and Kumar, 2006), as well as the sand beaches on the south-west coast of Sri Lanka (Doody, 2012, p.187).

Secondary dunes are a developed stage from the primary dune and may be due to directly continued aeolian processes on the beach (Davies, 1980, p.98), see Figure 2.4. Secondary dunes are often located further from the beach, where they are separated from nearshore processes. Further, secondary dunes mostly include many dune types such as blowouts, parabolic dunes, and dune fields.

Secondary dunes are derived from the restricted sand dunes, and extend along coasts in various forms (Van Der Hagen *et al*., 2008), termed Crescent, Longitudinal (seif), and Parabolic. These dunes appear when there is a limited amount of sand (Cook *et al*., 1993). The growth of such dune forms requires long periods of time with a lot of storm winds from one main direction. They have been seen (Ritchie and Penland, 1990) on the south eastern coast of Australia, where the movement of dunes was affected by the strength and direction of winds on shore (Etrab, 1993, p.65). The most important of these characteristics associated with different types of sand accumulations are presented in the sections below.

2.4.1 Coastal dune formation

Dunes at the coast depend on three features in their formation: a supply of sediments, an air speed which is sufficiently fast to cause the sediment to move, and somewhere for the sand grains to be deposited where they will not be swept away by waves. If plant cover is present, this increases the deposition of sand grains that are being blown around, and also hold what is already present in place (Sherman and Hotta, 1990).

2.4.2 Forms arising from the process of movement

The completion of the sedimentation process happens when there is an obstacle to streaming winds which decreases the speed of wind movement (Goldsmith and Gertner, 1990). Subsequently the wind deposits the material in the form of accumulations of the sands and if strong winds continue with a sufficient source of the sand, several types of sand form can be created (Del Valle *et al.,* 2008) as indicated below.

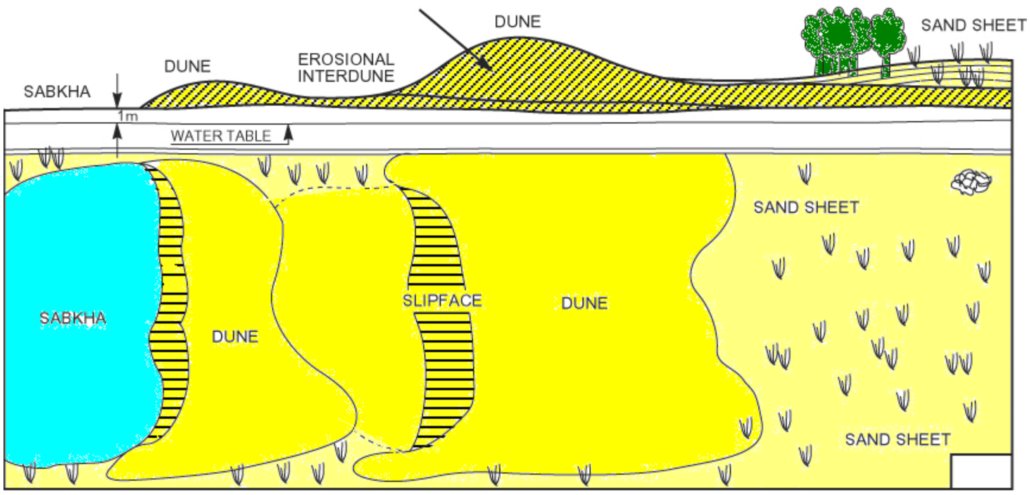
2.4.2.1 Sand ripples

Small wrinkles of sand often cover the surfaces of sandy formations, particularly in the deposition of copious quantities of sand, which is a clear indication of the beginning of the movement of sand (Cook *et al.,* 1993). The sand ripples are perpendicular to the wind direction, where the wavelength is matched to the movement of sediment, and the length of the distance separating the first ripple from the second is 50-200 mm, also, the degree of slope varies on both sides of the sandy ripples, which are between 8-10 degrees, according to the direction of the winds (Carter and Wilson, 1990).

2.4.2.2 Sand sheets

Sand sheets consist mainly of sandy flat areas which have a low angle of eolian stratification (Fryberger and Ahlbrandt, 1979), they often form on the margins of dune fields or through trailing margins of migrating belts of dunes (see Figure 2.5). Further, sand sheets mostly occur in areas not suitable for the formation of sand dunes (Pye and Tsoar, 2009, p.173), one third of the formation of sands being diverted into sheets. They cover between 50-70% of the area occupied by sand formations (Sherman and Hotta, 1990). They also often consist of coarse sand.

Figure 2.5 Schematic illustration of the formation and composition of sand sheets.



Source: Fryberger and Ahlbrandt,(1979),(adapted by researcher).

2.4.3 The form of sand dunes

Sand dunes are found in various environments of the world, and are found both in wet and arid environments. The sand dunes are classified into two types of sand dunes, longitudinal sand dunes, and transverse or oblique sand dunes; the first one is associated with deserts, and the second is associated with seas (Livingstone and Warren, 1996, p.121).

Differences in the origin of sand dunes are reflected in their forms height and extent, and also in their movements. For example, desert sand dunes mostly are more limited in their extent and show more movement (Cook *et al*., 1993), while the sea sand dunes are relatively larger grain size and therefore a lower amount of movement (Livingstone and Warren, 1996, p.164). This difference has been reflected in the forms of those sand dunes. The desert sand dunes are consisting of clay and silt, with minute grains, and move rapidly. Also, this type of sand dunes appears only in dry areas due to the erosion of the earth's crust.

Beaches may be a source of quartz grains, where they are linked to the presence of sea dunes, mostly as a result of the erosion and fragmentation of beaches or what emerges from the sea (Livingstone and Warren, 1996, p.77). It is clear that in terms of origin there are two types of sand dunes, coastal and continental.

Coastal dunes usually consist of coarse sand with contrast in colour and they contain carbonate, chloride and sulphate, they are also usually poor in nutrients and clay materials (Saliem, 1991, p.134). They stretch the length of the coasts of the seas and oceans and are created by wind carrying sand from the beaches, which was deposited during the operation of tides or the action of the marine currents (Nickling and Neuman, 2009). Examples of those dunes, which extend to the shores of the North Sea between the French border and the north of Denmark, are also found on the shores of the Baltic Sea, as most of these dunes are mobile with an absence of vegetation.

When lacking vegetation, such dunes are known as white dunes; sometimes dunes are termed grey dunes; these dunes have been fixed by the vegetation. These dunes sometimes reach up to 24 metres in height (Embabi, 1992).

2.4.4 Dune types and their relationship to wind systems

There is a strong and direct relationship between wind systems and dune formation in different areas of the world. The climate regions in the world have special wind systems and differ from one area to another. Wind strength and direction is one of the essential features in the difference between wind systems in climatic regions of the world. Therefore, the power and continuity of wind with their trends have been significantly factors determining the forms and styles of sand dunes in those regions of the world. Further, most dune types which have been formed by a particular direction of wind or through more than one direction of winds are associated with those trends of wind in different regions of the world for example the linear dune caused by two parallel directions of wind; while crescent dunes caused by a one direction of wind. Also, stars and transverse dunes are resulting from more than one direction of wind.

Some times when the wind systems are bidirectional with opposing directions, these wind systems are working to re-form a transverse dune with a complete reversing profile (Burkinshaw *et al*., 1993). Also, when the wind rotates from two reverse directions, the dune will trend to form the straight, linear, triangular shape of a reversing dune.

Further, the mechanism of wind power may directly affect the dune form, particularly on unvegetated sand dunes through emergence of different types of dune either the transverse (barchan) form, in which, the sand is eroded from the windward slope and deposited on the lee slope; or the linear (seif) form, where there is plenty of sand transported along the dune to the lee side by winds encountering the dune at an acute angle from both sides (Livingstone *et al.,* 2007). However, in some areas the wind systems can be bidirectional, with the first direction oblique to the crest line and the other perpendicular to it. For example these wind systems are noted in Oregon coastal dunes by Cooper (1965), and he termed these dunes, which resemble both transverse and linear (seif) dunes, oblique ridges (Bristow *et al*., 2000). Finally, there is an other type of dune forms, namely star dunes; this type of dunes is the most prevalent type of sand accumulations and sand dunes often stand out in the bed forms which cover a wide area. Mostly, the star dunes are formed by winds systems with a high multi-directional variability. Therefore often they are found in high desert latitudes which are characterized by seasonal changes in wind direction (Tsoar, 2005).

2.5 Vegetation cover and its impact on changing free dunes to pinned dunes

Vegetation plays an important role in reducing soil erosion by wind in arid and semi-arid lands (Godone, 2011, p.84). The effect of vegetation on wind erosion is attributed to several mechanisms:

(A) Sheltering of the soil surface from the erosive force of the wind, both by covering a proportion of the ground, or by creating wakes of reduced wind velocity.

(B) Momentum extraction from the wind by absorbing a part of the wind shear velocity and thereby decreasing the shear stress acting on the ground surface.

(C) Some plants reduce wind erosion by altering soil and atmospheric characteristics, such as soil structural stability and near-surface air moisture (Godone, 2011, p.114). Furthermore, they can trap soil particles, particularly windborne ones (Wolfe and Nickling, 1993).

2.5.1 Surface roughness caused by vegetation and its influence on sand movement

Dynamics and morphology of sand dune within desert and coastal environments are determined by a set of variables, including vegetation cover which influences the roughness of the surface. This factor has a direct influence on the creep and transport of sand by the wind (Wiggs *et al*., 1996). The main important points for vegetation are its protection of the surface by directly covering it, its action in trapping soil particles, and assistance in impeding movement through extracting momentum from the air flow (Wolfe and Nickling, 1993). Roughness is an important parameter in which vegetation influences sand movement.

Over smooth unobstructed surfaces, shear stress mostly has a greater affect and acts across the entire surface by wind blows. In contrast, the roughness elements on the underlying surfaces work to absorb a great proportion of the shear stress. Thus, they have a greater degree of protection for surfaces, according to their size, geometry and spacing (Miller and Yool, 2002). Low intensities of roughness elements over the surfaces cause increased erosion around those elements, which tend to reduce the threshold velocity of the surface, therefore causing the development and continuation of eddies (Morgan and Bull, 2007). By contrast, higher densities of roughness elements may increase the threshold velocity of the surface. The vegetation cover has been shown experimentally to have a great influence on wind blows, which suggested that the threshold wind shear velocity for transport (u*t) is greatly affected (Wolfe and Nickling, 1996). There are many studies addressed to the effects of vegetation on sand transport rates when sand surfaces are vegetated. For example, studies in Australia indicated that sand movement occurs most often even if the proportion of vegetation cover present was as much as 45 per cent (Wanke and Wanke, 2007). Further, in the Kalahari Desert, studies have indicated that the effects of vegetation on dune dynamics can lead to large changes in erosion and deposition rates within those regions, particularly when vegetation is reduced (Wiggs *et al.,* 1994).

The growth of natural vegetation is a reflection of the type of soil, climate and topography within an area. However, local differences between types of soil and topography represent the most influential factors affecting the natural plant life within the same region. Further, some studies of wind erosion have indicated that the effects of the presence of vegetation are complicated by the variability of vegetation characteristics and their dynamic interactions with different soil properties, atmospheric conditions and land surface characteristics; for example; the humidity and temperature of the soil and soil texture, composition, aggregation and crusting (Shao, 2008, p.105). Also there are many plant species, each with their own characteristics regarding spread size, ability to retain moisture, resistance to drought and many such aspects (Doody, 2012, p.187). There is an enormous diversity of plant species across the world with different properties and potential (Lambin and Helmut, 2006, p.97).

A succession of drought periods on any sand areas may directly affect the vegetation which covered those sand dunes, particularly if this drought coincides with the pressure of human activities, therefore this situation will enhance the likelihood of winds being able to move the sand. Foremost among the factors that make the sand ecosystem sensitive and unstable are winds, humidity and temperature which act more strongly of there is scarce vegetation cover.

Density of vegetation has a direct impact on the piles of sand through its contribution in determining the different sizes of dunes but these dunes take many different forms.

2.5.2 Stabilisation process of dunes

Vegetation is the best method used to stabilize sand dunes because it is effective in stabilizing sand, as noted by Li *et al*. (2006). Furthermore, it encourages biodiversity within the environment of sand dunes, especially when there is adequate moisture in those regions (Livingstone and Warren, 1996, p.145). The objective of sand dune fixation is not limited to stabilization, but also can contribute to production in various ways. Revegetation is the best alternative method used to stabilize coastal sand dunes compared to several other techniques which have been used, according to many studies (Woodhouse, 1978, p.38). Revegetation is the best technique, because this method is less costly, most enduring, and only this technique has the property of being self-repairing (Woodhouse, 1978, p. 76).

Many plants face great difficulty in their growth within the coastal environment of a dune, therefore, all plants which can be successfully established must have characteristics that allow them to survive such an extreme environment affect by erosion processes, temperature fluctuations, drought periods, sand encroachment deposition of salt and low nutrient levels. Despite the presence of many severe restrictions, there are several plants able to stabilize the coastal dunes which can be established within most coastal regions with enough rainfall to support plant growth (Woodhouse, 1978, p.41).

For example, in the United States there are some degraded coastal dunes have been stabilized by planting a small group of pioneer plants and perennial grasses (Woodhouse, 1978, p.71). The most commonly used plants in America and Europe are beach for dune stabilization (Seliskar, 1995). These types of plants have some favourable characteristics, namely being easy to proliferate vegetatively and easily available commercially (Woodhouse, 1978, p.56).

Moreover, these types of plants have good practical to produce viable seeds and occasionally spread into dune areas by seeds, however direct seeding is not generally an adequate means of establishing preliminary vegetation cover on coastal dunes, particularly in bare sand, for the reason that seeds will often become uncovered or buried too deeply before they can germinate (Wilggs *et al.,* 1996).

2.5.2.1 Sources of dune plants

Sufficient supplies of different types of plants are essential to any successful programme for dune stabilization, and to get these types of plants big planting projects are usually needed, thus involving a major cost. There are two main sources of dune plants:

(1) Plants which have been grown within nurseries, usually produced specifically to order for a sand dune fixation project.

(2) Plants obtained by taking material from existing fixed stand areas (Al Kataly, 1988).

2.5.2.2 Growth factors of dune plants

For dune stabilization projects to be successful there are several factors which should be taken into account along with a sufficient supply of planting stock, for example, suitable soil wetness and the low water retaining ability of sand are essential components influencing dune plants growth. Also, the salinity concentration is an important factor that can greatly affect the growth of dune plants, particularly with coastal dunes; deposition of much salt on dunes greatly hinders the growth of dune plants along any coast (Almasoudi, 1984).

2.6 Sediment supplies and their composition in different types of dunes

There are several sources for sand supply according to two types of sand: Sea sand and desert sand. Most coastal dunes are formed from sand produced and delivered to the coast by glaciers, rivers draining from them, or decline sea level in some other areas which has occurred in the Holocene (Gawdah, 1998, p.176). This means that the major source of sand started to decline about 10,000 years ago at the end of the last Ice Age. The generally hard rocks forming cliffs and the near shore seabed around much of coastal yield little fresh sand for the beaches (Asal, 1997, p.234). Some rivers in tropics regions still supply sand to the coastline, although much of this stabilizes out in estuaries instead of moving directly to the open coast.

Most of the desert features a varied topography, and its landscape has been shaped over time by wind, with sand dunes comprising around 25% of the desert. By weathering, sand is liberated from it sources (Al Emsalati, 1995). Weathering is the process of fragmentation and decomposition for rocks, soil and mineral constituents in the same location. Those rocks are influenced physically or chemically by the water, and blow-wind, or changing temperatures experienced in those regions. Weathering is different from erosion; the latter includes breaking of rocks with transfer of the crumbs and their deposition. The main sources for sand which have been liberated by weathering are igneous, metamorphic and sedimentary rocks (Saliem, 1991, p.179). The process of sand dunes formed requires providing a source of sand and mechanism to transport sand, also the size of area in which sand can be deposited by wind.

2.7 Methods of measuring the movement of sand

Many studies have been used to measure the movement of sand dunes depending on the environment of the region, and their suitability of use. Some of these studies relied on field work and direct observation of the movement of sand dunes, while others used models and statistical methods, as well as there also being recent studies which rely on modern methods such as satellite images and aerial photographs to determine the movement of sand dunes. These methods which have been used can be stated as follows.

2.7.1 The traditional method

This method, which is accomplished through field surveys and direct observation of the movement of sand dunes, uses special tools (traps and pickets) to determine the size and quantity of the movement of sands, and also identify the trends for this movement. Traps are sunk into the sand level with the sand surface and then they are monitored periodically to assess how much sand has moved into them. This method was used in several studies (Davidson-Arnott and Law, 1990.; Dong *et al*., 2000; Goldsmith *et al*., 1990; Kocurek *et al*., 2007; Livingstone *et al*., 2007; Psuty, 1990; Wang *et al*., 2003b; Wiggs *et al*., 1996). This method is the basis of studies in geomorphology; furthermore, this method is very useful and is of great importance in contributing to the interpretation of the phenomenon of mobile sand dunes. However, using this method requires a long period of time as well as requiring considerable effort.

2.7.2 Sediment transport models

A set of formulas is used to calculate the rate of sand movement on the basis of theory, where these models consist of basic variables such as the shear velocity of the wind and grain size diameter with sand density, in addition to gravitational acceleration and air density in some equations. The first of these equations was developed by Bagnold (1941), followed by Belly (1964), Fryberger and Ahlbrant (1979), Mckee (1979) and Sarre (1987). All these models have been modified subsequently in order to fit the actual movement of sand in the field.

Many studies have used these methods; For example (Dong *et al*., 2003a; Dong *et al*., 2000; Livingstone *et al*., 2007; Sherman and Hotta 1990; Tsoar 2005; Wang *et al*., 2004; Wang *et al*., 2003a; Wiggs *et al*., 1996; Zhang *et al*., 2000). Despite the fact that many models have been used to calculate the movement of sand, they still all depend on determining the precise amount of the actual movement of sand dunes. The reason for this is the fact that the equations depend on theory (default values) and are not real movements. However, this method should not be ignored as it contributes significantly to clarify the movement of sand dunes in theory (Nordstrom, 2000, p.124).

Following Bagnold's work, further contributions have been made in this subject by Sharp (1978) and McKee (1979), among others. The use of aerial photography has been advocated by Smith (1968), and of satellite remote sensing by Fryberger and Ahlbrant (1979). Also they have used satellite images and data on local winds to highlight the relationship between wind regimes and dune morphology. This author developed a "sand rose," which is similar to the traditional wind rose. For each location being studied, the amount of sand capable of being moved in each direction by the wind is modelled, based on wind direction, direction and intensity (cf Fryberger and Ahlbrant, 1979).

2.7.3 Satellite images and aerial photos

Remote sensing techniques have evolved dramatically in the past three decades, providing a suite of sensors to provide satellite images of land, which represent with a high scale of resolution of the objects on the surface of the Earth (Lambin and Helmut, 2006, p.97). This representation is of great importance to planners and land managers, where a wide range of imaging scales are operating (Livingstone and Warren, 1996, p.248). Landsat images are also available over a considerable time period, from the 1970s onwards. These pictures are used with SPSS statistical programs, and using advanced three-dimensional Geographic Information System (GIS) software. This method puts a group of control points in the field to check the accuracy of the measures of mobility of sand dunes (Cook *et al*., 1993, p.236).

Many studies have used this method (Bailey and Bristow, 2004; Del Valle *et al*., 2008; Hugenholtz and Wolfe, 2005; Janke, 2002; Mitasova *et al*., 2005, and Rubin *et al*., 2008).The results of these studies clearly demonstrate the importance of this method in measuring the movement of sand dunes, where the characteristics of this method are precision and ease of use in addition to the shortened time and effort (Pye and Tsoar, 2009, p.153). Various procedures can be used to assess the movement of dunes, including aerial photographs, satellite images, and topographic surveys. It is also possible to use marker poles to monitor dune movement over short periods (cf. Lancaster *et al*., 2002). However, these studies noted that topographic surveys have a very great importance for measuring sand movement according to the traditional method.

The rate of advance of sand dunes can be assessed by finding where the front of the dune (the slip face) is at different times. The slip face can be identified either through the location of shadows or by finding where plants start growing at the base of the dune. The amount of distance by which the dune is advancing is then usually based on the distance between two slip face measurements (cf Levin *et al*., 2004).

Digital aerial photograph analysis and the methodology developed more recently combine digital image processing and geographical information system (GIS) analysis; dune movement is detected from the aerial photographs, and the GIS software is used to correlate dune activity with climate variations. Until recently, there was a minimum size of 300m before satellites could detect dunes (cf Janke, 2002, Wang *et al.*, 2002).

Available aerial photographs were used in several studies for testing comparable photographs on the earth (Gullstrom *et al*., 2006; Mitasova *et al*., 2005 and Tsuchiya and Oguro, 2007). Many sites studied had a photographic record going back as far as the 1940s, and some went back even further (to the early 1930s and late 1920s). However, most early photographs cannot be used for digital analysis because the illumination conditions are different or because of poor film quality (Janke, 2002). Ideally, there are conditions for photographs of a given site to be selected to be used: they should have the same sun illumination, and have established principal points of location depending on the (GIS) database with data layers of topography and other characteristics from different times, so that the dynamic evolution of the sand dunes can be assessed, (Lambin and Helmut, 2006, p.114).

In recent years there has been tremendous development in the methodology of integrating elevation data which has been obtained by different mapping techniques including use of historical maps and aerial photographs (Lambin and Helmut, 2006, p. 117). The key characteristics of sand dunes are dune formation (where depend on several features in their formation: a supply of sediments, wind speed, the size of grain, moisture and the vegetation cover), the characteristics of sand grain form (where depend on the form of sand grains and its link with the local sedimentation environment), and the characteristics of morphology of dunes (where depend on form and size of dune, also in terms of movement and stability).

There has been considerable progress in recent years in the methods of tracking the movement of sand on beaches or in the desert (Nordstrom, 2000, p.201). On the beaches and across the seafloor, for example, some material has been found or used which resembles the natural sediment in the beaches in terms of size, density or quality and degree of hardness, with the distinctiveness of specific colours or some other characteristics (Saliem, 1991, p. 193).

The attempt at quantitative measurements of the movement of sediment was made by Bauer *et al.,* (1990), where coloured materials were used to determine the rates of transfer of sands from the front beach to the coast of

Sandy Hook in New Jersey, USA. At the front beach four different sizes of materials were placed with a distance of a hundred feet between each size, where there was movement of a stream along the coast. It was proved that the particles of 0.59 - 0.70 mm diameter arrived first, followed immediately afterwards by those of 0.70 - 0.84 mm diameter. Where the maximum speed for the flow of sand was measured per minute, size 2 mm was coming at the first rank, and size 2.6 mm was coming secondly. This method has also been applied along the shore of the southern coast of England by Allen (2000), when many positive and useful results were obtained.

However, it is difficult to apply this experience to all beaches in the world because many factors affect the sediment movement on the beaches (Salime, 1991, p.211), these factors being:

A. Coast form:

An irregular coast hampers sediment movement, whereas regular coasts (few embayments) help the process of sediment movement on those beaches. Artificial facilities such as breakwaters also act to change the degree of regularity of the coast (Goldsmith and Gertner., 1990).

B. Declivity of the beach:

Shallow water reduces the action of strong waves, which helps to stop the transfer of sediment towards the shore (Ritchie and Penland, 1990).

C. The difference in the extent of tides:

Whenever the difference between the phenomena of tides on the beach is wide this may cause an increase in the movement of sediment on shore, particularly around marine headlands. Also, the repetition in the tides leads to strong currents which help the movement of sediments (Psuty, 1990).

D. Action of the waves at the beach:

The action of the waves near the shore is necessary for movement of sediment to the coast; marine currents also contribute to that. It has been noted by Tsoar *et al*., (2004) that waves work to move sediments toward the shore, while their retreat towards the sea along the coast leads to the gradual transport of deposits.

2.8 Effects of and methods of controlling the movement of sand dunes (sand dune fixation)

The phenomenon of sand encroachment is the final stage of the deterioration of the natural environment which starts either from the sources of sand in the deserts, particularly arid desert (which has received a yearly total of rainfall less than 250 mm, with relatively few rainfall days, a mean daily temperature of about 22 °C and low humidity, with increasing rates of evapotranspiration), or from areas of fixed sand (Etrab, 1993, p.188). Imbalance in and degradation of the environment arises mostly by human factors, particularly within those inhabited regions, often due to inappropriate exploitation of the resources available such as water, soil and vegetation (Al Korachy, 1992). Sand encroachment can be a natural process, particularly within dry and severe drought areas as is the case in great Sahara desert, where the main conditions of wind erosion are available: blow-wind, stunted vegetation and bare-dry soil. In general, this phenomenon is a direct result of the sensitivity of natural environmental resources in their early stages of development;

where these resources are evolved to more advanced stages, so that the land is fertile and where there are good rates of rainfall and thick vegetation, degradation is less likely. As a result of this problem, the continents of the world lose annually nearly 24 million tons of topsoil, and there is deterioration of about 70% of the total area of dry lands used for agriculture during the last two decades; sand encroachment also makes 135 million people face the risk of emigration from their lands in these areas (ACSAD, 2004). Sand encroachment can be a natural process caused by a variety of factors (high rates of wind speed and temperature, low rates of rainfall and humidity, besides a decline in vegetation cover), these factors are associated mainly with the processes of active erosion by wind. Often, these conditions are located in certain regions of the world, as is the case near the tropics of Capricorn or Cancer (arid and semi-arid lands), areas where erosion processes by wind are active. Therefore, the phenomenon of sand encroachment may be a result of purely natural process and does not need to be a consequence of other factors such as human activities within other regions in the world.

2.8.1 The effect of sand dune encroachment

Sand dune movement affects human activities through continuous movement of sands; their effects can be divided into two as shown below:

2.8.1.1 The impacts of sand encroachment on agricultural and pastoral activities

The movement of sand covers areas of agricultural and marginal lands in addition to pastoral land (Darraz, 1995). The movement of sand not only affects the agricultural lands, but even agricultural crops such as the seasonal vegetables are affected by this process. Mobile sand dunes also generally affect pastoral land by covering large areas of it in the dry and semi-dry areas, reflecting the effects of this process on these regions through the loss of considerable areas of natural pasture of the world in recent times (Ayad, 1995).

Sand movement affects the agricultural production within these regions through some seasonal crops had exposed to damage (Darraz, 1995). As noted by Aljadedie (1992, p.219), there are two types of cost of damages. The first type is a decrease of the productivity of land due to salinity of lands, about 40% of productivity; this means the loss of actual income from productive land because of a decrease of about 40% of production. This amount of loss has been reported by Ayad (1995), studying desertification in Syria, where this loss represented about 250 U.S. dollars per hectare of irrigated agriculture, about 38 U.S. dollars per hectare of rainfed agriculture, and about 7 U.S. dollars per hectare of grasslands.

The estimate adopted by those studies represents only the actual cost of the immediate effects of this phenomenon on the site only, whereas the cost of indirect effects outside a site may be much higher than that. The first type of cost is the actual income of land. There is a great discrepancy of existing production between one site and another within the same area, including the types of desertification which can give rise to severe damage, medium damage, and greater than average damage (Ayad, 1995).

The second type is the cost of tackling this problem, in terms of assessing destructive effects due to this phenomenon. Not all studies specify the value of actual losses experienced as a result of desertification, for the simple reason that these studies cannot determine how long it would take for rehabilitation of those lands back to their previous state of production. Preventing the effects of this phenomenon on the local environment requires a long period of time, as well as control methods, which require constant care and renewal.

2.8.1.2 The impacts of sand encroachment on buildings and transportation

Sand dunes affect buildings through the continuous and permanent movement of wind which cause buildings to be covered in a short time, especially in those areas which are suffering from drought for long periods. This is what actually happened in some areas, as in Mauritania and southern Morocco in recent times (ACSAD, 2004). Libya has also been exposed to this phenomenon in previous periods. Many studies have pointed to this, for example one by Aleqwan Bietche (1821-1822), who stated that some coastal villages from Libya had been covered by moving sand during that period.

Mobile sand dunes also affect the road links, impeding traffic and movement on the roads through the continuous movement of sand, particularly in those areas characterized by high rates of drought together with an increase in wind speed (Abo Lugma, 1996, p.169). For example, Tripoli city in Libya was exposed during the nineteen twenties to the encroachment of sand on most main roads that link the city with the neighbouring cities, which led to the closure of roads and the blocking of traffic (Libyan Agriculture Ministry, 1973).

Also, the effects of sand dunes has reflected on planning processes and construction within the centres of human settlement through the breadth of spaces which are covered by sand, especially those which are spread near the cities and urban centres. All previous operations required significant effort and large sums of money to deal with this phenomenon, both at the planning level and the level of protection of road links and other human activities (Al Kataly, 1988).

2.8.2 The causes of sand dune encroachment

There is a combination of factors which led to the emergence of the phenomenon of sand dune encroachment. These factors include the elements of climate and human activities overall. The problem of soil degradation and the reduction of vegetation occupy an important place among the environmental problems in the contemporary world (Darraz, 1995). Usually this problem arises as a result of human activities through the attempted exploitation of natural resources, where efforts were concentrated in the past to increase agricultural production, without enough attention given to the environmental consequences of these development activities (Aljadedie, 1992, p.211).

The land area used for food production has increased at the expense of natural vegetation in most countries of the world, leading to deterioration in many regions (FAO, 2004). This applies particularly to some productive agricultural systems such as forests and pastures, and more agricultural ecosystems are affected in agricultural development projects, desert environments and semi-arid places (Ayad, 1995). The deterioration of vegetation in the study area as a result of poor land use has led to an increase in the area of moving sand (Almasoudi, 1984).

Thus, stabilized sand can provide pastoral regions with supplementary sources for food, especially since this phenomenon has a direct impact on the natural evolution of plant and soil (Doody, 2012, p.177). It can also provide land to meet agricultural expansion and thereby food security in the long term in view of the increasing need for food, due to the growing numbers of the population. Such stabilized areas can also contribute to the rising of productivity rates for agricultural areas, providing protection from dry-wind and increasing the rates of rainfall needed for harvesting (Lambin and Helmut, 2006, p.143). Thus, the economic benefits of vegetation are no less important than the environmental benefits, through multiple products which are used to meet human needs and requirements.

2.8.3 Methods to control the movement of sand dunes

The different systems using to prevent the encroachment of sand all have the objective of reducing wind speed (zhang *et al*., 2004); in this way the deposition process of sand can be made to occur away from agricultural land. Most of the methods which are used to stabilize the sand dunes are concentrated on two principles (Cook *et al*., 1993).

1. Stop the movement of sand, through the cultivation of the most appropriate types of plants on sand dunes or through providing a cover to the dunes by oil.

2. Reduce the wind speed through the use of barriers, especially in agricultural lands, for protecting the crops from the dangers of encroaching sand.

Further, some studies of wind erosion have indicated that the effects of the presence of vegetation are complicated by the variability of vegetation characteristics and their dynamic interactions with different soil properties, atmospheric conditions and land surface characteristics; for example; the humidity and temperature of the soil and soil texture, composition, aggregation and crusting (Shao, 2008, p.103). There are many plant species, each with their own characteristics regarding spread size, ability to retain moisture, resistance to drought and many such aspects (Syvitski, 2003). There is an enormous diversity of plant species across the world with different properties and potential (Thomas, 2011).

Many special methods which have been used in the world for stabilizing sand dunes are similar in principle and goals, differing only at the implementation level (Al Korachy, 1992), which in turn is often due to the availability or lack of raw materials used and the technical possibilities available to each country (Almkasbie, 2001). For example, some countries in North Africa such as Algeria and Tunisia have used dry plant material which is placed horizontally on the surface of dunes (overall cover) to reduce the movement of sand (Abd Elgawad, 1997, p.93). Other methods are used to stop the movement of marine sand, through the establishment of barriers opposite the trend of the winds (Livingstone and Warren, 1996, p.189). Libya has used several methods to reduce the risk of encroaching sand, which has been referred to in reports published by the Ministry of Agriculture in Libya. The work of fixing of sand dunes on a massive scale began in 1916. Among these methods and the most common is the reforestation, and it has been used extensively within the northern parts of Libya (Almasoudi, 1984). However, sand dune fixation is subject to two key processes (Darraz, 1995): mechanical fixation, and fixation using plants. The mechanical fixation of sand dunes aims to mitigate wind speed, therefore making it impossible for the wind to relocate the sand and also to impede access by the wind to sand grains on the surface of dunes (Lancaster, 1995, p.95). According to Psuty (1990), the process of mechanical fixation can include creating defensive barriers; establishing small windbreaks; and covering sand dunes with plant residues or oil or chemical materials.

The methods of sand dune fixation are different from one dune type to another and from one country to another, depending on the type of available material and the cost (Ayad, 1995). The most important methods used to stabilize sand dunes are afforestation and establishing barriers and fences. These will be discussed in turn.

2.8.3.1 Afforestation

The aim of sand dune fixation is to create sustainable vegetation, especially tree cover (Psuty, 1990). Primary fixation (by mechanical or chemical means) is a short term solution to stabilize the surface of sand dunes for a certain period (2 - 4 years), which is enough to allow the growth of trees or shrubs, which are installed on the sand dunes (Abd Elgawad, 1997, p.178). The roots of bushes and trees help with the cohesion of sand grains, and also plants help to act as windbreaks and protect the surface of the sand from erosion (Syvitski, 2003).

2.8.3.2 Establishing barriers and fences

This method is one of the means of temporary stabilization for sand dunes. It requires permanent observation (Pye and Tsoar, 2009). It involves building a barrier in places where sand and wind blow, to reduce the wind speed and erosion; the reduction in the movement of sand by having it accumulate on these barriers is designed to protect all existing lines of economic installations (Shao, 2008, p.123). Also this type of method may involve perennial plants as a barrier such as cactus and other similar plants (Psuty, 1990). The materials used for building barriers usually are different from country to country according to remains of plants that are available locally, this reflecting the role that may be played by both the climate of the region and the type of available plants (Syvtski, 2003).

2.9 Conclusion

This study is the first which has been done on this subject within this territory of North Africa. The region suffers from a scarcity of research studies which address the important environmental problems, including the phenomenon of sand dune encroachment. When exploring this topic it was realised that most previous literature in this field has been restricted to the reports, particularly those found in the local administration of government institutions, but almost no primary research investigations.

Moreover, all of the existing reports are limited to an illustration of the problems and obstacles caused by this phenomenon; the apparent lack of adequate research coverage for this field appears to be due to the absence of clear strategic plans by the government, and the necessary support of them. Also, there may be deficiencies in centres of research with respect to this field of specialization to address these problems of the local environment.

Therefore, this project is the initial nucleus in this specific field of research for this region, to elucidate the problems to the local environment, helping to understand them, and to find solutions for the problems. There are many studies that have been made in the region in various fields of research, such as in desertification, pasture degradation, shrinking forests and vegetation, and urban expansion, in addition to some other studies in the field of population growth and industrial development; but despite the abundance of various lines of research covering the region, there is a clear insufficiency of field research covering sand movement within the region. The relevance of the interest in sand movement is its link to desertification as well as the phenomenon of sand encroachment on human populations and agriculture in a region which is already quite marginal in its ability to grow its own food. Therefore this study will hopefully provide information of wider relevance to an important aspect of research in the field of applied geomorphology with human activities, and in general in field research of dry land management which would be applicable to other countries.

3 CHAPTER THREE: The study area

3.1 Introduction

The location and extent of the study area were mentioned in Chapter 1. This chapter gives more information about the geographical characteristics of the study area, in terms of geomorphology, climate, soil and natural plant cover. Furthermore, it also explores the nature and dimensions of processes of sand movement.

The region chosen is considered to be a good example for studying the evolution of sand dune movement, because of a combination of factors: There are many sand dunes over most of the different parts of the study area, therefore this sand coverage represents a big challenge in the formulation and implementation of development plans in the region. Also the study area is representative of an extensive area of the semi-arid region found in northern Africa. A dry climate with an abundance of sand is ideal conditions to use Bagnold’s equation, and it is possible to get the best results of predicted sand movement. The study area is one of the biggest parts of one of the important provinces in Libya, in terms of the number of inhabitants and the extent of agricultural land. Thus the role of human activities is a key feature to be found within the region. An increase in the human population means to increasingly more human activities, which at the sometime the location of the region within the dry lands means that there may be erosion activities due to this, therefore the area can be used to investigate the relative influence of natural processes and human activity. A further advantage of studying this area was that the researcher could access local information such as about known impact of sand movement, and carry out fieldwork in the local language. So, all of these facts contributed to the motivation to select this region for conducting this research.

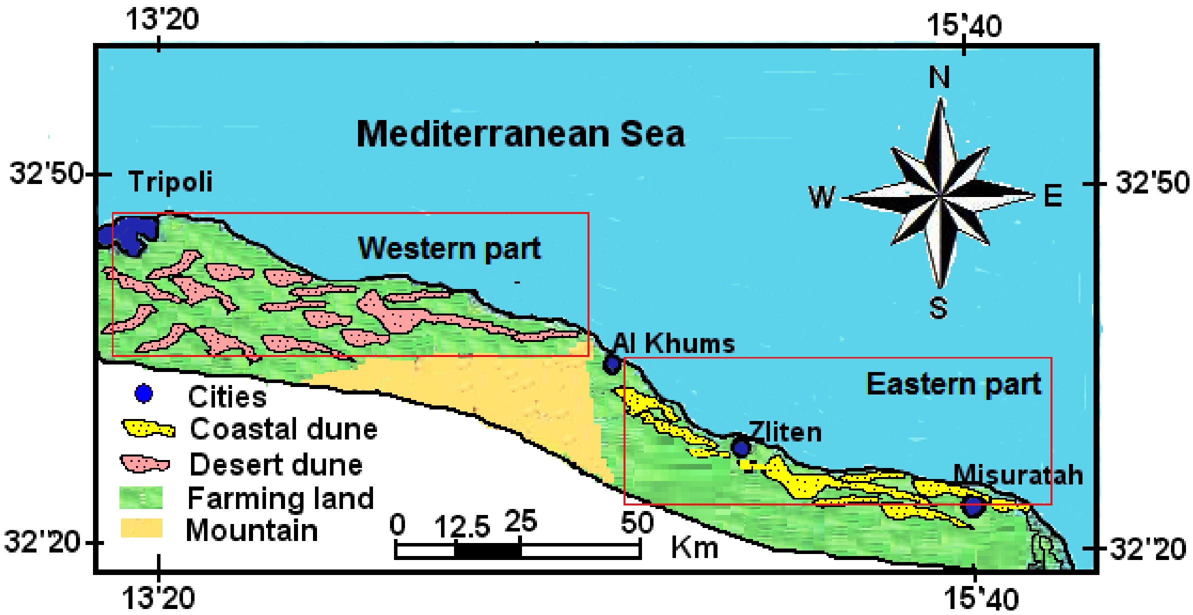
The movement of sand dunes represents a direct threat to population and sites of economic activities. This is shown by the proliferation of sand dunes in the north-western part of Libya, considered to be one of the most important plains in Libya, both in relation to its size and its population (comprising the Alajafarh plain, and the Zliten Misurata plain).

Therefore it is necessary for there to be successful programmes to resist the encroachment of sand. For this reason all necessary studies should be undertaken for the implementation of scientific and technical operations. It is hoped that the present study will make a contribution to the identification of the phenomenon of sand dune movement and the problems caused. The study area is considered as one of the most vital regions in Libya, where more than 50% of the population of Libya live (Abo Lugma, 1995), and where more than 70% of agricultural production, particularly vegetable farming, takes place (GAIL, 2006), including 80% of fruit production in the country, due to the fertile soil and the average rainfall of between 250-300 mm/ year (GAIL, 2006).

Thus, this chapter seeks to highlight relevant information such as the geomorphology of the area, its climatic characteristics and the main vegetation types, and to explore their significance in relation to the present study and the earlier literature.

The study area can be divided into two parts, which include two main types of sand dunes. The coastal sand dunes extend along the coastal plain in the eastern part, namely the Zliten - Misurata plain. This part includes many areas of farming land and forest, as well as intensive human activity. These dunes are characterized by their colour ranging from white to grey, sometimes also mixed with black and orange molecules. As well as the marine sand these dunes include carbonate salts, chlorides and sulphate, and are devoid of mud and organic materials (Al Masalati, 1995). The second main types of dunes in the study area are the desert sand dunes. This type of sand is wide spread over a large part of the western part of the study area, covering an extensive area of the Alajafarh plain. This part includes much farming land and forest areas, as well as many human activities, which have focused around some big cities in this region, as shown in figure 3.1.

Figure 3.1 Map of the study area showing the two parts of the region, and which covered by types of land cover in each area. (Source: Soil-Ecological Expedition of the USSR V/O, 1980)



3.2 Geomorphology

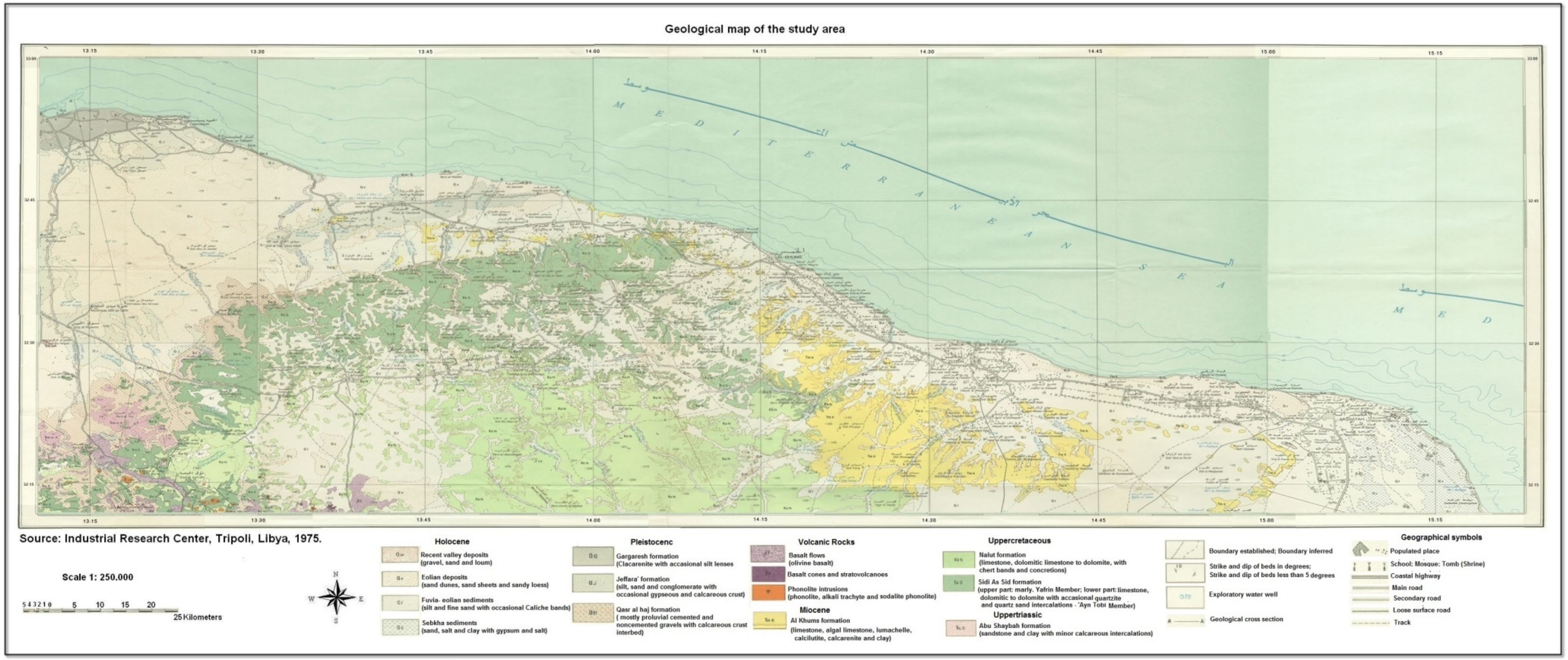
Between 1972 - 1975 was carried out a basic geological survey and the constructing of geological maps for all Libyan regions by the Industrial Research Centre of Libya, with participation of the Czechoslovak National Enterprise Praha, represented by the “Geoindustria" Company; a team of technicians and the experiences of various scientific bodies were used to implement this work. This program produced two map sheets on a scale of 1:50,000 and 1:250,000, illustrated in Figure 3.2. The study area has also been covered by two geological map sheets; the Al Khums sheet and Musrata sheet.

In the following is a detailed description of the geomorphological status in the study area, also a detailed view for stratigraphic formation of Quaternary rocks which are relevant to sand dunes within the region, based on the statement in the explanatory booklet and geological map sheets referred to above (Hallet, 2002). The area can be divided into three main morphological units. These units are known as the plains, the slopes and the plateau (Figure 3.2).

3.2.1 Coastal plain

The study area includes two distinct parts of the plains; the first one is the Misurata - Zliten plain, which extends from Tawerga Marsh in the east to Al kums in the west. Also it extends from the Mediterranean Sea in the north to the edge of the plateau in the south, which rises to 150 - 200 meters above sea level (Frohlich *et al*., 2010). Features of this plain include that it is very flat, with altitudes as little as 30 meters above sea level. It includes some broad and shallow vales which are one of the prominent morphological features in this coastal plain. Other conspicuous morphological features are the calcarenite ridges which extend along parallel to the coast, with ridges of an extensive sand dune to the south of the coastline. Also there are some dry vales which drain through the plateau, and flow over this part of the Jeffara plain where they spread out as they move towards the coast; other valleys are longer and their channels incise deeply into the flat plain, such as the Al Majinin Valley.

Figure 3.2 Geological map of the study area, according to geological map of Libya, 1975.



The second part is the Jaffara plain which covers the western part of the study area. In general, this plain is a nearly flat area stretching, as noted above, from the Mediterranean Sea to the north and slopes of the Nafusa Mountains to the south. It could be differentiated into three parts, all of them covered by Quaternary deposits, with occasional outcrops of limestone hills belonging to the Al Aziziyah formation outcropping occasionally. These parts are the coastal strip, which forms part of the study area, the central part and the mountain edge.

The coastal strip extends from the sea in the north to the south for a distance ranging from 10 to 20 km (Hallet, 2002). The most important geomorphological features of this part of the coastal area are sand dunes and brown silt of the Jeffara formation. Its low-lying topographic areas are covered by marsh sediments. The central part of the Jeffara plain stretches from the southern boundary of the coastal strip to a distance ranging from 60 to 90 km; towards the south it can reach an altitude of about 130 meters above sea level. Also it includes outcrops of dolomite limestone hills of the Al Aziziyah formation which rise to about 100 meters above sea level (Belaid *et al*., 2010).

The central part of the Jeffera plain is covered mainly by aeolian deposits mixed with the brownish silt of the Jeffara formation. Its southern border interlocks with the mountain edge which is mainly made of coarser fluvial and proluvial sediments of the Qasr al Haj formation. These deposits were formed by the coalescence of pre-existing alluvial fans at the foot of the slope. Through this strip the Jeffara plain assumes elevations ranging from 130 to 200 meters above sea level.

3.2.2 Slope or mountain

A mountain range is a prominent morphological feature of north western Libya in general, including the study area, called the Nefusa mountain range. In places it has been given local names such as Gharyan Mountain (Yafrin - Gharyan strip) and Emsalata mountain (Tarhuna - Emsalata strip).

The sloping land inclines approximately in an east-west direction from Al khums and westwards to beyond the Libyan border. This mountain overlooks the Jeffara plain and rises above sea level to elevations ranging from 500 to 700 meters. Also this phenomenon features clearly in the study area at Naqaza slopes near the Al khums region.

It is highly dissected by deep valleys and canyons, by which the slope is highly developed into promontories with corresponding embayment. As a result of tectonic events, the central part of the slope has an irregular outline which is clear from the several trends of the slope direction in this part. Northeast – Southwest, Northwest – Southeast and East – West trends are present, among which the Northeast – Southwest is more frequent.

The slope is built up of Mesozoic rocks, which are made of limestone, sandstone, clays and dolomite limestone. The soft rocks from the slopes are often covered by debris and limestone masses.

The origin of the slope has been the subject of two different opinions. The first suggestion was mentioned by Al Emsalati, (1995) who believed that the mountain front was uplifted as a cliff, which has been eroded and gutted on the northern side by wave action when the Jeffara was still submerged. The second suggestion was described by Al Haram, (1995) who attributed the formation of the slopes to the Al Aziziyah fault which took place in pre-Miocene time.

3.2.3 The plateau

The plateau consists mainly of hard and resistant dolomite limestone of upper Cretaceous age. Also this plateau is almost a natural level extension of the Red Hamada plateau which is covering the western parts of Libya. There are some unusual features of this plateau in the southeast area of Gharyan, where it is covered by basalt sheets forming flat and broad plains. In addition to that the northern part of the plateau surface is highly undulated, dissected by deep valleys and canyon- like channels.

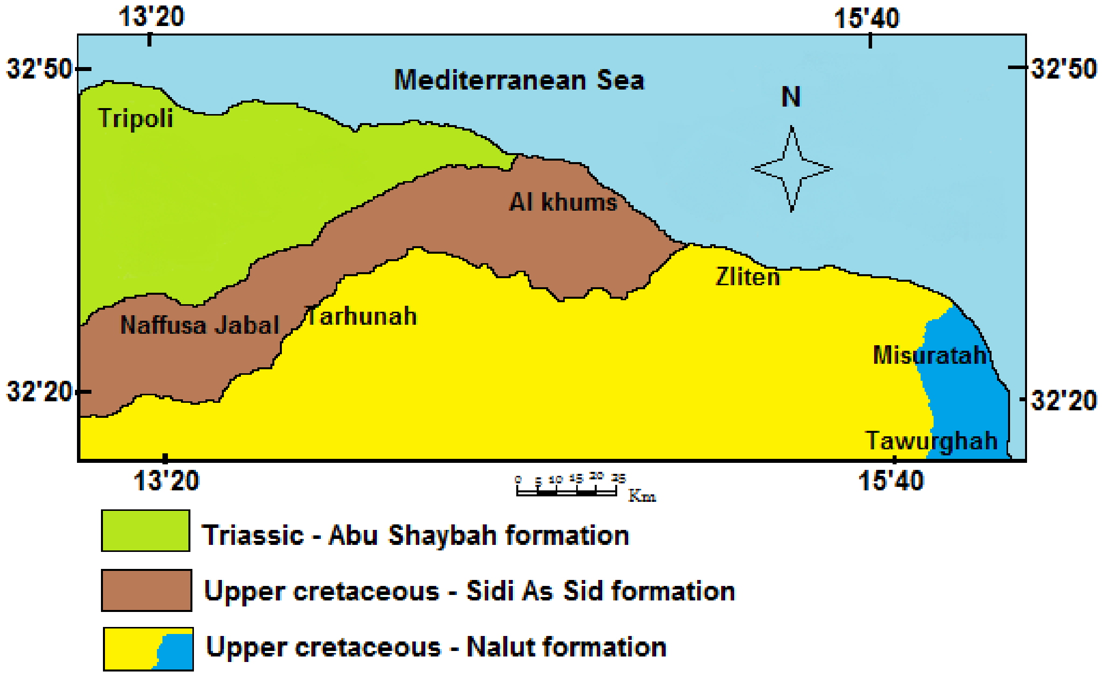
The average elevation of the east plateau of the area is 500 - 700 meters. Elevations of 800 meters above sea level are common in the hilly parts of the plateau between Gharyan and Yafrin. The low topographic areas are mostly covered by fluvio-aeolian deposits. Meanwhile, the plateau in the eastern part of the region reaches altitudes between 150 and 200 meters above sea level.

Supply sediment is a very essential for understanding sand movement and their extent evaluation in the future. Therefore it is very important to know about the key sources for sand formations in the study area. For a comprehensive understanding about the origin of sand formations in the region in terms of the history age which belong to it of these formations, and extent of availability of sand supply in the future, therefore, can browse the rock formations for these sediments as in the following

3.3 Stratigraphy

Most of the deposits which cover the study area are from Quaternary sediments, with a few formation units from the Triassic, as described below (Figure 3.3).

Figure 3.3 Map showing the extent of the Mesozoic deposits in the study area (adapted from Smetana,1975).



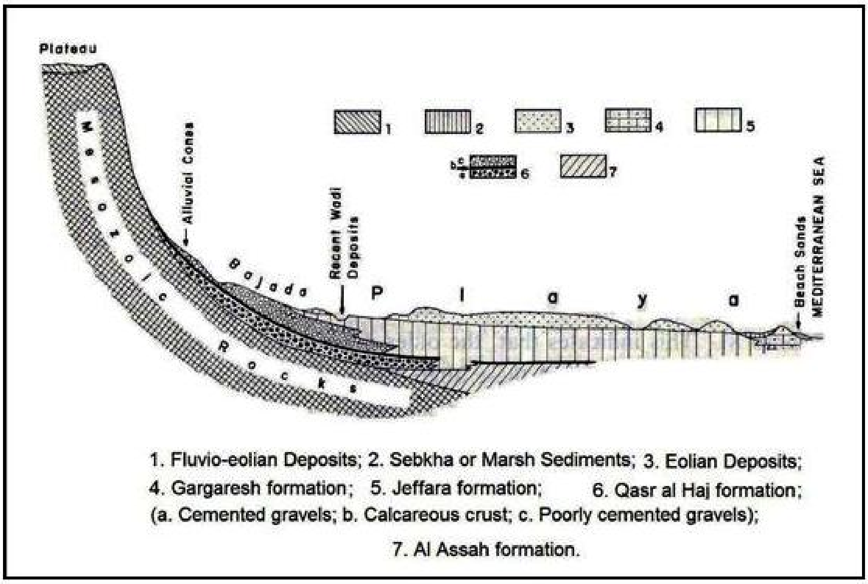
3.3.1 Quaternary rocks

The Quaternary rocks cover most of the Jeffara plain as well as patches of the plateau. It was possible to differentiate the Pleistocene deposits into three rock units, within the study area, based on the geomorphology of the area (Figure 3.4), while the Holocene sediments were differentiated into five units.

The Pleistocene deposits which mainly cover the study area were divided into the following rock units from top to base: Gargaresh formation, Jeffara formation and Qasr al Haj formation.

Field observation indicates that the relation between these units is also a lateral passage from one to the other. Each of these units can be described below.

Figure 3.4 Relation and distribution of Quaternary deposits through the area, according to Smetana (1975).



3.3.1.1 Qasr al Haj formation

This term is used here to describe the bajada deposits at the base of Nefusa Mountain. They extend for several kilometres to the north of the mountain where they spread in different parts of the region. The sediments of the Qasr al Haj formation are mainly alluvial fans and cones consisting of materials derived from the slopes.

The Qasr al Haj formation can be differentiated into two distinctive members separated by a calcareous crust band. The lower member is known as the Qasr al Haj conglomerate, best developed at Qasr al Haj village where it rests above the clays of the Kiklah formation. The upper member is partly equivalent to the Al Hira valley formation described by Al Emsalati, (1995) and is reduced here as a member of the Qasr al Haj formation. The two members are described lithologically in Figure 3.5.

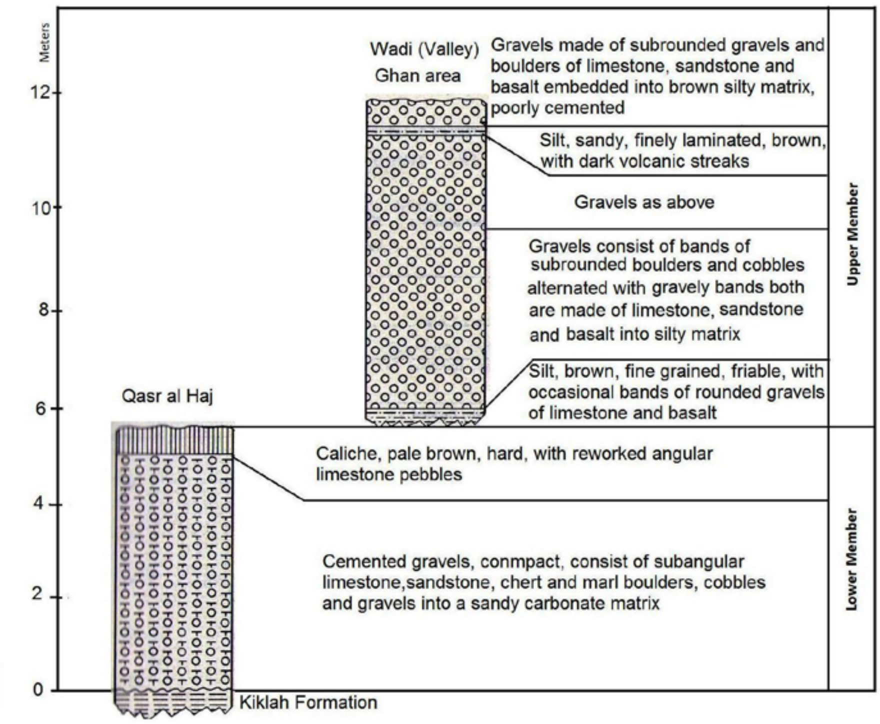


Figure 3.5 Composite section of the Qasr al Haj formation, according to Smetana (1975).

The alluvial cones, which are best developed on the slope faces, were assigned in the western part of the study area to the Qasr al Haj formation even though they represent younger slopes. The lower member is from the Plio - Pleistocene Epoch.

3.3.1.2 Jeffara formation

This formation included the sand and gravels. It also consists mainly of fine materials, mostly silt and sand, occasionally with gravel and caliche bands (Figure 3.6). It covers extensive eastern parts of the Jeffara region.

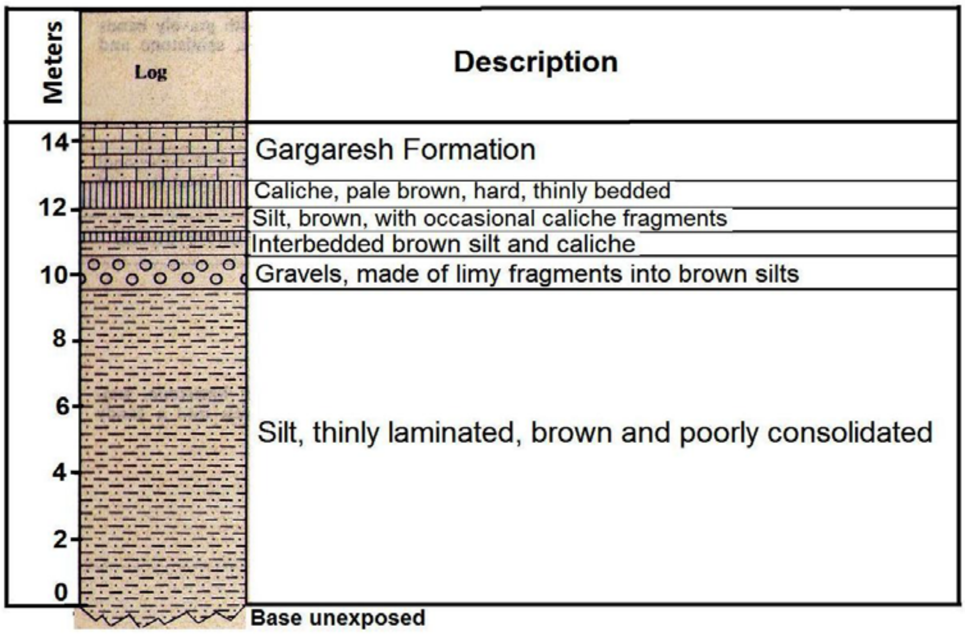


Figure 3.6 Type section of the Jeffara formation, according to Smetana (1975).

3.3.1.3 Gargaresh formation

This rock unit was described in the "Lexique Stratigraphique International" (1960) as Gargaresh Sandstone of Tyrrhennian age (Figure 3.7).

The Gargaresh formation is spread along the shore of the Mediterranean sea of the region, where it stretches from Tawerga Marsh in the east to the Tunisian border in the west. It extends southward from the present shore line for a distance of 3 to 6 kilometres.

This formation consists mainly of calcarenite sediments, since it includes fossilized shell fragments and minor sandy grains, with occasional silty lenses.

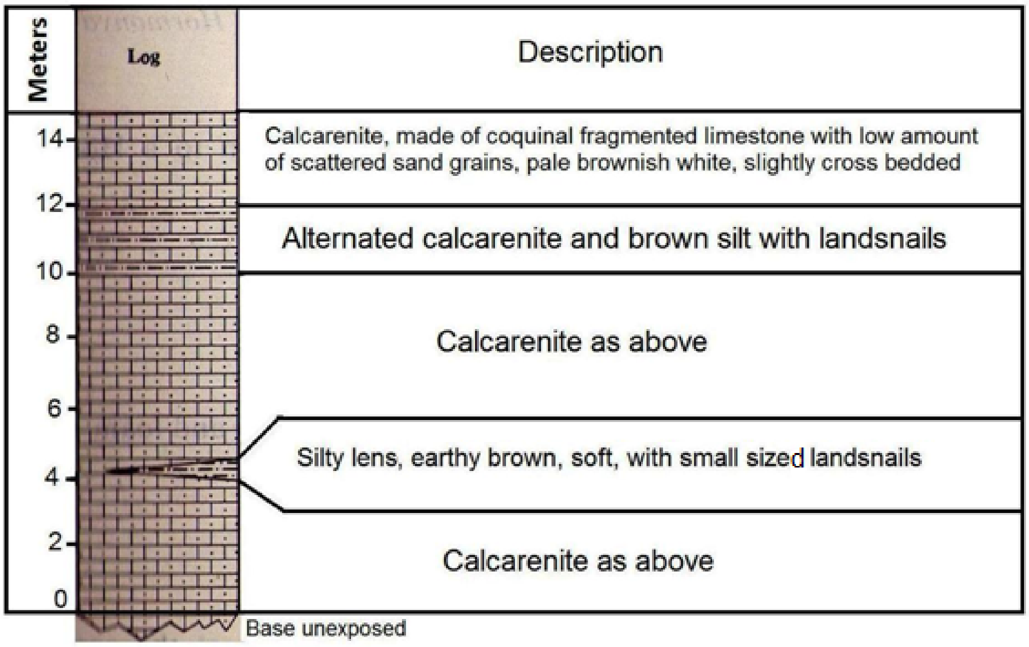


Figure 3.7 Type section of the Gargaresh formation, according to Smetana (1975).

These sediments occur as hills and steep cliffs along the shore; also this formation is found as far as about 15 km east of AlKoms. In old quarry faces within the Gargaresh formation, zones of marine fossils may be observed and are especially pronounced in the Zliten-Misurata area and Zuwarah in western Libya.

These fossils indicate the existence of a previous marine environment, which is followed up by calcarenite deposits, which are believed to be fossil dunes. The marine fossil content of the Gargaresh formation was identified by Al Emsalati (1995), who assigned it to the Tyrrhenian.

3.3.2 Holocene deposits

3.3.2.1 Recent valley deposits

The name “Recent valley (wadi) deposits” indicates that this group includes most recent sediments which are still developing in the valley (wadi) beds. These deposits may be correlated with the younger valleys fill (Lebda Al-luvium) as defined by Al Emsalati (1995). The deposition of this kind of sediment depends on climatic conditions and it occurs in dry valley areas which are having strong rainfall, with enough to produce strong streams.

Therefore, such materials were transported by water, and deposited in valley bottoms, which were shaped by recent stream activity. Despite limited rainfall which is largely restricted to winter, there is the presence of coarse and fine grains of sand with gravel and silt.

The grain size of these sediments is governed by the gradient of the valleys and the transporting capacity of the stream. The sediments are especially abundant on both sides of the stream line, often form meanders on valley bottoms, and respond to changes in direction of the stream; these deposits are up to 50 metres wide in some cases. This geological phenomenon may be graphically expressed on a 1: 250,000 map only by enlarging the actual width of the sediments eight to ten times.

These deposits are spread throughout different parts of the coast, especially at the mouths of dry valleys and are made of shell fragments with a low proportion of silica sands.

3.3.2.2 Aeolian deposits

The geological activity of wind in the area is one of the principal forces which have been studied as the main determinant of the surface of sediments of the Quaternary age. The influence of wind activity was reported by McKee (1979) and Bagnold (1941). These deposits are represented by sand dunes and sheets covering large areas in the Jeffara plain, as well as parts of the eastern coastal strip of the region. Most the sands are distributed into parallel longitudinal dunes which are oriented South East and North West. The height of the dunes varies from 5 to 20 meters above the plain.

Morphologically striking is the occurrence of the dune field covering a few square kilometres east of Zliten. Big dunes attain a thickness of more than 50 metres and form prominent ridges. Also they are light in colour and contain a large proportion of quartz grains.

These sands consist of a high proportion of silica, with shell fragments, and have grain sizes from fine to medium. There are two types of dunes; desert and sea interlocked in the area about five kilometres south of the present shore line.

The dune fields and individual sand dunes are regarded as Quaternary, specifically Holocene in age, but these deposits continue to develop even in the present.

3.3.2.3 Sebkha (marsh) sediments

Sebkha sediments are spread along the coastal area near Misurata, in the Kaam valley and the Jeffara plain. They occupy the relatively low-lying topographic areas, and are separated from the sea by the sea cliffs.

Some of the Sebkha have had occasional incursions of the sea and others may have a subsurface connection with sea water. Most of them are marked by the presence of scattered sand islands which are mostly vegetated by some trees.

The surface of the Sebkhas sometimes has a thin layer of black materials as a result of decayed vegetation. Shallow pits dug into the Sebkhas to a depth of about one meter revealed two bands, an upper one 0.50 meters thick, which consists of brownish silt with calciferous mixture, and a lower band of gypsum sands (Le Heron *et al*., 2006).

From the south these Sebkha deposits are covered by wind-blown sediments; the height of the small dunes does not exceed 1.5 metres. The total thickness of the Sebkha sediments is more than 10 metres; the sediments probably rest on calcarenites of the Gargaresh formation.

3.3.2.4 Origins of sand in the study area

Most of the deposits which cover the study area are from Quaternary sediments, with a few formation units from the Triassic. The Quaternary rocks cover most of the study area, these formations spread from the top of the surface to several meters at base (Gargaresh formation, Jeffara formation and Qasr al Haj formation). Field observation indicated that the relation between these units is also a lateral passage from one to the other.

Furthermore, sand formations in the western part of the study area belong to the recent valley sediments (Holocene deposits). Such sediments are still developing rapidly in the valleys, as a result of the supply of available sediments. Their deposition is dependent on there being enough rainfall to produce strong streams to transport the different grain sizes. After the grains have been transported and deposited in the valley bottoms, erosion processes will begin to operate.

In contrast, sand formations in the eastern part of the study area are due to the role of sea level falling during the Holocene, where the fossilized formations emerged along the shore line. After the emergence of these formations active erosion will begin, which has produced more mobile dunes. Therefore, there is a low rate of supply of further sediment in these formations, in contrast to the sands from the western part of the study area where sedimentation is still operating, as mentioned earlier. In general, however, there is plenty of sediment supply within the study area to provide a source of mobile sand dunes.

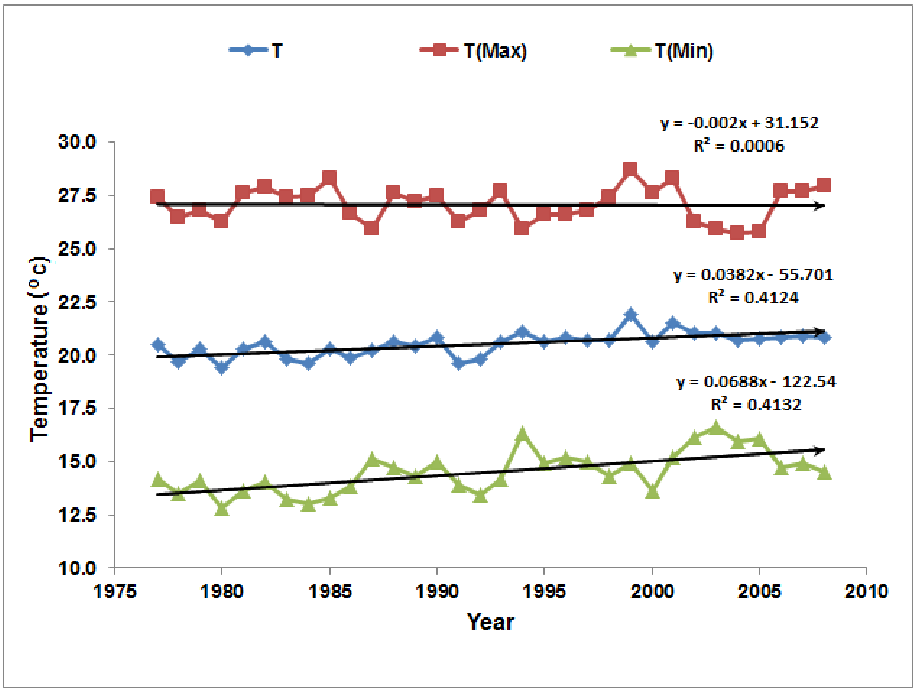
3.4 Climate

The climate of the study area in Libya is a reflection of the relationship between the dry desert in the south and the Mediterranean Sea in the north, due to the study region lying in the coastal strip, where there is the influence of the sea. The extensive desert to the south of this region makes it vulnerable to invasion by desert influences which vary in severity from one season to another and from place to place depending on the relative location with respect to the sea and the desert, being stronger and more pronounced further to the south (Al Jadedie, 1992, p.128). Through climate data (1977 - 2008) which were obtained from the main centre of meteorology in Tripoli, Libya, based on the meteorological stations within the study area (Tripoli, Alkoms and Musrata) the basic features of the climate of the region can be determined as indicated below. Initial analysis revealed little variation in the data recorded at the other two stations, compared to that from Tripoli, and therefore the analyses reported below are all based on the data from the Tripoli station unless otherwise noted.

3.4.1 Temperature

In order to understand the temperature variability and change throughout the period 1977-2008, and its impact on vegetation and soil within the region, the data obtained from the Tripoli meteorological station have been analysed to assess whether there have been any trends of variation in the temperature parameters (annual mean, maximum and minimum temperatures), Figure 3.8 shows that the trend of annual mean temperature during this thirty two year period within the region has tended to increase slightly, however this trend was not statistically significant. Also the trend of annual maximum temperature in the same period exhibited a slightly increasing trend, but which again was not statistically significant. Similarly, there was a statistically non- significant increasing trend of annual minimum temperature through the same period.

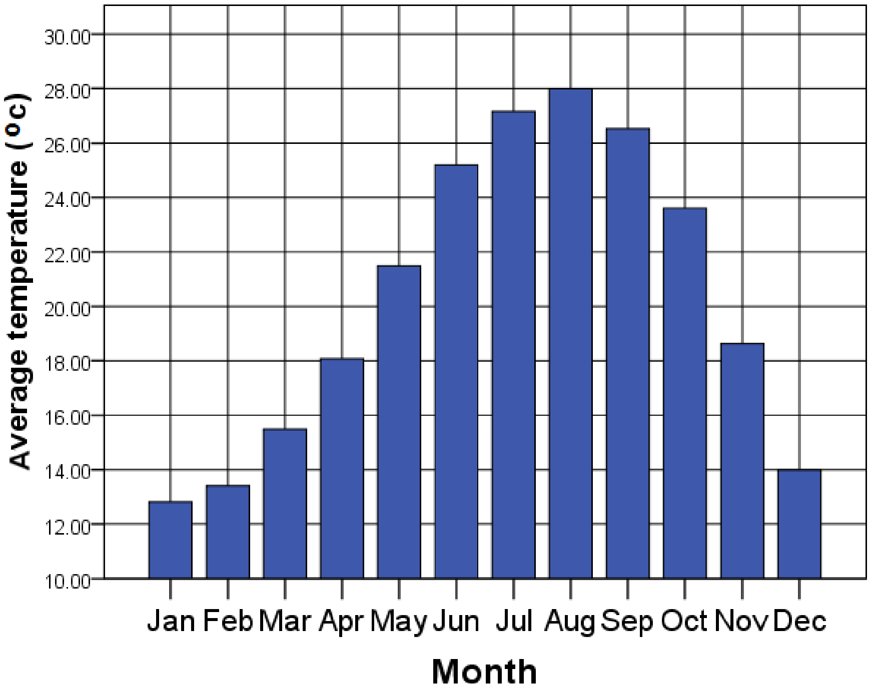
Figure 3.8 trend of annual maximum, minimum and average temperature (^{o} C) in the study area during 1977 - 2008 (Source of data: Meteorological Office, Tripoli, Libya, 2009).



Mean monthly average temperature values are shown in Figure 3.9. As expected, the peak temperature (c. 28 ^{o} C) is in August, having increased gradually up to this since the lowest value in January (c. 13 ^{o} C); this peak is then followed by a more rapid decline with large drops especially between October and December.

In the middle of winters the cool western and north western winds flow towards the coast and inland areas. During the months of April and May, in particular, warm Tribal winds (sirocco) coming from the southern desert raise the temperature. In the summer months (June, July and August) the temperature is at its most stable, due to the influences of high pressure (sub-orbital) weather systems. Therefore, weather conditions are similar throughout all days of this season, except for a daily cycle of wind between sea and land (Emqaily, 1995).

Figure 3.9 Mean monthly averages of temperature (^{o}C) in the study area, based on data for 1977- 2008 (Source of data: Meteorological Office, Tripoli, Libya, 2009)

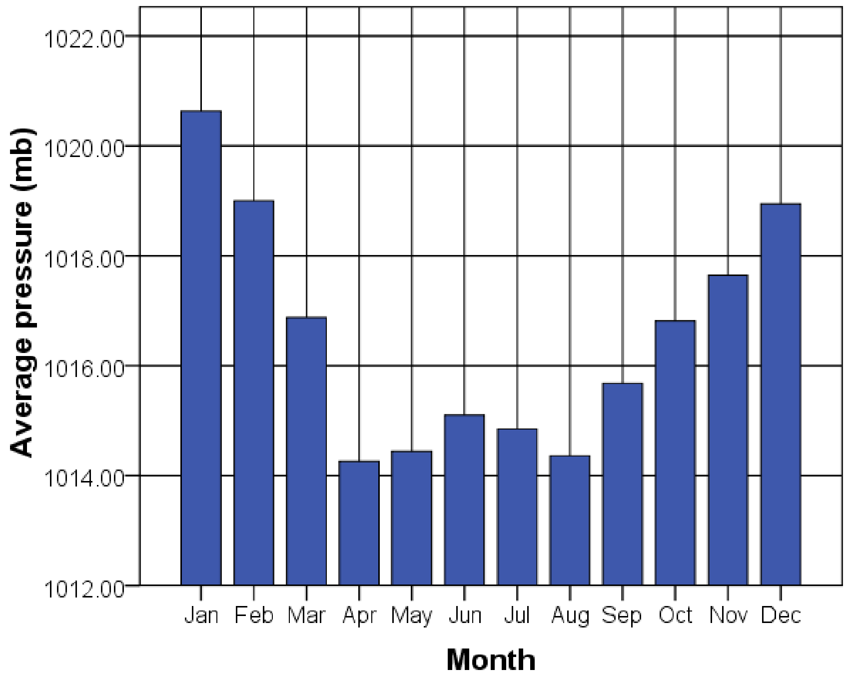


The high temperatures in summer affect the movement of sand by drying out the surface layer, especially where there is an absence of vegetation, which will make a sand dune more susceptible to disintegration because it will move with only a modest wind speed.

3.4.2 Pressure level and wind

The graph of mean air pressure in the different months of the years (Figure 3.10) shows essentially a mirror–image pattern to that of temperature, high in the winter (especially January) and low in the late spring and summer months (approximately constant pressure from April to August).

Figure 3.10 Monthly average of pressure level in the study area, based on data for 1977- 2008 (Source of data: Meteorological Office, Tripoli, Libya, 2009).



Generally, the winds in winter come particularly from the south west, however, the weather fronts which are invading the Mediterranean Sea in winter and spring seasons cause turbulence of the weather in the region. With continuation of the passage of these weather fronts in the area, the wind directions deviate from the south-east to south west. Often these winds arrive with tropical air loaded with dust, and with the succession of weather fronts in those areas can occur a sudden change in the wind direction from south to north and north west (Emqaily, 2002).

In the spring season of a year, the weather fronts have clear impacts on the weather of the study area. There is a difference in terms of emergence or formation of those fronts, where the weather fronts that occur in winter arise from the Mediterranean Sea whereas most weather fronts which occur in spring come from the Sahara (desert). Weather fronts which arise during spring in the Mediterranean Sea region move toward the north due to the shifting of the general thermal areas and ranges of atmospheric pressure. Often, these fronts are less strong and their impact is weaker on the weather of the study area than those from the winter weather fronts. Also the change in the weather may continue only for short periods. Weather fronts which arise during the spring season are responsible for the sirocco winds; this type of wind is a local wind which is characterised by its high temperature and dry, plus being loaded with dust. However, there are some periods where this type of wind stops, because of a change in wind direction from the south to the west and the north, accompanied by a decrease in temperature.

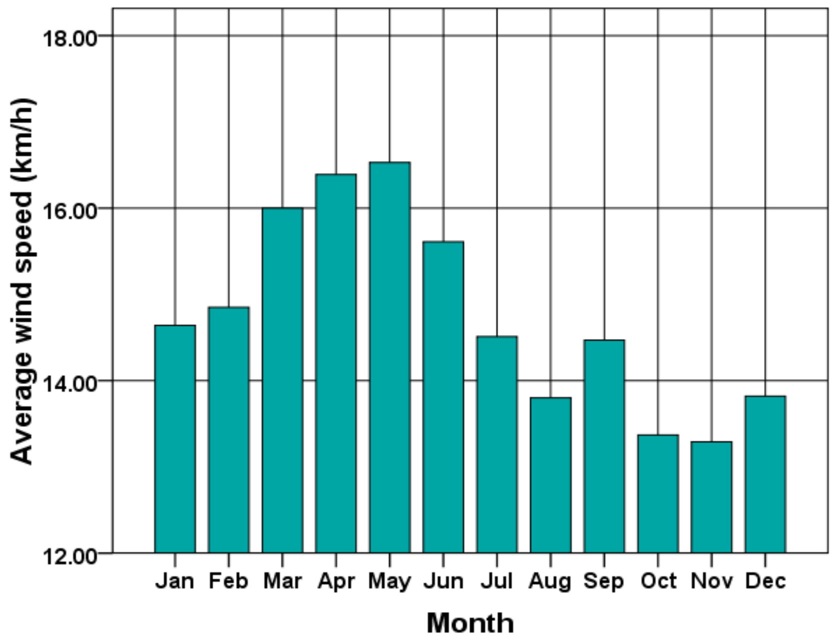
In summer, where part of a high pressure system extends over the Mediterranean Sea region, this high pressure prevents the weather fronts which might come from the Atlantic Ocean; this means that the region experiences relatively low pressure which has arisen mainly in sub-Saharan Africa. Also, however, at such a time the study area would come under the influence of north-eastern trade winds which help the moderation of temperatures in the costal parts of the region.

In autumn, the weather fronts begin to emerge again, but most of these fronts are less strong and have less impact than those formed during winter and spring. However, these weather fronts greatly affect the region, by causing strong winds with a lot of rainy cloud (Emqaily, 1995).

3.4.2.1 Wind speeds

Data of wind speeds as shown in the following Figure (3.11) represent the mean of monthly wind speeds per hour at standard height (10 m) over the whole study area. Moreover, as part of the analysis in this project, these data will later be evaluated and categorized with respect to wind direction.

Figure 3.11 Monthly averages of wind speed in the study area, based on data for 1977- 2008 (Source of data: Meteorological Office, Tripoli, Libya, 2009).

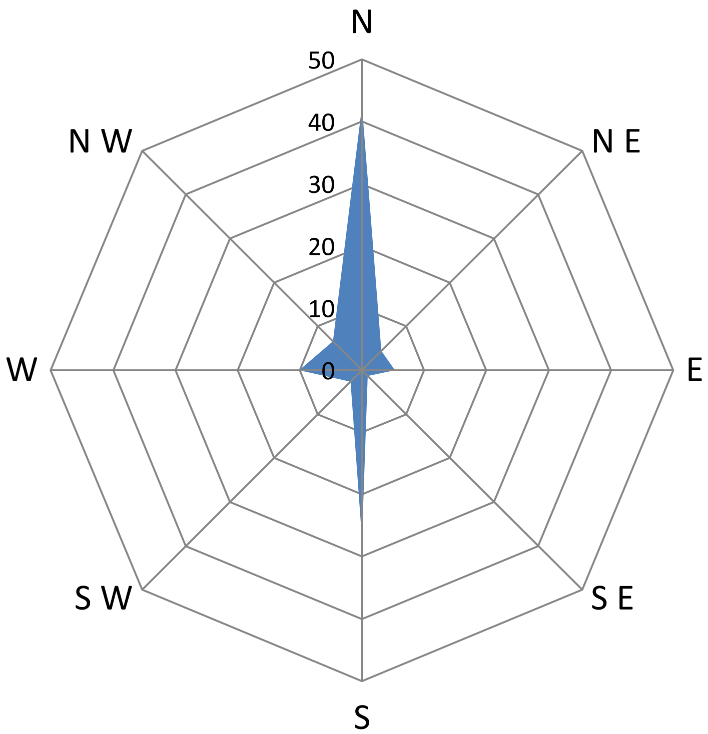


The pattern of wind speeds, illustrated in Figure 3.11, show a peak in the spring months, particularly May, and a subsequent decline to a minimum in November. However, this decline is not regular, as there is a rise in the wind speed in September compared to the months before or after it.

3.4.2.2 Wind directions

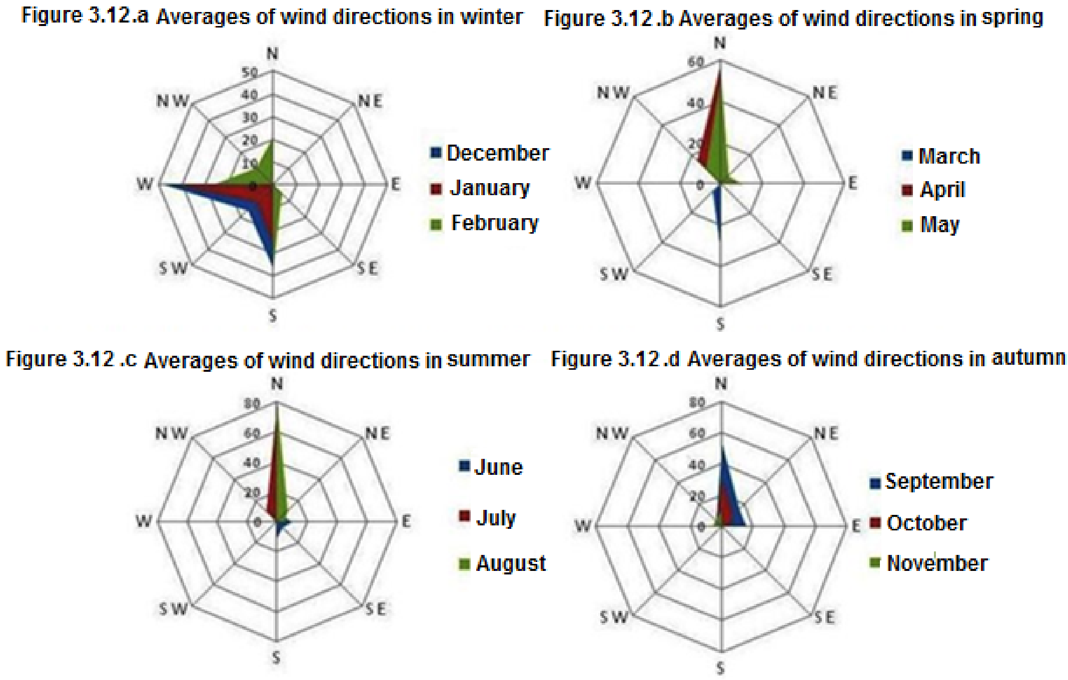
From Figure 3.12 it can be seen that, for the year as a whole, north and north westerly winds dominate the wind directions in the study area. There is a reasonably large proportion of winds which are southerly, but very few from the east or west.

Figure 3.12 Annual averages of wind directions in the study area, based on data for 1977- 2008 (Source of data: Meteorological Office, Tripoli, Libya, 2009).



The wind directions during the different seasons of the year can be explored by reference to Figure 3.13. In winter (Figure 3.13a), the winds are mainly westerly or southerly; by spring (Figure 3.13b) the winds are mostly northerly but with some southerlies; this pattern then continues into summer and autumn (Figure 3.13c and d respectively), except that southerly winds stop entirely.

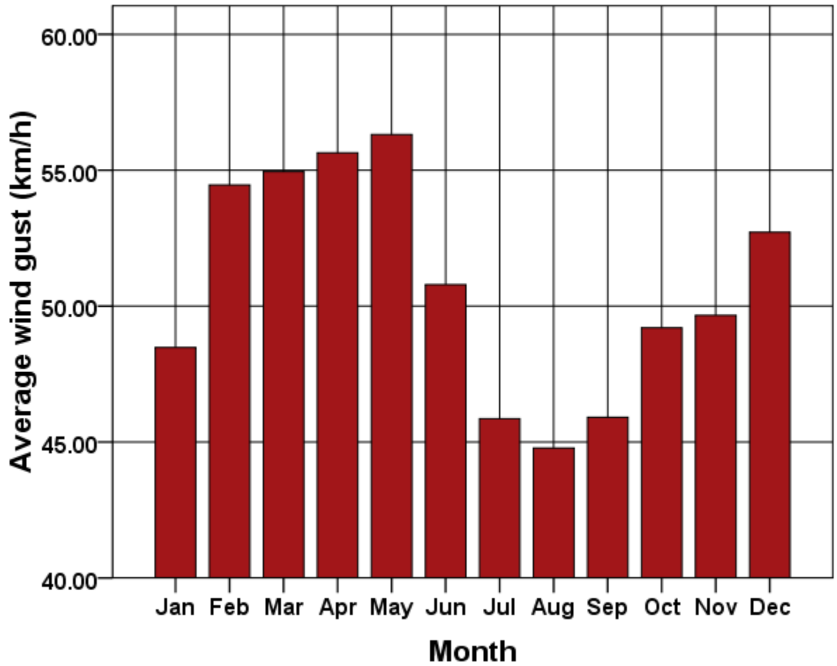
Figure 3.13 Seasonal averages of wind directions in the study area, based on data for 1977- 2008(Source of data: Meteorological Office, Tripoli, Libya, 2009).



3.4.2.3 Wind gusts

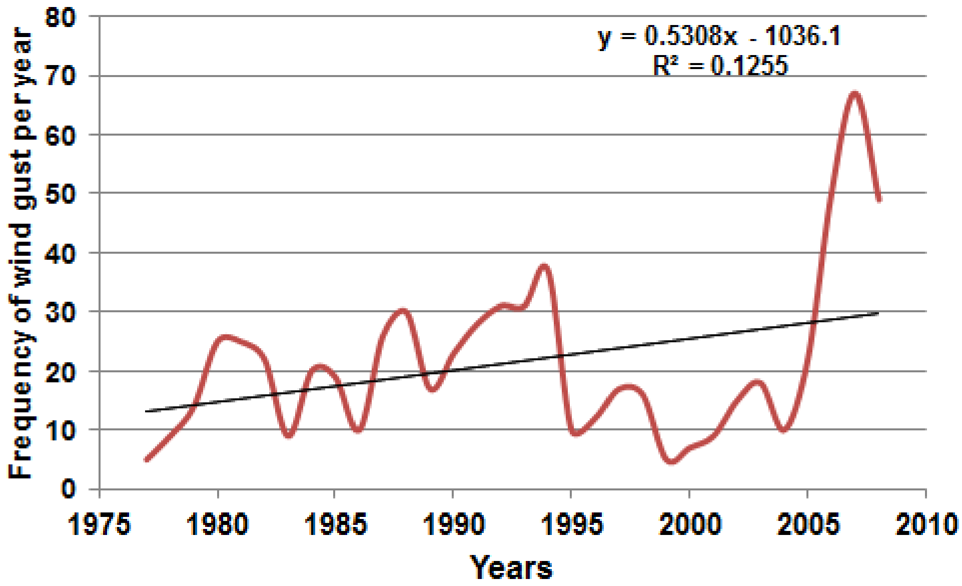
In the Sahara, or dry and semi-dry areas where there are desert sandstorms, the term dust is used to refer to finer particles carried by the wind. Storms carrying dust or sand are commonly caused by thunderstorm outflows, or else by strong pressure gradients which increase the wind velocity over a wide area in what are called wind gusts. How high the dust or sand is lifted into the atmosphere is largely determined by how stable it is above the ground (Emgaily, 2002). In Figure 3.14 can be seen the monthly average of wind gust velocity in the study area, where there is a great increase of wind gust speed in spring, high values in early summers, with a gradual reduction in autumn, and subsequent increase again in winter, leading to more dust storms in the early summer. Poor land management, such as not following a crop with a period of fallow, has led to increasing dust storms from desert margins, which will impact local economies. Moreover, drought and wind together particularly lead to dust storms, and poor farming and grazing practices also contribute by exposing the dust and sand to the wind.

Figure 3.14 Monthly mean wind gust speeds (km\h) in the study area, based on data for 1977- 2008 (Source of data: Meteorological Office, Tripoli, Libya, 2009)



There has been an upsurge of the annual frequency of gusts during the last few years, as seen in Figure 3.15, with the trend being just significant at $p < 0.01$. Also the period from 1975 to 2005 can be characterized as a sequence of years with low gust activity alternating with other years with high gust activity, though with a sharp decline in 1999.

Figure 3.15 Annual frequency of wind gusts in the study area, based on data for 1977 – 2008 (Source of data: Meteorological Office, Tripoli, Libya, 2009).

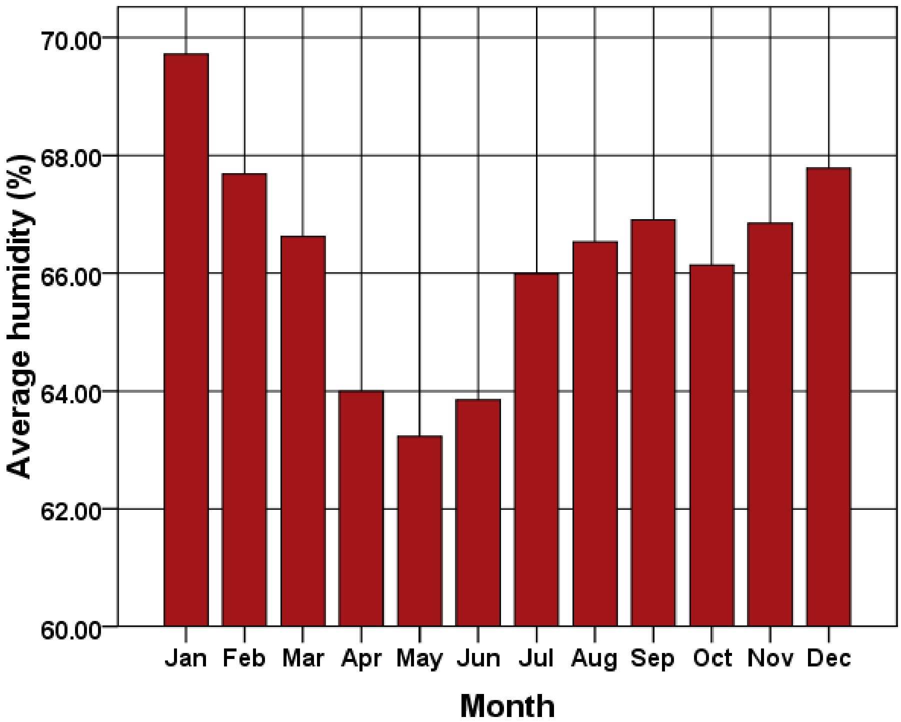


However, dry land farming is also another cause of dust storms. Agriculture of dry land depends on rainfall to a large extent to irrigate crops; also, ways of maintaining moisture in the soil in those areas include a period of fallow for a year after harvesting a field so that the soil can build up. These practices of agriculture make dry land susceptible to movement of particles in strong gusts of wind.

3.4.3 Humidity

Humidity is the measure of saturation of the air with water vapour. A humidity value of 50% means that the air is dry; from 60% to 70% would be considered normal, whereas a humidity of more than 70% means the air is of high humidity (Sharaf, 1985, p.439). From Figure 3.16 it can be seen that most values of monthly humidity in the study area are normal except for the high humidity level in January; this is due to the low temperature during this month, making the air closer to full saturation which increases the percentage humidity. May had the lowest humidity value, and April and June were only slightly higher, due to the warm sirocco winds coming from the desert during these months.

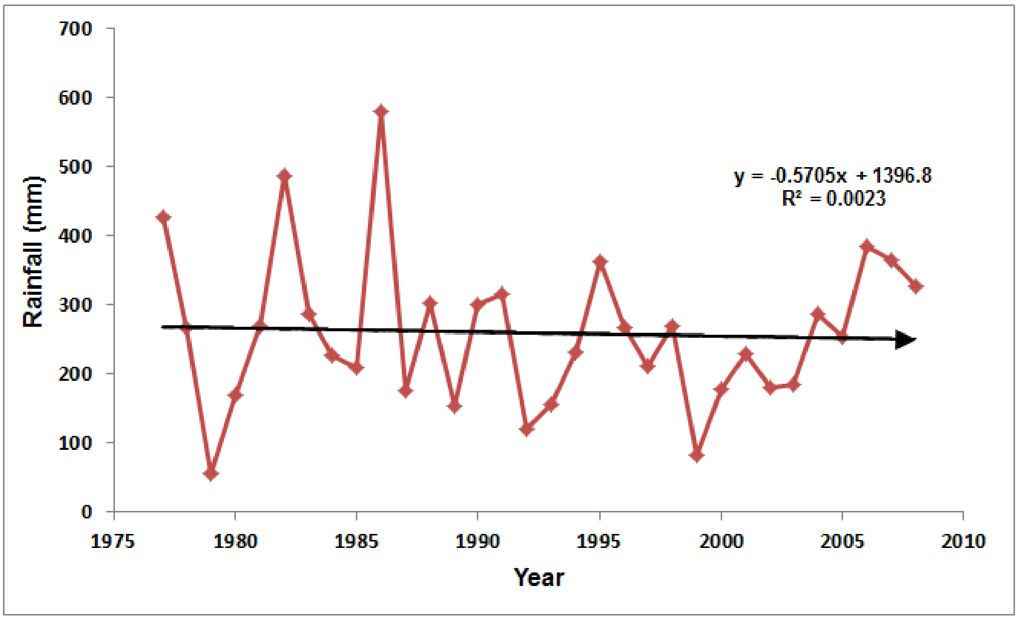
Figure 3.16 Monthly means of humidity (%) in the study area, based on data for 1977- 2008 (Source of data: Meteorological Office, Tripoli, Libya, 2009).



3.4.4 Rainfall

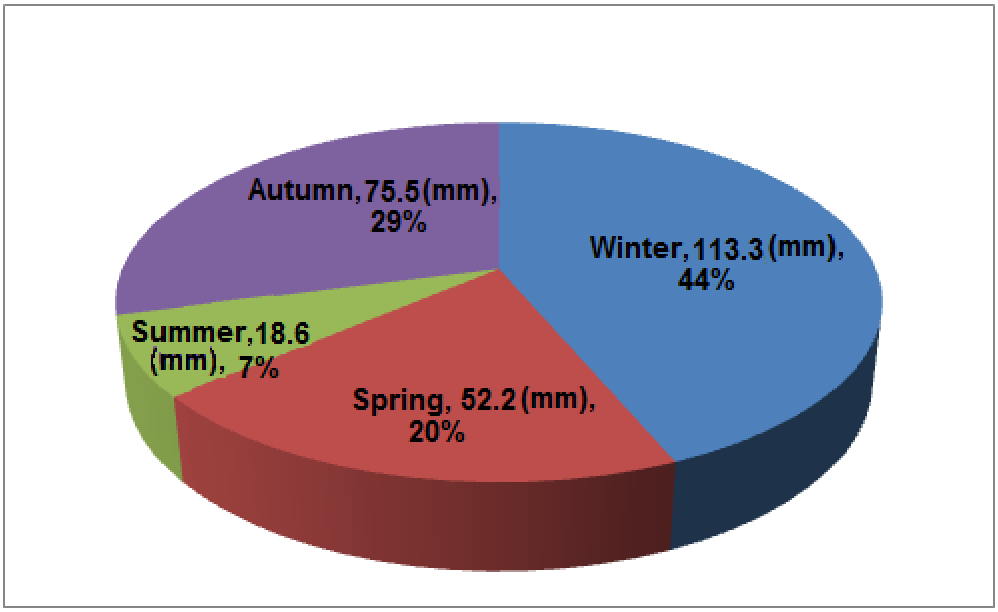
Often the type of rainfall in the study area is a hurricane rain, caused by the weather fronts which are coming from the Mediterranean Sea region or from the west. These fronts usually are formed as a result of the coming into contact of two different types of air, the first being tropical air, with its origin from the Sahara and the second being polar air, coming from the north. Moreover, the rainfall within the study area is not regular and continuous, but is intermittent depending on the passage of these weather fronts. From the data of rainfall in the study area during 1977 – 2008, it can be seen that the mean overall annual rainfall is 260 mm, but with marked variation between years (eg. In 1979 the annual figure was 50 mm but in 1986 it was 580 mm) (Figure 3.17). It is evident that the region is exposed to periods of drought from time to time, as well as periods of having rains, according to the climatic fluctuations which occur in the region.

Figure 3.17 Average time series and annual trend of rainfall (mm) within the study area during 1977– 2008 (Source of data: Meteorological Office, Tripoli, Libya, 2009)



Also, Figure 3.17 shows the trend of annual rainfall during thirty two years in the study area, namely that the moving average of the annual total rainfall had a slight decreasing trend, which was not statistically significant, although large inter annual variability is evident between different years. In general, the region during the whole period experienced decreasing rain precipitation with fifteen years, and a slight increase in the remaining nine years. There is sudden peak of rainfall in three years, offset by a subsequent decline over a number of years.

Figure 3.18 Average and percentage of seasonal rainfall (mm), (%) within the study area, during 1977- 2008 (Source of data: Meteorological Office, Tripoli, Libya, 2009)



The seasonal rainfall over the study area for the period 1977-2008 is shown in Figure 3.18. The winter season had the highest percentage of average rainfall, which was 113.3 mm (44%). In contrast, the summer season rainfall was the lowest at 18.6 mm. The rainfall average for spring was notably lower than for the autumn season. The seasonal rainfall for the period 1977-2008 therefore indicates that the normal seasonal rainfall pattern has rainfall concentrated during autumn and winter, while the drought period occurs in summer and spring.

3.4.4.1 Classification of climate of the region

Given the importance of the drought factor and its impact on the local environment through its relation with vegetation distribution and agricultural production, this may have a particularly important link with land degradation.

Therefore, many indices and directories have been used to defining an index for aridity, the aim of those indices being to classify the scope of a dynamic climate for different regions.

3.4.4.1.1 Aridity index

The study area was classified into climatic regions according to the De Martonne (1952) index, for climate classification based on the duration of the aridity period over the year, which has been modified by Sharaf in 1985 (Emqaily, 1995).The aridity index (A) is defined by:

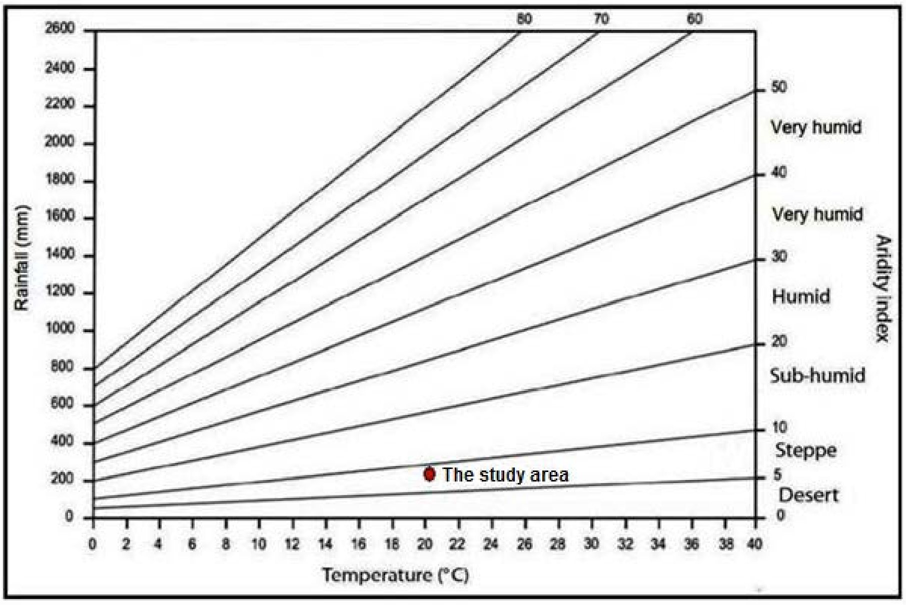
A = [P/ (T+9)].

Where P is total annual precipitation (mm) and T is the mean annual temperature (°C). According to the Sharf (1985) aridity index, climate can be identified by the following types as Desert (0-5), Steppe (5-10), Sub-humid (10-20), Humid (20-30) and Very humid (>30). Based on precipitation and temperature data (from1977-2008), the aridity index was computed for the study area as illustrated in Figure 3.19 and Table 3.1, which show that the study area is falls under the heading of the Steppe climate type.

Table 3-1 Showing the aridity index calculated for the study area according to De Martonne (1952) and Sharaf (1985)

Annual precipitation total (mm)	260
Mean annual temperature (°C)	20.49
Aridity index by De Martonne(1952)	8.5
Aridity index modified by Sharf (1985)	8.8

Figure 3.19 Climate type in the study area, according to the De Martonne climate classification scheme.



3.4.5 Soil types

Soil is an important part of an agricultural system, since it is the layer in which plants root, and it consists of materials including weathered rock particles and decayed organic matter (Tromp-Vanmeerveld and Mcdonnell, 2006). Soil forms very slowly, taking over 500 years to form two centimetres of topsoil (Strudley *et al.,* 2008).

There are many different soil types, varying in particle size, water holding capacity and resistance to erosion amongst other factors, and therefore leading to different properties and potential (Monger and Bestelmeyer, 2006). Several factors including the parent rock type, the climate, the plants and animals present, the topography and human influence all affect soil development and therefore the soil type (El-Swaify, 1997). The ways such factors combine give rise to the many different soil types in the world.

The factors which affect the type of soil in the study area can be summarized as follows:

A. Climate of the region, characterized by mild temperatures, with low rainfall rates (semi-arid region)
B. Poor vegetation cover including poor plant growth with some small dwarf trees.
C. The material of origin of the soil, formed by the Quaternary sediments.
D. Topography in the area being very flat, with deposits being commonly spread by wind.

Classification of the soil has been performed in the western regions of Libya by Selkho Zprom Export, USSR (1980). Based on this classification, the most important soil types in the study area are shown in Figure 3.20, described below.

3.4.5.1 Reddish brown arid soils

This type of soil covers different parts of the study area. The contents of this type of soil include carbonate, with proportions of salt and gypsum, sometimes with a crust of salt and gypsum on the surface of the soil. Also it contains some proportion of potassium, with low levels of phosphorus, nitrogen and iron, with a pH value of 8 - 8.6 (Ben mahmod, 1995, p.78).

3.4.5.2 Sandy soil

This type of soil has its origin from the weathering of limestone’s, quartz, granite or shale. Sandy soil with sufficient organic matter is easily cultivated. Sandy soils in the study area originate from Quaternary deposits, resulting from wind erosion processes which have taken place in the study area (Ben mahmod, 1995, p.69).

However, these soils have a high proportion of sand where particle sizes range from 0.4 -2 mm, with only a little clay (about 10%) (Al-Enezi, 2008). Such light soils drain quickly after rain or watering because they have high porosity, and are easily cultivated and worked. They warm up further in spring than do clay soils, but also dry out more quickly and have fewer plant nutrients, because they will be rapidly leached out by rain rate. Typically, such soils are very acidic. They are widely distributed over large parts of the study region (Table 3.2) and (Figure 3.20).

3.4.5.3 Chalk soils or Limestone soils

This type of soil is distributed over different parts of the region, especially near the hills which are located to the south of the study area. Chalk soils are alkaline and contain many stones; the high proportion of chalk or lime in these soils (about 15%) changes their particle size designation (Al Jadedie, 1992, p.265). The soil may be light or heavy, but are often very shallow, and severely limit the plant species capable of being grown in areas with these soils. Calcareous soils are porous and therefore prone to drying out in the summer; therefore needing more watering and fertilizing than other soil types to successfully grow plants on them.

3.4.5.4 The two main types of sand dunes in Libya

Desert dunes: This type of sand is distributed over the large area of Libya which covers the Northern Plains, such as the Alajafarh plain and also covers large parts of the Libyan Desert, represented by the largest accumulations of extensive sand (Al Emsalati, 1995). It is the result of erosion by the wind, where winds from desert and mountainous areas carry large quantities of sand and deposit this sand in those areas. These dunes are bigger than the marine dunes in height, and have an average height of 10 meters (Al Harram, 1995). They are the result of rapid transition and easy movement by winds. Most granules of continental dunes are composed of quartz together with feldspar and a large proportion of carbonate salts, between red and brown in colour. The humus in this sand has been subjected to oxidation by high temperature. The soil resulting from this process is homogeneous and non-coherent, and also does not retain moisture for long (Aljadedie, 1992, p.124).

The coastal sand dunes (marine): This type of sand is spread along almost the whole northern coast of Libya except the eastern part near the Green Mountain which represents only a small part of the area of Libya. The coastal sand dunes consist of large coarse grains with the presence of fragments of marine shells. These dunes have a colour between white and grey; they are also sometimes mixed with black and orange material. The marine sand includes carbonate salts, chlorides and sulphate, they are also poor in organic materials and clay (Bagnold, 1973, p.168). Therefore there is no homogeneity in grains, which makes the sand dry and often allows the sand to move quickly.

Table 3-2 Soil types which distributed over the study area (Source: Soil-Ecological Expedition of the USSR V/O, 1980)

Soil types	Locations
Reddish brown arid differentiated soils	The southern parts of Kaam; eastern parts of Tajurah and Al ataya – the Side Omear areas; and the eastern part of the Zliten to Misurata area.
Reddish brown arid differentiated crust soils	Western parts of Zliten; southern parts of the Zrieq – Aburwiya area; and south Alqweaha,
Reddish brown arid slightly differentiated soils	The western parts of the Tajourah – Al Nshiea area; the Wadi Kaam and Dafniea area.
Reddish brown arid slightly differentiated crust soils	The southern parts of Misurata; eastern parts of Zliten; and the Bear Tourky area.
Reddish brown arid non-differentiated soils	The northern parts of the Misurata - Al Koms area; the North Qasr Alakyar area.
Non- monolithic crusts	The northern parts of Tajuora; south east Zliten; and south Misurata.
Maritime sands	The northern parts of Misurata – northeastern part of Zliten; and North Aolad Huseen area – North Side Omear area.
Rocky outcrops	The Al Koms – West Nqaza area; the North Kaam area; and the North Qasr Al Gyar area.
Hydromorphic solonechaks	The northeast of Misurata , north Kaam.

3.5 Natural plant cover

The climatic conditions of the study area do not appear to have contributed significantly to the diversity and density of the vegetation within the region (Aljadedie, 1992, p.211), despite the coastal location of the region and the effects of the sea in increasing the humidity and giving relatively mild weather for the vegetation. For a clear picture of the current status of vegetation within the study area see Figure 3.19. Further, the plants in the area can be divided according to their ability to retain moisture and their resistance to drought, (Sharaf, 1982, p.175).

3.5.1 The current case of vegetation cover

The observations which obtained from the fieldwork in this research project during two periods time 2008 - 2009, have indicated that the pastures in the study area were degraded or poor in vegetation cover, also of limited coverage, particularly in the western and the north eastern part of the region, as illustrated in figure (3.19).

Reports and studies which have been published by Libyan Agriculture Ministry (2007) have also indicated that there has been a decrease in the size and number of diversity of annuals and perennial plants during the last two decades, to only 35 - 45% of its previous value. Also, the vegetation coverage has been less than 40% of most pastures within the region.

The rest of the proportion of the density of vegetation cover in these pastures is of seasonal plants, which depend on rate and time of rainfall, as shown in Figure 3.21. More than 70% of the ground cover of the study area is un vegetated and local state administration is not having a control management for it through a particular system to maintain the vegetation cover. Moreover, the region mostly is classified as suitable for grazing, prompting much of the population to be dependent on grazing of animals as a source of livelihood. This combined with the climatic conditions has increased pressure on the vegetation, and has helped in the deterioration of the vegetation cover which prevailed in these areas since ancient times. Further changes in vegetation cover and forest will be reported on through the use of satellite images in chapter 5.

However, the current situation of vegetation in Libya is generally very critical. This is reflected in the shrinking areas of vegetation and the disappearance of endemic plants (Almkasbie, 2001). The reason for that is the degradation of natural environments which has happened in the past and is still happening at the present time (though much more rapidly than in the past) as a result of over exploitation of natural resources by people through grazing and firewood collection (Al Jadedie, 1992, p.215). The factors which could be attributed to the reducing in vegetation include exploitation of the natural environment through grazing which can lead to a decrease in annual production of pasture plants, the extinction of species of perennial plants which help to conserve soil and the deterioration of plants which are normally found on the dunes (Gillies *et al*., 2002).

A further factor which causes loss of vegetation is firewood collection which causes a loss of forest cover. According to estimates by the FAO (2007), the logging of forest lands in the dry tropics occurs at a rate of four million hectares every year. Africa is the continent most affected by this, where the loss is about 2.7 million hectares every year (Abd Elgawad, 1997, p.209). This phenomenon in Libya is caused by excessive exploitation of forest cover, which has led to the shrinking of large areas of trees and shrubs, which had previously helped to stabilize sand dunes (Al Jadedie, 1992, p.247).

Natural factors can also damage vegetation and, in Libya, the rainy season is very short compared to the length of the dry season (Al Jadedie, 1992, p.254). This can place environmental pressure at certain times on vegetation, such as that in the north of Libya (Ben Mahmod, 1995, p.186), where the natural vegetation had a large capacity to regenerate. Sometimes the climatic conditions lead to the dominance of certain species of plants which may not be so suited to stabilizing sand (Almkasbie, 2001).

As a result of the climatic conditions prevailing in Libya, reforestation is often the best method to reduce the movement of sand dunes, and this approach has been used since the 1920s (Almasoudi, 1984), in the form of afforestation operations for sand dunes scattered along the Libyan coast. The actual beginnings of these operations followed the research of the committee assigned by the Ministry of Italian Colonies at the time (1913) to report on the status of the situation environmentally, economically and socially in the region (Abo Lugma, 1996, p.186). Farmers in the study area have also been using the following methods to reduce the risk of encroaching sand:

A. Cultivation of spiny plants, such as spiny cactus.

B. Cultivation of semi-woody plants, which are characterized by rapid growth and with a short life span, such as castor bean and cane, in front of sand dunes.

In the north of Libya the most important materials used as barriers are palm fronds, pieces of cement and plastic fabric, in addition to using the perennial plants which are resistant to drought, such as cactus spines (Al Masoudi, 1984). Farmers in the study area have also been using the method of barriers of soil around their farms to reduce the risk of encroaching sand.

Although in general vegetation cover is very important in helping to regulate sand movement, this project did not address the study of vegetation cover except for that provided by trees. The reasons for this are the following:

1) The detailed study of vegetation would need to use satellite images which have special specifications and are of high quality, and would need to be monitored daily or monthly; these images are expensive (and funds for this were not available), but also they give different results compared with the specifications of images used to measure changes in land cover.
2) The study area contains much farming land which, while vegetated for part of the year, will not necessarily be vegetated for the whole year if annual crops are cultivated, and therefore this will not prevent sand movement. If trees are cultivated they will be included within the category of forested areas anyway.
3) Apart from forested areas and farming land, the remaining vegetation cover in the region consists of either seasonal plants or very sparse shrubs, because of the relatively low annual rainfall. In the former case would not be sensible to monitor by one annual satellite image and in the case of the latter would do little to prevent sand movement through wind action.

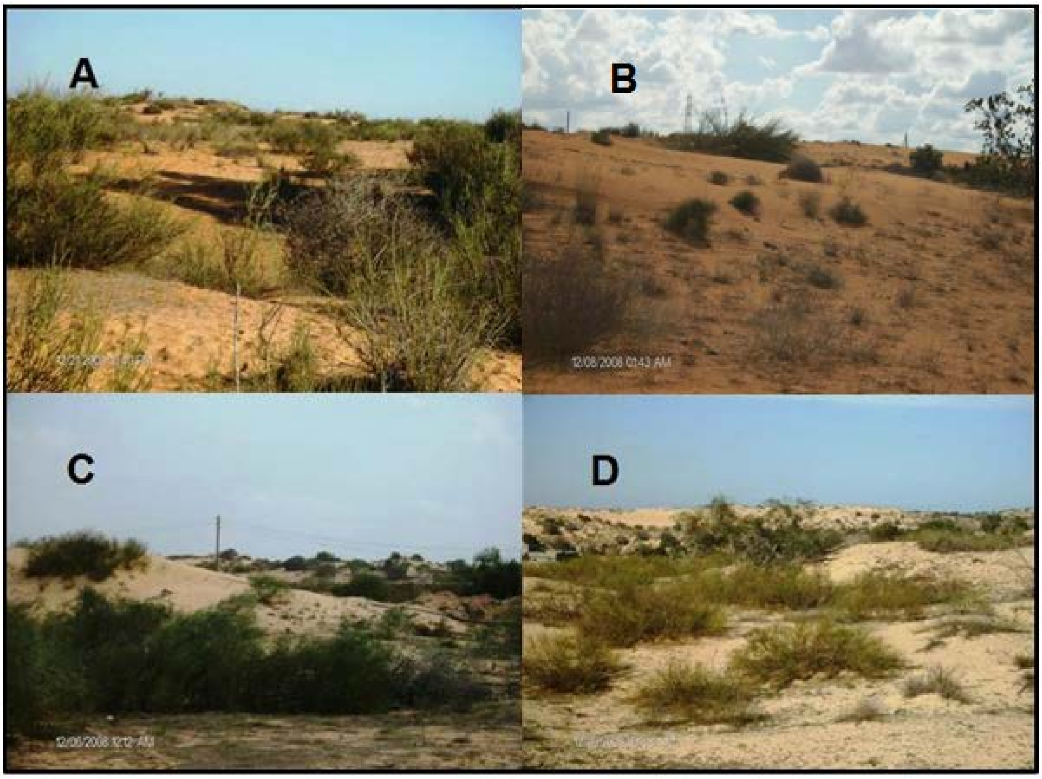


Figure 3.20 Photographs showing the current status of the vegetation within the study area, namely, A. South Algaweah region, B. Awlad huseen region, C. Naaiemah region, D. Abourwia region. Photos by the researcher (October, 2008)

Figure 3.21 Soil map of the study area (Source: Soil-Ecological Expedition of the USSR V/O, 1980)

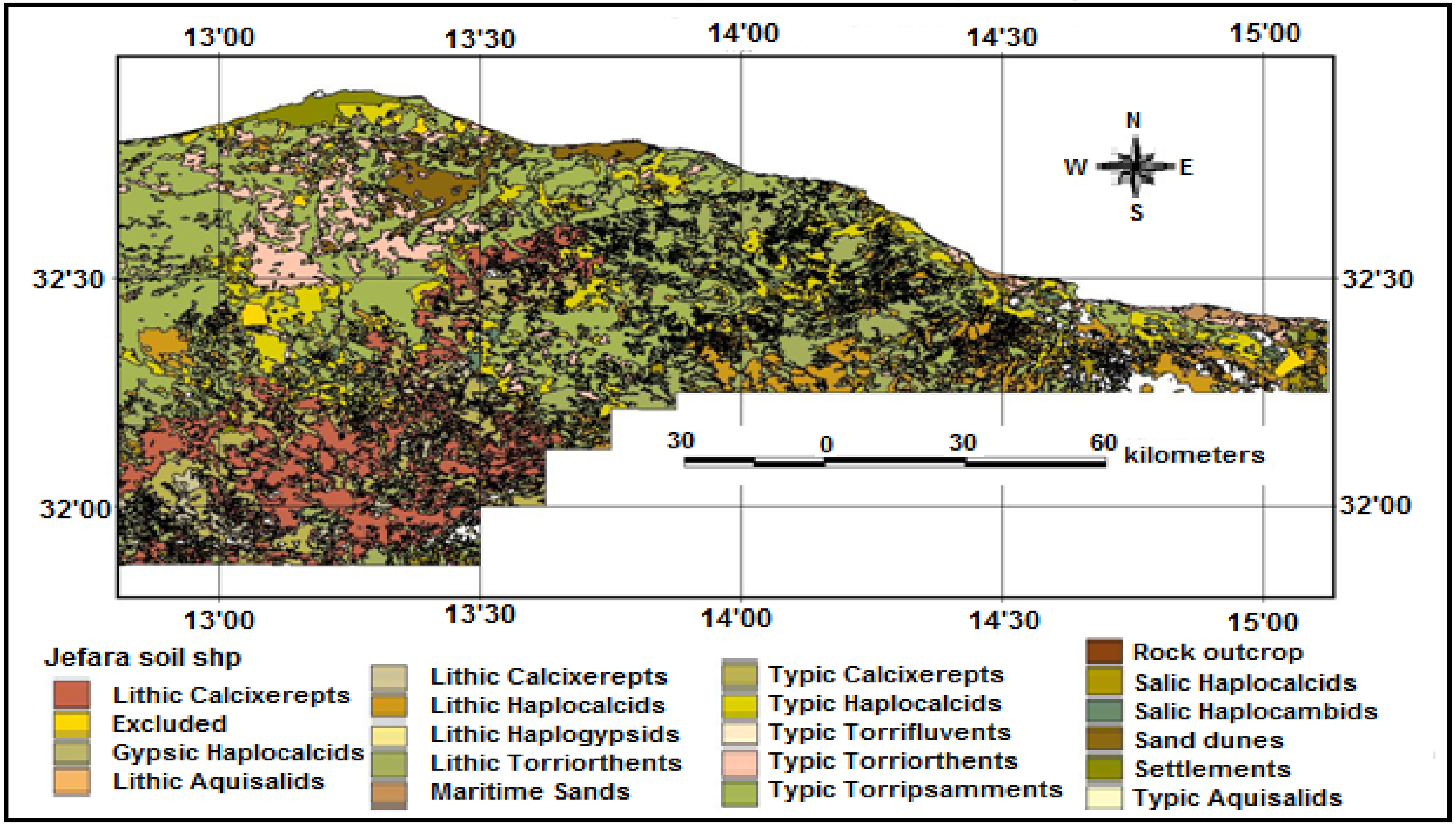
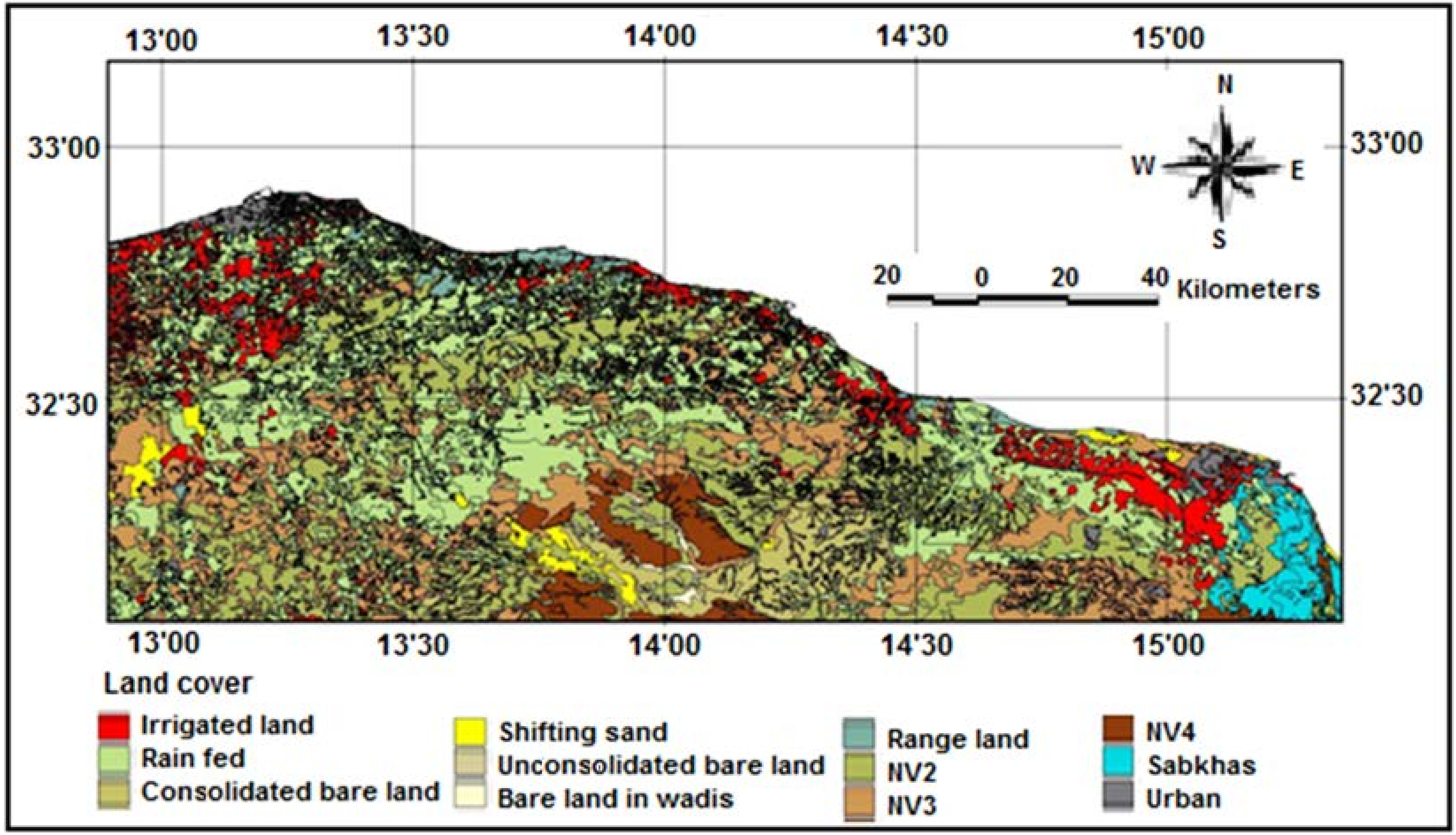


Figure 3.22 Land cover map in the study area (Source: Soil-Ecological Expedition of the USSR V/O, 1980)



3.6 Conclusions

Topography may be the factor which is the most important in activating erosion processes, with the geological structure of the region having a clear impact in shaping the topography. Also, most of the deposits which cover the study area are from Quaternary sediments. Features of the study area are a very flat plains area, with altitudes as little as 30 meters above sea level, and bounded from the north by the Mediterranean Sea and from the south by the slopes of the Nafusa Mountains, with Miocene hills in the eastern parts. This flat region includes some broad and shallow vales which are one of the prominent morphological features in this coastal area. Other conspicuous morphological features are the calcarenite ridges which extend parallel to the coast, with ridges of an extensive sand dune to the south of the coastline. Also, the most important geomorphological features of the study area are the sand dunes. The spread of sand dunes reflects the role of wind erosion and its influence within the region, and the topographic situation of the region may have facilitated this movement of sand dunes.

As stated earlier in section 3.4.5.4, there are two types of sand according to their origins. The first group consists of sand formations in the western part of the study area, these group belong to the recent valleys sediments (Holocene deposits), which are developing rapidly, and have plenty of sediment supply from recent erosion of the Gargaresh, Jeffara and Qasr al Haj formations. The second group consists of sand formations in the eastern part of the study area, which are due to sea level changes during the Holocene, and which will have only a limited rate of supply of further sand.

The study area was mostly classified as belonging to the steppe climate type, with dry periods lasting for most months of the year, although there can be a sudden peak of rainfall in some months, at different times in different years. The annual average of rainfall is 260 mm. In general, the region during 1977 - 2008 experienced decreasing rain precipitation for fifteen years and a slight increase in the remaining nine years. There was a sudden peak of rainfall in three years, offset by a subsequent decline over a number of years. The trend of annual mean temperature during the period studied (1977- 2008) in the region has tended to increase slightly (but non-significantly). Also the trend of annual maximum temperature in the same period exhibited a slightly increasing trend. Similarly, there was an increasing trend of annual minimum temperature through the same period; however these trends were not statistically significant. The fact that these trends were not statically significant indicates that, if there are changes in amount of sand dunes over time, these changes are not primarily driven by climate variations.

The one exception is that there has been an overall upsurge of the annual frequency of gusts during the same years. These periods can be characterized by a sequence of years with low gust activity alternating with other years with high gust activity; overall, there was a statistically significant increasing trend of annual frequency of wind gusts, largely associated with large increases move in recent years. The annual average of wind speeds at standard height (10 m) over the whole study area is 5.2m/s. Moreover, the pattern of wind speeds in the study area has recorded a peak in the spring months, particularly May, and a subsequent decline to a minimum in November. However, this decline is not regular, as there is a rise in the wind speed in September compared to the months before or after it. Moreover, north and north westerly winds dominate the wind directions in the study area. There is a reasonably large proportion of winds which are southerly, but very few from the east or west. These conditions can contribute to faster drying of the soil and decline of vegetation cover, thus, sediments are exposed to winnowing and transport. More recent changes in frequency of wind gusts might contribute to difference in amount of sand mobility recorded.

Moreover, the soil of the region is immature soil of recent origin, with most being formed from Quaternary sediments, which are mainly composed of the deposits of floods and silt, or from the sand which has been collected by the wind. There is a poor vegetation cover, with little species diversity, and therefore the vegetation has not been a primary focus of this research except as revealed by satellite images.

4 CHAPTER FOUR: Physical attributes of sand dune movement

4.1 Introduction

This chapter provides an analysis of predicted sand dune movement in NW Libya (see chapter 3) using an equation for predicting sand transport rates. Bagnold (1973) made an extensive survey on the subject in 1941 and found that the potential amount of transport is a 3-order power function of the wind velocity. Bagnold and many other researchers worked in nearly ideal circumstances. They had noted that the actual rate of sand transport is mostly lower than the potential rate of sand transport with these conditions. Ideal circumstances are horizontal, dry, unobstructed and unvegetated sand surfaces (Sherman and Hotta, 1990). Further, these conditions can be clearly observed in different parts of the western Libyan coasts.

This chapter aims to achieve a better knowledge of the process of aeolian sediment transport within the region with close to ideal circumstances. The equation was presented by Bagnold in 1941 through his laboratory experiments on sand of the Libyan Desert. This equation has been used in many studies and is recognized as the benchmark model for predicting sand transport rates (see review in Horikawa *et al.*, 1984).

Moreover, the equation has been developed during subsequent years to calculate the annual budget of sand transport without ideal circumstances. This equation depends on the following variables: wind speed and air density; the size of sand grains and sand density in addition particularly to wind shear velocity. In order to be able to predict how mush sand movement is likely in the study area, therefore, data were gathered on wind speeds from different heights at the location of the sand dunes, obtained from the Libyan National Meteorological Centre, for the period (1977-2008). This relates to three meteorological stations (Misurata, Alkoms and Tripoli), which are located along the coast of the study area. The properties of the sand have been obtained from analysis of sand samples collected by the author, followed by dry sieving and determination of sand particle density.

4.2 Methods

There currently exist many models to predict sand transport rates (Bagnold, 1941; Zingg, 1953, In: Dong *et al.*, 2003a; Arens, 1996 and Dong *et al.,* 2003b) with the most widely quoted approach being that of Bagnold (1941). Subsequent studies led to some amendments and additions on the first equation, with the modern methods of fieldwork being used to develop the models further.

4.2.1 Explanation of the model

In the early 1970s appeared the single most important work on sand dune formation, written by Bagnold; in this work results are reported of wind tunnel experiments used to make quantitative predictions about sand movement and accumulation. However, most of the predicted results from this work have subsequently been confirmed in field tests in the Libyan Desert (Bagnold, 1973). He was not able to test larger- scale phenomena by using a wind tunnel, but he did make some speculations about them. However, Bagnold was able to formulate an equation to calculate the expected rate of sand movement. This equation depends on two important variables, grain diameter and shear velocity of the wind, and also includes some constant values namely air density, gravitational acceleration and density of the sand grains.

There are many further important contributions which followed the work of Bagnold on the study of sand movement and generally of sediment movement, including those by Sharp (1978) and McKee (1979). It is very important to note that although the work of Bagnold is comparatively old, it is still regularly quoted in work on sand movement. All modern field studies of sand dunes use Bagnold's work as the basis of their work which "with relatively few modifications, has stood the test of checking since publication" (McKee, 1979).

Given the importance of the work presented by Bagnold as a basis to predict the rates of sand movement, as well as the fact that the sample area has close to the ideal circumstances which were assumed for this equation (the ideal circumstances being a plentiful supply and abundance of sand, limited vegetation cover, relatively high wind speed, and high rates of dehydration with low rates of humidity). The Bagnold equation therefore has been selected as a basis to predict the rate of sand movement within the study area, but with reference to some of the models that have been used more recently. The Bagnold equation formula is as follows:

$$q = C\left(\frac{d}{D}\right)^{0.5} u_*^3 \frac{\rho}{g} \qquad (1)$$

Where *q* = sand transport rate (g $m^{-1}s^{-1}$), *d* = grain diameter (mm), *D* = standard grain size diameter (0.25 mm), *C* = coefficient of grain size (which for a naturally sorted sand dune will be 1.8*),* u_* = shear velocity of the wind (ms^{-1}), ρ = air density (kg/m^3) and *g* = gravitational acceleration (9.8 ms^{-1}). Alternative sand transport equations that have been proposed by other authors since Bagnold's work use similar terms and are also based on the cubic power relationship between wind shear velocity (u.) and sediment flux (Sarre, 1987).

4.2.1.1 The shear velocity

The shear velocity, sometimes called friction velocity, is a method used in fluid mechanics for measuring the movement of any objects (Musharraf, 1987), also it is essential for comparing the actual velocities at the interface of different blocks, for example, the velocity of flow in a stream, where the shear velocity relates to the friction between the flow of the layers. Similarly, the impact of the wind on sand particles will move the sand and the force induced is the shear velocity (Bagnold, 1973). This method has been used to calculated the rate of sediment transport, and has been used by Bagnold in his equation on movement of sand by wind, which was dubbed (A). Also as a general rule the shear velocity value is one tenth of the mean flow velocity. The value of shear velocity (U_*) is calculated by using the following equation:

$$U_* = A\left[\left(\frac{\rho_s - \rho_a}{\rho_a}\right) gd\right]^{0.5} \qquad (2)$$

Where: ρ_s = density of the sand grains, ρ_a = air density (kg/m3), g = gravitational acceleration (9.8 ms^{-1}) and d = grain diameter (mm), and where the threshold shear velocity (*A*) equation is:

$$A = [(\frac{\pi}{6})\ (\frac{tan\theta}{\beta})]^{0.5} \qquad (3)$$

Where: β is an empirical constant, and θ is the angle of internal friction of the sand.

According to Bagnold (1973), *A* is an empirical constant which during saltation will be 0.085, as identified in his laboratory experiments on saltation. As a result of the evolution of research on this subject, the value of *A* has been identified based on the average sand diameter. When the average sand diameter is greater than 200 mm, *A* = 0.1. The value of U_* is not a constant, because it is affected by changes in humidity and the profile of the surface. Often this can cause errors in the prediction of the transport rate for lower or high shear velocities, therefore, it cannot be neglected. The formula of U_* thus becomes in the formula the constant of value (A) which was used in Bagnold's equation, which has been replaced by a range of values of (A) developed by Dong *et al*. (2003a) which depend in the grain size.

There is a strong correlation between the rate of air density and the size of grain diameters in the sediment transport process, through the critical shear velocity, where this velocity is the point at which sand begins to move. In the same time when particles have started to move, the critical shear velocity begins to decrease. This gradual decrease in critical shear velocity occurs due to the impact the mobile small particles on fixed large particles over the surface. Therefore, this is called the lower impact shear velocity. Table 4.1 shows the range in U_* for common values of grain diameter (d) and air density (ρ).

Table4-1 values of threshold shear velocity (m s^{-1}) (after Bagnold, 1941, p.156)

		Grain diameter (mm)			
		0.3	0.4	0.5	0.6
Air density (Kg m^{-3})	1.1	0.266	0.307	0.344	0.376
	1.2	0.255	0.294	0.329	0.360
	1.3	0.245	0.283	0.316	0.340

Due to the importance of shear velocity on the investigation of the best results for sand movement rates, many researchers have developed their research to find a real value for the shear velocity, an example being Dong *et al*. (2003a) who noted the shear velocity for some samples of sands, as shown in Table 4.2. The correlation coefficient in this study was ($R^2 \geqslant 0.98$), which indicated a strong relationship between the results observed and those predicted by Bagnold's threshold equation (Equation 3). The coefficient A from Bagnold's equation varies between 0.12 and 0.18 (mean = 0.15), according to the results of this study.

Table 4-2 The shear velocity and grain size of sands from the paper by Dong *et al*. (2003a).

d (mm)	$U_{*1}(m\ s^{-1})$	$U_1(m\ s^{-1})$	*A*	R^2
0.80 – 1.00	0.51	12.15	0.12	0.98
0.63 – 0.80	0.5	11.35	0.13	0.99
0.56 – 0.63	0.49	9.9	0.14	0.99
0.50 – 0.56	0.47	9.06	0.14	0.98
0.40 – 0.50	0.45	8.21	0.15	1
0.25 – 0.40	0.41	7.59	0.16	0.98
0.20 – 0.25	0.39	7.11	0.18	0.98
0.15 – 0.20	0.31	5.56	0.16	1
0.10 – 0.15	0.27	4.73	0.17	0.99

Note: d = the grain diameter, $U_{*1}(m\ s^{-1})$ = the threshold of friction velocity, $U_1(m\ s^{-1})$ is the centreline height of the velocity measured, *A* is the coefficient of Bagnold's threshold equation, R^2 is the square of the correlation coefficient between grain diameters and their shear velocity.

There are three different forms of sand movement when the critical shear velocity is exceeded, according to Bagnold (1973):

A) Creeping of the grains where the sand grains always stays near the surface with continuing movement of these particles.

B) Jumping of the grains (saltation), where the sand grains detach themselves from the surface through a short path in the air, then fall back to the surface.

C) Suspended transport of grains where the sand grains leave from the surface and stay in the air for a long time before falling back to the surface.

Also Bagnold (1973) has noted that the ratio between creep and saltation on beaches is about 1:3. He noted that it is possible to distinguish between causes of grains moving by creeping and those moving by saltation. Grains moving by saltation receive their momentum directly from the pressure of the wind, while the grains which are creeping and affected by both the wind and the impact of saltation from other grains.

4.2.2 **Grain size variations**

Processes of transport and deposition occurring for sediments are a clear reflection of the extent of grain size diversity. To find out the source of sediment and their deposition conditions there are methods which provide important clues to the history of their transport, among them the analysis of grain sizes (e.g. Folk and Ward, 1957, In: Musharraf, 1987; Friedman, 1978, In: Allen, 1979; Hartmann, 2007). The dry sieving technique for grain size determination was used in this study. However, in the recent years the GRADISTAT program (originally produced by Dave Thornley and John Jack of Reading and Royal Holloway Universities, respectively) has been used with a wide range of geomorphology and sedimentology researches, in order to process all the resultant data of particles size analysis and also to make easy the graphical presentation and statistical manipulation. This program uses Microsoft Excel spreadsheets, and can cope with grain size data that is of typical or non-typical size; it produces several graphs such as frequency plots. This program is useful for analysing data on grain sizes obtained by sieve or laser granulometer analysis, or from the percentages of sediment which were retained through graded sieves. This program provides rapid statistics calculations for approximately 50 samples per hour by both methods.

The statistical processing of all data samples uses the moments method within Microsoft Visual Basic programming language, producing standard descriptive statistical information. Statistical results of parameters are presented for arithmetic and geometric parameters (units in microns) and also logarithmic ones (termed the ‘phi’ scale) according to the following equations:

Mean size (M z)

The standard descriptive measurement of the overall particle sizes is the mean size (Mz) of these particles. Folk and Ward (l957) suggested the following formula; based on the percentages of phi (Ø) units (based on particle size categories) $Ø_{16}$, $Ø_{50}$ and $Ø_{84}$.

$$M\,z = \frac{Ø_{16}+Ø_{50}+Ø_{84}}{3} \qquad (4)$$

Standard deviation

$$\sigma_1 = \frac{Ø_{84}-Ø_{16}}{4} + \frac{Ø_{95}-Ø_{5}}{6.6} \qquad (5)$$

This formula includes 90% of the distribution and is the best overall measure of sorting. Folk (1968) has also suggested a descriptive scale for sorting.

Skewness (SK_1)

This standard measure is used to determine the asymmetry of the size distribution of sediments. Folk and Ward (1957) have suggested a standard formula for measuring skewness:

$$SK_1 = \frac{Ø_{16}+Ø_{84}-2Ø_{50}}{2(Ø_{84}-Ø_{16})} + \frac{Ø_{5}+Ø_{95}-2Ø_{50}}{2(Ø_{95}-Ø_{5})} \qquad (6)$$

Many studies have used skewness as a standard way of measuring the sizes of sediments because it determines the skewness of the curve “tails” and not just the central portion. The values of skewness are always recorded with a positive or negative sign, to avoid any possible confusion. According to the equation, symmetrical curves have SK1 = 0.0. Those with an excess of fine material have positive skewness. Curves representing excess coarse material have negative skewness. The more the skewness values depart from 0.0, the greater the degree of asymmetry. Folk and Ward (1957) have suggested descriptive categorisations of skewness, as given later in Table 4.7 with the results.

Before dealing with the stratigraphic distribution of skewness, its geologic meaning is briefly reviewed. Frohlich *et al.*, (2010) interpreted the variation of the sign of skewness as due to varying energy conditions of the depositional environments. They explained positive skewess as being due to the competency of the unidirectional flow of transporting media where the coarse fraction is removed. Negative skewess, on the other hand, is caused by the winnowing of fine material. Musharraf (1987) gave a similar explanation. He stated that negatively skewed curves are indicative of areas of erosion or no deposition, whereas positively skewed curves indicate deposition. Morgan and Bull (2007) explained negative skewess in terms of intensity and duration of the depositing medium agent. Also, he stated that the sediments that are negatively skewed are due to the high energy of the deposition factors; either being moved for a longer period of time or where the velocity has tended towards higher values more often than normal.

Linear interpolation is also used by Folk and Ward (1957) to calculate statistical parameters graphically and to provide physical descriptions (for example “very coarse sand” and “moderately sorted”). This program also provides an essential description of the structural group which the sample belongs to and the sediment name (such as “fine gravelly coarse sand”) (Musharraf, 1987). Table 4.3 also gives the proportion of grains falling within each size fraction, based on the groups given by Udden (1914), and Wentworth (1922).

4.2.3 Procedures for Calculating Wind-Blown Sand Transport

To understand the impact of wind living organisms there is a need to know the measurements of vertical wind speeds (Tamura *et al*., 2007).The wind velocities change with height above ground, length of uniform surface, and surface roughness through the shape of a vertical wind profile (Briggs *et al*., 2001). There are formulas to estimate the wind velocity, as suggested by Zhang *et al*. (1997), contributing to the understanding of complex predictions of wind speed. The ultimate aim of these measurements is to analyse the value of shear velocity and its correlation with mechanical power which obtain due to wind pushing on the sand.

Table 4-3 Size groupings used within the GRADISTAT program (ϕ, and mm units), compared with those of Udden (1914), Wentworth (1922) and Friedman and Sanders (1978, In: Allen, 1979).

Grain size		Descriptive terminology			
phi	mm/um	Udden (1914) and Wentworth (1922)	Friedman and Sanders (1978)	GRADISTAT program	
-11	2048 mm		Very large boulders		
-10	1024		Large boulders	Very large	
-9	512		Medium	Large	
-8	256	Cobbles	Small boulders	Medium	Boulders
-7	128		Large cobbles	Small	
-6	64		Small cobbles	Very small	
-5	32		Very coarse Pebbles	Very coarse	
-4	16	Pebbles	Coarse pebbles	Coarse	
-3	8		Medium Pebbles	Medium	Gravel
-2	4	Granules	Fine pebbles / Very fine pebbles	Fine / Very fine	
-1	2				
0	1	Very coarse sand	Very coarse sand	Very coarse	
1	500um	Coarse sand	Coarse sand	Coarse	
2	250	Medium sand	Medium sand	Medium	Sand
3	125	Fine sand	Fine sand	Fine	
4	63	Very fine sand	Very fine sand	Very fine	
5	31		Very coarse silt	Very coarse	
6	16	Silt	Coarse silt	Coarse	
7	8		Medium silt	Medium	Silt
8	4		Fine silt / Very fine silt	Fine / Very fine	
9	2	Clay	Clay	Clay	

Wind velocity profiles are needed to determine the shear velocity. The shear velocity can be calculated by using equations (2 and 3). For this calculation the interception height between the wind velocity profile and the Y axis is needed, this height is called z0. There are some recent studies such as (Dong *et al*., 2003b; Tsoar, 2005; Blumberg, 2006; Weaver, 2008) which have calculated the interception height for ten minute periods, since this is the period for which the wind data were stored. Theoretically every ten minute velocity profile intercepts with each other in a fixed point, the focal point (Bagnold, 1973, p.98). The height of the focal point is dependent on the roughness of the surface. The roughness of the surface can be divided into three classes, according to Bagnold namely: roughness caused by the individual sand grains, roughness caused by surface forms like ripples and dunes and roughness caused by disturbances of the surface for instance by shells or human waste. If no sand transport occurs the focal point is situated on the Y axis.

4.2.4 Data collection

4.2.4.1 Fieldwork

One period of field work was undertaken for this part of the research, from *October to the middle of November 2008*. The field work was divided into three stages: the first stage was a primary survey of the area including identifying the location of sand dunes by using a topographic map and GPS system which through it has been determines the exact locations of sampling. Also identify elevations of dune and their directions, as well as assessing the vegetation cover on the dunes. Moreover, some photos of the sand dunes were taken, to illustrate the current status of the vegetation on the sand dunes. A second stage was to collect 125 samples of sand from 25 sites from the whole area. The samples of sand were collected during field work from twenty five locations in the whole region using a systematic sampling strategy with samples taken approximately every 10 kilometres along the coastal line, with the same interval toward south of the coastal line for two sites in the western part of the region. These samples were selected so as to fairly represent the character of the sand over the whole study area as shown in Figure 4.1, and the name and grid references of samples is given in Table 4.4. The sub – area marked 1 from the western region comprises desert sand, while sub - area 2 in the east comprises coastal dune sands.

Table 4-4 List of sample site names and grid references from the study area.

S.N	Name of Location	Grid reference
(1)	***Qaser Ahmad Region***	*N32'22" E015'11"*
(2)	***Aljazeera Region***	*N32'24" E015'01"*
(3)	***Alsawawa Region***	*N32'24" E014'59"*
(4)	***Zawiat Almahgob Region***	*N32'23" E014'58"*
(5)	***Abourwia Region***	*N32'24" E014'56"*
(6)	***Zeriq Region***	*N32'25" E014'53"*
(7)	***Aldafniya Region***	*N32'24" E014'50"*
(8)	***Naaiemah Region***	*N32'27" E014'40"*
(9)	***Azdo Region***	*N32'28" E014'38"*
(10)	***Aboruqiya Region***	*N32'29" E014'36"*
(11)	***Almontaraha Region***	*N32'28" E014'33"*
(12)	***Ekaam Region***	*N32'30" E014'30"*
(13)	**Soukh Alkamies Region**	N32'33" E014'25"
(14)	**Alawashier Region**	N32'44" E013'57"
(15)	**Awlaad huseen Region**	N32'45" E013'56"
(16)	**Siede Amier Region**	N32'46" E013'51"
(17)	**Alnachiea Region**	N32'45" E013'40"
(18)	**Alkrawa Region**	N32'44" E013'44"
(19)	**Al ataya Region**	N32'46" E013'41"
(20)	**North Algaweah Region**	N32'45" E013'39"
(21)	**South Algaweah Region**	N32'43" E013'35"
(22)	**Alwady Alsharqy Region**	N32'45" E013'32"
(23)	**Bear Turky Region**	N32'45" E013'30"
(24)	**Wady Alrabieh Region**	N32'47" E013'28"
(25)	**Alwady Alqarby Region**	N32'43" E013'26"

Furthermore, each site was defined as having an area of 1km^2, and then five samples of sand were taken from each site; these samples were taken from the four cardinal directions at the national boundaries of the 1km^2 areas and the middle of the site, including all the different formations of dunes in the region. A standardised sampling procedure was carried out for the sampling from each site; five kg of sand were taken from a first meter of the crest layer of dune surfaces and the same quantity also taken from both sides of the dune, as well as a further five kg taken from the middle of the point where the dune front terminates. All samples were mixed together and one sample taken from this mixture to represent each dune from the site, as is standard practice for screening of sand (Musharrf, 1987, p.168).

The third stage was to record the climate data in order to use it for equations of measurement of sand movement in the study area, including taking wind data records at two field sites. Figure 4.3 shows the general characteristics of the areas where a series of 10 minute wind events were measured at the two sites during the field study. The process of installing wind-measuring equipment and taking the reading of the data was under the supervision of staff from meteorological stations (Tripoli and Misurata). The selected events (data given later in Table 4.12) were chosen on the basis of their differing properties ranging from high to low wind velocities. Consequently, these selected 18 data runs will be used in all subsequent data analysis within this chapter, along with the meteorological data which have been obtained from the Libyan National Meteorological Centre, for the period 1977-2008. These data relate to three meteorological stations (Misurata, Al khoms and Tripoli), as shown in Figure 4.1.

4.2.4.2 Sample locations

From Figure 4.1 it can be seen that the locations of sand dunes which were studied have been divided into two parts, the first part included 12 locations in the western part of the study area, while there were 13 locations in the eastern part of the study area. In order to reflect the topography of the area, the study sites have included two plains, which have sand dunes over much of their area. Sand dunes in the western part are separated from the sand dunes in the eastern part by the Alqarby Mountain which terminates in the Mediterranean Sea. The western part of the study area consists of the Aljafarah plain, which has an elevation that predominantly rises to only 50 to 100 meters above sea level. The eastern part of the study area is known as the Zliten Misurata plain, which extends from Leptis Magna in the west to the Taorghae marsh in the east. Its height generally ranges between 8 to 18 meters above sea level.

4.2.4.3 Analysis of the samples selected

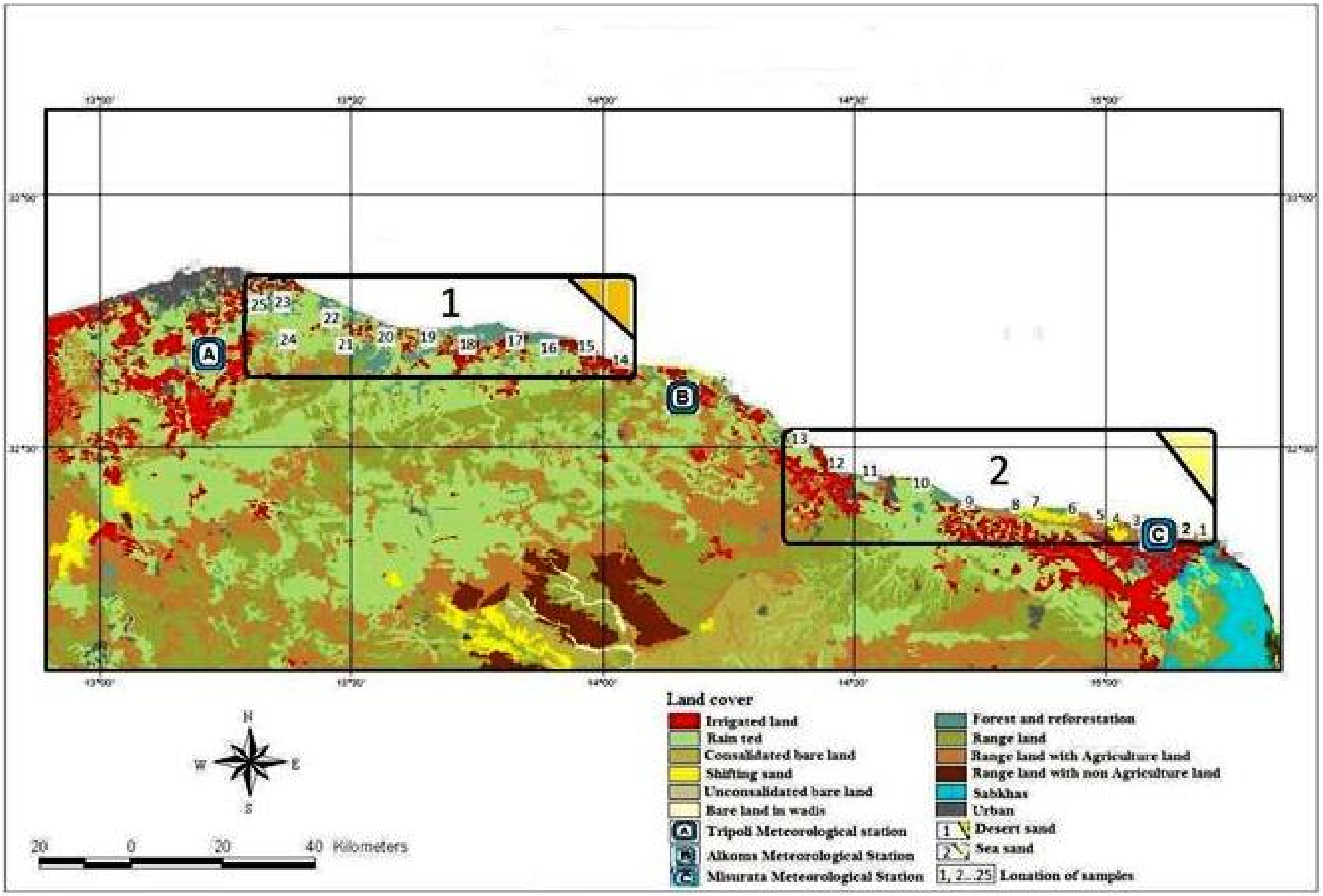
Analysis of sand grain sizes is crucial when classifying sedimentary environments. All the results have been obtained using the dry sieving method so they can be directly compared and processed. The resultant data divides the sample of sand into a series of sizes, where the grain sizes distribution may be based on either the weight or percentage volume of the variously sized grains in the sample. These results were then divided into six classes based on Ø and µm units. Sieve analyses of samples have been done at the laboratory of Industrial Research Centre in Libya under the supervision of the centre staff (see Figure 4.2).

Moreover, all results which were obtained were then entered into the GRADISTAT program described earlier. Descriptive statistics, namely mean, mode, sorting, skewness and others were calculated arithmetically and geometrically (in metric units) and logarithmically (in phi units), using the moment and graphical methods of Folk and Ward. Results obtained by other authors show that the Folk and Ward measures, expressed in metric units, are a good way of summarising and comparing data of this sort.

4.2.4.3.1 Sand density analysis

Determination of sand particle density or test weight or bulk density of sand has a major influence on the velocity of wind shear. Test weight can be used to identify the size of moving grains and thus the velocity shear. The samples of sand have been analysed for sand density using the method by Black *et al* (1965, In: Lancater *et al.,* 2002), by placing sand in a hole and using equation 7.

Figure4.1 Land cover, location of sand samples and meteorological stations in the study area



$$\rho_d \frac{M/V}{1+W} \qquad (7)$$

The volume of the hole is determined by filling it with clean, uniform sand whose dry density (ρ_d) is determined separately by calibration. The volume of the hole is equal to the mass of the sand placed in the hole divided by its dry density. The dry density of the excavated soil is determined, with the terms of the equation as follows: M = mass of the excavated soil, V= volume of the hole and W = water content (Weaver, 2008).

Figure 4.2 Photos showing dry sieve equipment which was used for analysis of the particle grain size.

4.2.4.4 . Measurement of wind speed and direction

The wind data have been measured by means of cup-anemometry. The cup anemometers that were used have three cups in the shape of half spheres. The number of rotations per time unit is registered in a data logger that stores the average wind speed each ten minutes. Furthermore, the wind velocity has been measured at six different heights in order to construct wind velocity profiles according to Bagnold. These height measurements were at 0.35 m, 0.5 m, 1m, 1.5 m, 2 m and 10 m. 10 m value has been measured from two main stations in both sides of the region, because they are very close to both sites for these cup-anemometry, and due to have some technical problems which prevented installation of these cup anemometers at an altitude of ten meters. In general, the wind velocities have been measured by the author during different hours at two sites, over nine separate days; from 14/10/2008 to 13/11/2008. Also included were the measurements of wind direction and temperature. The six anemometers were, on each occasion, placed vertically with a levelling-instrument (see Figure 4.3). Further, using the same method the annual wind speed has been obtained but only at the normal height of approximately 10m-high during the last 32 years at three meteorological stations within the study area. These data included the wind direction, with also the annual maximum sustained wind speed, and were obtained from the relevant meteorological station office.

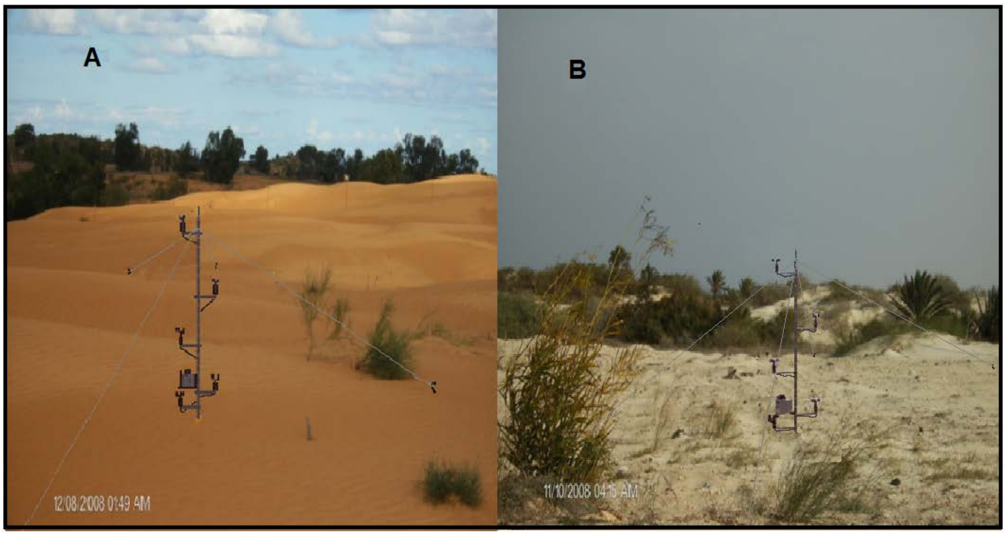


Figure4.3 Anemometry equipment as used in (A) the western part of the study area, and (B) the eastern part of the study area.

4.3 Sand types

There are two types of sand dune systems which were studied in this research project, desert sands and sea sands. The desert sands occupy the western part of the study area (see Figure 4.1), and cover most of the Jaffara plain area. The average height of these dunes is less than 10 meters. Small-scale dunes (Nabakat) are found within these dune chains, with example illustrations in Figure 4. 4. It can be seen that their colour ranges between red and yellow, and the grains of desert sand include quartz, feldspar and a large proportion of carbonate salts.

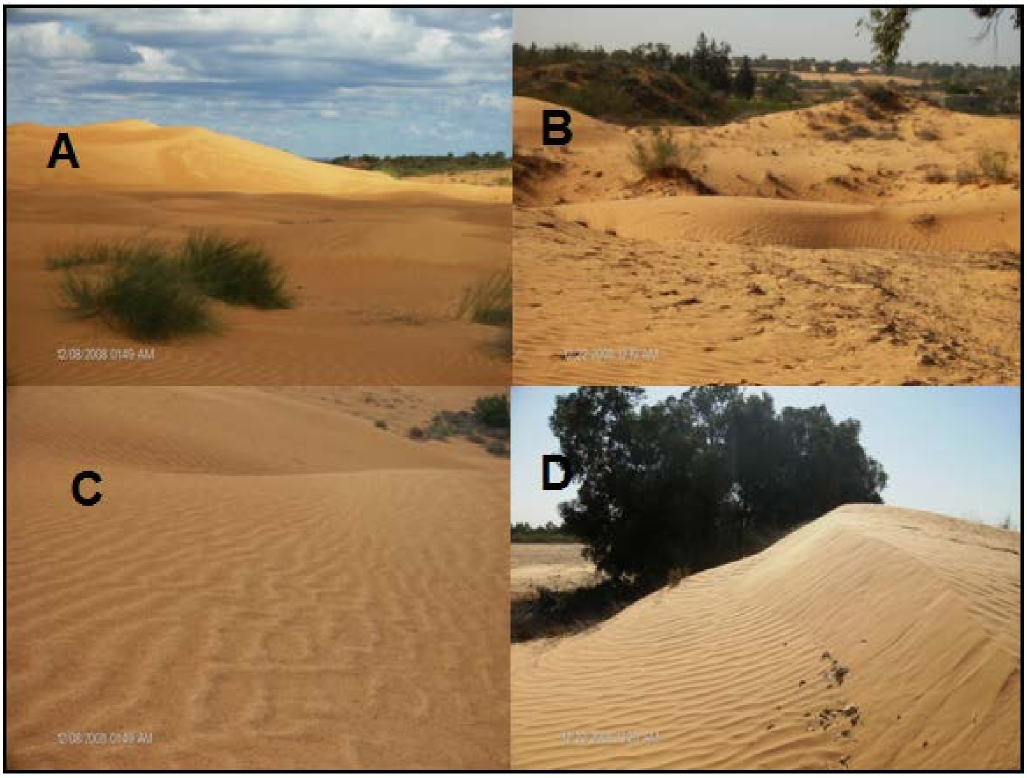


Figure 4.4 Illustration of the desert sands distributed in the western part of the study area, namely (A) Al ataya region, (B) Alwady Alqarby region, (C) Bar Torky region, (D) Wady Alrabieh region, also showing the limited vegetation cover on the sand dunes. Photos by the researcher (October, 2008)

The sea sands occupy the eastern part of the study area (see Figure 4.1). It can be seen that these dunes have been formed from longitudinal dunes (swords) and transverse dunes. The length of these dunes is more than 200 meters, while their width ranges between 100 to 150 meters and their height is about 30 meters. The sea sands consist of coarse grains with the presence of residual marine shells. The colour of these dunes is between white and grey, and sometimes mixed with black and orange mottles. It also includes carbonate salts, chlorides and sulphate. (See Figure 4.5 for illustrations of these sands).

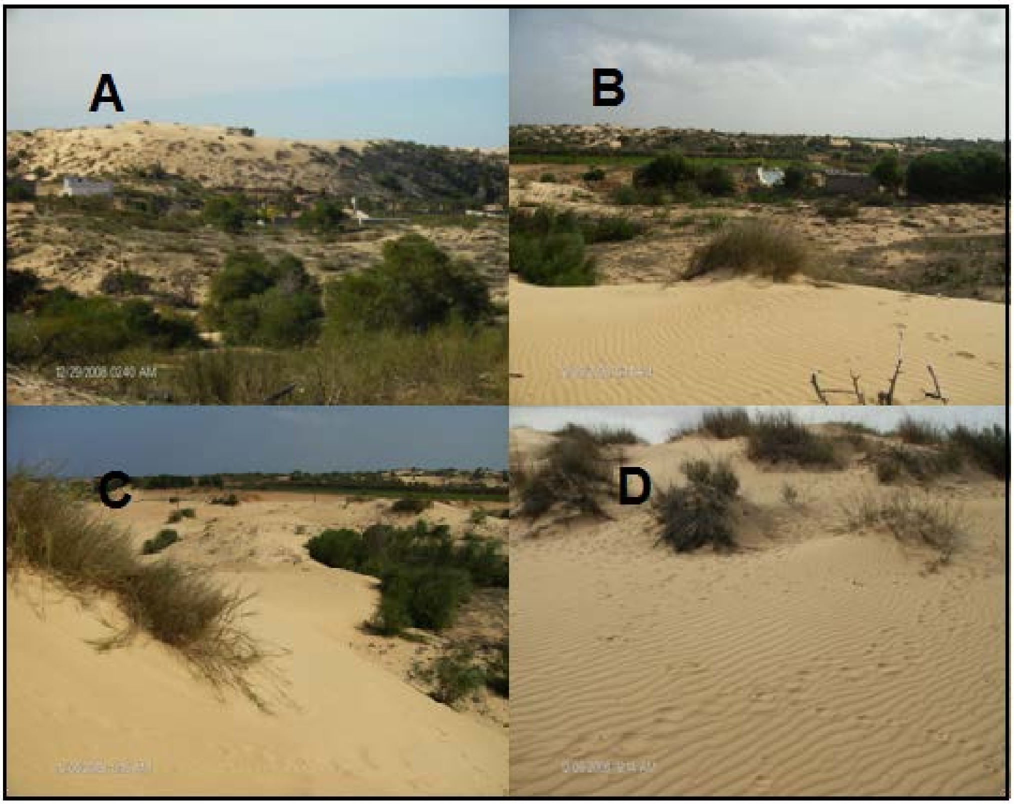


Figure 4.5 Illustrations of the sea sands distributed in the eastern part of the study area, namely, (A) Abourwaia region, (B) Zeriq region, (C) Azdo region, (D) Ekaam region, which also shows the beginnings of the reduced vegetation cover on the sand dunes. Photos by the researcher (October, 2008)

4.4 Results of the distribution of sand grain sizes within the study area

Processes of transport and deposition by wind are largely accomplished according to size of sediment particles. All techniques which are used to analyse the sediment size have involved the division of the sediment sample into a number of sizes, in order to allow a grain size distribution to be constructed from the weight or volume percentage of each sample. Furthermore, to compare distributions of different sand particle sizes in the samples, most distributions of grain size are compared with a prescribed ideal distribution. Computations are performed assuming a normally distributed sample.

There are two groups of results from the all samples obtained. The first group relates to sand sampled from 12 locations, all in the west of the study area. Mostly the size of sand in these locations was medium sized sand (2Ø). The second group (from the eastern part of the study area) was the samples from the other 13 locations. Mostly the sizes of sand found in these locations were fine sands (3Ø) (Table 4.5).

Furthermore, the histograms of the size of sand grains in the study area indicate that most of the samples fall into a range of between “two and three bars” of size types. The size classes used in the histograms in this part were divided into the coarse sand (500-1000µm), medium sand (250-500µm), fine sand (125-250µm), and very fine sand (62.5-125µm). Only 32% of the samples fell into the “one bar“ situation where all the particles fall into one size class (medium sand). Each site is illustrated separately (Figures 9.1 to 9.25 in appendix 1). Also included in the figures are cumulative frequency curves for the data, where the present results indicate that most samples range between near symmetric and strongly fine skewed (Table 4.7); a few samples only are coarse skewed. The results are displayed in detail later in the histograms and cumulative curve for each sample.

Table 4-5 Analysis of results for size of sand grains in the study area (ϕ, mm units); values in the table are weights of the different size fractions in the sample, in g.

Sieve size	(ϕ units)	0	1	2	3	4	5
	(mm units)	1mm	0.5mm	0.250mm	0.125mm	0.063mm	pan
Classification size / Name of Sample site		Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	silt
Qaser Ahmad	(1)	0.21	6.48	245.25	11	3.04	0.87
Aljazeera	(2)	0.36	15.33	205.77	27.41	1.98	0.69
Alsawawa	(3)	0.23	18.33	136.47	120.73	6.36	1.03
Zawiat Almahgob	(4)	0.33	7.9	205.54	7.49	3.43	0.55
Aboarwia	(5)	0	0.82	338.37	68.35	5.25	0.86
Zeriq	(6)	1.88	30.17	305.37	56.43	2.86	0.28
Aldafnya	(7)	1.74	31.95	247.96	83.57	5.07	2.2
Naaiemah	(8)	2.32	101.96	304.94	24.85	16.28	0.83
Azdo	(9)	0.19	20.13	258.53	64.6	2.46	0.34
Aborquiya	(10)	1.03	21.33	147.1	44.93	2.93	0.96
Almontaraha	(11)	0	8.3	345.65	61.66	8.41	0.47
Ekaam	(12)	0	3.48	133.95	251.87	0.94	0.15
Soukh Alkamies	(13)	0	0.1	217.4	178.58	2.05	0.18
Alawashier	(14)	0.17	0.36	0.47	204.98	146.13	4.38
Awlad hseen	(15)	0.16	21.83	224.08	251.77	110.51	2.84
Siede Amier	(16)	0	0	126.49	148.69	6.68	0.32
Alnachiea	(17)	0.06	2.48	26.8	140.31	80.15	6.47
Alkrawa	(18)	0.11	163.94	236.54	145.92	89.92	7.2
Al ataya	(19)	0	0	0	202.37	46.79	0.44
North Alqewah	(20)	0	0	0.35	260.61	21.08	0.27
South Alqewah	(21)	0.09	0.12	61.25	258.42	35.3	0.69
Alwady Alsharqy	(22)	0.94	1.3	1.15	259.98	93.41	1.57
Bear Turky	(23)	0.05	0.08	0.29	432.14	90.58	0.66
Wady Alrabieh	(24)	0	0	1.87	144.54	12.01	2.63
Alwady Alqarby	(25)	0	0	0	297	3.12	0

4.4.1 Stratigraphic distribution for size of sand grains

The results obtained from the grain size analysis of sand are represented in the form of histograms and cumulative curves, also to assure maximum accuracy in determining grain size, statistical parameters of average grain size, standard deviation and skewness (in phi units) proposed by Folk and Ward (1957, In: Musharraf, 1987) have been determined. The detailed results for each sample location separately, of sand particle size analyses in the study area can be found in Appendix 1, and are summarised in this section. The mean particle sizes for the dune types within the two parts of the study area were analysed by two a sample unpaired t-test, with the results shown in Table 4.6.

The result of the t test was 6.77 (df = 21, $p < 0.001$) which shows a very highly significant difference between grain sizes from the sand dunes of the eastern and western parts of the study area. The western area has lower grain sizes, this result may be due to the difference in origin of this sand (desert) compared to that of the eastern area (coastal).

Table 4-6 The results of t - tests for grain diameter comparing mean values of two types of sand in the study area (with 21 degrees of freedom).

Type of sand	Mean	St Dev	SE Mean	t	p
Coastal sand	*0.2650*	*0.0415*	*0.012*	6.77	< 0.001
Desert sand	0.1521	0.0436	0.012		

Although the samples selected had included two different types of sand, most results within both types converged in the proportions of particle sizes of their sand, giving a low standard Error value. To give more information about the descriptive parameters of particles size, all data concerning the size analysis of the samples are given in detail in Table 4.7, including descriptive terms that can be assigned to the numerical statistics. The parameters used to describe a grain size distribution fall into three principal groups: Mean grain size, the Standard deviation (sorting) of the sizes around the average and the Skewness (symmetry).

From the results, as shown in Table 4.7, the mean size (Mz) values of the size of sediments in the study area indicate that the samples divided into two groups.

The first group was composed of fine sand and consisted of 65 samples from 13 locations, comprising 52% of all the samples. The second group was composed of very fine sand found in 55 samples from 11 locations, comprising 44% of all the samples.

Using the descriptive scale for sorting indicated in Table 4.7, the present study reveals that all samples tested from the study area range from very well sorted to moderately well sorted. The most frequent category of sorting was observed in samples that were moderately well sorted (44% of the tested samples). On the other hand, the least common category of sorting was from moderately sorted samples (12%). Very well sorted and well sorted samples respectively accounted for 24% and 20% of the tested samples. The overall average, including the standard deviation, of the sediments tested was moderately well sorted. The stratigraphic distribution of standard deviation indicates that all samples tested in the study area have been exposed to rapid and erratic changes.

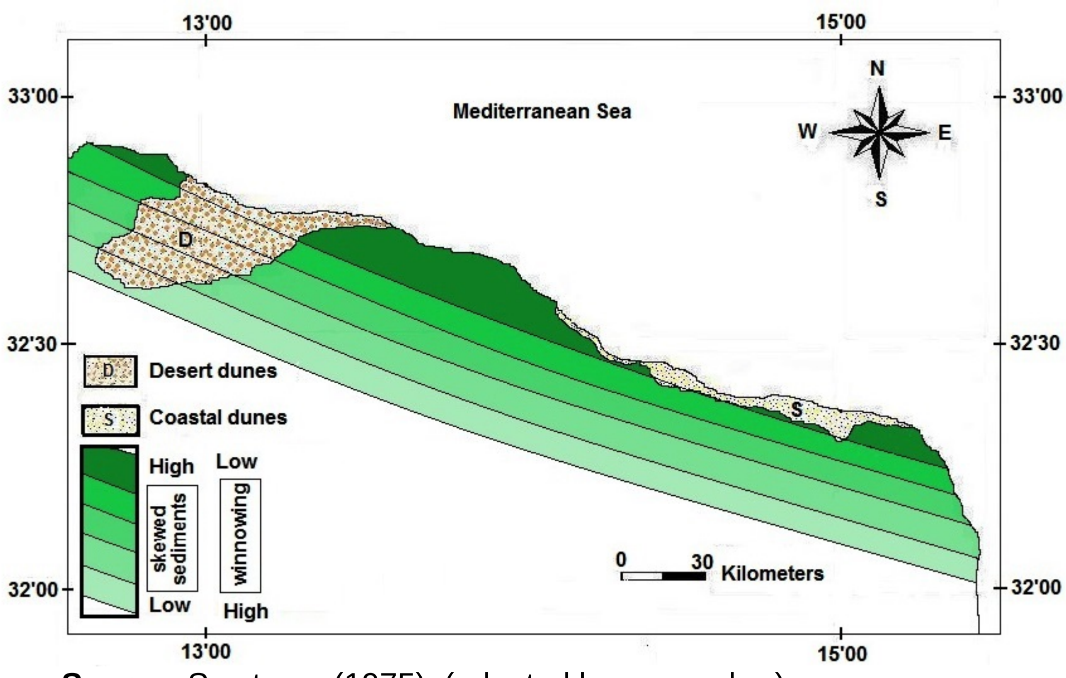
Table 4-7 Analysis and distribution of sand grains size within the study area based on mean $(\bar{x})$ Standard Deviation (σ) and Skewness (*SK*), according to Folk and Ward (1957).

Sample's Name	Geometric (µm)				Logarithmic Ø (phi units)				Description				Sample type	Sediment name	Textural group %
	$(\bar{x})$	(σ)	(*Sk*)	(*K*)	$(\bar{x})$	(σ)	(*Sk*)	(*K*)	$(\bar{x})$	(σ)	(*Sk*)	(*K*)			
Qaser Ahmad	296.2	1.190	-0.261	1.550	1.756	0.251	0.262	1.550	M S	*V W S*	F S	*V L*	U V W S	*V W S M S*	99.7Sand
Aljazeera	294.3	1.315	-0.046	2.535	1.765	0.395	0.046	2.535	M S	*W S*	Sy	*V L*	U W S	*W S M S*	99.7Sand
Alsawawa	229.4	1.543	-0.200	0.828	2.124	0.626	0.200	0.828	F S	*M W S*	F S	*P*	B M W S	*M W S M S*	100 Sand
Zawiat Almahgob	297.2	1.125	0.000	0.738	1.750	0.169	0.000	0.738	M S	*V W S*	Sy	*P*	U V W S	*V W S M S*	100 Sand
Abourwia	254.0	1.360	-0.574	1.808	1.977	0.443	0.574	1.808	M S	*W S*	V F S	*V L*	B W S	*W S M S*	99.8 Sand
Zeriq	293.2	1.340	-0.024	2.553	1.770	0.422	0.024	2.553	M S	*W S*	Sy	*V L*	B W S	*W S M S*	99.9 Sand
Aldafniya	248.7	1.525	-0.288	2.337	2.008	0.609	0.288	2.337	F S	*M W S*	F S	*V L*	B M W S	*M W S M S*	99.4 Sand
Naaiemah	354.7	1.541	0.251	2.508	1.495	0.624	-0.251	2.508	M S	*M W S*	C S	*V L*	B M W S	*M W S M S*	99.8 Sand
Azdo	254.2	1.463	-0.328	2.368	1.976	0.549	0.328	2.368	M S	*M W S*	V F S	*V L*	B M W S	*M W S M S*	99.9 Sand
Aboruqiya	252.3	1.521	-0.280	2.390	1.987	0.605	0.280	2.390	M S	*M W S*	F S	*V L*	B M W S	*M W S M S*	99.8 Sand
Almontaraha	257.6	1.355	-0.567	1.823	1.957	0.438	0.567	1.823	M S	*W S*	V F S	*V L*	B W S	*W S M S*	99.9 Sand
Ekaam	190.2	1.416	0.499	0.608	2.394	0.502	-0.499	0.608	F S	*M W S*	V C S	*V P*	B M W S	*M W S F S*	100 Sand
Soukh Alkamies	227.0	1.422	-0.436	0.584	2.139	0.507	0.436	0.584	F S	*M W S*	V F S	*V P*	B M W S	*M W S M S*	100 Sand
Alawashier	115.3	1.426	-0.448	0.590	3.117	0.512	0.448	0.590	V F S	*M W S*	V F S	*V P*	B M W S	*M W S F S*	98.8 Sand
Awlaad huseen	164.6	1.772	-0.042	0.852	2.603	0.826	0.042	0.852	F S	*M S*	Sy	*P*	T M S	*M S F S*	99.5 Sand
Siede Amier	195.5	1.427	0.399	0.584	2.355	0.513	-0.399	0.584	F S	*M W S*	V C S	*V P*	B M W S	*M W S F S*	99.9 Sand
Alkrawa	272.8	2.049	-0.149	0.749	1.874	1.035	0.149	0.749	M S	*P S*	F S	*P*	P P S	*P S M S*	97.5 Sand
Alnachieah	121.3	1.574	-0.227	0.913	3.043	0.655	0.227	0.913	V F S	*M W S*	F S	*M*	T M W S	*M W S F S*	98.9 Sand
Al ataya	127.0	1.365	-0.558	1.705	2.977	0.449	0.558	1.705	F S	*W S*	V F S	*V L*	B W S	*W S F S*	99.8 Sand
North Algaweah	147.8	1.207	-0.277	1.652	2.758	0.271	0.277	1.652	F S	*V W S*	F S	*V P*	U V W S	*V W S F S*	99.9 Sand
South Algaweah	175.5	1.481	0.263	2.376	2.544	0.567	-0.263	2.376	F S	*M W S*	C S	*V L*	B M W S	*M W S F S*	99.8 Sand
Alwady Alsharqy	122.3	1.400	-0.542	0.669	3.031	0.486	0.542	0.669	V F S	*W S*	V F S	*V P*	B W S	*W S F S*	99.6 Sand
Wady Alrabieh	147.6	1.223	-0.291	1.762	2.760	0.291	0.291	1.762	F S	*V W S*	F S	*V L*	U V W S	*V W S F S*	98.4 Sand
Bear Turky	128.4	1.355	-0.555	1.720	2.961	0.438	0.555	1.720	F S	*W S*	V F S	*V L*	B W S	*W S F S*	99.9 Sand
Alwady Alqarby	149.7	1.120	0.000	0.738	2.740	0.163	0.000	0.738	F S	*V W S*	Sy	*P*	U V W S	*V W S F S*	100 Sand

Key $(\bar{x})$: M S = Medium Sand; F S = Fine Sand; V F S = Very Fine Sand. SORTING (σ): V W S = Very Well Sorted; W S = Well Sorted; M W S = Moderately Well Sorted; M S = Moderately Sorted; P S = Poorly Sorted. SKEWNESS (Sk): V C S = Very Coarse Skewed; C S = Coarse Skewed; F S = Fine Skewed; V F S = Very Fine Skewed, Sy = Symmetrical. KURTOSIS (K): M = Mesokurtic; P = Platykurtic; V L = Very Leptokurtic; V P = Very Platykurtic. SAMPLE TYPE: B W S = Bimodal, Well Sorted; B M W S = Bimodal, Moderately Well Sorted; T M S = Trimodal, Moderately Sorted; T M W S = Trimodal, Moderately Well Sorted; P P S = Polymodal, Poorly Sorted; U W S = Unimodal, Well Sorted; U V W S = Unimodal, Very Well Sorted. SEDIMENT NAME: M S F S = Moderately Sorted Fine Sand; M W S F S = Moderately Well Sorted Fine Sand; M W S M S = Moderately Well Sorted Medium Sand; P S M S = Poorly Sorted Medium Sand; W S F S = Well Sorted Fine Sand; W S M S = Well Sorted Medium Sand; V W S M S = Very Well Sorted Medium Sand; V W S F S = Very Well Sorted Fine Sand.

The stratigraphic distribution of inclusive graphic skewness is shown in Table 4.7. The majority of samples from both of the two study areas are positively skewed; about 82% and 85**%** for east and west respectively. The abundance of positively skewed sediments in the north of the study area indicates that deposition has dominated over winnowing. The negatively skewed sediments in the south of the study area possibly represent an area where winnowing action was active (see Figure 4.6). This interpretation is further supported by a rapid increase in size of grain and consequently a trend of increasing sedimentation from south to north.

Figure 4.6 Illustration of friction rate and value skewed of sediments within the study area.



Source: Smetana, (1975), (adapted by researcher).

4.4.2 Sand density analysis in the study area

Although the study area contains two types of sands, the results of sand density analysis for both parts of the region indicated in general that there is a convergence in the sample density values. In the eastern part of the region, the sea sand density ranged between 2.63 - 2.68 g/cm^{-3}, while the desert sand density in the western part of the region ranged between 2.58 - 2.65 g/cm^{-3} (Table 4.8).

Furthermore, analysis of density of grain components indicated that the average is approximately equal to 2.6 g/cm^{3} over all the samples (Table 4.8), and agrees with results found in other studies of sand dunes (e.g. Wang *et al*. 2003b; Weaver 2008).

Table 4-8 Results of analysis of sand density in the study area

Type of sand		Location of Samples	Density (gcm^{-3})
Sea sand	1	Qaser Ahmad	2.66
	2	Aljazeera	2.66
	3	Alsawawa	2.63
	4	Zawiat Almahgob	2.63
	5	Abourwia	2.68
	6	Zeriq	2.64
	7	Aldafniya	2.65
	8	Naaiemah	2.66
	9	Azdo	2.67
	10	Aboruqiya	2.68
	11	Almontaraha	2.67
	12	Ekaam	2.65
	13	Soukh Alkamies	2.67
Desert sand	14	Alawashier	2.63
	15	Awlad hseen	2.64
	16	Siede Amier	2.59
	17	Alkrawa	2.65
	18	Alnachiea	2.62
	19	Al ataya	2.58
	20	North Algaweah	2.6
	21	South Algaweah	2.65
	22	Alwady Alsharqy	2.61
	23	Wady Alrabieh	2.65
	24	Bear Turky	2.63
	25	Alwady Alqarby	2.62

4.5 Wind velocity and direction within the study area

The number of days per year where the wind speed exceeded the value required to move sand grains (Table 4.11), as derived from Bagnold equation and the grain sizes accorded in section 4.4.1, are given in Tables 4.9- 4.10. Data of wind speeds as shown in Figure 4.7 represent the mean daily wind velocity in meters per second at standard height (10 m) for the whole study area.

Table 4-9 Number of wind days in the year which have potential to move sand within the western part of the study area during 1977 - 2008

1977	1978	1979	1980	1981	1982	1983	1984
119	115	140	114	109	84	62	95
1985	1986	1987	1988	1989	1990	1991	1992
90	96	79	104	86	100	93	98
1993	1994	1995	1996	1997	1998	1999	2000
110	126	123	127	112	118	121	95
2001	2002	2003	2004	2005	2006	2007	2008
155	100	196	138	123	92	75	85

Table 4.9 shows the number of wind days which have the potential to move sand within the western part of the study area over 32 years, as based on Bagnold (1973) results. In 2003 was recorded the highest number of wind days in one year, where this threshold of being able to move the sand grains was exceeded on over half the days of the year. In contrast, the lowest number of wind days which exceeded the threshold was recorded on 1983. Even so, two months worth of the year worth of days where sand could be moved is still not a small period. In totality, most years had recorded a high number of wind days exceeding the threshold, ranging between 90 – 140

days. These numbers of year days are equivalent to a proportion of a quarter to a third of each year of those periods. Thus, there is ample evidence of the possibility of sand being able to be moved on the basis of the wind speeds recorded in the study area.

Table 4-10 Number of wind days in the year which have potential to move sand within the eastern part of the study area during 1977 - 2008

1977	1978	1979	1980	1981	1982	1983	1984
120	123	129	119	114	87	75	108
1985	1986	1987	1988	1989	1990	1991	1992
105	108	85	115	93	112	99	100
1993	1994	1995	1996	1997	1998	1999	2000
115	119	130	134	115	120	120	99
2001	2002	2003	2004	2005	2006	2007	2008
162	108	204	150	125	101	83	95

Table 4.10 shows the number of wind days which have the potential to move sand within the eastern part of the study area over 32 years, as based on Bagnold (1973) results. In 2003 was recorded more than 200 days which would have been able to move the sand grains, which means the threshold speed was exceeded on over half the days of the year. In contrast, the lowest number of wind days was recorded in 1983, where the threshold was exceeded two months worth of the year where sand could be moved, still a appreciably large numbers of days. In entirety, most years had recorded a high number of wind days exceeding the threshold, ranging between 99 – 150 days. These numbers of year days was slightly greater compared to the number of wind days in the western part of the study area, and are equivalent

to a proportion of a third of each year of those periods. Therefore, there is a probability of slightly greater rates of sand movement within the eastern part of the study area. Thus, there is ample evidence of the possibility of sand movement on the basis of the wind speeds recorded generally in the study area.

Table 4-11 Average number of wind days in the year based on wind speed rates which have potential to move sand, plus the speed required to transport the sand grains (from Bagnold's equation) in the study area during 1977 – 2008.

Sample's Name	Grain diameter (mm)	Average number of wind day during year according to wind speed rates						Diameter of sand grains according Bagnold (1973)	The speed required to transport the sand grains according to Bagnold (1973)
		< 2.5m/s	2.5 – 4.5 m/s	4.5 -- 6.5m/s	6.5 -- 8.5m/s	8.5 -- 10.5m/s	> 10.5m/s		
Qaser Ahmad	0.30	91	144	83	33	11	4	0.25 --- 0.50 mm	From 4.5 to 6.7 metres per second
Aljazeera	0.29	91	144	83	33	11	4		
Alkrawa	0.27	71	184	86	19	4	2		
Zawiat Almahgob	0.30	91	144	83	33	11	4		
Abourwia	0.25	91	144	83	33	11	4		
Zeriq	0.29	91	144	83	33	11	4		
Aldafniya	0.25	91	144	83	33	11	4		
Naaiemah	0.35	91	144	83	33	11	4		
Azdo	0.25	91	144	83	33	11	4		
Aboruqiya	0.25	91	144	83	33	11	4		
Almontaraha	0.26	91	144	83	33	11	4		
Alsawawa	0.23	91	144	83	33	11	4	< 0.25 mm	< 4.5 metres per second
Ekaam	0.19	91	144	83	33	11	4		
Soukh Alkamies	0.23	91	144	83	33	11	4		
Alawashier	0.12	71	184	86	19	4	2		
Awlad huseen	0.16	71	184	86	19	4	2		
Siede Amier	0.20	71	184	86	19	4	2		
Alnachiea	0.12	71	184	86	19	4	2		
Al ataya	0.13	71	184	86	19	4	2		
North Algaweah	0.15	71	184	86	19	4	2		
South Algaweah	0.18	71	184	86	19	4	2		
Alwady Alsharqy	0.12	71	184	86	19	4	2		
Wady Alrabieh	0.15	71	184	86	19	4	2		
Bear Turky	0.13	71	184	86	19	4	2		
Alwady Alqarby	0.15	71	184	86	19	4	2		

Table 4.11 shows the average number of wind days in the year on the basis of the wind speed rates which had the potential to move sand in the study

area during 1977 – 2008; there are two different peaks of number of wind days during this time period, recorded in the study area. Within the eastern part of the study area (Qaser Ahmad - Ekaam), the total number of wind days which had the potential to move sand was 131 days in the year. These break down into 83 days with a wind speed of 4.5 - 6.5 m/s, 33 days for a wind speed of 6.5 - 8.5 m/s, while 11 days reach a wind speed of 8.5 - 10.5 m/s and 4 days have a wind speed of > 10.5 m/s. In contrast, 111 days of wind with the potential to move sand were recorded within the western part of the study area (Alawashier - Wady Alrabieh). This period of time included the same four levels of wind speed (namely 4.5 - 6.5 m/s, 6.5 - 8.5 m/s, 8.5 - 10.5 m/s and > 10.5 m/s) recorded for 86, 19, 4 and 2 days, respectively.

Furthermore, the slight differences in the number of wind days in the two areas is largely offset by the difference in size of the sand grains found in the two sites. In the eastern part of the study area the size of sand grains ranged between 0.25 - 0.30 mm, and the number of wind days which had the potential to move these sizes of sand grains was 83 days for all but one of the sites, plus a further 48 days which were strong enough to move even heavier grains. In contrast, the size of sand grains in the western part of the study area ranged between 0.12 - 0.23 mm; the number of wind days which had the potential to move these sizes of sand grains came to 72 extra days based on wind speeds of 2.5 - 4.5 m/s, Therefore, on the basis of these data there is more potential for sand movement in the western part of the study area, where the desert sands are found.

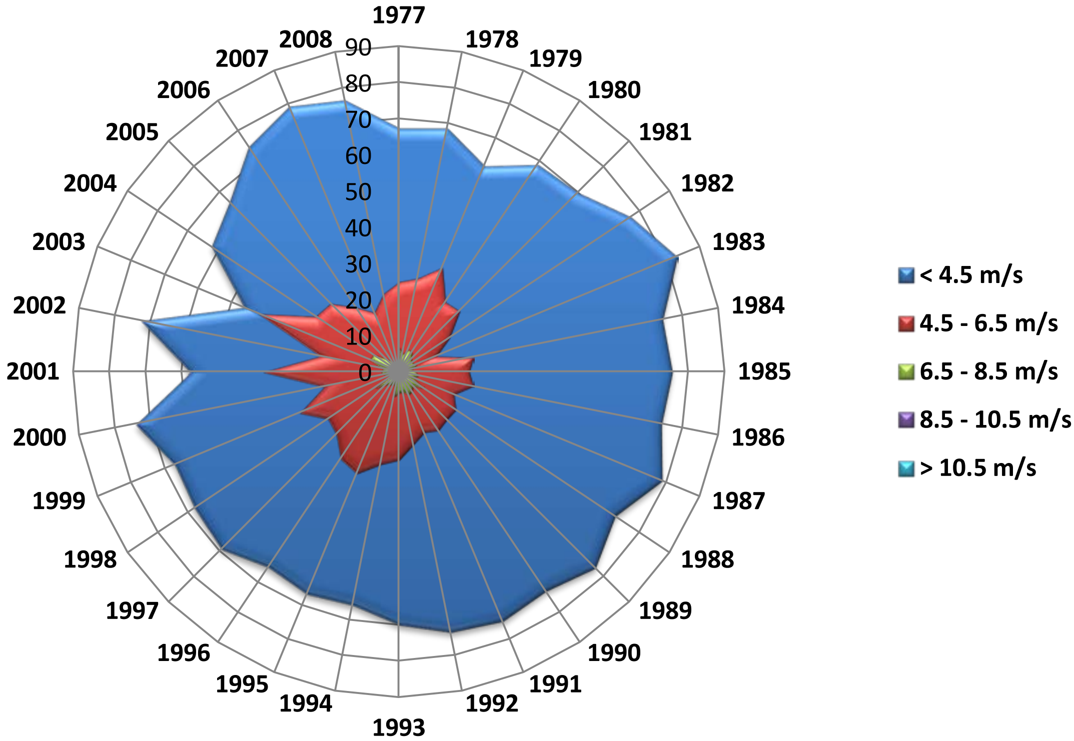


Figure 4.7 illustrates the distribution proportions of the daily wind speeds within the study area during 1977 - 2008

The pattern of five wind speed rates, illustrated in Figure 4.7, shows a peak of wind speed rate of 4.5 to 6.5 m/s, which had the ability to transport sand during 1979, 2001 and 2003. In contrast, the lowest peak of wind speed rate of 4.5 to 6.5 m/s was during 1983, 1987 and 2007. From 1977 to 1979 there was an increase in the wind speed rate which had the ability to move sand, with a subsequent decline to a minimum during 1983. However, this decline was offset by a sharp increase in the wind speed rate of 4.5 to 6.5 m/s in 1984 compared to the previous year.

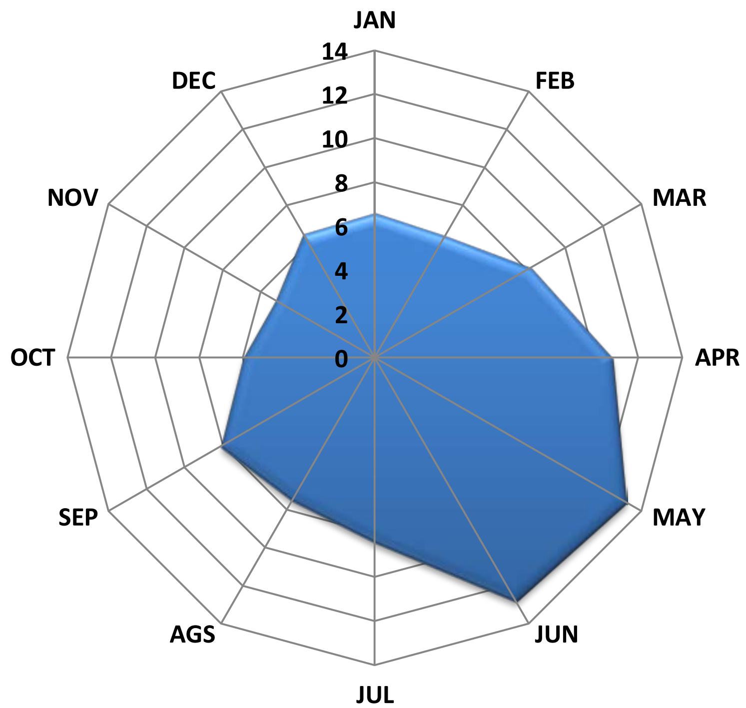


Figure 4.8 Diagram representing the distribution of days where the wind speed exceeds the threshold to move sand, expressed as the percentage of the total number of such days that fall in each calendar month (based on data from the study area during 1977 – 2008)

The pattern of wind speeds with the ability to transport sand during the months of the year within the study area, illustrated in Figure 4.8, shows a peak in the late spring and early summer months, particularly May and June, and a subsequent decline to a minimum in November. However, this decline is not regular, as there is a rise in the wind speed in September compared to the months before or after it. Most wind speeds which have the ability to transport sand occur from the beginning of March until September.

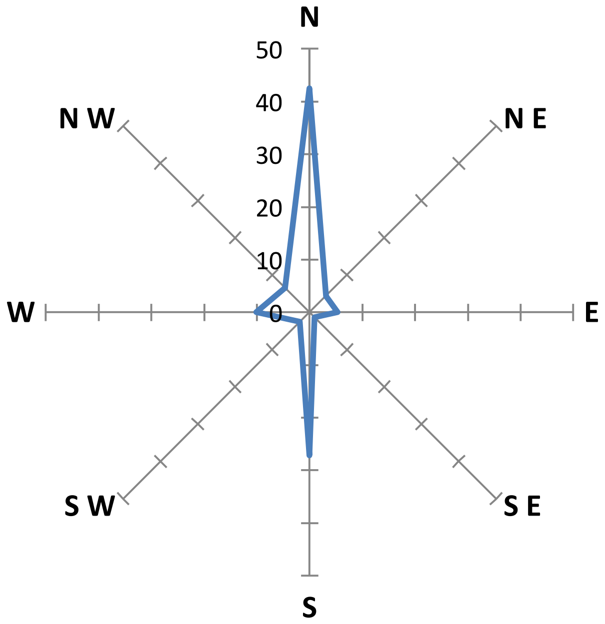


Figure 4.9 Percentages of annual wind directions within the study area during 1977 - 2008

The wind directions, illustrated in Figure 4.9, show that the north winds dominate the wind directions in the study area during the 32 years. There is a reasonably large proportion of winds which are southerly, in contrast very few from the east or west. There are no winds at all which are south easterly. The exploration of wind directions contribute to a great extent to determining the direction expected for the movement of sand, which is likely to be towards the northern coast from the southern desert .

Figure 4.10 Average annual extreme wind speed in the study area (v^* m/s), expressed as the cumulative distribution function (CDF), representing the probability that a variable is less than or equal to a particular value, together with the best fit Gumbel distribution.

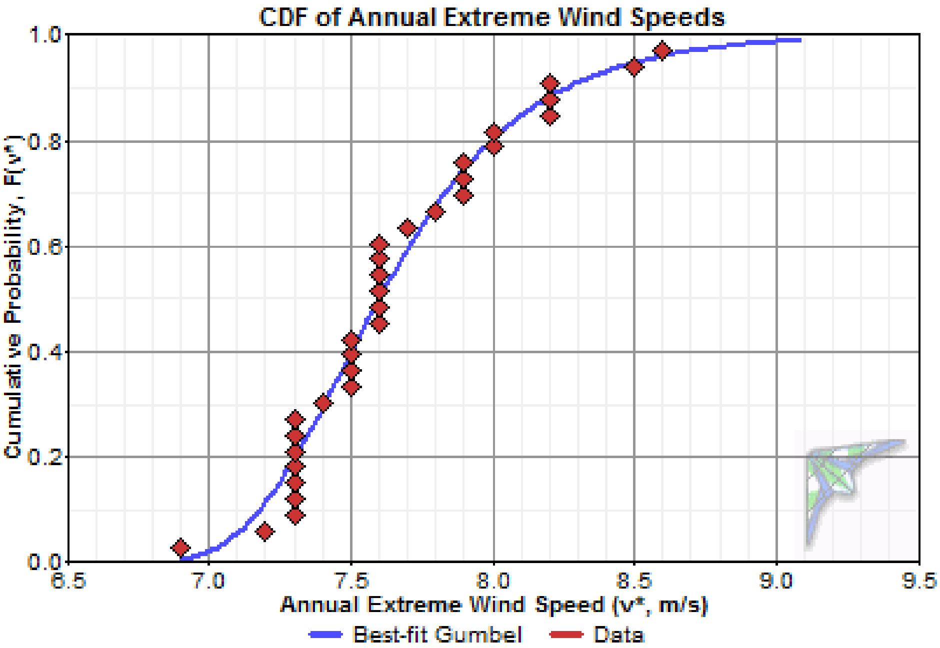


Figure 4.10 shows the cumulative distribution function of the annual wind speed along with that of the best-fit Gumbel distribution in the study area. The y-axis indicates the probability that the annual peak wind speed will be equal to or less than a particular value. The data is from the 32 year data set of average wind speeds at 10m above ground. This figure shows that according to the best-fit Gumbel distribution, there is a 80% chance that the highest wind speed at 10m in any particular year will be less than or equal to 8 m/s, and a 94% chance that it will be equal to or less than 8.5 m/s.

Table 4-12 General characteristics of nine wind events displaying varying velocity from two anemometers recorded at two selected locations during the field study (October to November 2008), with temperature and wind direction.

Date	Location	Time	Mean wind velocity at different heights (ms^{-1})						Wind direction (°)	Temperature (°c)
			03 m	05 m	1 m	15 m	2 m	10 m		
14/10/08	*A*	*11:30 – 11:40*	*7.3*	*7.7*	*8.2*	*8.7*	*9.4*	*12.5*	*44.2*	*20.4*
	B	*15:30 – 15:40*	*7.1*	*7.5*	*7.9*	*8.4*	*8.9*	*10.1*	*48.4*	*20.8*
21/10/08	A	15:30 – 15:40	5.5	5.9	6.3	6.7	7.2	8.5	36.5	24.9
	B	11:30 – 11:40	5.1	5.4	5.8	6.2	6.6	7.5	37.8	24.8
22/10/08	*A*	*11:30 – 11:40*	*5.7*	*6.1*	*6.6*	*7.1*	*7.7*	*9.1*	*21.2*	*24.1*
	B	*15:30 – 15:40*	*5.1*	*5.4*	*5.9*	*6.6*	*7.1*	*8.6*	*17.3*	*24.3*
23/10/08	A	15:30 – 15:40	6.3	6.6	7.1	7.5	8	9.7	16.8	24.3
	B	11:30 – 11:40	5.9	6.2	6.6	6.9	7.4	9.2	13.9	23.9
28/10/08	*A*	*11:30 – 11:40*	*7.1*	*7.5*	*8.1*	*8.6*	*9.2*	*11.9*	*356.1*	*25.8*
	B	*15:30 – 15:40*	*8.5*	*8.9*	*9.4*	*9.9*	*10.5*	*13.1*	*356.8*	*26*
04/11/08	A	15:30 – 15:40	6.2	6.4	6.9	7.4	7.9	9.3	345.2	27.4
	B	11:30 – 11:40	5.5	5.8	6.3	6.8	7.3	8.7	342.8	27.6
05/10/08	*A*	*11:30 – 11:40*	*6*	*6.2*	*6.7*	*7.2*	*7.8*	*9.1*	*315.7*	*22.1*
	B	*15:30 – 15:40*	*5.4*	*5.7*	*6.1*	*6.5*	*6.9*	*8.1*	*325.9*	*22.4*
06/11/08	A	15:30 – 15:40	7.7	8.2	8.6	9	9.5	12.3	311.1	21.7
	B	11:30 – 11:40	8.1	8.5	8.9	9.4	10	13.1	315.7	21.5
13/11/08	*A*	*11:30 – 11:40*	*5.5*	*5.8*	*6.2*	*6.6*	*6.9*	*8.9*	*289.1*	*20.8*
	B	*15:30 – 15:40*	*5.8*	*6.1*	*6.5*	*6.9*	*7.4*	*9.6*	*283.3*	*20.9*

Table 4.12 shows the mean of wind velocity and its directions at different heights in two sites over nine separate days within the study area; there are approximately three highest peaks during this time period, observed in both sites but not being identical in the two; also can be seen the gradual sequence of increasing wind speed with greater height in both sites during all occasions. In general the rates recorded are comparable in both sites, with similar wind directions also, where the north and north west winds were dominant as the wind directions during these time periods. Further, the average temperature in these sample dates had two days with more than 25^{o}, and in the other days ranged between 20.4^{o} to 24.9^{o}. These data are

very important in determining the threshold velocity, and to clarify the threshold shear velocity, and also for more details of the wind tunnel.

4.5.1 Shear velocity (*u.*) calculations in the study area

Some studies have indicated that the grain size might increase with increasing shear velocity, because a greater velocity has more power and can transport larger grains. The results which were obtained in this study have proved this hypothesis correct; therefore, these variations should be taken into account when using the formulas to predict the sand transport, as follows based on equation (2) given earlier:

$$U_*^{-3} = 0.1\ [(\frac{\rho_s - 1.22}{1.22})\ 9.81 \times d]^{0.5}$$

Where: ρ_s = density of the sand grains, 1.22 (ρ_a) = air density (kg/m^3), 9.81 (g) = gravitational acceleration (ms^{-1}), d = grain diameter (mm), and 0.1 (*A)* is an empirical constant which applies during saltation.

The values of shear velocity for different sites in the study area were between 0.194 as the lowest value and 0.324 as the highest value, as shown in Table 4.13. There is a convergence of values in the samples selected from the eastern part as in sites (9 and 10) of the study area. These values do not vary very much between all of them. The same convergence of values also can be found with the samples selected from the western part as in sites (23 and 25) of the study area. However, there is some variation in the values of the shear velocity between the two groups of samples, which is consistent with the values of grain diameter of these samples and their density. The average value of shear velocity for all sample sites is 0.252; this value also is very consistent with the general value in many studies; overall, the sites from the western region have a higher shear velocity values than those from the east (Table 4.13). The value of shear velocity is one of the main points to know how the particles start to move and is the main variable in the questions of predicted rates of sand transport.

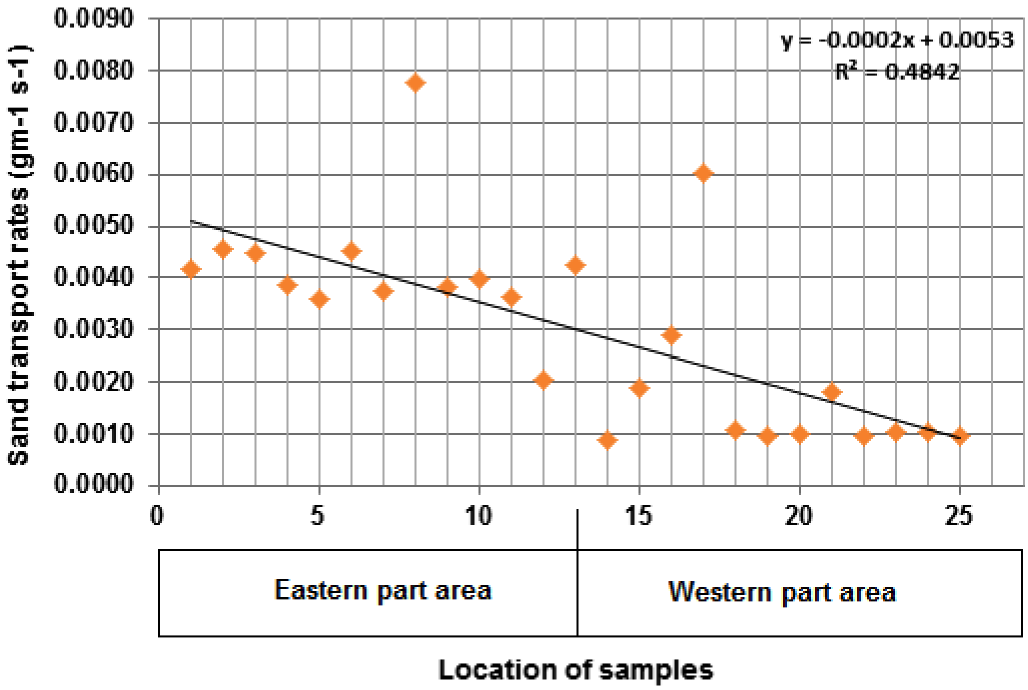
Table 4-13 Values of sand density (gcm^{-3}), grain diameter (mm) and shear velocity ($u_*^{-3}m/s^{-3}$), plus the predicted rates of sand transport from Bagnold's equation, for the different sites in the study area.

No	Sample's Name	Density (gcm^{-3})	Grain diameter (mm) d	Shear velocity $u_*^3 = (ms^{-1})$	*q* = sand transport rate *($g\ m^{-1}s^{-1}$)*
1	Qaser Ahmad	2.66	0.296	0.296	0.0042
2	Aljazeera	2.66	0.294	0.295	0.0046
3	Alsawawa	2.63	0.229	0.290	0.0045
4	Zawiat Almahgob	2.63	0.297	0.294	0.0039
5	Abourwia	2.68	0.254	0.276	0.0036
6	Zeriq	2.64	0.293	0.293	0.0045
7	Aldafniya	2.65	0.248	0.270	0.0037
8	Naaiemah	2.66	0.354	0.324	0.0078
9	Azdo	2.67	0.254	0.275	0.0038
10	Aboruqiya	2.68	0.252	0.275	0.0040
11	Almontaraha	2.67	0.257	0.277	0.0036
12	Ekaam	2.65	0.190	0.236	0.0020
13	Soukh Alkamies	2.67	0.227	0.293	0.0042
14	Alawashier	2.63	0.115	0.194	0.0009
15	Awlad hseen	2.64	0.164	0.219	0.0019
16	Siede Amier	2.59	0.195	0.264	0.0029
17	Alkrawa	2.65	0.272	0.283	0.0060
18	Alnachiea	2.62	0.121	0.198	0.0011
19	Al ataya	2.58	0.127	0.200	0.0010
20	North Algaweah	2.60	0.147	0.204	0.0010
21	South Algaweah	2.65	0.175	0.227	0.0018
22	Alwady Alsharqy	2.61	0.122	0.199	0.0010
23	Wady Alrabieh	2.65	0.147	0.208	0.0010
24	Bear Turky	2.63	0.128	0.205	0.0010
25	Alwady Alqarby	2.62	0.149	0.207	0.0010

4.5.2 Sand transport rate prediction formula in the study area

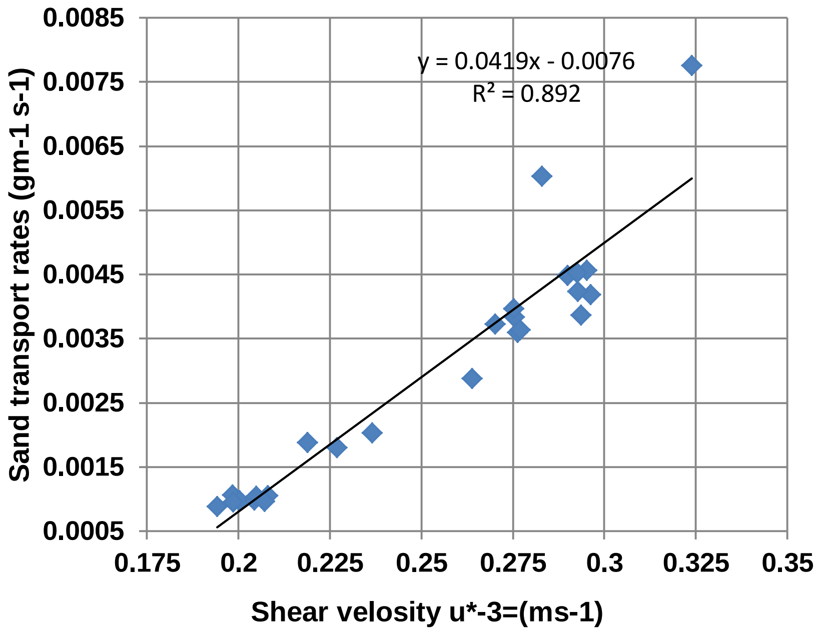
Table 4.13 shows the rates of sand transport predicted for the sample sites in the study area, based on equation (1). The average rate of sand transport predicted for the whole study area was 0.0030 g/m^{-1} s^{-1}, while for the eastern part of the study area it was 0.0042 g/m^{-1} s^{-1} and, in contrast, the rate predicted for the western part of the study area was lower at 0.0017 g/m^{-1} s^{-1}. This contrast between the results of the predicted rates of sand transport may be due to the differences in values of the shear velocity and the particle sizes and types of sand in different sites.

Figure 4.11 Sand transport rates (gm^{-1}s^{-1}) compared with the numbered location of sites along the coast in an east to west transect in the study area.



Also Figure 4.11 shows predicted rates of sand transport in the study area ranged between the highest rate expected of 0.0078 g/m^{-1} s^{-1} at Naaiemah site, and the lowest rate expected of 0.0009 g/m^{-1} s^{-1} at Alawashier site. The sands of Abourwia, Almontaraha, Aldafniya, Azdo, Zawiat Almahgob and Aboruqiya sites had roughly similar expected rates of 0.0036, 0.0036, 0.0037, 0.0038, 0.0039 and 0.0040 g/m^{-1} s^{-1} respectively, while the sands of Qaser Ahmad, Soukh Alkamies, Zeriq, Aljazeera and Alsawawa locations had nearly the same rate expected of 0.0042, 0.0042, 0.0045, 0.0046 and 0.0046 g/m^{-1} s^{-1} respectively . Seven locations had an expected rates of sand transport from 0.0010 to 0.0011 g/m^{-1} s^{-1}, while four sites had expected rate of sand transport from 0.0018 to 0.0029 g/m^{-1} s^{-1}.

Figure 4.12 The relation between shear velocity ($u_*^{-3} m/s^{-1}$), and rates of sand transport predicted ($gm^{-1}s^{-1}$) in the study area.



There is a strong relation between the value of shear velocity and the rate of sand transport predicted in the study area, as shown in Figure 4.12, where the R^2 = 0.89. This result agrees with many studies which have conducted similar tests, and also it supports the hypothesis of a strong relationship between the shear velocity and rate of particle movement. Although there is similarty in particle sizes of sand within the study area, there are some differences in the predicted rate of sand transport in east and west, these differences may be attributed to the major role played by shear velocity on friction of particles and how this moves the particles.

4.5.3 Statistical test for the results between two types of sand in the study area

Given the importance of statistical tests in bringing greater precision to the results of such studies and to get a clear understanding of the diffreneces between the two sand types in the two parts of the study area, statistical analyses were peformed for grain diameter, sand density, shear velocity and sand movement rate values which were obtained earlier. A two sample t-test was used to compare the mean values of the two types of sand, calculated using the Minitab statistical packege version 16.

Table 4-14 The results of t - tests for grain diameter, sand density, shear velocity and sand movement rate comparing Mean values of two types of sand in the study area (with 21 degrees of freedom).

	Type of sand	Mean	St Dev	SE Mean	t	p
Grain diameter (mm)	Coastal sand	0.2650	0.0415	0.012	6.77	< 0.001
	Desert sand	*0.1521*	*0.0436*	*0.012*		
Sand density (gcm^{-3}),	Coastal sand	2.6577	0.0169	0.0047	4.39	< 0.001
	Desert sand	*2.6231*	*0.0229*	*0.0063*		
Shear velocity ($u_*^{-3} m/s^{-3}$)	Coastal sand	0.4715	0.0264	0.0073	6.70	< 0.001
	Desert sand	*0.5562*	*0.0371*	*0.010*		
Sand movement rate ($gm^{-1}s^{-1}$)	Coastal sand	0.3294	0.0329	0.0091	7.36	< 0.001
	Desert sand	*0.2181*	*0.0435*	*0.012*		

All tests were very highly significant ($p < 0.001$), so the two areas with their sand of different origins differ markedly on all parameters. The eastern coastal area have larger grain sizes and higher densities, which result in lower shear velocities and higher predicted sand movement rate.

4.6 Discussion and Conclusion

The GRADISTAT program has been taken to address the results of grains size in this chapter. It should also be noted that there are some factors such as, density, grain shape, and sometimes optical properties which affect the methods of particle size analysis (Zhang *et al*., 2011)**.** In contrast, there are some methods used in other studies which determine particle size based on the frequency of each unit volume, and some others which determine grain size of each unit weight (Morgan and Bull, 2007). The method of total weight for each sample has been used here to specify the particle size, in order to avoid erroneous interpretation of results. Direct comparison of results from the different methods for analysis of the data is not appropriate although some cases it may be possible to calibrate between the two methods. Earlier studies have indicated that comparison between methods (such as that of Folk and Ward, and the method of moments) had recorded some drawbacks. Use of a graphical method is not helpful particularly when sediments have a large amount of data in the distribution tails because it is relatively insensitive (Ghrefat *et al*., 2007).

In contrast, the moment method overemphasizes the importance in the results of sediments which have an elongated tail with limited data in it, in this situation the Folk and Ward method is more accurate. In the present study results for particles size obtained by a graphical method have been useful in interpreting the statistical differences between east and west areas, because here only the means and sorting values are required. The Folk and Ward method is most useful for routine comparisons of variable sediments because of the extra statistics it provides **(**Breton *et al*., 2008**)**. Most sedimentologists works with phi units and metric units, which is preferred compared to using phi units only, and both are used extensively in the equations for estimating the particles movement (Wang *et al*., 2003a). Results have shown clearly the varying grain sizes of sand in the region, which have been used to calculate the predicted rate of sand movement.

Generally, the results of particle size analysis have shown that the samples from the study area have a mean sand grain size of between 1.7 - 3 phi, are either well or moderately sorted, with less than 6% of the particles of a size less than 63 µm (Table 4.5). The results obtained strongly suggest to the origin of sediments for both types of sand (coastal and desert) in the region. Through the results which have been obtained from the GRADISTAT program data it can be seen that the difference in mean particle size, degree of sorting and skewness is only modest between the older sand found in the eastern part of the study area, and the particle sizes of sand in the western part of the study area. The latter were, however, slightly smaller than those from the eastern part, perhaps due to their origin from the mid-Holocene or maybe because they have not been exposed to further movement since their formation. In general the sand from the western part of the study area is finer (mean = 2 phi) and it is well sorted, with a range of (2 - 1 phi), and also has a positive skew compared with the sand from the eastern part of the study area.

Shear velocity (u_*^{-3}) calculations

The acceleration of wind velocity up the windward slope, with maximum acceleration close to the surface, results in increasingly logarithmic profiles, see Figure 4.9. Similar logarithmic profiles have been found by Wiggs *et al*., (1996) over transverse and barchan dunes, highlighting the problems in predicting sand transport with the use of shear velocity derived from the log-linear profile method, as shown in Figure 4.11. The reference profile exhibits a log-linear profile, permitting the successful calculation of shear velocity. Attempts to measure $u_\bullet^{-3}$ above this critical layer result in data indicating a increase in mean $u_\bullet^{-3}$ from the dune of the region. Lancaster *et al*. (2002) demonstrate that values of $u_\bullet^{-3}$ derived from wind profiles in their field investigation on a barchan dune show a very different pattern to that of mean wind velocity with values of u decreasing from the dune to the brinkline (see Figure 4.10 and relevant discussion in chapter 2). This finding is similar to that obtained by *Wang et al.,* (2003a) who found increases in u_*^{-3} up the windward slopes of crescentic sand dunes. Such data produce a pattern that implies sand flux should decrease up the dune, which is something not evident in the natural dynamics of sand dunes, see Figure 4.10.

It is now accepted that shear velocity (u_*^{-3}) is not an appropriate measure to apply to complex terrain (Livingstone *et al.,* 2007). However, an assessment of wind shear at a point over a dune can be obtained from measurements of the turbulent Reynolds shear stress, presented in section 4. 2. Results obtained from section 4.5.2 of the thesis also indicate the importance of turbulence and turbulent flow within the aeolian sediment transport system. Subsequently the section 4.5.1 explores the relationship between varying measures of turbulence (specifically in the horizontal plane) and sediment transport along the centre-line of the dune. Such field derived data have not previously been presented.

Finally the results which have been obtained in this chapter about the potential transport rates of sand dune movement in the study area have indicated that there are different rates of movement between numbered sites within the study area, as shown in Table 4.13, and Figure 4.11. It is obvious that the potential rates are not exactly the same as the actual rates, but all available data about the local environment of the study area has supported those results. In order to let the potential rates correspond more with the actual rates the formulae can be adjusted. Most formulae have variables that are derived empirically and it is possible that these variables are not the same in different areas. These variables have been varied to fit the potential rates better with the actual rates. These rates were very comparable with results of some studies which have similar conditions (Dong *et al*., 2003a; Wang *et al*., 2004; Weaver, 2008).

However, the results of predicted rates of sand transport in the whole of the study area ranged between the lowest rate expected of 0.23 g/m-1 s-1 at

Naaiemah site in the eastern part, and the highest rate expected of 0.47 g/m-1 s-1 at Alawashier site in the western part (averages of grains size, sand density and shear velocity respectively), such predications for two areas being significantly different according to a t-test (section 4.5.3). The sand in the western part of the study area had a greater predicted rate of sand transport, compared with the sand in the eastern part. The difference in sand transport predicted in the two parts may be due to the size of the sand particles and the sand density, which therefore may have given rise to differences in the value of shear velocity. The particle sizes of sand are significantly different in the two parts of the study area. In general, the sand from the western part of the study area is finer (on average 0.2 mm). This size of sand grains has a considerable potential to move and stay in suspension for a long time according to Bagnold (1973), therefore its impact is greater. The sand from the eastern part is more bimodal because there is a smaller peak within the coarse fraction size range; therefore, the particle size of sand in the eastern part of the study area was greater (average of 0.2 mm) than the size of sand in the western part(average of 0.15 mm), possibly due to the origin and type of sand.

Also it is worth noting the results of wind velocity and its directions in the study area, where the mean annual average of wind speed was 5.2 m/s. However, there has been an upsurge of the annual frequency of wind gusts during the last few years, as seen in chapter 3 (Figure 3.15). Also there was an increasing trend of annual frequency of wind gusts during (1977 - 2008). Furthermore, the north and north-west directions were the dominant in most periods of the year, with a reasonably large proportion of winds which were southerly, but in contrast very few from the east or west. Putting these various results together may lead to the prediction that the movement of sand is likely mainly to be to the south, with retreat to the north in some periods; further inference and discussion of these results is possible according to tests by Bagnold for the correlation between wind speed and the size of sand grains, as shown in Table 2.1. 60% of sand grains within the study area have a diameter of less than 0.25 mm; in contrast, 36% of sand grains within the study area have a diameter between 0.25 - 0.30 mm. According to Bagnold, the speed required to transport the sand grains of 0.25 mm is from 4.5 to 6.7 meters per second, this rate of wind speed has been recorded in the western part of the study area during 83 days per year. The eastern part recorded such speeds on 86 days per year (Table 4.9), a value similar to that recorded by Livingstone *et al*., (2007) who observed in Namib Desert, Namibia

Furthermore, the wind speed rates of 4.5 to 8.5 m/s within the whole of the study area had been recorded in 30.6% of the year days during the last 32 years (1977 - 2008).The number of wind days with the potential to move sand of the relevant sizes during this time period recorded within the eastern part of the study area was 131 days in the year (see section 4.5). In contrast, 111 days of wind with the potential to move sand were recorded within the western part of the study area. This means that sand of the region may well be moved by the wind over more than three months per year, particularly in the dry months, when there is a decline of the seasonal vegetation cover. The results of wind speed recorded in this study showed that high wind speeds which were recorded dominated during the months from April to June of each year.

On the basis of these analyses of sand particle sizes and wind speeds and directions, the prediction can be made that there would be more sand movement in the western part of the study area. This is because there is little difference in wind speeds recorded (between areas or over time) but the sand grains are smaller, therefore allowing more of them to be moved. These predictions need to be tested by analysing actual movement of sand in these areas. For further investigation about the actual sand movement within the study area, the next chapter will present the evidence for sand movement, through the measurement of actual changes of land cover categories within the study area, based on detailed analysis of Landsat images over four time periods.

5 CHAPTER FIVE: Evidence for sand movement from satellite images

5.1 Introduction

Data obtained from orbiting satellites, whether images or other remotely sensed information, is important to enable natural resources and the environment to be monitored and managed. Such data are widely used to classify land according to the amount of different land usages (Eiumnoh and Shrestha, 2000). An important aspect of classifying land use is the discriminating power and accuracy of the classes produced using sensed data (Burnicki *et al.,* 2007).

In recent years, remote sensing has been used in many studies by interpreting satellite images, for problems such as the desertification of grassland and its influence on environmental change (Li *et al*., 2006), the continuous monitoring of forest (Huang *et al*., 2007); aeolian transport and mobile dune field (Kocurek *et al*., 2007), and the estimation of dune migration rates (Necsoiu *et al*., 2009).

In the urban environment, the shadows cast by buildings have been used to estimate the heights of the buildings in several studies, and Landsat satellite images have also been used to detect drainage channel networks through the shading visible.

Analysis can be performed of different features of geomorphology by using satellite images, such as mapping changes in elevation, making contour maps, or identifying where erosion or deposition is occurring (Siart *et al*., 2009; Levin *et al*., 2004). Also, it is possible to use archived satellite images from different times to enable studies to be made of how dune processes, for example, change over time (Rasmussen *et al*., 2001).

As far as can be determined, however, there has only been one attempt to determine relative heights outside of urban areas by using shading in optical satellite images, by Lodwick and Paine (1985). Those authors used Digital Elevation Models (DEM), but this produced results more like itemized contours from a direction surface.

A previous endeavour to determine the landmarks of topographical dunes by satellite images was that of Tapiador and Casanova (2003), who proposed a method to estimate slope and height of a dune by using images from Synthetic Aperture Radar (SAR).

In the present study, as a first step towards better understanding the extent of dune encroachment and clear evidence of the movement rates in the study area, a remote sensing study has been undertaken which has analysed a time-series of satellite images. These data also help to identify the size of free sand dune areas in the region and can be used to assess vegetation cover during past periods.

The sand dunes present in the study area are very appropriate for monitoring by remote sensing methods, partly because they are found over extensive and remote areas, and also because of the lack of existing ground-based data. The factors that influence the reflectance spectra detected by the sensor from sand dunes are: (A) the form of the dunes and dune surfaces; (B) Direction of the topographical dunes for the reflection of sun angle; (C) The condition of the atmosphere (Levin *et al*., 2004). Other influencing factors associated with sand dunes are the amount of vegetation on the dunes and their mineral composition (White *et al*., 2007; Ben-Dor *et al*., 2006), their texture (Gerbermann and Neher, 1979), and whether or not they have biogenic crusts of soil (Karnieli *et al*., 2004).

Note there are other platforms (MODIS, ASTER, SPOT), but Landsat was chosen because Landsat images provide a particularly appropriate data source for monitoring sand dunes. Each image covers a relatively large area (c. 180 km×180 km); also, the images are made up of a set of pixels, where each pixel covers 30m × 30m, the size of pixel often is suitable to detect the size of any cover of sand dunes, as long as the space which can be covered by a smaller dune may exceed the size of the pixel area. Often the size of some dunes range from a kilometre to several kilometres, that means the dunes can be monitored easily through the pixel size. However it is possible to resolve the images to a level of detail which allows many of the changes due to disturbances to be identified (Townshend and Justice, 1988). Since images stretch back to 1972, changes of many years can be analysed (Karnieli *et al*., 2004).

Landsat data have been important in monitoring disturbances since 1972 (Wulder *et al*., 2008). Although the Landsat 7 and Landsat 5 sensors have been performing less well and less consistently more recently (Loveland *et al*., 2008), Landsat imagery is still likely to be useful for landscape change detection into the foreseeable future (Loveland *et al*., 2008). Landsat images will be used in the present study.

Selection of Landsat was due to the accuracy of their results in studies such as the present one. Many studies have used Landsat to explain the evolution of sand movement, as has been mentioned previously. These studies showed the feasibility and usefulness of using Landsat in this research.

5.2 Remote sensing and GIS methodology used

The satellite images available have been analysed by using remote sensing and GIS software. There are images available which have been taken in four different periods which include images from 1986, 1990, 1999 and 2003, these specific dates were chosen based on their suitability and availability, as described in section 5.2.1, and which can therefore be investigated to explore sand dune movement. This analysis has been done through comparing the old locations of sand dunes with their position in recent years.

In this study the Landsat images have been used to assess how much free sand dune there has been in the eastern part of the Jeffara plain in Libya, including the Zliten - Misurata plains, in each of the four years. The data consisted of 4 Landsat images for the same location; the years were chosen from 1986 to 2003 to provide an approximate interval of one image every 4 years. Further, all images have been collected at the middle of the dry season for the study area. It is better if images can be obtained from the dry season because they are more likely to be cloud-free and less likely to be affected by the spectral properties of the soil surface and there are less likely to be plants growing on the sand surface (Foster *et al*., 2008).

The Landsat data was processed using Earth Resource Data Analysis (ERDAS); the images of the study area have been referenced as latitude geographic coordinates and Datum: WGS 84.

In order to produce land use images for the study area in the four years, and to explore how they have changed from one period to another, the following seven land use cover categories were considered when analysing the images: Urban, Forest, Farming land, Bare soil with sparse vegetation, Bare soil, Sand and Water, as listed in Table 5.1, together with a brief description of each category. Also, the categories which have been selected in this study were based on what has been concluded was important in the results from previous studies to produce the best ways to divide and select the land cover maps in accordance with the circumstances of the region and the precise wavelengths needed from within the colour bands.

The choice of these categories was guided by:

A) The objectives of the research, that includes investigating the size of sand cover.

B) The expectation of an acceptable level of accuracy in classifying the images, according to the time that the image has been collected and the ground verification that has been conducted in the area.

C) The ease of identifying classes on satellite images (Wentz *et al*., 2006).

Table 5-1 The land cover classification system used for this study according to Wentz *et al*., (2006).

No.	Theme	Associate Class
1.	Urban	Residential, Industrial, Transportation, communications, and utilities, Industrial and commercial complexes, Mixed urban or built-up land, and Road.
2.	Forest	Evergreen forest land, Agricultural land.
3.	Farming Land	Agricultural land, Grassland, Shrub and brush.
4.	Bare soil with sparse vegetation	Transitional areas of steppe with some turf, and fewer scattered bushes.
5.	Bare soil	Exposed soil, Bare exposed rock, and transitional areas
6.	Sand	Shifting sand dunes, Bare exposed sand.
7.	Water	Streams and canals

Remote sensing analysis is based on the pixels from an image being grouped into clusters or classes; pixels with similar characteristics should be grouped into the same class (Stefanov and Netzband, 2005). This approach depends on being able to identify the different categories of land cover from the patterns of wavelength bands reflected, and then separate out the different response patterns present (Stuckens *et al*., 2000). This requires the use of selected wavelength bands and not others, so that the distinctive signatures for the land cover classes can be identified (Hilker *et al*., 2009). The wavelength bands from the Landsat sensors that are useful for capturing different cover features of importance in this study are given in Table 5.2: (based on Chander, 2007).

Table 5-2 Landsat TM and ETM+ sensors Utilities, according to Chander, (2007).

Landsat 5 TM and Landsat 7 ETM+ Spectral Bands	Wavelength(µm)	Useful for mapping
Band 1 - Blue	0.45 – 0.52	Bathymetric mapping distinguishing soil from vegetation and deciduous from coniferous vegetation
Band 2 - Green	0.52 – 0.60	Emphasizes peak vegetation, which is useful for assessing plant vigour
Band 4 - Near Infrared	0.77 – 0.90	Emphasizes biomass content and shorelines
Band 7 - SWIR	2.09 – 2.35	Hydrothermally altered rocks associated with mineral deposits

In general, ways of classifying data from remote sensing can be described as either being unsupervised or supervised techniques. Supervised techniques extract a specified number of clusters through multivariate statistics, using a selected algorithm, with no reference to information external to the data set (Lang *et al*., 2008). The potential drawback of such a technique is that these clusters do not always correspond to the land cover categories actually present; however, an advantage of this approach is that it is not necessary to know what the ground cover in that area is in advance (Nie, 2008). By contrast, unsupervised classification needs to be cross-referenced with the ground cover actually present in the study site. The algorithm that performs the classification is 'trained' by using pixel data from the sample area or spectral signatures from a spectral library (Cleve *et al*., 2008), and then used to produce the final classification image.

A remote sensing method involving a land cover mapping study should test how accurate results are; such an assessment of accuracy is important to evaluate the final results of a remote sensing study. Such an assessment provides a warranty of classification quality and therefore user confidence in the outcome (Foody and Mathur, 2004). Normally**,** accurate results can be obtained from either supervised or unsupervised classification, or a combination of both techniques. However, supervised and unsupervised techniques usually show differences in levels of accuracy during an accuracy assessment of the same results (Kuemmerle *et al*., 2006).

5.2.1 Image processing stages with this study

LandSat TM and ETM+ images Libyan map grid reference 188 / 37 corresponding to the study area for the years 1986, 1990, 1999 and 2003 have been used in this project. The aim of this study is to investigate the changes which may occur in land cover, and the choice of four periods should be enough to clarify the changes which have taken place. Besides, there are some difficulties that were an obstacle to the selection of a larger number of periods to be included, namely the season in which the image was taken, the purity of image, and the financial cost. Software of Erdas Imagine version 9.3 and ArcGIS version 9.3 were used to process the images from remote sensing. Firstly, using Erdas software each original image was changed from a Tiff to an img format so that the images were compatible with other Erdas Imagine files. The layers were stacked and a sub-set used to separate the sand dune category. The UTM Zone 33N Coordinate on the WGS 84 was used to geocode the imported image. After this the WGS 84 projection was used for georeferencing using units in meters.

Red, blue and green (RBG) bands were used for displaying the images in frequently-used colour combinations. Which combinations of spectral band are used to display images can vary depending on the purpose (Trotter *et al*., 1998). The present combination used was necessary to enable the images to be interpreted visually, and is a common combination to display images for land use and vegetation mapping (Trotter *et al*., 1998). LandSat TM images are often displayed in a band combination of 7, 4 and 2 (RBG), which is standard for visual interpretation of mobile sand mapping in the tropics (Prakash and Gupta 1998; Trotter *et al*., 1998).

In this study the categories of bare soil, forest, farming land, urban areas, sand dunes and water land covers are being distinguished. The ratio bands of 7 and 4 and 2, therefore, enable the major land cover classes to be differentiated.

Although seven land cover classes were used, the main category of interest was the extent of the area of sand dunes and a major goal was to test the detection accuracies of this category. The classifiers did not work very effectively to identify the categories of land cover area from the images (presented in section 5.3 below). In general, images which were involving the whole of the regions have produced lower user's accuracies in all classes compared with the accuracy of land cover maps in the small sample sites selected in two parts of the study area (see Table 5.3 later). These inaccuracies may be because the categories of forest, farming land and bare soil might sometimes get confused with the category of bare soil with sparse vegetation, and this may have lead to some under or over-representation of some categories.

Even so, there is acceptable user's accuracy for each class in every image regardless of classification technique. To complete the classification of an image its accuracy must be assessed (Kashaigili and Majaliwa, 2010). Therefore, the classification accuracy is determined through testing pixel samples of classified images and their class identity is compared with the reference data for the fieldwork, where 150 sites were chosen from the study area to complete this work and support it to get a accurate description. Note this process cannot be done except by using unsupervised classification. The assessment of classification accuracy is affected by the process of choosing a suitable sample and also the determination of sample size (Chen *et al*., 2004). To assess the accuracy of the image classification in the present study standard criteria were used: overall accuracy with Kappa coefficient.

(1) The overall accuracy method divides the total number of pixels which have been correctly classified by the total number of reference pixels (Rogan *et al*., 2002).

(2) The coefficient of kappa is a statistical method to evaluate the accuracy of classification, and it determines how much better the classification of the

image is compared to randomly assigning class values in each pixel. The coefficient of Kappa ranges between 0 and 1, so for example a Kappa of 0.79 means the classification accuracy is 79% greater than chance (Miller and Yool, 2002).

Through a confusion or error matrix the processing of the accuracy assessment has been made with both supervised and unsupervised classifications. A confusion matrix contains more information on actual and predicted classifications as prepared by a classification system; this matrix was prepared with the ERDAS IMEGIN 9.3 software.

Maps were initially drawn for the first year for which information is available (1986), based on the categorisation into land – use closes. Subsequent map have been designed to show the amount and location of change from one time – period to another. These 'subtraction maps' have, within the GIS package, worked at the pixel level to compare the assigned class in time T with that in time T+1, and if the class was the same then the pixel is shown in white on the map, while if it was different it is shown as black. Parts of the study area with considerable black present have therefore been experiencing notable change. To try to minimise problems associated with misclassifications of individual pixel, or errors associated with the images possibly not being exactly aligned one to another despite efforts to ensure that they were, a filtering process was performed in the GIS analysis prior to determining the subtraction maps. This filtering process determined what the majority classification was for pixels within a radius of three units of each pixel, and if appropriate replaced the pixel class value with that of the majority. This ensued that the changes observed in the subtraction maps were, as for as possible given the native and accuracy of the data, reflecting subtractive changes and not misclassifications, although the possibility of this still exists.

It should be noted that the indications of the extent of change given by these subtraction maps will be likely to be substantially greater than those given by the changes in percentage area given in pie charts and tables. This is because of three reasons. Firstly, if successive maps are not exactly aligned this will give apparent changes which are not reflective of a red change, and would be seen on the subtraction maps but not giving any change in percentage cover values. Secondly, particularly with sand dunes, if they change location but not total amount the subtraction maps would note this change while percentage cover values would not alter. Thirdly, the process of image classification involves the possibility of any pixel being misclassified, especially with similar categories such as ‘bare soil’ and ‘bare soil with sparse vegetation’; such misclassifications many, on averages not be very different from are time to another, but any misclassifications which are not consistently misclassified for the same pixel will be recorded as changes (subject to the filtering technique used which would reduce the scale of this problem) in the subtraction maps.

5.3 Sand dune area classification

In this research the images have been classified by the unsupervised classification method in order to estimate the sand dune cover in the study area. The unsupervised classification is a method which depends initially on data which have been taken directly from the field. Some locations were visited during the field work period and the land coverage assessed. This was done at 100 points throughout the area to enhance the reliability of the process. These data are input into the ERDAS program, which then uses the information to complete the classification of the remaining pixel of the satellite image. The organizing is done automatically in that the image data are first grouped into natural clusters based on spectral characteristics (ERDAS, 2006). Initially a certain number of clusters is chosen automatically, and the method then proceeds iteratively, assigning each pixel to one of the clusters. After each iteration the parameters are altered based on the means just calculated for the data clusters. The process is repeated until there are no further significant changes of cluster means. Finally, the land cover types associated with each of the groupings produced is compared with the ground reference data to determine which land cover types they refer to. The Erdas 9.3 Imagine software was used for this process. Maps were then drawn using the ArcGIS (Version 9.3) software. Having done the unsupervised classification and produced these maps they were secondarily checked for accuracy by visiting 150 of the sites to determine whether the classification agrees with what was actually present, as a separate process to the original data collection on which the classification was based. This field checking was undertaken in October 2008. The method of Cogalton (1991) was adopted, which has been used previously, for example in the NPS/NBS Vegetation Mapping Project (2002). A number of samples were selected at identified map locations, which were then checked in the field. GPS coordinates of 25 locations were selected. The geocoded coordinates were used to define the relevant cover categories for comparison with the actual field situation.

5.3.1 Classification accuracy assessment

In order to produce the high accuracy classification for land cover maps in the study area, a test of the accuracy of the computer classified maps has been applied, and the error matrix technique was used. The confusion matrix is the simplest descriptive statistic used to compare a classification result with fieldwork data. Furthermore, an accuracy assessment was applied to all land cover maps produced from satellite imagery by using a stratified random sampling technique. This method has been mentioned in more detail in an earlier section. The results of the assessment of classification accuracy were obtained for the land cover map of the whole region and summarized in Table 5.3.

Table 5-3 Results of classification accuracies for land cover maps in the whole of the study area

Land cover class	1986	1990	1999	2003
Overall Accuracy	66.5%	63.3%	61.7%	65%
Kappa statistics	0.615	0.564	0.543	0.586

The result of the overall accuracy test in the land cover map for each year only show comparatively moderate accuracy with all of them indicating less than 66%, as shown in Table 5.3. The highest accuracy map was 66.5% for 2003 while the lowest rate was 61.7% for 1999. Kappa statistics for all maps gave values from 0.543 to 0.615; these results mean that there is only moderate agreement between all for land cover maps produced in this study compared with fieldwork survey data.

To obtain the highest classification accuracy for land cover maps produced, eight small size maps were used from two sites of sand dunes within the study area by using the unsupervised classification method. These small maps produced higher classification accuracy compared with the accuracy of the previous land cover maps for the whole area. This suggests that using smaller areas, which contain fewer categories of land cover, has resulted in greater separation between the categories and therefore greater classification accuracy. The results of the assessment of classification accuracy were obtained for the land cover map of the two sub-areas separately and summarized in Table 5.4.

Table 5-4 Results of classification accuracies for land cover maps in two parts of the study area separately

Land cover class		**1986**	**1990**	**1999**	**2003**
Overall Accuracy	**Western part**	87.3%	85.7%	89.2%	88.6%
Kappa statistics		0.803	0.787	0.818	0.809
Overall Accuracy	**Eastern part**	90.5%	88.5%	89.7%	91.1%
Kappa statistics		0.835	0.817	0.822	0.841

Table 5.4 shows the test of overall accuracy for land cover maps produced in the two separate parts of the study area. Overall accuracy for land cover maps in the western part of the study area are comparatively high with all of them indicating more than 85%. The highest accuracy map was 89.2% in 1999 while the lowest overall accuracy was 85.7% for 1990. Further, the overall accuracy test for land cover maps in the eastern part of the study area is comparatively high also with all of them indicating more than 88%. The 2003 map had the highest accuracy of 91.1%, while the lowest overall accuracy was 88.5% for 1990. Kappa statistics for all maps in both parts of the study area have given values from 0.787 to 0.841, meaning a high level of agreement between all land cover maps produced in this study compared with fieldwork survey data. The high accuracy which was recorded with the maps in the two parts of the study area separately may be, due to the small size of maps, where there is a less overlap in the resolution rate, and therefore, recording the highest accuracy in the clarity of colour. In contrast, the low accuracy recorded with the whole region map may be due to the large size of map, so that there is a larger overlap in the resolution rate. The result is a lower percentage of accuracy.

5.4 Results of observed changes in the study area

Six land cover categories were identified in the study. These were sand dune, forest, farming land, bare soil, bare soil with sparse vegetation and urban areas, and grassland as shown in Figures 5.1, 5.2, 5.4 and 5.6.

A. Changes in size of sand area during 1986 -1990

The map for 1986, showing the land cover categories, is shown in Figures 5.1. A subtraction diagram of changes in land cover categories over the time period 1986 – 1990 is given in Figure 5.2.

It can be seen from Figure 5.2 that the changes appear to be quite notable even over just this four- year period, with such changes being concentrated on the west of the area and two main fair towards the eastern end of the map.

Figure 5.1 Land cover classification of the 1986 LandSat image

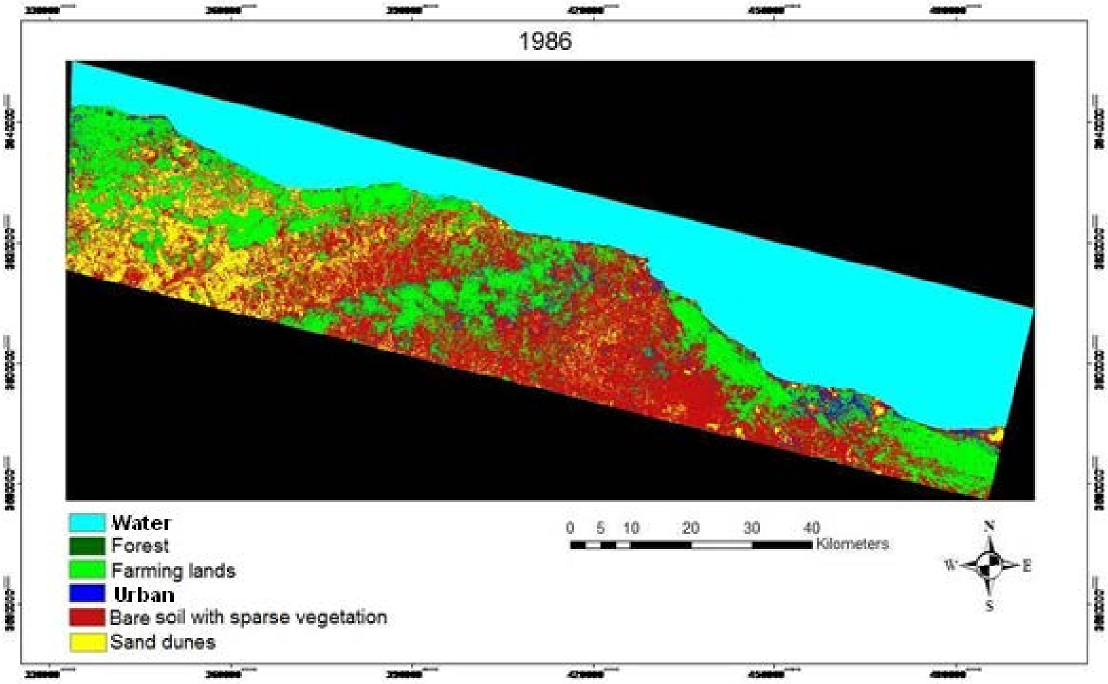


Figure 5.2 Subtraction diagram of land cover classification in the study area showing the extent of changes to land use categories over the time period 1986 - 1990.

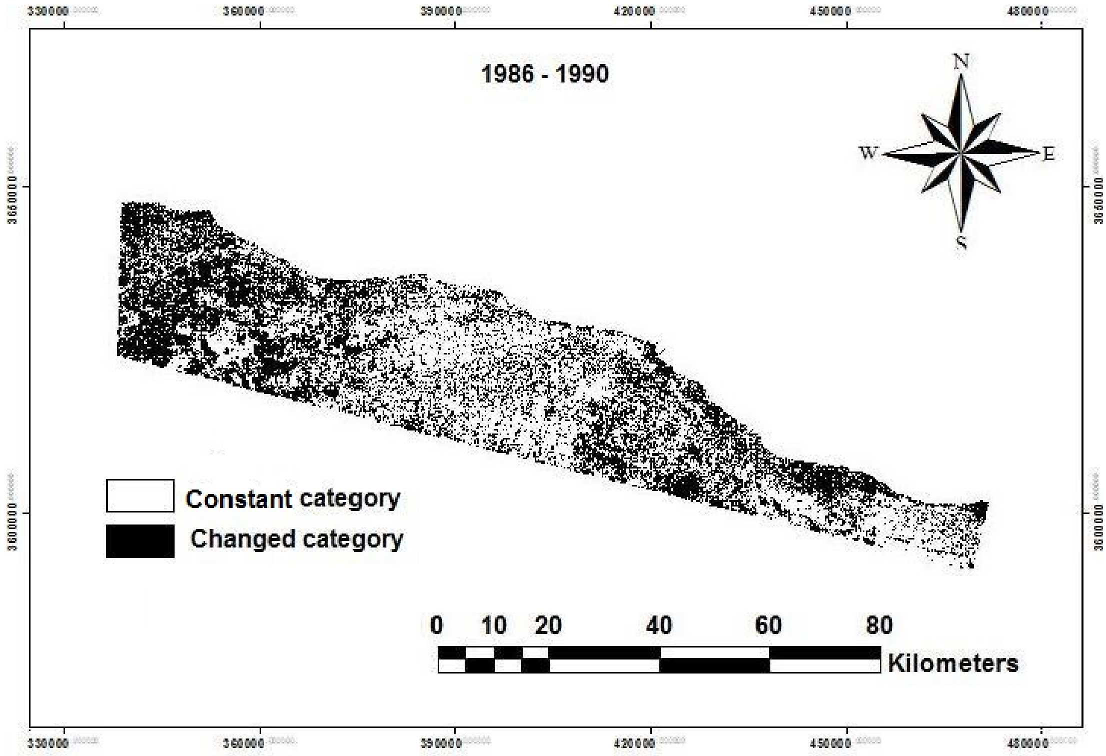


Figure 5.3 Percentage values of different land cover categories in the study area during the period between 1986 -1990

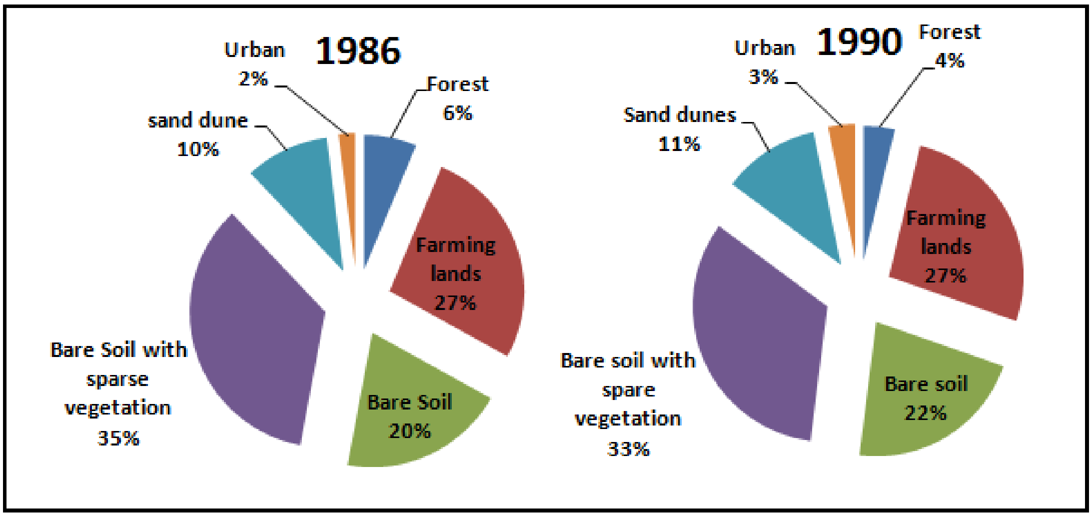


Figure 5.3 shows the different percentages occupied by the land cover categories of the study area in 1986 and 1990. In 1986, forest covered about 6% of the study area; this coverage had decreased by 1990 to 4%.Other categories which had changed in their coverage somewhat are the bare soil and the bare soil with sparse vegetation, where the bare soil coverage had increased by 2% by 1990, while the bare soil with sparse vegetation had decreased by 2% by the same year. Of particular interest to this project, the sand dune coverage had slightly increased by 1% by 1990. The coverage of the category of urban area had also increased by 1% by the same year. The extent of cover of farming land had remanded unchanged between 1986 and 1990.

B. Changes in size of sand area during 1990 – 1999

During this period (Figure 5.5) the region had a slight increase (by 1%) of the percentage area of sand while farming land has increased by 4% of the total, and urban areas have increased by 1%, while bare soil and bare soil with sparse vegetation have declined by 2% each. The forest area has halved (from 4% to 2% of the total). The same areas as in the 1986 – 1990 period appear from the subtractions map (Figure 5.4) to be where most change is occurring.

Figure 5.4 Subtraction diagram of land cover classification in the study area showing the extent of changes to land use categories over the time period 1990 - 1999.

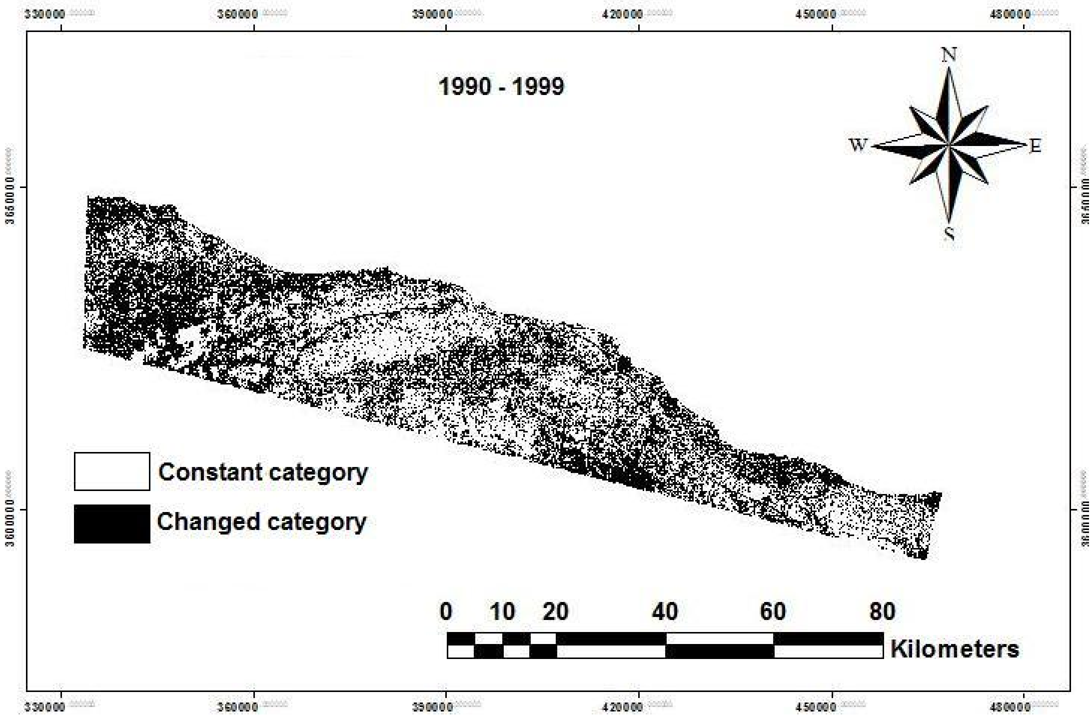
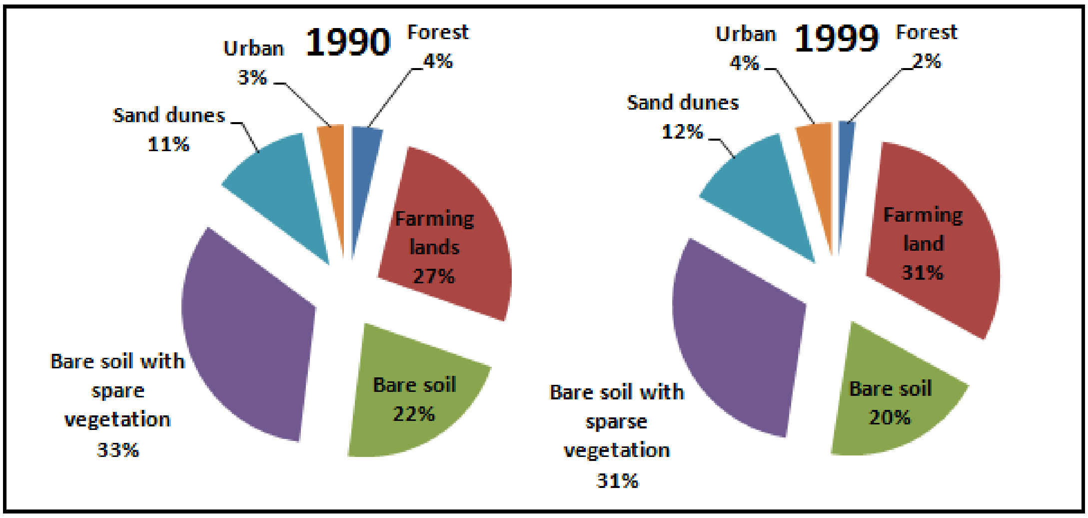


Figure 5.5 Percentage values of different land cover categories in the study area during the period between 1990 -1999



C. Changes in size of sand area during 1999 – 2003

The map of the subtraction diagram of land cover between 1999 and 2003 is shown in Figure 5.6 and emphasizes even greater change in the some fair during this period than in the previous ones. The area along the coast in the eastern part shows particularly subs tactical change.

Figure 5.6 Subtraction diagram of land cover classification in the study area showing the extent of changes to land use categories over the time period 1999 - 2003.

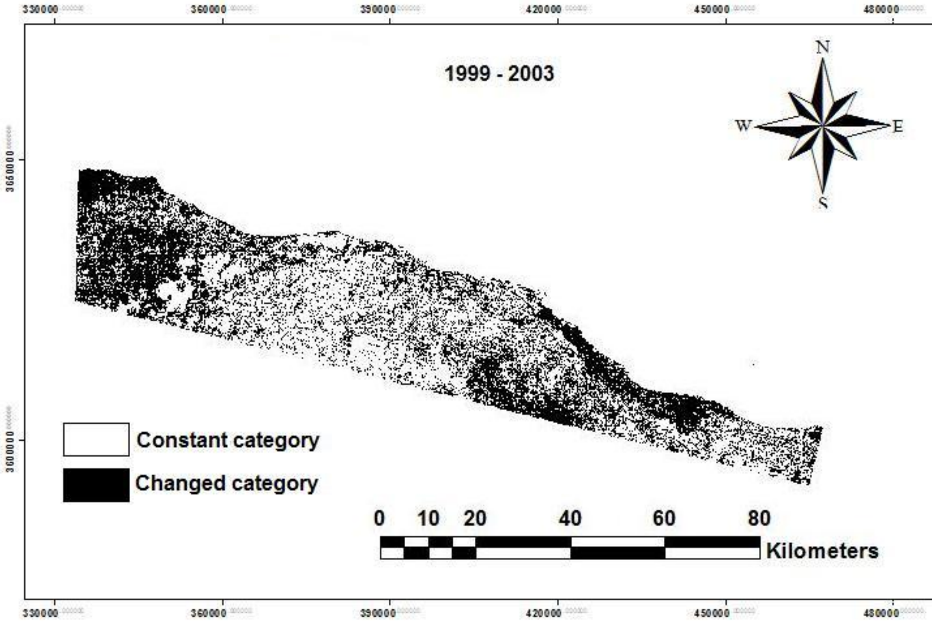


Figure 5.7 Percentage values of different land cover categories in the study area during the period between 1999 -2003

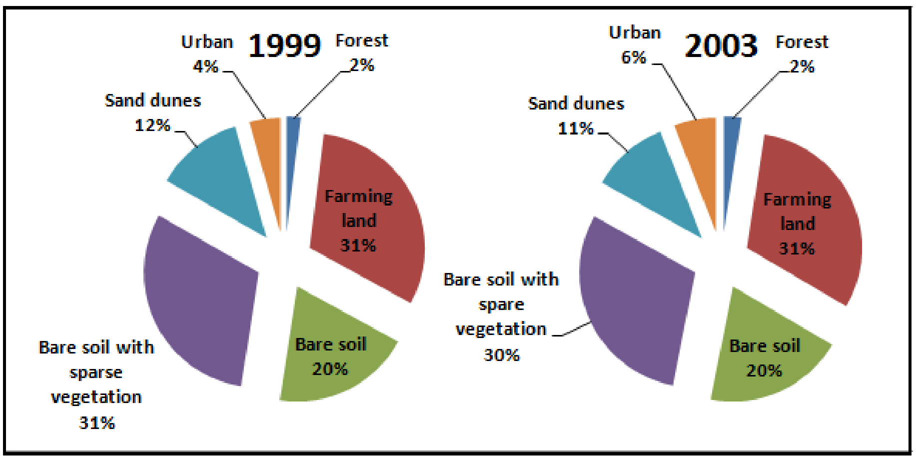


Figure 5.7 shows the differences of land cover categories in the study area comparing 1999 and 2003. In 1999, the bare soil with sparse vegetation covered about 31% of the study area; this coverage had decreased slightly by 2003 to 30%.The urban area category had increased for 4% to 6% in 2003. The sand dune coverage had again slightly decreased by 1%. On the other hand, the forest, farming land and bare soil categories had the same percentages of coverage in both 1999 and 2003.

D. Changes in size of sand area during 1986 – 2003

The region had a clear increase (by 4% of the total) of the percentage area both of urban areas and of farming land, as shown in Figure 5.8. In contrast the bare soil with sparse vegetation has declined by 5%, and forest land has decreased by 4% of the total. The sand dune coverage had slightly increased by 1% by 2003, while bare soil category had same percentages of coverage in both 1986 and 2003.

Figure 5.9 shows the extent of changes to land use categories over the time period 1986 - 2003. Interestingly, although the areas which were seen as the main fair of changes remain very evident in the broader western part of the study area and in a coastal strip towards the east, the focal point further south of the changing coastal strip (marked 1 on Figure 5.9) is not very evident here while it was in Figures 5.2, 5.4 and 5.6. This suggests that there are apparent changes which are more to be do with the problems of accuracy / reliability of the data and its processing (see section 5.2.1) than red changes in this area, or which have been reversed over time (in contrast to the other areas of change which have been consistent).

Figure 5.8 Percentage values of different land cover categories in the study area during the period between 1986 -2003

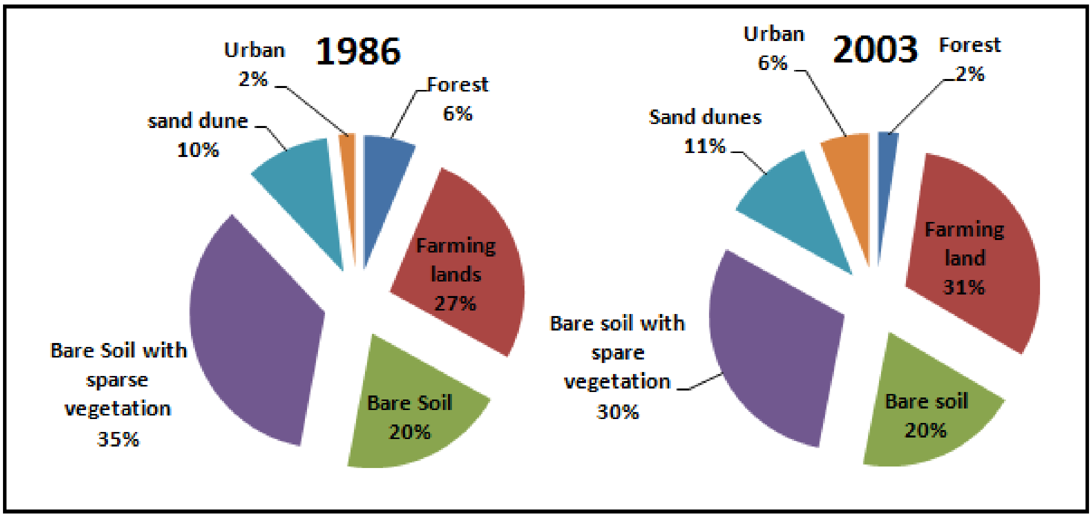


Figure 5.9 Subtraction diagram of land cover classification in the study area showing the extent of changes to land use categories over the time period 1986 - 2003.

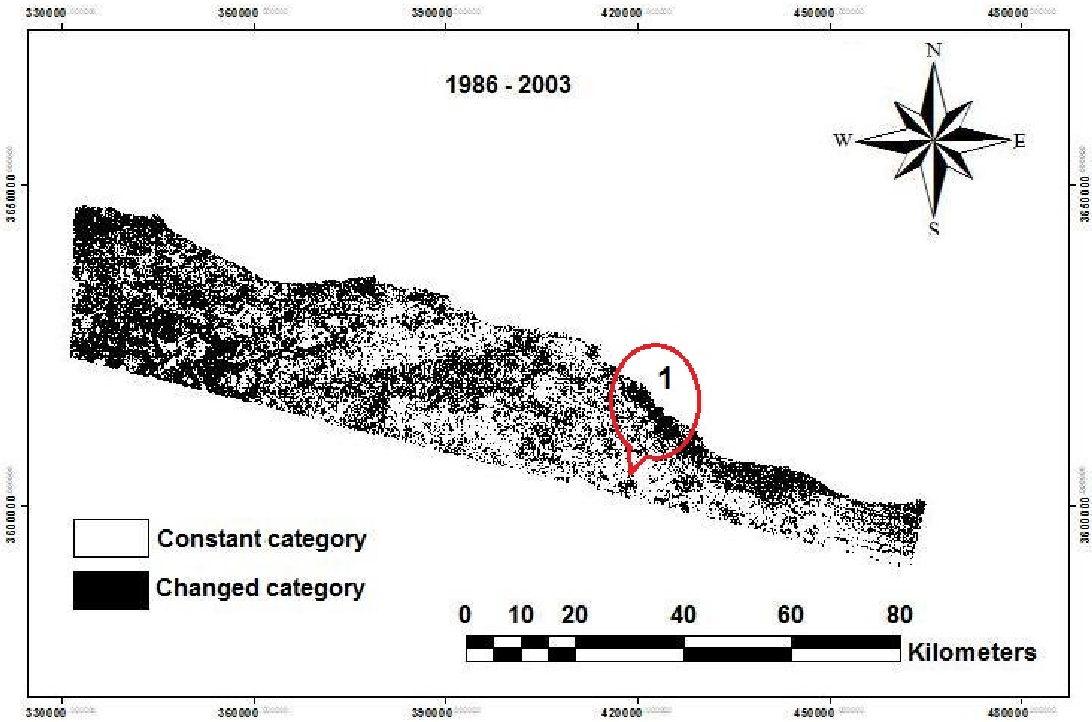


Table 5-5 The changes of land cover categories (Ha and %) in the study area during the periods between 1986 - 1990; 1990 - 1999; 1999 - 2003, and 1986 - 2003.

Land cover class	Area size	Forest	Farming land	Bare soil	Brae soil with Sparse vegetation	Sand dunes	Urban
1986 - 1990	(Ha)	-1392	-1906	+201	-14475	+6774	+10797
	%	30.7%	1.4%	7.6%	4.7%	7.5%	47.8%
1990 - 1999	(Ha)	-2268	+3225	-7108	-15249	+6786	+14615
	%	53.1%	14.3%	8.8%	7%	13%	43.6%
1999 - 2003	(Ha)	-79	-54	-3551	-12422	+182	+15925
	%	0.1%	1.4%	1.1%	8.6%	4.6%	34.8%
1986 - 2003	(Ha)	-2691	+6363	-1122	-38315	+13032	+22731
	%	67.5%	17.5%	0.8%	19%	26.9%	186%

NB: (+) indicates increase, (-) indicates decrease

Considering the changes shown by the different categories over the whole seventeen year period (1986 – 2003), Table 5.5 includes the changes expressed as both the total change in area (in ha) and also the percentage change from the original 1986 values. The two biggest area decreases in percentage terms are in forest (- 67.5%) and bare soil with sparse vegetation (- 19%) and they are also the largest absolute decreases. Bare soil also decreased overall (by 0.8%), but there is no consistent trend of decline. The other three categories (farming land, sand dunes and urban area) have all increased notably. In the particular context of this study, the area of sand dunes increased by nearly 27%. It a clear indication that there is instability of old sand dunes within the region, with a large potential for the emergence of new dunes, mostly in the phase of growth, in both cases, the increase in the size of exposed cover of sand due to tree lass means that these sands have very rapidly became liable to be moved by wind. This emphasizes the growing problem of sand dunes in this region of Libya.

E. land cover change matrix

In order to understand move clearly which categories are changing most, and into what, a conversion matrix value between land cover classes for each pair of images presented has been calculated. Thus has been calculated to show which land cover type converted to which other land cover type, expressed in both absolute and percentage terms. This has been done for all of the relevant comparisons of time periods.

Table 5-6 Conversion matrix value (Ha and %) in the study area during the period between 1986-1990

			1990					
			Forest	Farming land	Urban	Bare soil	Sparse*	Sand
1986	Forest	Ha	8798	2165	87	261	287	913
		%	70.3	17.3	0.7	2.1	2.3	7.3
	Farming land	Ha	1285	29414	5344	1607	1687	843
		%	3.2	73.2	13.3	4.0	4.2	2.1
	Urban	Ha	0	0	14205	1154	15	15
		%	0.0	0.0	92.3	7.5	0.1	0.1
	Bare soil	Ha	184	1610	3036	37583	2208	1400
		%	0.4	3.5	6.6	81.7	4.8	3.0
	Sparse	Ha	484	3488	2325	3198	77335	10078
		%	0.5	3.6	2.4	3.3	79.8	10.4
	Sand	Ha	369	1598	1188	2418	901	34519
		%	0.9	3.9	2.9	5.9	2.2	84.2

*Sparse: Bare soil with sparse vegetation.

Table 5.6 shows the conversion matrix of the land cover classes from 1986 to 1990. As can be from the leading diagonal, all categories had at least 70% of pixels continuing to be of the same category in the later date as in the earlier one. The changes of most land cover classes have been to several other categories. For instance the majority of decrease in forest was from conversion to farming land but a sizable area also converted to sand. The majority of the decrease in the farming land and bare soil was from converting to urban. Also bare soil with sparse vegetation mostly converted to sand. The slight increase of overall sand cover recorded previously therefore was derived from the categories of bare soil with sparse vegetation and the forest land, (while losing a little to other categories including farming land), while the sharp decrease of forest land mostly goes to farming land and sand however the pronounced increase of urban land was diverted from the farming land, bare soil and bare soil with sparse vegetation.

Table 5-7 Conversion matrix value (Ha and %) in the study area during the period between 1990-1999

			1999					
			Forest	Farming land	Urban	Bare soil	Sparse*	Sand
1990	Forest	Ha	6641	2387	545	618	605	1321
		%	54.8	19.7	4.5	5.1	5	10.9
	Farming land	Ha	2145	30151	4006	2833	688	647
		%	5.3	74.5	9.9	7	1.7	1.6
	Urban	Ha	0.0	0.0	16111	1067	0.0	34
		%	0	0	93.6	6.2	0	0.2
	Bare soil	Ha	290	6060	3054	33017	4266	1793
		%	0.6	12.5	6.3	68.1	8.8	3.7
	Sparse	Ha	343	3164	7394	2407	63194	9457
		%	0.4	3.68	8.6	2.8	73.5	11
	Sand	Ha	429	1933	716	1432	1957	41242
		%	0.9	4.05	1.5	3	4.1	86.4

*Sparse: Bare soil with sparse vegetation.

The land cover conversion matrix from 1990 to 1999 in the second period gives results shown in Table 5.7, emphasising particularly that there was pressure on forest land which had converted to farming land and sand land (less than 55% remaining as forest from what was there previously). In the same time the urban had continued to increase at the expense of all the other land cover classes to varying degrees. The decrease noted in bare soil goes to farming land and bare soil with sparse vegetation. Also, most of the decrease observed in the bare soil with sparse vegetation has gone to urban and sand land categories. In contrast, the increase which was obtained in sand land had come from the forest and bare soil with sparse vegetation.

Table 5-8 Conversion matrix value (Ha and %) in the study area during the period between 1999-2003

			2003					
			Forest	Farming land	Urban	Bare soil	Sparse*	Sand
1999	Forest	Ha	8305	1892	168	235	191	1253
		%	68.9	15.7	1.4	2.0	1.6	10.4
	Farming land	Ha	2850	23476	4821	8761	1718	293
		%	6.8	56.0	11.5	20.9	4.1	0.7
	Urban	Ha	0.0	0.0	18461	1718	20	20
		%	0.0	0.0	91.3	8.5	0.1	0.1
	Bare soil	Ha	249	12998	3137	29133	3286	996
		%	0.5	26.1	6.3	58.5	6.6	2.0
	Sparse	Ha	309	1779	8899	3869	55950	6577
		%	0.4	2.3	11.5	5.0	72.3	8.5
	Sand	Ha	253	1720	658	2530	3796	41656
		%	0.5	3.4	1.3	5.0	7.5	82.3

*Sparse: Bare soil with sparse vegetation.

In Table 5.8 the land cover conversion matrix from 1999 to 2003 has shown that there were minor changes of most land cover classes, except for the forest and urban. The decrease of forest goes mostly to sand and farming land. In contrast, the increase of urban comes mostly from farming land and bare soil with sparse vegetation. A slight decrease in bare soil with sparse vegetation mostly goes to urban, while a slight increase in sand mostly comes from the forest. Also there is approximately equality between the values of loss and add addition in both farming land and bare soil.

Table 5-9 Conversion matrix value (Ha and %) in the study area during the period between 1986-2003

			2003					
			Forest	Farming land	Urban	Bare soil	Sparse*	Sand
1986	Forest	Ha	5804	2464	414	734	924	1504
		%	49.0	20.8	3.5	6.2	7.8	12.7
	Farming land	Ha	2376	21678	4454	5440	3934	3114
		%	5.8	52.9	10.9	13.3	9.6	7.6
	Urban	Ha	0.0	0.0	11725	3753	10	15
		%	0.0	0.0	75.6	24.2	0.1	0.1
	Bare soil	Ha	229	13478	5374	14271	6754	5819
		%	0.5	29.3	11.7	31	14	12
	Sparse	Ha	580	6390	14998	17163	46513	11133
		%	0.6	6.6	15.5	17.7	48.1	11.5
	Sand	Ha	163	3351	1270	3442	327	32407
		%	0.4	8.2	3.1	8.4	0.8	79.1

*Sparse: Bare soil with sparse vegetation.

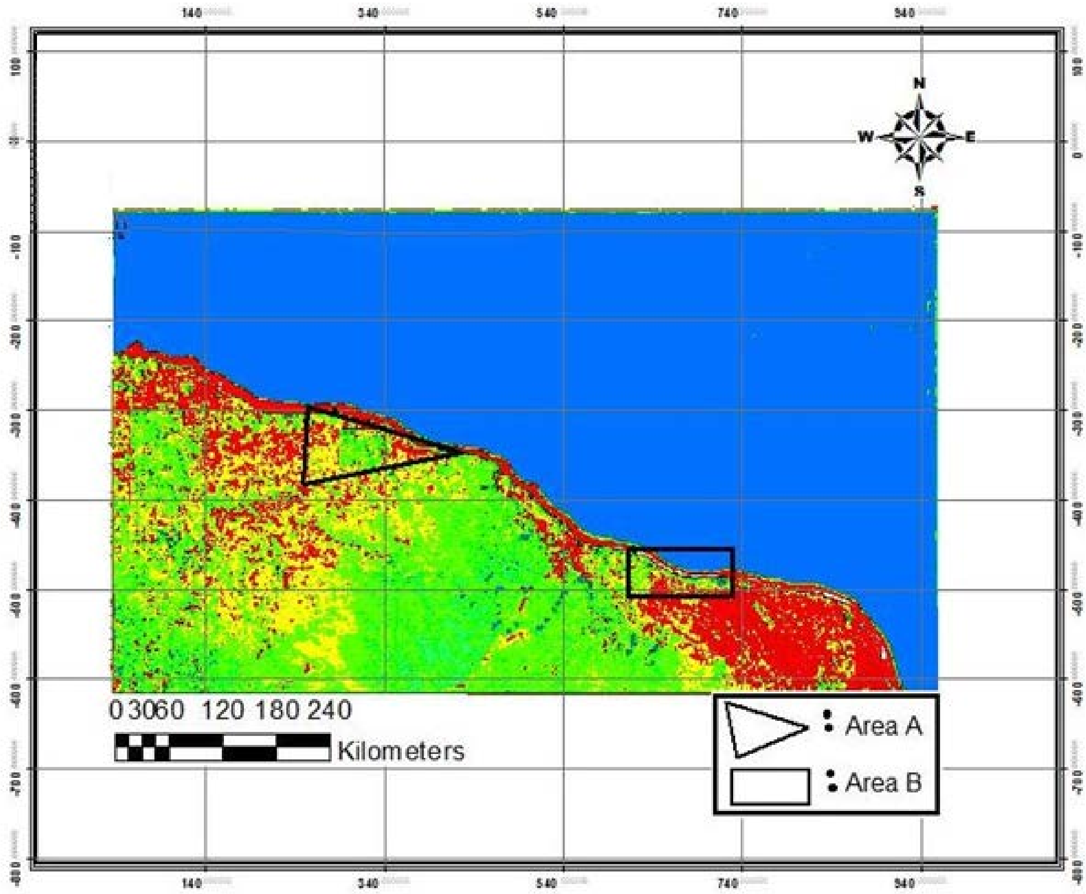
Table 5.9 shows the land cover conversion matrix for the whole period from 1986 and 2003. The significant decrease in forest was converted mostly to sand and farming land. However, it should be noted that there were some gaining from farming land, though not enough to compensate the losses. Also there is a clear decline in bare soil with sparse vegetation which changed mostly to urban and sand categories. In contrast, there were clear increases in sand, urban and farming land. The increase of sand has converted mostly from forest and bare soil with sparse vegetation, while the increase in urban has converted mostly from bare soil with sparse vegetation and farming land. Likewise the increase in farming land has converted mostly from the forest and bare soil. A different result can be seen for the values for bare soil, for which there was equivalence in the losses and additions to and from the other categories. During this period it is clear that there has been increasing pressure on forest land of the area for the 18 years covered by these data.

Furthermore, it is worth referring to some of the actual differences between the overall results (1986-2003); the actual transformation from forest to sand was 1340 ha. There is apparently some re-forestation of the sand area, by 163 ha; also there was an absolute shift from forest to farming of only 87 ha, because changes from forest to farming involved 2464 ha, but in contrast, changes from farming to forest involved 2376 ha which nearly offset the losses. The absolute shifts in bare soil with sparse vegetation to urban and sand were, respectively, 14987 and 10805 ha. Similarly, the transformation in farming to urban was 4454 ha.

5.4.1 Detection of changes in two small sample sites containing sand dunes within the study area

To achieve the objective of this study concerning the investigation of sand movement, in this part of the project two sample areas from different parts of the study area were taken for more detailed study. Area A is from the western part of the study area, and represented the largest extent of sand dunes area, also its size was estimated as 15 Km^2. Area B is from the eastern part of the study area, and it represented also the largest extent of sand dunes area in this part of the region with an estimated size of 8.5 Km^2, as shown in Figure 5.10.

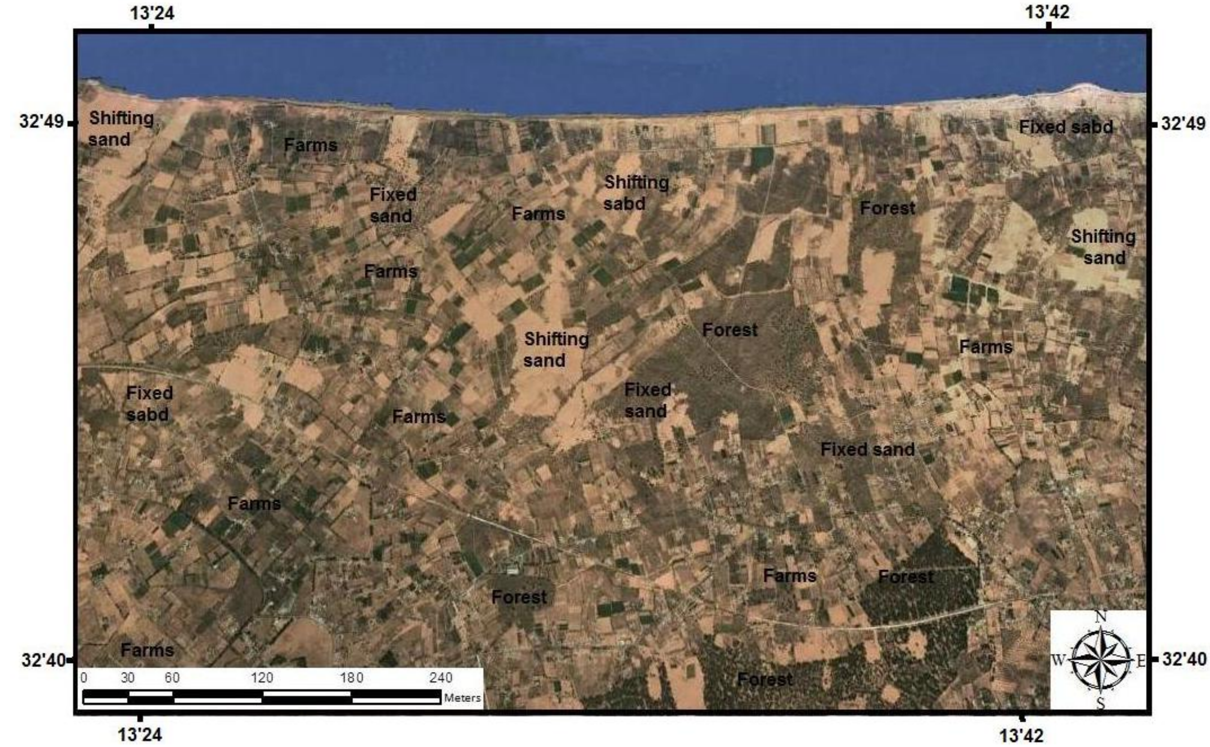
Figure 5.10 Illustration of sample sites selected in both of the western and eastern part of the study area. (Source: Google Earth, 2003).



5.4.1.1 Detection of changes in the selected site from the western part of the study area

A total of four land cover categories were identified and classified in the western study area. These were sand dune, forest, farming land, and bare soil with sparse vegetation as shown in Figures 5.12, 5.14 and 5.16. Also, Figure 5.11 shows an aerial image apparent of the area, showing the mosaic of farming land, forest and sand dunes which have been used to analyze the change of their covers within the western part of the study area.

Figure 5.11 Illustration the pattern of farms, forests and sand locations, which have been used to analyzed the change of their covers within the western part of the study area (Source: Google Earth, 2003).



A. Detection of changes in area of sand coverage during 1986 -1990.

Figure 5.12 shows the land cover map for the western sample study area in 1986 and Figure 5.13 shows the subtraction diagram of land use categories over the time period 1986 - 1990. The relative proportions of the study area occupied by the four land cover categories are shown in Figure 5.14.

Figure 5.12 Unsupervised classification images of the western part of the study area, 1986

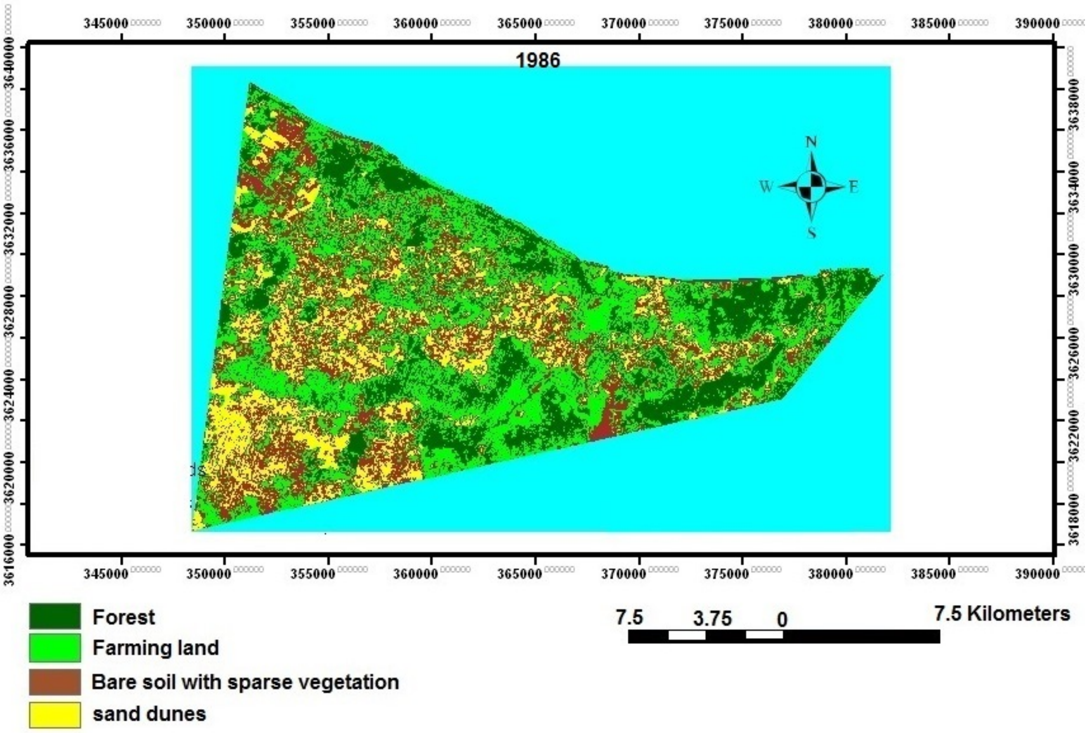


Figure 5.13 Subtraction diagram of land cover classification in the western part of the study area showing the extent of changes to land use categories over the time period 1986 - 1990.

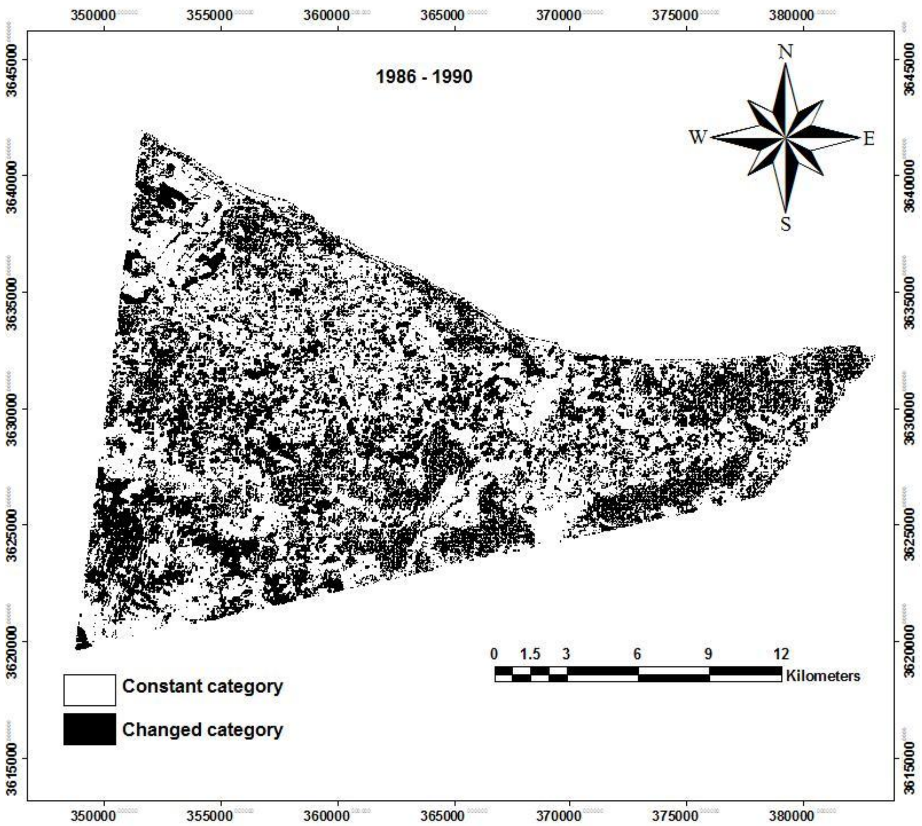


Figure 5.14 Percentages of land cover categories in the western part of the study area, in 1986 and1990.

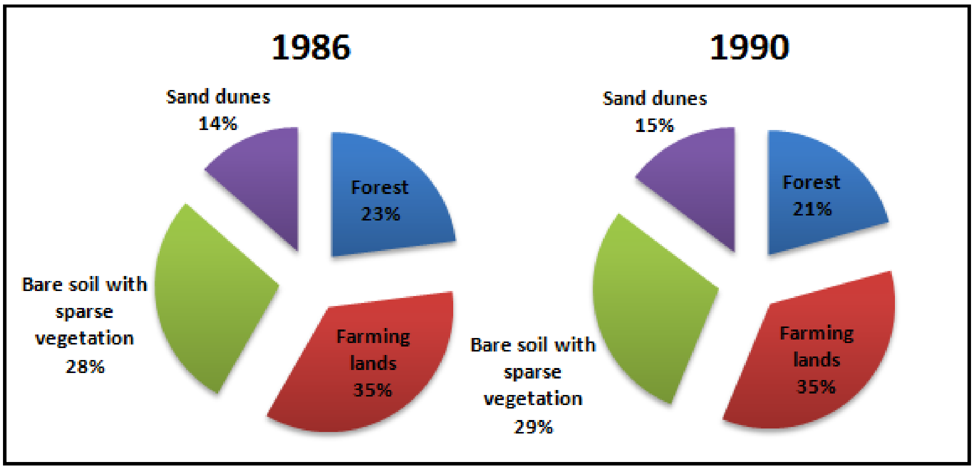


Figure 5.13 shows a mosaic of areas where change is apparently occurring. It can be seen from Figure 5.14 that there are some differences in percentage cover of land cover categories in the western part of the study area in 1990 compared to 1986; the farming land category was essentially unchanged at 35%, but the bare soil with sparse vegetation had increased by 1% in 1990 to 29%; the forest category had declined by 2% from 23% in 1986 to 21% by 1990, while the sand dunes category had slightly increased by 1% from 14% in 1986 to15% in 1990.

B. Detection of changes in size of sand coverage during 1990 -1999.

The map showing the extent of changes to land use categories in the western part of the study area over the time period from 1990 and 1999 is shown in Figure 5.15, with the percentages of change illustrated in Figure 5.16.

Figure 5.15 Subtraction diagram of land cover classification in the western part of the study area showing the extent of changes to land use categories over the time period 1990 - 1999.

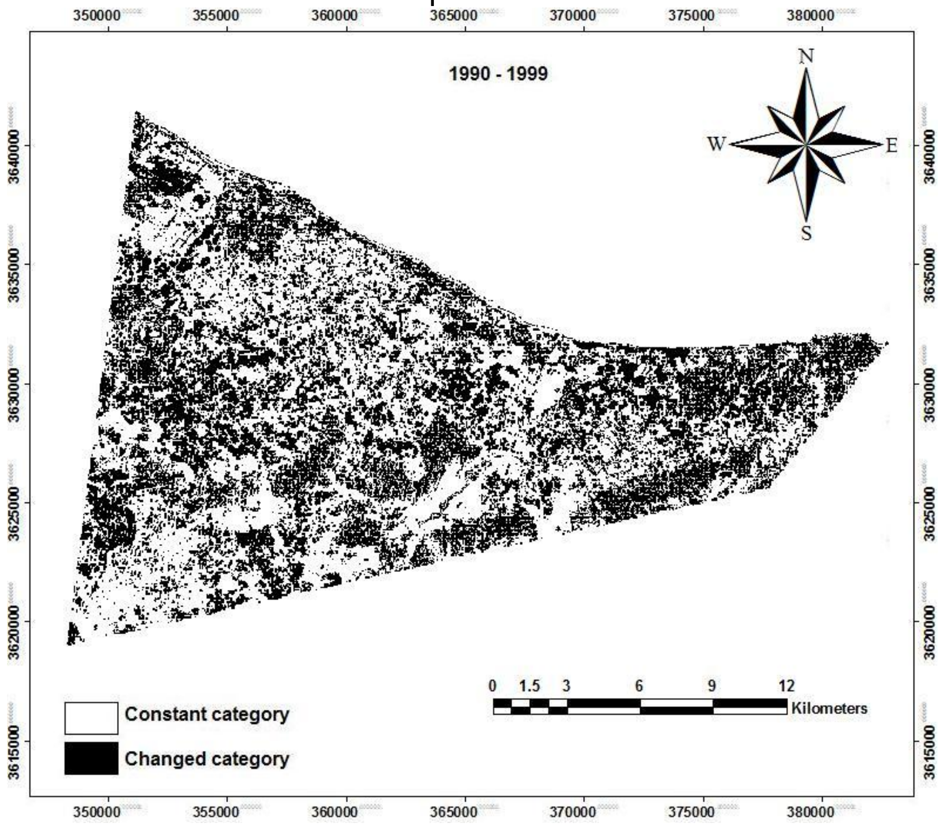


Figure 5.16 Percentages of land cover categories in the western part of the study area in1990 and1999.

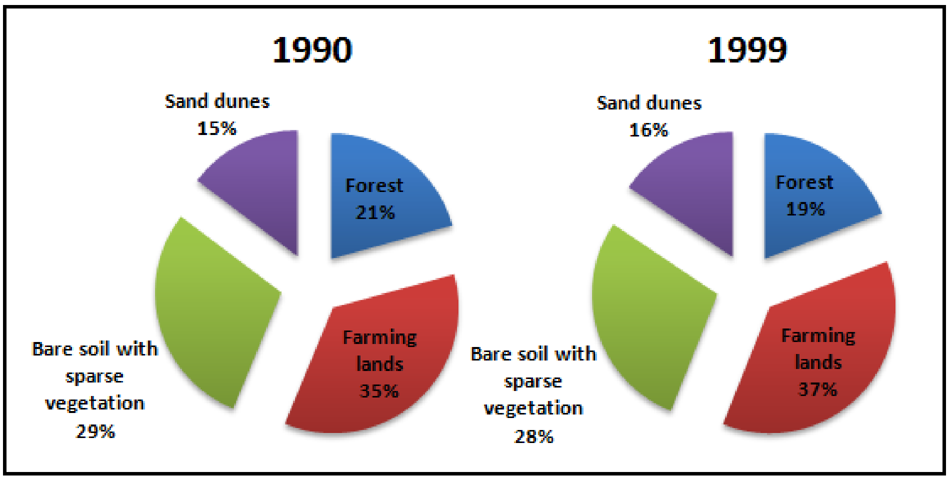


Figure 5.16 shows that there were further changes from 1990 to 1999. The farming land category had increased by 2% in 1999, with the same

percentage but a decrease for the forest category by 1999. Further, the sand dunes category had a slight increase of coverage by 1% in 1999, while the bare soil with sparse vegetation category had decreased its coverage by the same percentage in 1999. These changes are reasonably dispersed throughout the area (Figure 5.15).

C. Detection of changes in size of sand coverage during 1999 -2003.

Figure 5.17 shows a subtraction diagram of the land cover map for the western sample study area in two years, 1999 and 2003. Changes appear to be becoming concentrated in the lower central part of the area involved, which is more pronounced than in previous such diagrams (Figure 5.13 and 5.15). Thus corresponds to the area between the two largest stretches of forest illustrated in Figure 5.11.

Figure 5.17 Subtraction diagram of land cover classification in the western part of the study area showing the extent of changes to land use categories over the time period 1999 - 2003.

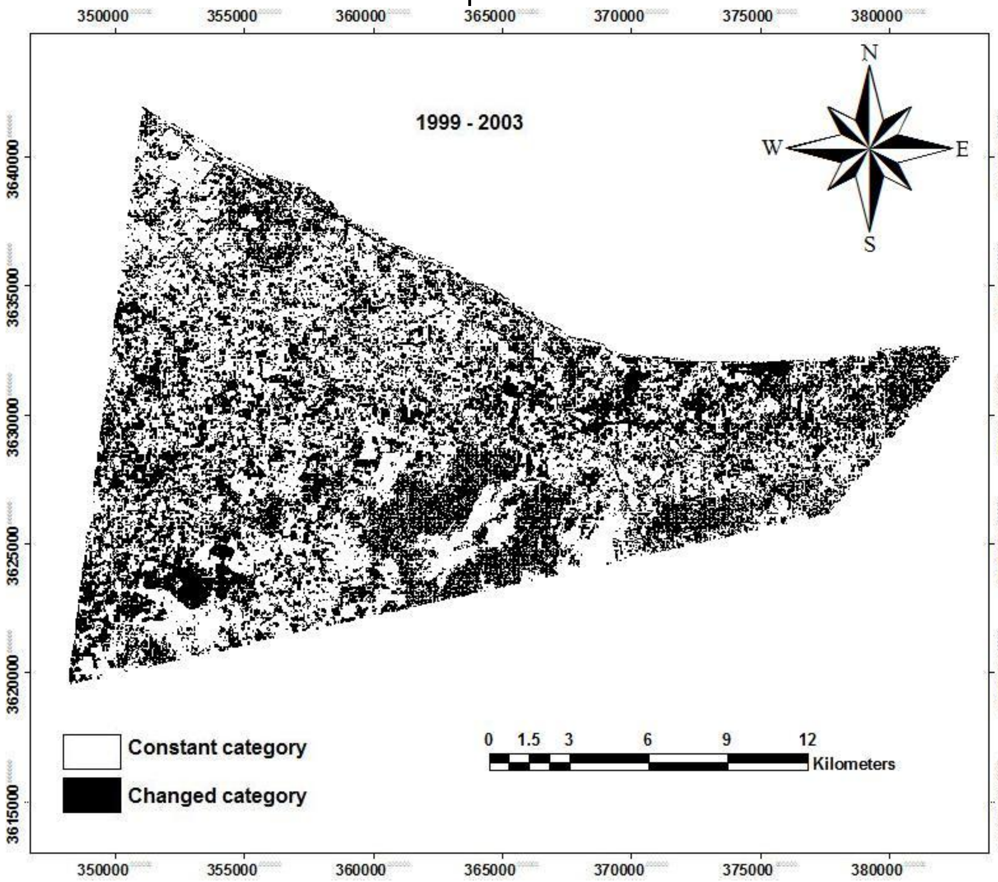
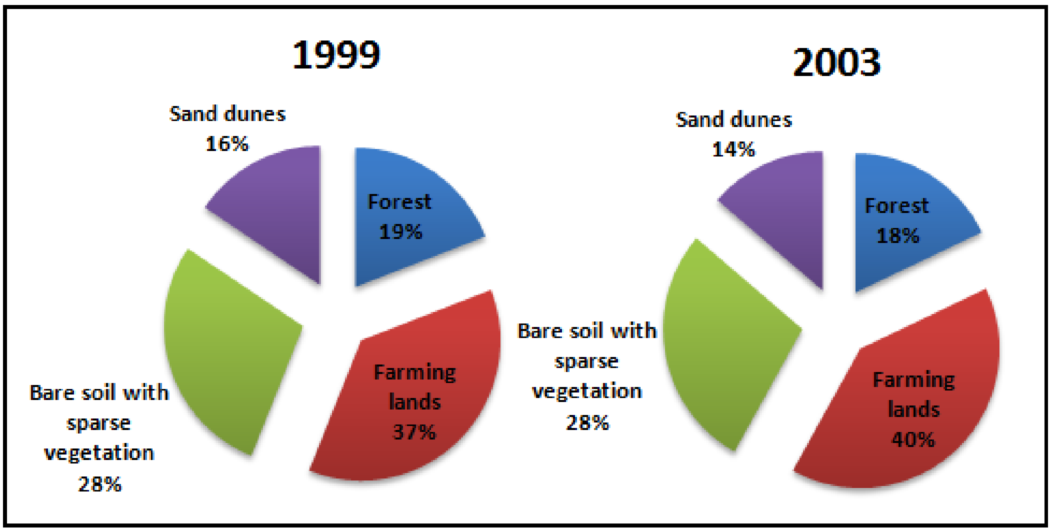


Figure 5.18 Percentages of land cover categories in the western part of the study area in1999 and 2003.



Some of the trends seen previously are continued from 1999 to 2003, but not all (Figure 5.18). Farming land continued to increase its coverage, by 3% in 2003, and the forest category continued to decline by a further 1% by 2003. However, the sand dunes category decreased its coverage by 2% while the category of bare soil with sparse vegetation remained with the same percentage over this period.

D. Detection of changes in size of sand coverage during 1986 -2003.

Combining all the years together to observe the longer term trends from 1986 – 2003, Figure 5.19 shows a subtraction diagram of land cover classification and the most important changes for the land cover categories in the sample site within the western part of the region over this period. There are some locally concentrated areas of change in the west of the maxed area, and in the central/ southern part mentioned in section C above, although less markedly than had seemed the case for the 1990 – 1999 periods. Overall the farming land category had increased by 5% by 2003 (Figure 5.20), with a corresponding decrease in the percentage for the forest category coverage by 2003. On the other hand, the sand dunes category and the bare soil with sparse vegetation category did not vary overall over time because the gains and losses balanced each other out over this time period as a whole.

Figure 5.19 Subtraction diagram of land cover classification in the western part of the study area showing the extent of changes to land use categories over the time period 1986 - 2003.

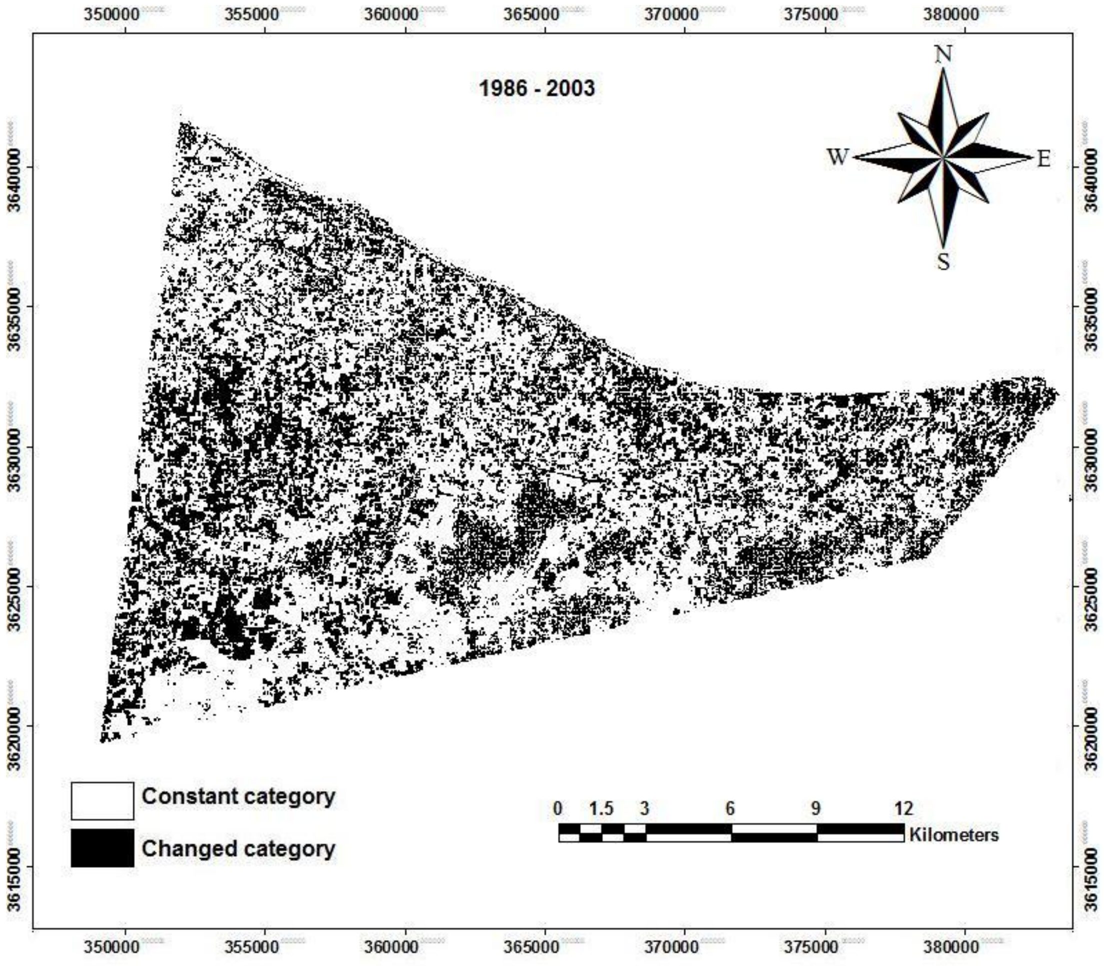


Figure 5.20 Percentages of land cover categories in the western part of the study area in 1986 and 2003.

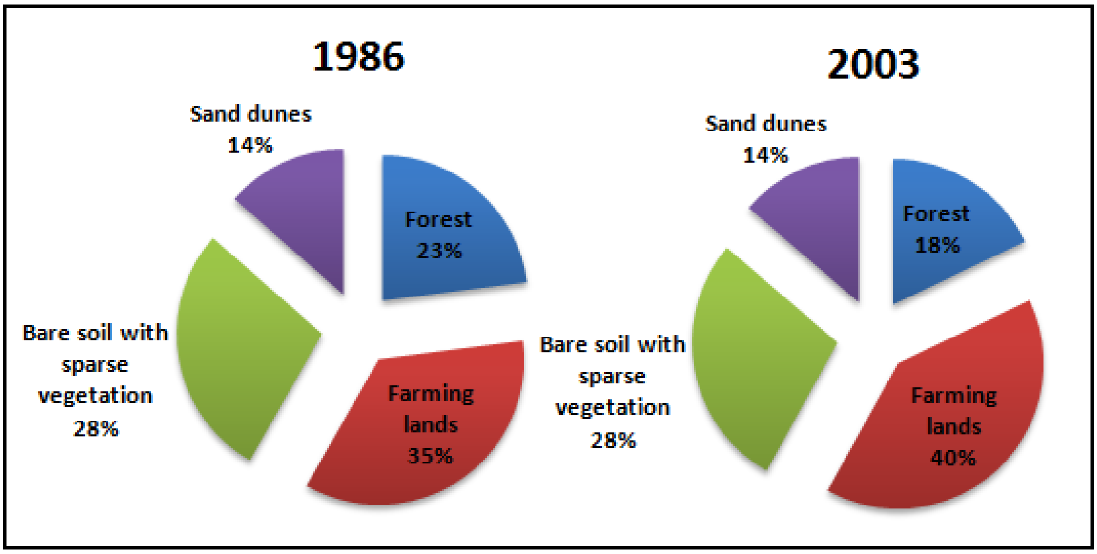


Table 5-10 The changes of land cover categories (Ha and %) in the western part of the study area during the periods between 1986 - 1990; 1990 - 1999; 1999 - 2003, and 1986 - 2003.

	1986 -1990		1990 - 1999		1999 - 2003		1986 - 2003	
	Change		Change		Change		Change	
Land cover class	**(Ha)**	**(%)**	**(Ha)**	**(%)**	**(Ha)**	**(%)**	**(Ha)**	**(%)**
Sand dunes	+381	7.9	+314	6.1	-655	11.9	+40	2.1
Forest	-813	10.0	-565	7.7	-422	6.3	-1801	24
Farming lands	+105	0.8	+94	0.8	+1126	8.6	+1325	10.2
Bare soil with. S. V.	+326	3.3	-301	3.0	-48	0.5	-23	0.2

NB: (+) indicates increase, (-) indicates decrease

Table 5.10 shows the changes in the various land cover categories both in absolute terms (ha) and relative terms (% change from original values) for the sample site within the western part of the study area; sand dunes had gradual positive changes during the periods 1986-1990 and 1990-1999, but then a sudden negative change during 1999-2003; over the whole period they had a slight positive change from 1986 to 2003, increasing by only 2% of their original extent. Forest category had gradual negative changes between each of the periods; with a major negative change in general, losing nearly one quarter of their 1986 coverage by 2003. The farming land category had great positive changes particularly during 1999-2003 and overall, with more modest positive changes in the periods 1986-1990 and 1990-1999. Finally, the bare soil with sparse vegetation category had both negative and positive changes, resulting in a slight negative change overall during the period 1986-2003.

It is clear from the trends discussed above that there have been notable changes in the western part of the study area. The increase in the sand dunes category during the periods 1986-1990 and 1990-1999, may have been linked to the decline in the area of the forest, although possibly indirectly, while the sudden negative changes during 1999-2003 was a direct result of the expansion in farming land. Half of the negative changes of forest area had gone to the sand dunes areas during the period 1990 -1999, while the other half of the forest area lost had transited to both, the bare soil and farming land categories. In 2003 the forest area which was lost had been turned into farming land. Further, the great positive changes of farming land category, particularly in 1999, had come from both, the forest and bare soil categories but in 2003 the increases in farming land came directly from the sand dune and forest areas. Finally, the positive changes of the bare soil with sparse vegetation category in 1990 was coming from the forest category as mentioned earlier, while the negative changes of bare soil in 1999 were because of it being turned into the category of farming land.

E. Transition matrix value between land cover classes in each pair of images presented.

The Land cover change matrices for the western part of the study area in the different time periods are shown in Tables 5.11 to 5.14.

Table 5-11 Conversion matrix value (Ha and %) in the western part of the study area during the period between 1986-1990.

	1990					
			Forest	**Farming land**	**Bare soil**	**Sand**
1986	**Forest**	Ha	5595	1341	308	886
		%	68.8	16.5	3.8	10.9
	Farming land	Ha	1250	7529	2458	1113
		%	10.1	61.0	19.9	9.0
	Bare soil	Ha	445	2009	5663	1782
		%	4.5	20.3	57.2	18.0
	Sand	Ha	79	302	1103	3465
		%	1.6	6.1	22.3	70.0

The change matrix for land cover classes from 1986 to 1990 is shown in Table 5.11. All categories showed some shift to all the other categories in this period. Most decrease of forest was due to a change to sand, while there was near symmetry in conversions between forest and farming land. Also, there is a slightly increase in conversions from farming land to bare soil. The highest converted land cover was forest to sand.

Table 5-12 Conversion matrix value (Ha and %) in the western part of the study area during the period between 1990-1999.

	1999					
			Forest	**Farming land**	**Bare soil**	**Sand**
1990	**Forest**	Ha	3965	1848	898	712
		%	53.4	24.9	12.1	9.6
	Farming land	Ha	1683	6831	2323	1534
		%	13.6	55.2	18.8	12.4
	Bare soil	Ha	1353	2420	3749	2727
		%	13.2	23.6	36.6	26.6
	Sand	Ha	162	376	1564	3198
		%	3.1	7.1	29.5	60.3

The land cover change matrix from 1990 to 1999 in the western part of the study area is shown in Table 5.12, revealing moderate transformation between the land cover classes. Forest has continued with moderate decrease by converting to the sand category. Also, the decrease which was obtained in bare soil goes to farming land and sand. The highest clarity of changes in land cover classes was the forest converted to sand.

Table 5-13 Conversion matrix value (Ha and %) in the western part of the study area during the period between 1999-2003.

			2003			
			Forest	**Farming land**	**Bare soil**	**Sand**
1999	**Forest**	Ha	4561	1599	230	329
		%	67.9	23.8	3.4	4.9
	Farming land	Ha	1465	8517	2717	382
		%	11.2	65.1	20.8	2.9
	Bare soil	Ha	940	1900	5722	1338
		%	9.5	19.2	57.8	13.5
	Sand	Ha	199	523	973	3960
		%	3.5	9.3	17.2	70.0

Table 5.13 shows the land cover conversion matrix from 1999 to 2003. The greatest change of most land cover classes is to farming land, particularly from forest and bare soil. More bare soil changed to sand than moved from sand to bare soil.

Table 5-14 Conversion matrix value (Ha and %) in the western part of the study area during the period between 1986-2003.

			2003			
			Forest	**Farming land**	**Bare soil**	**Sand**
1986	**Forest**	Ha	3099	1543	1061	661
		%	48.7	24.3	16.7	10.4
	Farming land	Ha	1386	8967	2687	1103
		%	9.8	63.4	19.0	7.8
	Bare soil	Ha	792	3613	3683	1811
		%	8.0	36.5	37.2	18.3
	Sand	Ha	188	455	1138	3168
		%	3.8	9.2	23.0	64.0

Considering the transitions between categories for the period from 1986 to 2003 as a whole (Table 5.14), about 64% of farming land and sand started the period as those categories; the change of both was to bare soil. There is considerable switching between bare soil and these two categories as well. Sand has a net gain from all of the other categories. In contrast, forest shows as net loss to all other categories and less than 50% of forest identified in 1986 is still forest in 2003.

Figure 5.21 Changes of the area of sand dunes in the western part of the study area, 1986 – 2003.

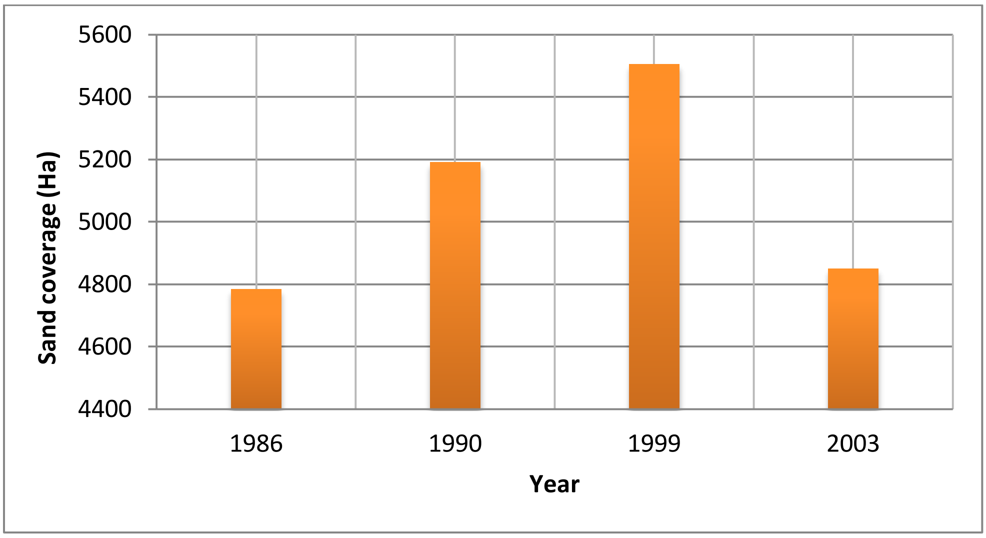
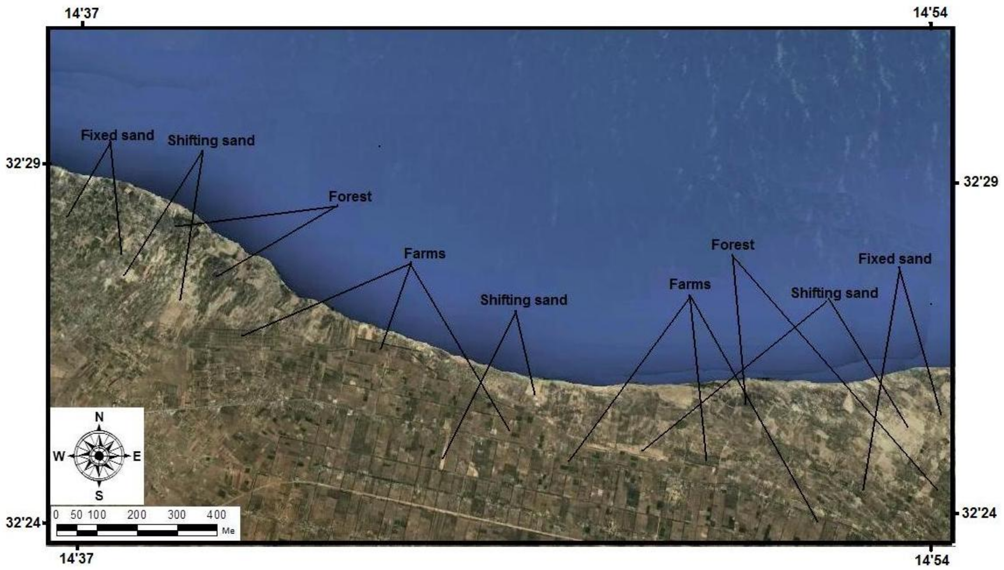


Figure 5.21 shows that there is a great peak in the area of sand dunes in the site within the western part of the study area during the 1990-1999 period, with a sudden decrease from then up to 2003. This result is due to some change in the factors influencing the extension of sand dune coverage during this latter period as indicated above.

5.4.1.2 Detection of changes in the sample site selected within the eastern part of the study area

The same four land cover categories were identified and classified in the eastern part of the study area as were used in section 5.4.1.1. These were sand dune, forest, farming land, and bare soil with sparse vegetation as shown in Figures 5.22, 5.24, 5.26. Also, Figure 5.22 shows illustration of farms and a sand location which has been used when interpreting the recorded changes of land – use covers.

Figure 5.22 Illustration of farms and sand locations which have been used to help interpret the change of land-use cover in the eastern part of the study area. (Source: Google Earth, 2003).



A. Detection of changes in size of sand coverage during 1986 -2003.

Figure 5.23 shows the land cover map for the eastern sample study area in 1986 and Figure 5.24 shows a subtraction diagram of land cover classification over the time period 1986 - 1990. The relative proportions of the study area occupied by these land cover categories are shown in Figure 5.25.

Figure 5.23 Unsupervised classification images of the eastern part of the study area, 1986

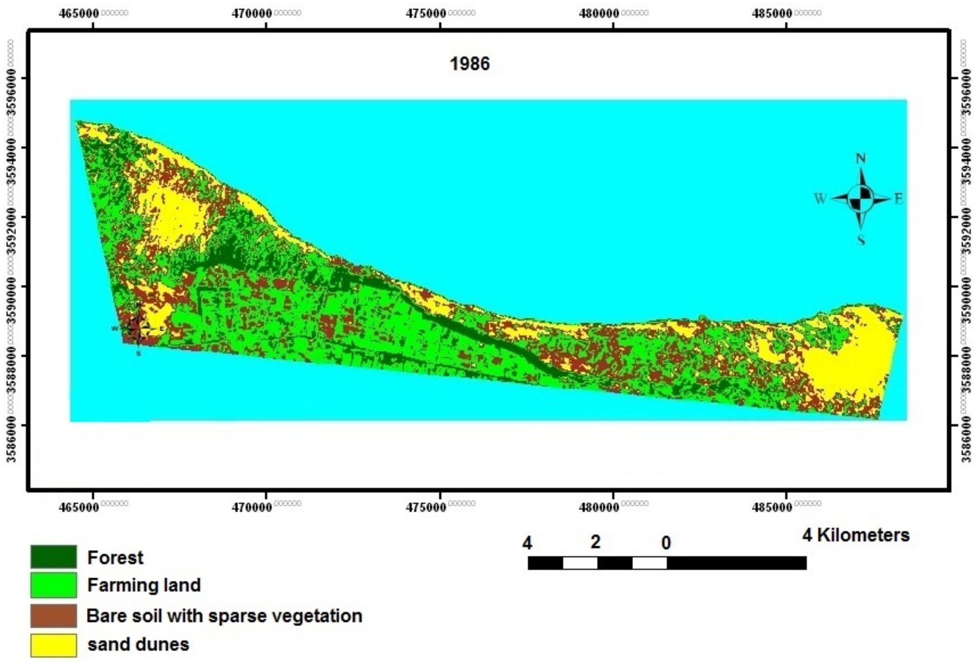


Figure 5.24 Subtraction diagram of land cover classification in the eastern part of the study area showing the extent of changes to land use categories over the time period 1986 - 1990.

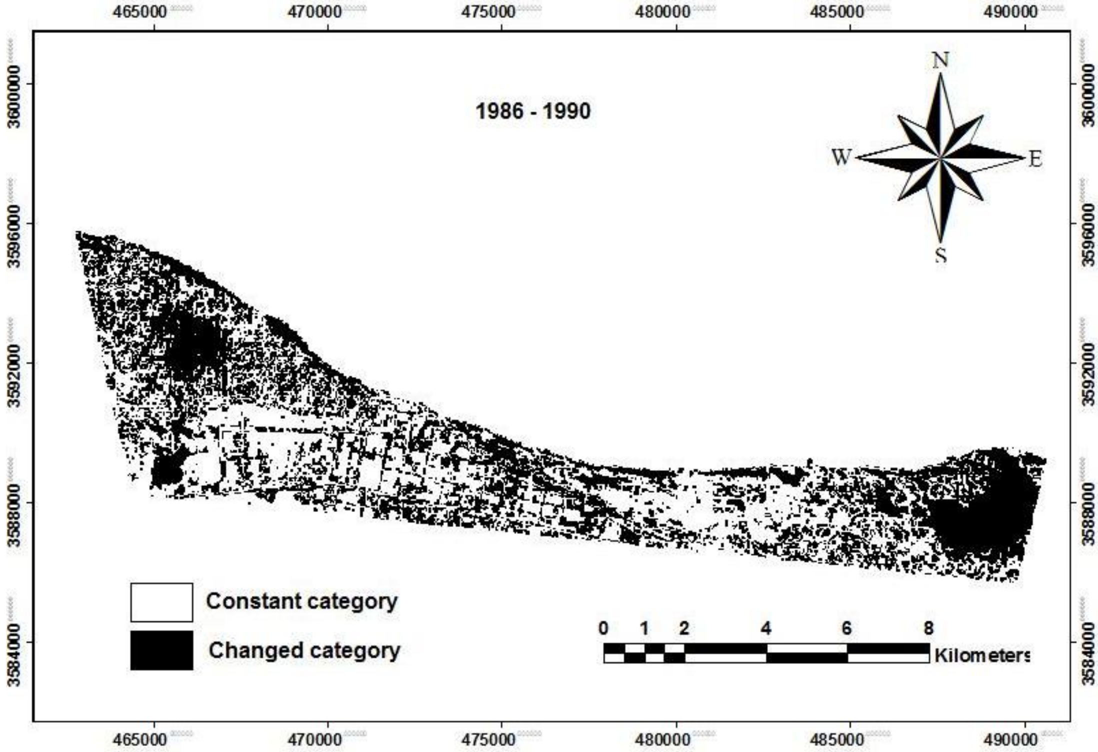
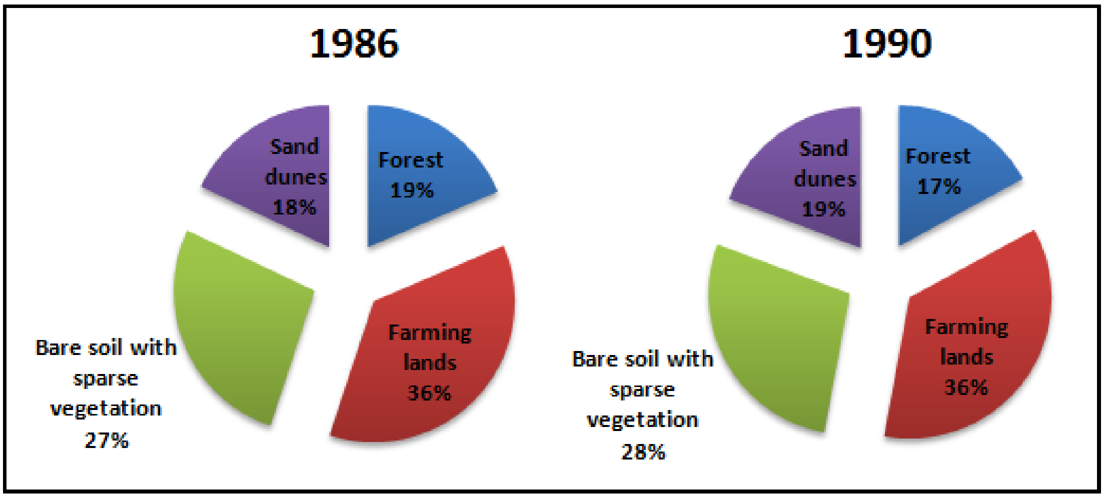


Figure 5.25 Percentages of land cover categories in the eastern part of the study area in 1986 and 1990



The subtraction map seems to be especially picking out the areas of sand dunes visible on Figure 5.23 as being the sites of most change. These are noted on Figure 5.22 as areas of shifting sand and farmland, suggesting some horizontal movement of the sand in this period, especially in areas of farmland. Comparing the percentage cover values in the two years (Figure 5.25), sand dunes and bare soil with sparse vegetation have both increased slightly (by 1%), while the forest category has decreased by 2% by 1990, and farming lands have stayed the same.

B. Detection of changes in size of sand coverage during 1990 -1999.

Figure 5.26 shows a subtraction diagram of the land cover map for the eastern sample study area between the years; 1990 and 1999. Again, this emphasises the main sand dune areas, although not as much as in Figure 5.24 for the previous time period.

Figure 5.26 Subtraction diagram of land cover classification in the eastern part of the study area showing the extent of changes to land use categories over the time period 1990 - 1999.

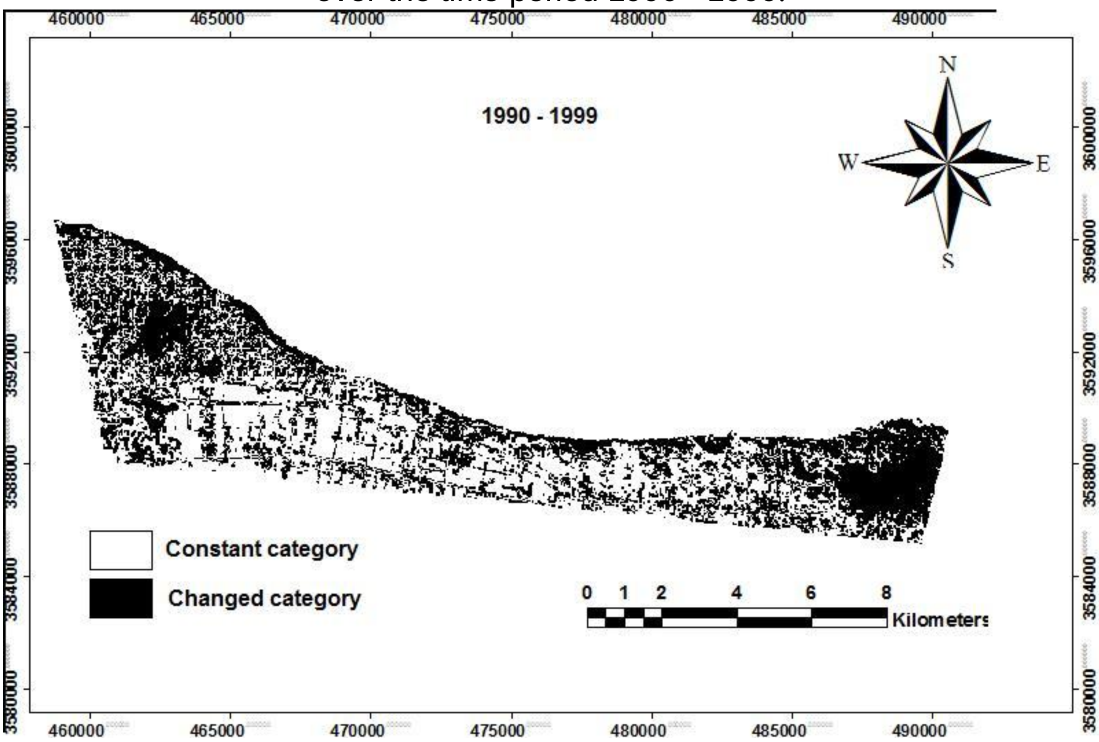
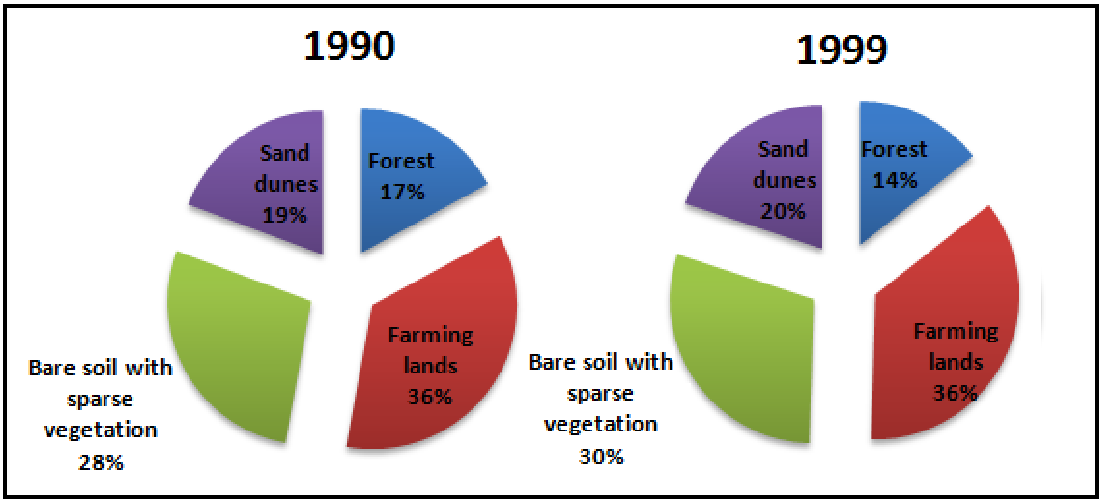


Figure 5.27 Percentages of land cover categories in the eastern part of the study area in 1990 and1999.



By 1990, again there is no change in the amount of farming land, but the earlier trends for forest and sand dune have continued (-3% and +1% respectively), and bore soil with sparse vegetation has also increased by 2% by 1999.

C. Detection of changes in size of sand coverage during 1999 -2003.

The subtraction map of land cover classification in the eastern part of the study area for 1999 and 2003, and the percentage land cover values showing changes in land use categories over the time period, are shown in Figure 5.28 and 5.29 respectively. Further change is still evident in the same three broad parts of the study area as previously.

Figure 5.28 Subtraction diagram of land cover classification in the eastern part of the study area showing the extent of changes to land use categories over the time period 1999 - 2003.

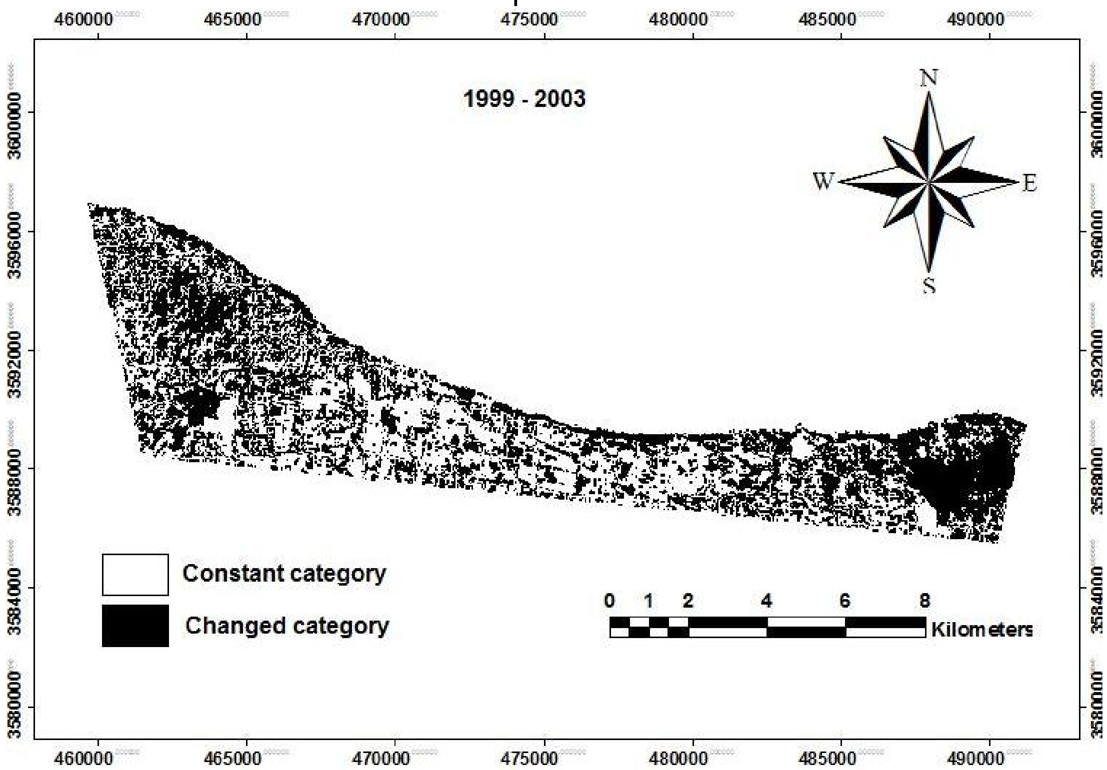
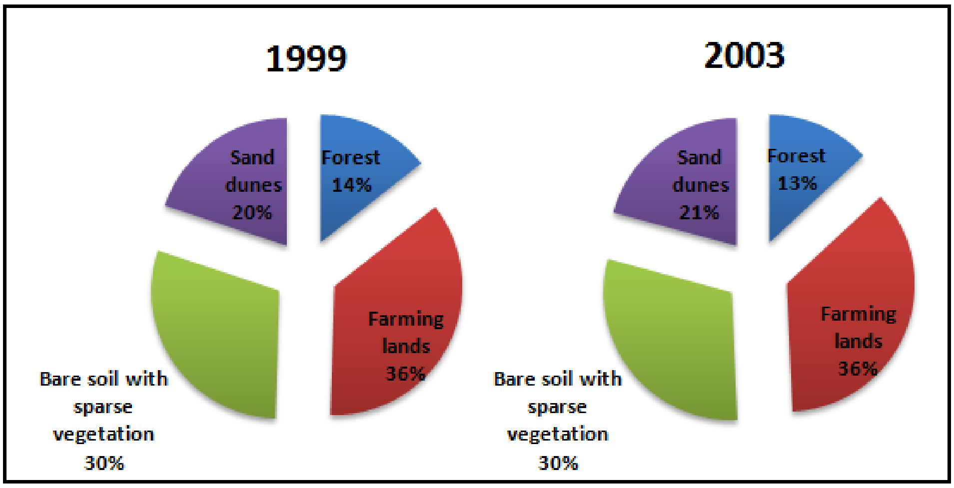


Figure 5.29 Percentages of land cover categories in the eastern part of the study area in1999 and 2003.

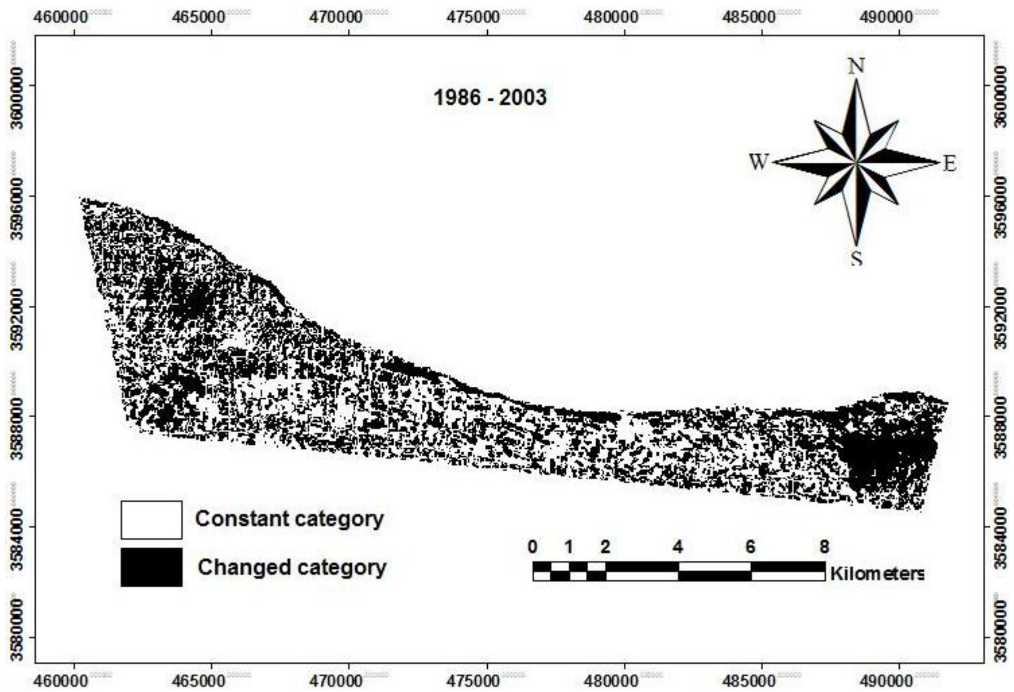


The changes between 1999 and 2003 are more modest, with forest occupying a further 1% less of the area by 2003 and sand dunes 1% more, the other two categories showing no change over this period.

D. Detection of changes in size of sand coverage during 1986 -2003.

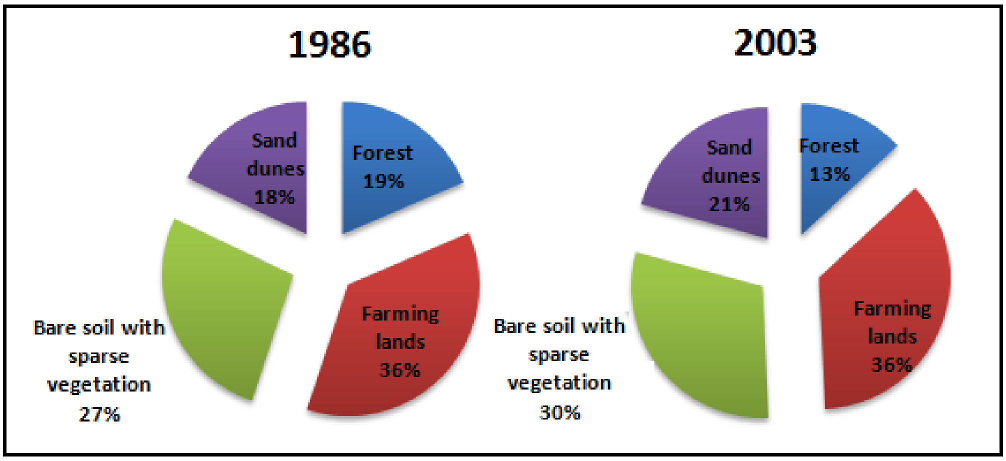
Figures 5.30 and 5.31 show the subtraction diagram and the percentages of change in land cover categories for the eastern sample study area in seventeen years, from 1986 to 2003.

Figure 5.30 Subtraction diagram of land cover classification in the eastern part of the study area showing the extent of changes to land use categories over the time period 1986 - 2003.



When considering the whole time period (1986-2003), the concentration of changes in three broad parts of the area seen in previous diagrams is still evident, but not as markedly. This suggests that some of the changes have been temporary or reversed. The areas remaining prominent are especially in the eastern part of the region where the area most affected was farmland, with shifting sand dunes towards the coast; and two focal points to the west of this region, the northernmost one relating to shifting sand dunes and the southernmost one associated with farmland.

Figure 5.31 Percentages of land cover categories in the eastern part of the study area in1986 and 2003



Taking the combined changes from 1986 to 2003 together, sand dunes and bare soil with sparse vegetation have both increased by 3%, at the expense of forest which has declined overall by 6% by 2003. The farming land category showed no change in coverage percentage during the same period.

Table 5-15 The changes of land cover categories (Ha and %) in the eastern part of the study area during the periods between 1986 - 1990; 1990 - 1999; 1999 - 2003, and 1986 - 2003.

	1986 -1990 Change		1990 - 1999 Change		1999 - 2003 Change		1986 – 2003 Change	
Land cover class	**(Ha)**	**(%)**	**(Ha)**	**(%)**	**(Ha)**	**(%)**	**(Ha)**	**(%)**
Sand dunes	+97	7.5	+43	3.1	+63	4.4	+203	15
Forest	-130	9.6	-194	12.1	-92	8.9	-417	30.6
Farming lands	-27	1.1	+21	0.8	+6	0.3	0	0.0
Bare soil with. s. v.	+61	3.1	+129	6.5	+24	1.1	+213	10.7

NB: (+) indicates increase, (-) indicates decrease

It is clear from table 5.15 that the absolute change in forest in this eastern area is smaller than in the western area studied (Table 5.15), but in percentage terms the loss is even greater. The area of sand dunes progressively increased over all the time periods, but particularly in 1986-1990, and in general increased substantially during the period 1986 to 2003. Farming land had negative changes during the various periods, including 1986-2003. On the other hand the bare soil with sparse vegetation category had slight positive changes during 1986-1990 and 1999-2003, and more substantial changes between 1990 and 1999, and in general increased substantially during the whole period.

The main changes in percentage cover in this sample area therefore mostly concern the loss of forest, which has probably changed directly into bare soil with sparse vegetation, and also changed to sand dunes. This change from forest to sand dunes has happened quickly. Whether; this change has involved any transitional categories will be explained in the next section.

E. Transition matrix value between land cover classes in each pair of images presented.

The land cover change matrices for the eastern part of the study area are shown in Tables 5.16 to 5.19 for the different time periods.

Table 5-16 Conversion matrix value (Ha and %) in the eastern part of the study area during the period between 1986-1990.

			1990			
			Forest	**Farming land**	**Bare soil**	**Sand**
1986	**Forest**	Ha	995	232	53	92
		%	72.5	16.9	3.9	6.7
	Farming land	Ha	218	1513	746	122
		%	8.4	58.2	28.7	4.7
	Bare soil	Ha	93	401	1174	280
		%	4.8	20.6	60.2	14.4
	Sand	Ha	29	54	140	1075
		%	2.3	4.2	10.8	82.7

The change matrix of land cover classes for 1986 and 1990 in the eastern part of the study area (Table 5.16) clearly shows a moderate transformation between the land cover classes. There has been moderate decrease of forest gone mostly to sand and the farming land, while there has been a slight decline in farming land changing to bare soil and also some change to forest (so that overall there is little net change between these categories). Sand and bare soils with sparse vegetation have both tended to increase slightly.

Table 5-17 Conversion matrix value (Ha and %) in the eastern part of the study area during the period between 1990 and 1999.

			1999			
			Forest	**Farming land**	**Bare soil**	**Sand**
1990	**Forest**	Ha	727	222	175	103
		%	59.2	18.1	14.3	8.4
	Farming land	Ha	434	1344	676	145
		%	16.7	51.7	26.0	5.6
	Bare soil	Ha	182	432	1094	314
		%	9.0	21.4	54.1	15.5
	Sand	Ha	42	131	175	1022
		%	3.1	9.6	12.8	74.5

Table 5.17 shows the land cover conversion matrix for the period between 1990 and 1999. The significant decrease in forest was from change to all three other categories. However, there was also change to forest from all other categories. Sand has gained more than it has lost from all categories, while farming land has lost more than it has gained to all other categories.

Table 5-18 Conversion matrix value (Ha and %) in the eastern part of the study area during the period between 1999-2003.

	2003					
			Forest	**Farming land**	**Bare soil**	**Sand**
1999	**Forest**	Ha	666	178	63	103
		%	65.9	17.6	6.3	10.2
	Farming land	Ha	325	1576	502	197
		%	12.5	60.6	19.3	7.6
	Bare soil	Ha	234	403	1191	338
		%	10.8	18.6	55.0	15.6
	Sand	Ha	31	60	311	1041
		%	2.2	4.2	21.5	72.1

In Table 5.18 the land cover conversion matrix from 1999 to 2003 is given. There are minor changes in absolute terms of most land cover classes, except for the forest and bare soil. Similar changes can be seen as in Table 5.17.

Table 5-19 Conversion matrix value (Ha and %) in the eastern part of the study area during the period between 1986-2003.

			2003			
			Forest	**Farming land**	**Bare soil**	**Sand**
1986	**Forest**	Ha	457	211	149	121
		%	48.7	22.5	15.9	12.9
	Farming land	Ha	288	1217	796	299
		%	11.1	46.8	30.6	11.5
	Bare soil	Ha	88	522	1107	448
		%	4.1	24.1	51.1	20.7
	Sand	Ha	40	183	223	1069
		%	2.7	12.1	14.7	70.5

The overall changes between the years 1986 and 2003 (shown in Table 5.19) show essentially that the pattern observed in individual time periods is reinforced when they are all combined together. Forest has had a net loss of area to bare soil and sand, but a net gain in area from farming land. Farming land has, despite this, had a substantial net gain in area from the other categories. Bare soil has gained from forest and farming land, but had a net loss to sand; while the sand category has gained in area from all other categories.

Figure 5.32 Changes of sand dunes area in the eastern part of the study area, 1986 – 2003

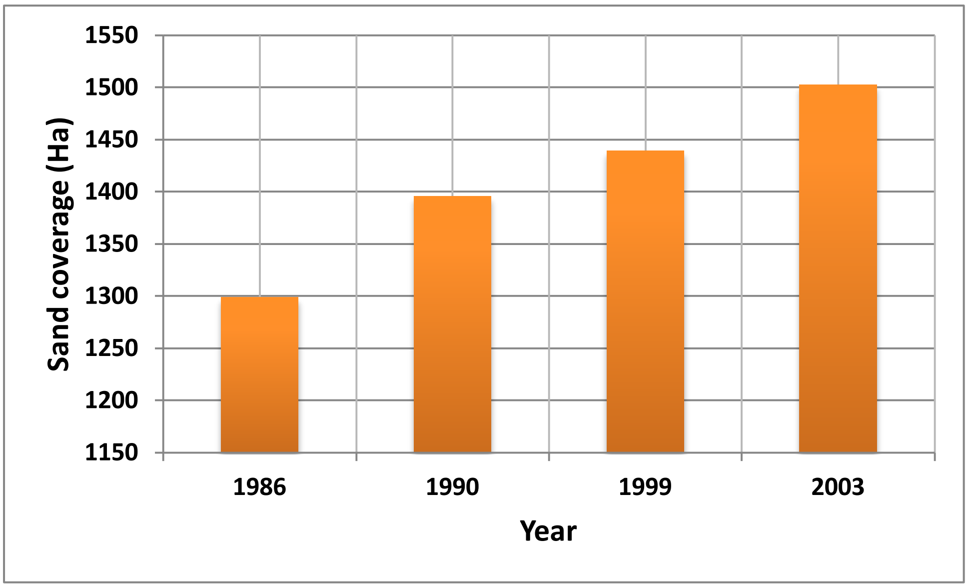


Figure 5.32 shows a progressive increase over time in the area of sand dunes in the sample site within the eastern part of the region. This result indicates that the extent of the problem of sand coverage within the area studied is getting worse over time.

5.5 Discussion and conclusion

The analysis of the LandSat images from 1986, 1990, 1999 and 2003 has demonstrated that land cover in the study area has changed with time. A number of broad land cover classes were used in analysing these images, through the classification process. These classes were sand dune, forest, farming land, bare soil with sparse vegetation, bare soil and urban area. The results for the whole of the study area showed that the sand dune area has increased in each of the periods, with a clear overall increase between 1986 and 2003 of 3%. This contrasts to the forest category which decreased substantially in the whole of the study area. Urban areas also increased, presumably associated with population growth, and farming land also had a great positive increase in area during the whole time period. On the other hand, the bare soil with sparse vegetation category had a clear decrease in area during 1986-2003.

Also, the increase in farming land during all periods was mainly from conversion from bare soil with sparse vegetation, bare soil and forest, with a slight conversion from sand areas. This means that there is a horizontal expansion in the volume of farming land within the study area.

The expansion of sand area during 1986-2003 was mostly at the expense of bare soil with sparse vegetation and forest, with a small amount from bare soil and farming land. However there is some disparity of percentages between classes for each period. This is a clear indication of complexity in the factors which lead to greater sand cover. The disparity of the size of transformation of land cover classes to the sand can be suggested to be due to a possible increase in wind gusts (see section 3.4.2.3) together with a significant pressure of human activity on certain categories of land cover within the study area.

In contrast, bare soil with sparse vegetation was converted mostly to urban, sand and bare soil, with a slight conversion to farming land. This means that there is a turning of grassland to bare land or sandy land as well as urban areas.

Furthermore, the increase of urban areas was derived mostly from bare soil with sparse vegetation and farming land, with moderate to slight amounts from the rest of the land cover classes.

Bare soil has reduced during 1990-1999, 1999-2003 and 1986-2003, with this category being converted mostly to farming land and urban. During 1986-1990, however, it increased having been derived mostly from bare soil with sparse vegetation and urban. The reason for the apparent transformation from urban category to bare soil category might be due to overlap in the same band, rather than actual changes in coverage in reality.

However, these changes described above were not uniform across the whole of the study area. When two sub samples from the western and eastern parts of the area were analysed separately, the changes were different especially with respect to sand dune coverage. Thus, in the eastern part sand dunes increased in area progressively over time, while in the western part the increase seen up to 1999 was largely reversed by 2003. This was seen also in the subtraction maps, where specific areas where change was concentrated apparently reversed those changes later on in the western region, but less so in the east. Both areas showed a major decline in forested area, while farming areas increased in the western part but not in the east; the reverse was true for bare soil with sparse vegetation which increased in the east but not the west. The subtraction maps also highlighted the impact of changes due to shifting sand and changes to farming areas, especially in the eastern region studied.

Another possible reason for the differences between eastern and western regions may be because of an increase in the number of quarry sites which are widespread particularly in the eastern part of the study area, because this type of sand has a high quality for being used in construction processes and it is widely used in the whole region. Therefore, these processes may be a cause of a decrease of vegetation cover, particularly over dunes. The increasing number of these quarries, and a lack of control of them from the local administration, together with successive dry periods, may be a cause of the increase of sand coverage over time within the region.

The results of the land cover change matrix within the western part of the study area indicate that the negative development of change in forest was converted mostly to sand and bare soil with sparse vegetation, while the positive evolution of sand change was converted from bare soil with sparse vegetation, farming land and forest, in terms of the coverage in hectares.

Also, the positive evolution of farming land changes was transformed mostly from bare soil with sparse vegetation; in contrast the negative development of bare soil changes was converted mostly to farming land and sand.

Furthermore, the results of the land cover change matrix within the eastern part of the study area indicate that the negative change of forest resulted from it changing mostly to sand and bare soil, while the increase in area of sand was from conversion from bare soil with sparse vegetation, farming land and forest, in terms of number of hectares. Farming land mostly altered to bare soil, forest and sand, with in contrast bare soil was gained from the categories of farming land and forest.

It is likely that the prime cause of the changes observed is population growth and the accompanying expansion of urban development, which is widely recognized as a major driver of environmental change, particularly with developing countries (Leemans *et al*., 2009). The average population growth rate of Libya has been high (3.4% per annum) according to statistics of 1984, 1996 and 2006 (GAIL, 2006).

Since agriculture is the main economic activity in the area, increases in population lead to the conversion of forest to farming land or grassland, as well as increases in buildings (Almkasbie, 2001). Moreover, uncontrolled farming activities and associated processes also contribute to a reduction in the amount of forest. This is particularly the case where the population are not sufficiently educated (Al Jadedie, 1992, p.187).

Often, the reductions of farming land observed were because of shifts to sand in both parts of the study area. This transformation can be explained according to notes which were obtained from conversations with the farmers in the fieldwork of this study in 2008, namely that there were some problems experienced in some years, such as financial expenses and the lack of some seeds, medicines and agricultural inputs. Consequently the farmers were forced to leave their land uncultivated for a season or two. Due to the nature of the sandy area, often these spaces very quickly turn into sand dunes, as a direct result of the dry ground, the lack of vegetation cover, and frequent strong winds.

The trends of land cover changes that have been observed in this chapter have suggested that substantial parts of the forest areas and bare soil with sparse vegetation have been converted to farming. These changes are potentially important in relation to the shifting of sand dunes. Since land cover is determined by the pattern and amount of precipitation, the soil type and the geomorphology (Milich and Weiss, 1997), a slight shift from forest to grassland and human settlement would alter the characteristics of the soil and sand dune geomorphology.

The forested areas have been a significant component of the study area because much of it has been created for fixation of sand dunes and combating desertification within the region. Forest areas cover less than 2% of the study area as a whole, this reflects an imbalance in the ecosystem of the local environment and may lead to further environmental imbalance. Such results have been observed by many studies, for example Hugenholtz and Wolfe (2005).

The changes of area of sand dunes observed in the eastern parts of the study area are considerably larger than those described in other studies of fixation of sand dunes in tropical areas (Almkasbie, 2001). This may simply be a function of changes in size observed in sand dunes area in those studies, which often varies depending on research scale and questions being addressed. An interesting feature of the present results is that even though the changes observed are large, they are still not as large as those sometimes found elsewhere. For example, Boakye *et al*. (2008) used Landsat images to assess the changes in land use categories in the Barekese Catchment in Ghana and found that over a 27 year period (1973 – 2000), there was a 43% decrease in forest, open forest likewise declined by about 32%, while grassland and open and urban areas increased by about 700% and 1000%, respectively.

The large changes of farming land which were observed especially in western parts of the study area are linked to water reaching the farmers from the Great Man-Made River Project. In recent years there has started to be a focus on exploitation of all lands for agriculture, including forest land and other grassland.

When forest cover is removed, storm water tends to flow overland rather than below the soil surface, and this may dramatically alter the soil as well as making the land more vulnerable to erosion, which in turn may lead to greater siltation of the sediments in dams or other watercourses**.** Farming and urbanization practices, for example compaction of soil during logging, can lead to water not infiltrating the soil as well and so reduce flow of water through the soil. Also, greater farming activities lead to increasing runoff, which will also increase erosion and sedimentation.

The present results were reasonably accurate using the unsupervised classification method when spot – checks were made for composition. It was possible to distinguish between all categories which had been selected in this study. The classification was more accurate for the smaller sample areas, where fewer land cover categories were used. Although some errors of classification will probably have occurred, is impact on the subtraction maps will have been reduced by the filtering technique adopted. It is clear that the use of subtraction maps is detecting much more apparent change than the simple percentages of coverage due to each land-use type show. Some of this recorded change may not be real, but a function of problems such as misclassifications, as indicated previously; however, some is probably genuinely due to changes in location of sand dunes, but without a change in total percentage cover. This point is reinforced by the extent of changes both to and from particular land use classes as shown in the conversion matrices, the changes sometimes partly offsetting each other.

It is clear that the two parts of the study are showing different patterns of change. In both parts of the study area there are negative changes in the cover of forested areas, this result indicating clearly that the forest in the study area has suffered from poorly managed exploitation. The sudden negative change in forest coverage during 1999-2003 particularly in the western part of the region appears to be a direct result of the expansion in farming land. The results of the conversion matrix value for land cover classes during all periods indicate that the negative change of forest was converted mostly to farming land. In contrast, in the same time any changes to the farming land had converted mostly to forest. Often the size of losses of forest exceeds the additive size of changing farming land to forest in the majority of periods. It can be explained that the region is witnessing a great expansion of farming land and a large part of this expansion is shrinking forest area, with emergence of an indication for reforestation or agriculture of dense trees through this expansion.

This agrees with some previous studies about the increasing pressure on forests recently through encroachment and conversion to agricultural land (AL Kataly, 1988). In the eastern part of the region, half of the reduction of forest area appears to have been linked to an increase in the cover of sand dunes, while the other half has changed to bare soil and farming land. Taken as a whole, the results show the bad conditions which plant life has faced within the study area in this time period.

Finally, the results which were obtained in this chapter reflect the extent of evolution of sand dunes within the study area. The relationship between the results observed here and those of Chapter 4 will be discussed later in Chapter 7. The role of human activity was very clear compared to climate factor in increase of the size of sand coverage through deforestation and overgrazing. Through the results of this chapter has been achieved one of the objectives in this project, namely providing tangible evidence of sand movement within the study area.

To complement the understanding of the size of damages which may be caused by the movement of sand within the study area, the next chapter will investigate the impacts of sand encroachment on farms through the analysis of questionnaire data which were obtained for this purpose.

6 CHAPTER SIX: Impacts of sand movement on farms

6.1 Introduction

This chapter aims to provide an insight into the problems which are caused to farms by sand dune movement, farming being an important part of the human activities within the study area. The agricultural production of this area represents more than 60% of the total agricultural land production in NW Libya (GAIL, 2006). In order to assess the extent to which sand dunes present problems to the inhabitants of the area and the need to control sand movement, a questionnaire was designed and distributed to families living in the study area to obtain information on the type and extent of damage which can be caused by sand dune movement there. The area within which the questionnaire was distributed included farms of the Musratah, Almerqeb and Tajurah regions. The questionnaire was directed to land owners to determine to what extent they have been affected by encroachment of sand on their farmland. Data was also obtained on seasonal crops grown, and the current status of the vegetation cover.

6.2 Research methodology

Selecting a good method to collect the data will influence the validity and reliability of the research results. The methodology chosen for this project will be consistent with the nature of the study which covers the geomorphologic aspects and their effects on human activities.

Most people consider that a questionnaire is the first tool when undertaking a research project (Preston and Ellis, 2009). It is important to consider the advantages and disadvantages of using questionnaires in order to compare there to other possible methods, most notably interview (Schwarz and Oyserman, 2001). Questionnaires and interviews can be used to collect data about phenomena that are not directly observable (e.g. inner experiences, opinions, values, interests, etc.), and are more convenient to use than direct observation, which is more suited to when collecting data on observable behaviour (Petric and Czarl, 2003). The advantages of using questionnaires are desorbed by Marshall (2005) as follows: 1) they can be targeted at large groups of samples; 2) all respondents of the questionnaire can complete the answers in a short time at their own convenience, can answer questions out of order, skip questions, and also can take several sessions to answer the questions, and also write some comments if it is necessary; 3) the questionnaires require a short time and little cost compared with interviews (Marshall, 2005).

Besides the points made above, the advantages of this method are that all data collected are uniform (apart from open aided questionnaire questions) and therefore they are easy to analyse; moreover, the results from this method can be compared with the results of similar surveys used elsewhere; the answers of respondents can also be anonymous, which may give more impartial and truthful answers; this method can be run as an online survey and is relatively inexpensive; and the whole process can be managed by one person if they have the necessary skills (Grassi *et al*., 2003).

The disadvantages of using a questionnaire include an inability to probe deeply into respondents understanding and their attitudes or inner experiences through the answers (Marshall, 2005). Also, it is not possible to make any modifications to the questions after the questionnaire has been distributed. Furthermore, sometimes the responses to a questionnaire may be inaccurate, in particular through incorrect interpretation of some question. Before being satisfied that the responses in the sample are a valid statistical representation of the whole population there is a need to determine a reasonable sample size; some of the target people in the sample may lack the motivation to complete or return the questionnaire, which may lead to a lower response rates as well as potential bias to responses, and consequently there should be some sort of incentives to encourage responses, for example, a prize draw. Producing, distributing, and analysing a large number of questionnaires may take a long time and make them more expensive; also the quantitative data may not be enough to answer some of the questions necessary to answer the research questions. Instead may be needed in depth interviews (Marshall, 2005).

In contrast, interviews typically depend on oral questions asked of individuals (e.g. Stansfield and Kenyon, 1992). Notes are taken using audio/visual equipment, computers, or are hand written during or following the interview. The features of the interview method are its adaptability in controlling the response situation, choosing a mutually convenient time and place, and also regulating the sequence and pacing of the questions asked. Moreover, the questions can be adjusted as needed to probe deeply into respondents understanding and their attitudes about the questions raised, therefore more information can be obtained and vague answers can be clarified. The interviewer can enhance the confidence of respondents and bring out their opinions about a subject, thus helping to get more information that might not have been revealed using another method of data collection. The limitations of interviews include the difficulty in standardizing the interview situation so the interviewer doesn't influence the respondents' answers, and summarising the information in a comparable way for different respondents. Interviews cannot provide anonymity for the respondent, but reporting of responses can be anonymous (Joinson and Reips, 2007).

A self – administered questionnaire was chosen in this study because the questionnaire is the best method to obtain a larger number of results the in time available, also it complies with achieving the desired objective of this project of seeking mostly factual information from respondents. There is a set of key points which have supported the choosing of a questionnaire in this study. Firstly, the large size of the region, so that the large size of sample needed cannot be covered adequately by the interview method compared with a questionnaire. Secondly, the time and effort which is required in such cases by the interview method compared to the questionnaire was not available. Thirdly, the type of information required and the nature of the questions sought for this study, in that the questions do not need to be explained or thoroughly interpreted by farmers, consequently the interview method is not required. A final point is the degree of responsiveness among farmers in terms of use of the questionnaire and interview methods; often the farmers do not wish to use the interview compared to the questionnaire and they are not prepared to give interviews in this way; partly because of the time required for an interview, partly because of concerns about the selection of questions which will be raised, and also because they are more likely to think there is a specific answer expected by the interviewer which would be less the case with the questionnaire. Therefore it was decided that the questionnaire method was the most appropriate for the aim of this study, which was to investigate the extent of damages which have been caused by sand encroachment within the region.

The questionnaire used sought to provide an insight about the problem of sand dune movement, as well as assessing solutions for controlling this movement in the study area, to protect farmland according to local environmental conditions. It was designed for purposes of verification of the extent of damage which can be caused by sand dune movement in NW Libya. This questionnaire was directed to land owners to determine the size of effects which were caused by encroachment of sand on their farmland, especially on seasonal crops, and also to establish the current status of the vegetation cover. This questionnaire also focuses on the methods which the farmers have used to stop sand dune movement, and the environmental advantages of these different methods, comparing these methods with methods used in other parts of the world.

6.2.1 Process of designing the questionnaire

The importance of a questionnaire may be varied. For example, the different questions used may have differing objectives, being more specifically relevant to different groups involved with the phenomenon studied. However, there are standard points for the importance of a questionnaire, namely that all questions should enable information to be gathered efficiently; further, they should help the interaction with the respondents to be more systematic. They should also help directly to determine the size of effects caused by the phenomenon studied (Petric and Czarl, 2003).

Questionnaires are designed to obtain a variety of data. Usually they start with seeking the simplest, factual information, for example age or place of birth. They may then bring in attitudinal questions which are designed to probe values, attitudes and opinions of people. Also, there are usually open-ended questions, which allow for 'free' responses recorded for this data and which are categorized. Often they are also designed for measuring different types of attitude (Westerberg *et al*., 1997).

These general principles have been adopted in designing the questionnaire used in this study. A suitable structure was developed to comply with the limits of the study and the main objective of the research. Thus it sought to directly investigate the size of damages which have been caused by sand movement and the main reasons for such movement within the region; moreover, it sought to evaluate the responses of farmers concerning their observations on sand movement. Consequently, the questionnaire developed was divided into four sections. These sections of the questionnaire each cover a particular aspect of responses; particularly, those that pertain to the damages which are suffered by the farms within the region. Section one of the questionnaire concerned the location and characteristics of the farms. This section is very useful to give further clarification on the responses relating to farming problems caused by sand creep and the damage which this causes. It also may help explain the results from other questions, for example whether a farm is irrigated or not may influence other responses. In section two the farmers were asked some questions concerning sand movement and farming problems caused by this movement. Through this section information will be obtained on the observation of sand movement by the farmers and the extent of its reflection in farming problems, thus giving a greater understanding for the size of sand movement within the region. The third section of the questionnaire was concerning the exploitation of vegetation cover and damages which are caused by sand movement. The responses are useful to know how much the farmer exploits the local vegetation cover and how this might be a reflection of the extent of sand movement within the region, part of a clearer understanding of the extent of damages caused by sand encroachment. The final section of the questionnaire contained questions on the methods used by the farmers to stop the sand movement and their costs. Through the questions of this section will be clarified the most important methods which were used within the region for sand dune fixation and how much they cost. This will contribute to a better understanding of how to deal with this environmental problem.

These responses can then be compared later with the results obtained in chapters 4 and 5.

The process of checking of the questionnaire before using it has passed through three stages. The first stage was subject to the general conditions for the formulation of the questionnaire, and how to use it to serve the purposes of research by the researcher, as indicated above. In the second stage the questionnaire (in Arabic) was submitted for examination to a group of specialist lecturers in this field at the Geography department of Al merqeb University in Libya. The questionnaire then had some adjustments made to it, particularly to simplify questions. For the third stage the questionnaire (in English translation) was submitted for final examination by the supervisors and a specialist in the field of analysis of questionnaire data at the Division of Geographical and Environmental Sciences of the University of Bradford. Some further changes were made to the questionnaire, particularly to facilitate use of the statistical analysis of the data. The final questionnaire used (in Arabic) is given in the Appendix 2, alongside an approximate English translation.

There are a number of general issues conceiving the manner in which questionnaire information is obtained. These can be summarised as conceiving whether the questionnaire is self – administered or interviewer – led; how they are distributed, such as by part; the size of the sample; the expected response rate; the target sample of respondents; and the avoidance of bias. These issues are discussed more fully by Grassi *et al* (2003), Marshall (2005) and Preston (2009).

6.2.2 Distribution and collection of the questionnaire

For the present research, it was decided to follow the procedure of using a self – administered questionnaire which, however, would be distributed and returned (between December 2008 and January 2009) in collaboration with a group of high schools in the study area with pupils whose parents were farmers. The three regions within which the farms were sampled by questionnaire are shown in Figure 6.1**.** Six schools were selected so that the entire region was covered, where the distribution and collection of the questionnaire was achieved by students of the schools for their parents to complete. Thus, the secondary schools were used for distribution and collection of the questionnaire. The purpose of the questionnaire and its importance was explained to the students. Four days were given to allow completion of the questionnaire before returning to the school to collect them. A total of 450 questionnaires were distributed and 344 completed questionnaires were collected, giving a high overall response rate of 76.4% (much higher than the standard response rate of 20% often predicted; Marshall, 2005). In terms of the regional spread of responses to the questionnaire, replies from the farmers in Misurata, Almerqeb, and Tajora areas were 123, 114, and 107 respectively (the percentage response rates per region are given in Table 6.1). The numbers are sufficiently similar that there is unlikely to be pronounced bias towards any one area, these not affecting the overall conclusions when the data are combined. The data which were obtained from the questionnaire have been processed and analyzed using SPSS software version**.**

Table 6-1 The regional locations of farms, how many returned questionnaires came from each region, the percentage of returned questionnaires coming from the different regions, and the percentage response rate per region and overall.

Location of farms	Number of farms	Percent of total farms	Response rate (%)
Misurata region	123	35.8	27.3
Almerqeb region	114	33.1	25.3
Tajoura region	107	31.1	23.8
Total	344	100.0	76.4

6.3 Perception on sand dune locations and farming problems

Table 6-2 Frequencies and percentages of responses for all regions combined in for categories of agreement to the question of whether the farmers had experienced problems caused by sand dunes

Answers	Frequency	Percent
Strongly disagree	4	1.2
Disagree	11	3.2
Agree	196	57.0
Strongly agree	133	38.7
Total	344	100.0

Table 6.2 includes the frequencies and percentages reported by farmers to the question of whether they had experienced problems caused by sand dunes in their farms. Only 4.4% disagreed or strongly disagreed with the statement, while 95.7% agreed or strongly agreed. Clearly, the overwhelming majority of farmers had experienced farming problems due to the locations of sand dunes which were near their farms, while there were only very few farmers who did not notice any problems due to the locations of sand dunes. However, the size of these problems can be different from are farm to

another, according to the extent of sand movement and the method used to stop it.

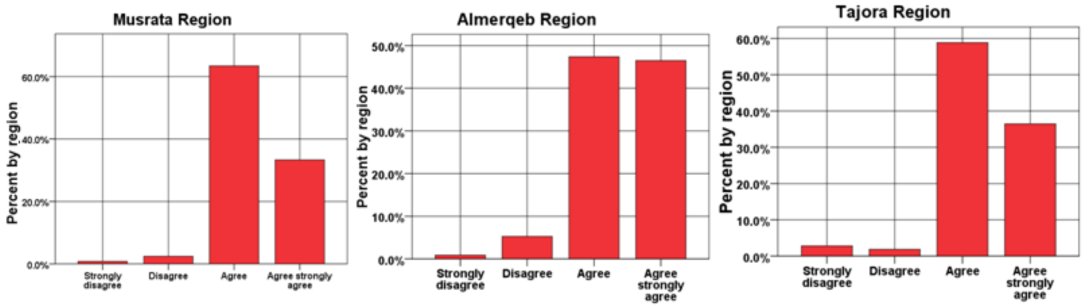
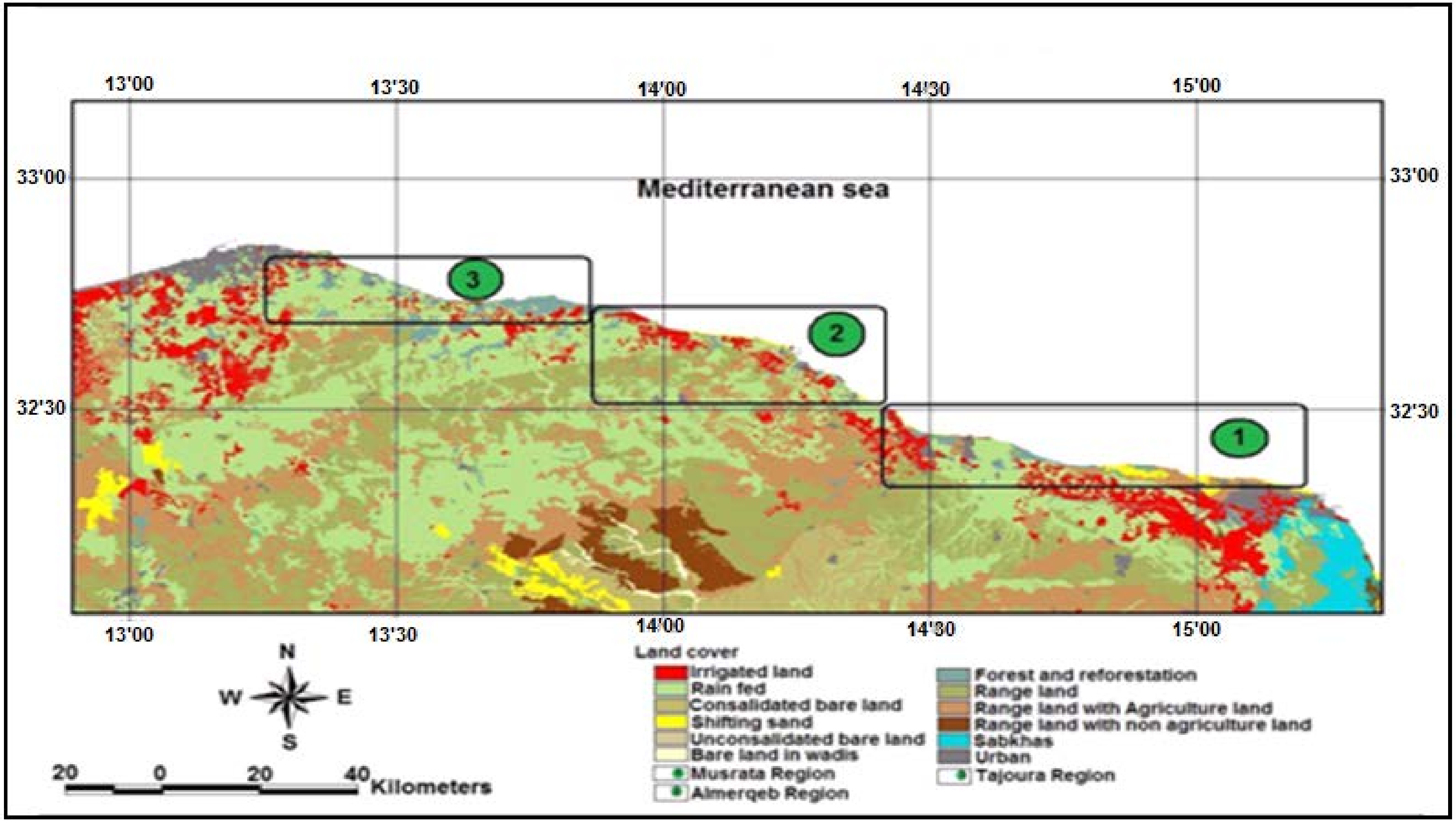


Figure 6.1 Responses to the statement that problems had been experienced due to sand dunes, divided up according to region.

The percentages of responses to this statement divided up according to the geographical regions are shown in Figure 6.2. The results are broadly consistent in all three regions; however, there was a even greater level of strong agreement with the statement in the Almerqeb region than in the others, perhaps reflecting greater problems with sand dunes in this area. The results show that there is a broad consensus in terms of the perception about farming problems resulting from sand dunes in the three regions. A chi-square contingency table test of the data (with six degrees of freedom) give x^2 = 12.217, p = .057, which is non-significant result. These results show that the responses to this question were broadly consistent across the three regions, so that there was no significantly different pattern of proportion associated with region.

Figure 6.2 Map of NW Libya showing the three areas covered by the questionnaire survey. The map also shows the types of land cover in the area.(Source: Land use map, Tripoli, Libya, 1980).



6.4 Number of years farmers have spent working on farms

Table 6-3 Frequencies and percentages of farmers who had been running a farm for different numbers of years

Run a farm (years)	Number of farms	Percent
0 ------------ <10	68	19.8
10 ----------- <20	92	26.7
20 ----------- <30	81	23.5
30 ----------- <40	103	29.9
Total	344	100.0

From Table 6.3 it can be seen that the number of farmers who had been working on their farms for the various lengths of time was quite evenly spread, between about 20 and 30% of farmers in each of the duration categories, but with a slightly greater number in the category of 30 – 40 years. Clearly many farmers have been working on farms for many years, which mean that there will be a substantial time period of firsthand knowledge covered for the information and data obtained from farmers. This will also help to identify the magnitude of the problems which have been facing farmers in the study area.

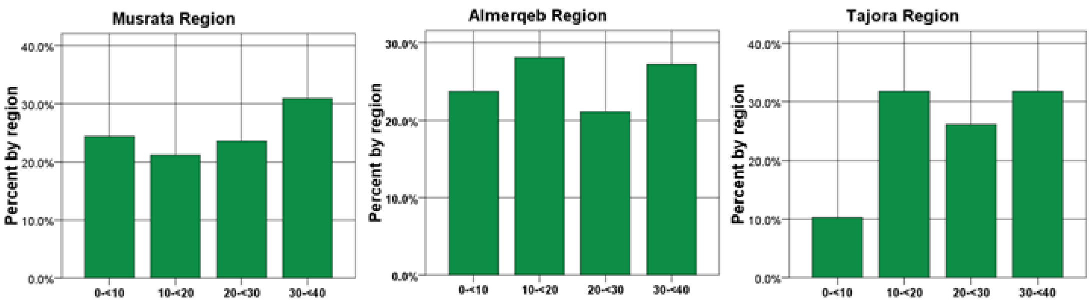


Figure 6.3 Responses to the question about how many years farmers had spent working on farms, divided up according to region.

Figure 6.3 shows the number of years farmers have worked on farms within the three regions separately Musrata had more farmers who had been working for 30-40 years, with a roughly equal number in the other three classes; Almerqeb and Tajora, by contrast, had the largest proportions of respondents equally from the second and fourth categories (10-20 and 30-40 years). The number of farmers from Tajora who had been working on farms for only 0-10 years was particularly low. Therefore, in all three regions there will be a good time span relating to the information obtained from farmers. A chi-square contingency table test of the data (with six degrees of freedom) give $x^2 = 13.678$, $p = .029$, which is a significant result**.** These results show that the numbers of years farmers have been running a farm in this group of study are statistically significant in the three regions.

6.5 The size of the farms

The farms in the study area differ in size and for the purposes of analysis they have been grouped into 3 classes: the smallest group is from 1 to 4.9 hectares; the second group is from 5 to 9.99 hectares; and the largest farms are of more than 10 hectares.

Table 6-4 Number of farms, for all three regions combined, that fall into each of the size categories indicated (in hectares)

Size of farm (hectares)	Frequency
1 ---------- 4.9	139
5 ---------- 9.9	127
10 +	78
Total	344

Table 6.4 shows that most of the farms range between in size 1 to 9.9 hectares. The percentage of farms in the three size classes were, respectively, 40.4%, 36.9% and 22.7% from the total number of 344 farms. This difference in the size of farms arises because of the widening and narrowing of the coastal plain and the area covered by sand dunes, which limit the size of some of these farms. Most farms in the study area are not included in the agricultural projects planned by the State .

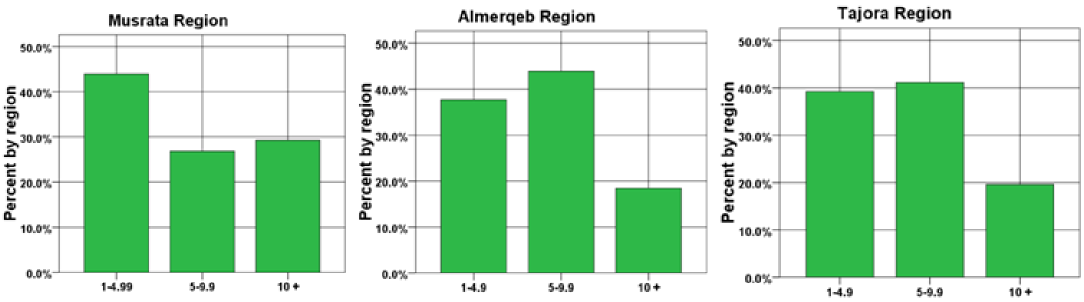


Figure 6.4 Farms location and size (in hectares)

Figure 6.4 shows that the farms in the three regions differed in their sizes, Musrata had a greater proportion of the smaller farms, with a roughly equal mix of the other two sizes; Almerqeb and Tajora, by contrast, had broadly equal numbers of the small and medium sized farms, but fewer large ones. This difference in the size of farms between the three regions is partly due to urban growth for cities at the expense of agriculture land; in Musrata region, for example, the farm sizes of the first class (1 -- 4.9 ha) have increased in number compared to the same class in the Almerqeb and Tajora regions. The coastal plain widens in the western part, in the Tajora region, and in the western part of the Almerqeb region, and this has led to increases in the farm sizes with more in the second class (5 -- 9.9 ha) compared to the same class in the Musrata region. Also the farm sizes of the third class (10+ ha) are more common in Musrata region compared to the same class in the other regions, this difference is due to the inclusion of the most southern parts of Musrata region in the agricultural projects planned by the state. A chi-square contingency table test of the data (with four degrees of freedom) gave x^2 = 9.709, p = .046, which is significant. Therefore, there is a difference in the pattern of farm sizes linked to the three regions, with Musrata in particular being different from the others.

6.6 The percentage of irrigated land in farms

Table 6-5 The percentage of fames reported as having different categories of percentage of irrigated land

Percentage of irrigated area	Number of farms	Percent
0 -------------- < 25%	8	2.3
25% ------------- < 50%	46	13.4
50% ------------- < 75%	111	32.3
75% +	179	52.0
Total	344	100.0

Table 6.5 shows that 52% of the farms had three quarters or more of their land irrigated and 32.3% of the farms had between half to three quarters of their land irrigated. The two categories of up to 50% irrigated together accounted for only 15.7% of the farms. The distribution of irrigated land within the study area reflects the use of different crop species, particularly those areas which require permanent irrigation; this was most common in farms that extend along the northern parts of the study area, as has been demonstrated in chapter five.

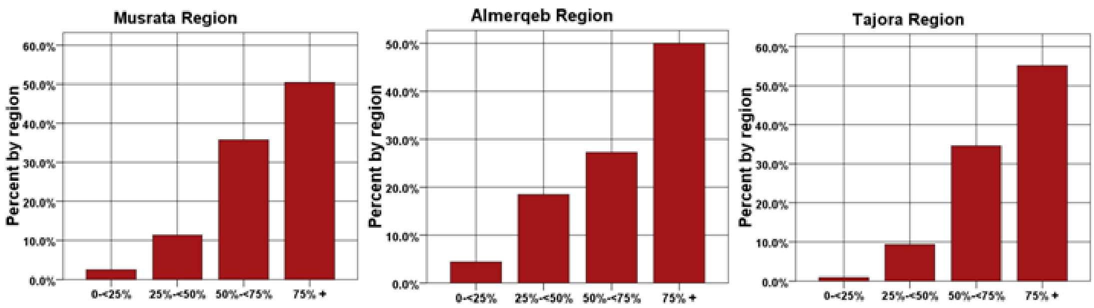


Figure 6.5 The percentage of each farm area that was irrigated, indicated separately for each region.

Figure 6.5 shows the percentage of irrigated land in farms illustrated separately for each of the three regions Tajora had a greater proportion of irrigated land in its farms, with a gradual decrease in the proportions of the other categories. The proportions for Musrata and Almerqeb were similar, but Almerqeb had a slightly greater proportion of farms in the category of 25-50% of land irrigated, and slightly fewer farms in the 50-75% category. These differences are probably related to the types of crops grown. A chi-square contingency table test of the data (with six degrees of freedom) give x^2 = 10.495[a], p = .105, which is a non-significant result**.** These results show that the responses to this question were broadly consistent across the three regions, so that there was no significantly different pattern of proportion associated with region.

6.7 Types of crops cultivated

Table 6-6 Types of crops cultivated

Types of crops	Frequency	Percent
Legumes	52	15.1
Fruit trees	86	25.0
vegetables	108	31.4
Other (Clover, Animal feed)	98	28.5
Total	344	100.0

The percentages of different types crop cultivated within farms which were studied are shown in Table 6.6. It can be seen that legumes comprised 15.1%, fruit trees accounted for 25%, vegetables were the most frequent crop at 31.4% and other crops (clover, animal feed) comprised 28.5%. It also can be seen that the highest percentages recorded may be due to the seasonal agriculture, this means that more than 60% of irrigated land in the study area is concerned with producing crops with financial returns, which can be reflected in development of the local environment, while there is a decrease in the cultivation of tree crops; this means that there are shortcomings in the administration and agricultural directives, or inappropriate application with a lack of attention to the environmental aspects of crop choice.

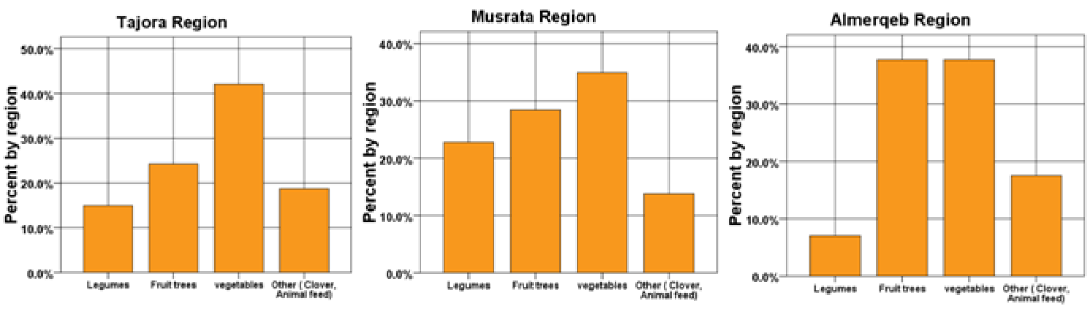


Figure 6.6 Types of crops cultivated, indicated for each region separately.

Figure 6.6 shows the proportions of crop types cultivated in the three regions, Misurata had a greater proportion of the vegetables crops, and also fruit terrs, with a mix in similar proportions of the other three crops (particularly low for the ‘other’ category); Almerqeb had a greater proportion of vegetable crops and fruit trees, with a reduced proportion of the other crops; Tajoura had a greater proportion of vegetable crops, with a moderately low proportion of the other crops. All three regions show a smaller proportion of growth of vegetable crops, which indicates that the farming system is dependent on permanent irrigation in most parts of the region. A chi-square contingency table test of the data (with six degrees of freedom) give x^2 = 14.875, p = .021 which is a significant result. These results therefore show that the crop types cultivated differ in the different regions studied, which are related to the proportion of the crops other than vegetables grown in the three regions.

6.8 Whether farms were created through removing sand

Table 6-7 Responses of farmers to the question of whether farms were created through removing sand

Answers	Region						Total for all regions	
	Musrata		Almerqeb		Tajora			
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Yes	83	24.1	101	29.4	92	26.8	276	80.2
No	40	11.6	13	3.8	15	4.4	68	19.8
Total	123	35.8	114	33.1	107	31.1	344	100

Table 6.7 shows that the percentage of farms which were created through removing sands was 80.2% out of the total number of farms which were studied, while there were 19.8% for farms which were created without removing sands. Thus, most of farms which were studied in this research directly related to the development of sand dune movement and their consequences.

Also from Table 6.7 the proportion of farms which were created through removing sands in the three regions can be seen. Almerqeb and Tajora had a greater proportion of farms which were created through removing sands; Musrata had a greater proportion of farmers saying that they had not removed sand to create their farms compared to the other regions. Even so, there were far fewer farms which were created without removing sands then had involved sand removal in all regions. The higher proportion of farms which were created through removing sands in the Almerqeb and Tajora regions, is due to these regions being located in the eastern part of the Aljafarah plain which is characterized by the widespread diffusion of Nbugat sand and desert sand dunes of local origin. In the Musrata region, the sand dunes are of marine origin, which are characterized by relatively limited movement. A chi-square contingency table test of the data (with six degrees of freedom) give $x^2 = 19.871$, $p < 0.0005$, which is an extremely significant result. This confirms that there is a very significant difference between the regions in how many farms required removal of sand to enable then to be created.

6.9 Methods used in creating farms

Table 6-8 Methods used in creating farms

Methods used	Frequency	Percent
primitive	89	25.9
latest technology used*	192	55.8
Other**	14	4.1
Never	49	14.2
Total	344	100.0

* = (Bulldozer, Caterpillar and Tipper Truck, Etc).
** = (Exploiting the flat land from the farms, and leave the rest of the rugged land).

Table 6.8 shows that over half of the farms were created using the latest technology, while over one quarter used primitive methods, a few used other methods, and 14.2% used no methods at all. The use of the latest technology involves the use of heavy machinery and trucks for example, typically removing the sand to somewhere else for the purpose of settling the land. This can have an undesirable effect on the environment because of destruction of vegetation which had formed on the sands in previous years, and therefore increasing the rate of sand movement.

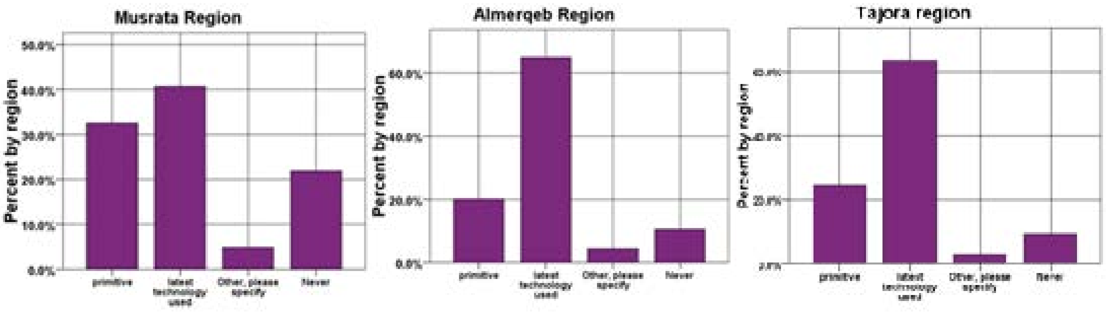


Figure 6.7 Methods used in creating farms

Considering the three regions separately, Almerqeb had a high usage of the latest technology when creating farms; in contrast, Musrata had a fairly high proportion of primitive methods used, or none at all (Figure 6.7). A chi-square contingency table test of the data (with six degrees of freedom) give x^2 = 20.224, p = .003, which is a very significant result. These results show that the methods used in these regions are statistically significant. The high proportion of farmers who had never used any of the methods for the establishment of these farms in Musrata is probably due to the topography of this region and the fact that the sand dunes are not so widespread as in Almerqeb and Tajora. However, the fact that these methods were used at all in creating the farms means that there are problems limiting the land reclamation process, regardless of the method that was used.

6.10 The current distance between farms and sand dunes

Table 6-9 The current distance between farms and sand dunes

Distance	Region						Total for all regions	
	Musrata		Almerqeb		Tajora			
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Less500 meters	60	17.4	41	11.9	43	12.5	144	41.9
More than 500 meters	63	18.4	73	21.2	64	18.6	200	58.1
Total	123	35.8	114	33.1	107	31.1	344	100

Table 6.9 shows that in response to the question about the distance between farms and sand dunes, 41.9% of farmers stated that sand dunes were within 500 meters, while 58.1% reported that they are further than 500 meters away. Clearly a sizeable minority of the farms had sand dunes quite close to them and through the split between nearer and further supports the objectives of this research project, namely to identify the extent of damage caused by sand dune movement within the study area, and obtaining responses relevant to a range of conditions of encroachment of sand.

Also it can be seen (Table 6.9), the proportion of distance between farms and sand dunes is different in the three regions, Musrata had a similar proportions of farms which were near and far from the places of sand dunes, while Almerqeb and Tajora had a greater proportion of the farms which were over 500 meters from the current locations of sand dunes. However, these differences were not enough to be significant when analysed by a chi-square contingency table test of the data (with two degrees of freedom) give x^2 = 4.171, p = .124, which is a non-statistically significant result, partly due to the low number of degrees of freedom (two).

6.11 Direction of sand dunes relative to farms

Table 6-10 Direction of sand dunes relative to farms

Directions	Frequency	Percent
North	86	25.0
South	63	18.3
West	82	23.8
East	47	13.7
All directions	66	19.2
Total	344	100.0

Table 6.10 shows farmers indicated that the percentage of farms which had sand dunes located to the north, south, west, east, and all directions relative to the farms, were 25%, 18.3%, 23.8%, 13.7% and 19.2%, respectively. The highest percentage was recorded for the north direction, with the west direction being the next highest. This means that nearly 50% of farms which were studied are bounded by sand dunes to the north and west. Therefore the current distribution of sand dune locations for farms highlights their relationship with the prevailing wind direction in the study area. It should also be noted, though, that sand dunes are present in all directions, not just north and west.

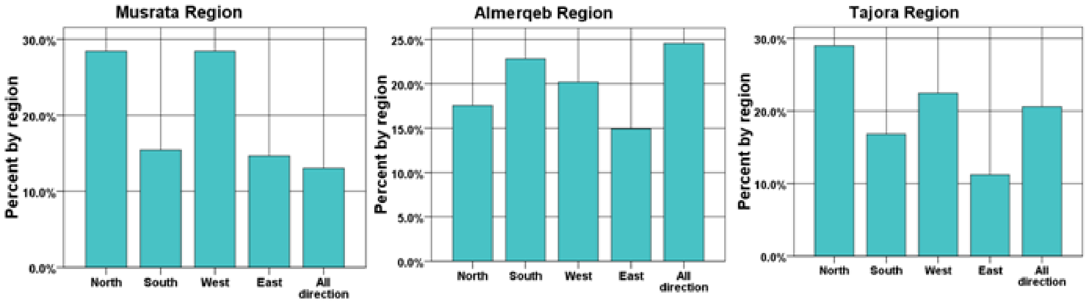


Figure 6.8 Direction of sand dunes relative to farms

The values for the three regions separately show some difference between them (Figure 6.8). Musrata had a greater proportion of the farms bordered by sand dunes from the north and west direction, with a roughly equal and lower proportion in the other directions; Almerqeb had a greater proportion of the farms bordered by sand dunes from all directions, with fairly high proportions for each of the other directions separately; Tajora by contrast, had a greater proportion of the farms bordered by sand dunes from the north direction, with a mixed decrease in the proportions of the other directions. The results show that there is variation in the direction of sand dune whereabouts for the farms in the different parts of the region. These differences did not prove to be significant, however ($x^2_{(8df)}$ = 12.520, p = .129).

6.12 Seasons in which sand movement is observed

Table 6-11 Seasons in which sand movement is observed

Year seasons	Frequency	Percent
Winter	29	8.4
Spring	124	36.0
Summer	59	17.2
Autumn	76	22.1
All year seasons	56	16.3
Total	344	100.0

Table 6.11 shows that the greatest percentage of seasonal movement of sand within farms was observed in the spring, while the lowest percentage occurred in the winter. The other seasons of the year, and the ‘All seasons’ option, were indicated by approximately the same number of farmers. This difference in proportions of seasonal sand encroachment could be due to several reasons; the amount of rain in the winter could lower the amount of sand movement then; the higher amount of movement in spring could be due to changes in wind direction, as well as the drying effect on the sand particles.

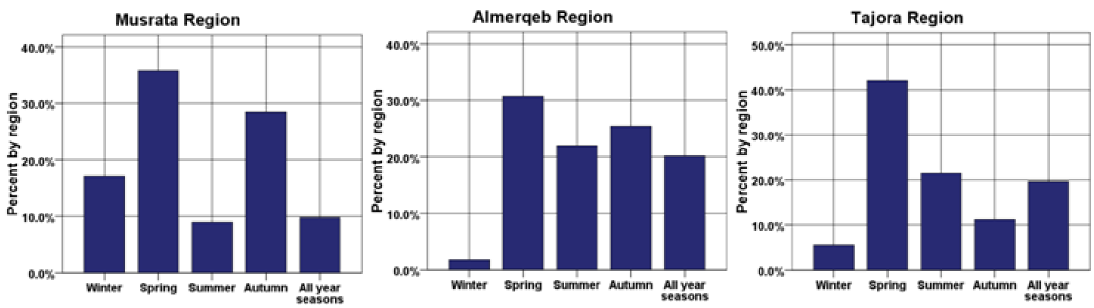


Figure 6.9 Sand movements observed in the different seasons, for each region separately.

There were substantial differences between the three regions in the season in which most sand movement occurred (Figure 6.9), which were shown to be significant in a chi-square contingency table analysis (df = 8,x^2 = 41.989, $p< 0.005$). Tajora had a greater proportion of sand movement in the spring season, with relatively little in the other seasons; Musrata had most sand movement in spring, but also quite a lot in autumn, and the lowest amount of movement in the summer; Almerqeb, by contrast, had quite high proportions of sand movement during most seasons of the year, but the lowest movement during the winter season. The results show consistency in the high proportion of sand movement during the spring season in the three regions, but with notable differences between the proportions in the other seasons. It is worth emphasising that this consistent reporting of sand movement during the spring season by farmers is largely consistent with the results of climate data in the region.

6.13 Percentage of crops damaged by sand movement

Table 6-12 Percentage of crops damaged by sand movement

Size of damage	Number of farms	Percent
Loss of Crop Production of more than 25%	2	0.6
Loss of Crop Production of between 12.5 and 25%	24	7.0
Loss of Corp Production of less than 12.5%	264	76.7
Never	54	15.7
Total	344	100.0

It is clear from Table 6.12 that the majority (more than three quarters) of farms were reported as having only a modest loss of crops due to sand movement, with a further 15.7% not being reported as having any damage at all. However, although infrequent, some farmers reported more significant amounts of crop damage. The differences in the amount of damage might be attributed to the methods which were used by farmers to stop the encroachment of sand on their crops.

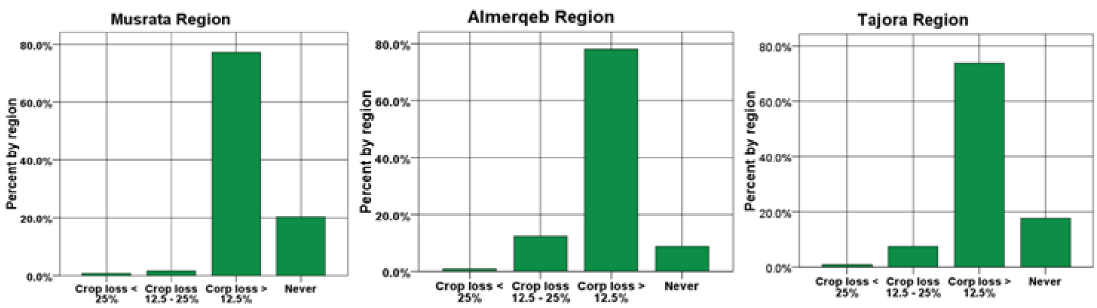


Figure 6.10 Percentage of crop damage due to sand movement, for each region separately.

Figure 6.10 shows that the proportion of crop damages resulting from sand movement is very similar in the three regions, Musrata and Tajora had a slightly greater proportion of responses indicating no loss of crops, while Almerqeb had somewhat more of the heavier proportion damaged (12.5-25%). Therefore, there is consistency in terms of the reporting of the scale of damages resulting from sand movement in the three regions. This result is consistent with the results of sand movement in the region which have been reached in chapter 4 and 5 dramatically. A chi-square contingency table test of the data (with six degrees of freedom) gave $x^2 = 16.421$, $p = .012$, which is a significant result. These results show that there is a different level of crop damage in the different regions.

6.14 Exploitation of sand dune vegetation for grazing

Table 6-13 Exploitation of sand dune vegetation for grazing for the three regions separately and combined

Answers	Region						Total for all regions	
	Musrata		Almerqeb		Tajora			
	Frequency	%	Frequency	%	Frequency	%	Frequency	%
Yes	*98*	*28.5*	*101*	*29.4*	*89*	*25.9*	*288*	*83.7*
No	**25**	**7.3**	**13**	**3.8**	**18**	**5.2**	**56**	**16.3**
Total	*123*	*35.8*	*114*	*33.1*	*107*	*31.1*	*344*	*100*

Table 6.13 shows that in response to the question about whether the sand dunes vegetation was exploited for grazing, of farmers said yes 83.7%, and 16.3% said no. This means that more than three-quarters of respondents are exploiting the vegetation cover for grazing of their animals. The high

percentage of vegetation exploitation may have lead to an increase in sand movement. However, it can be seen that the proportion of exploitation of vegetation for grazing in the three regions is not the same; Almerqeb and Tajoura had a greater proportion of vegetation exploitation, with a slightly lower usage in Musrata. A chi-square contingency table test of the data (with two degrees of freedom) give x^2 = 3.489, p = .175, which is a non-significant result, partly due to the low number of degrees of freedom (two).

6.15 Sand movement frequency

Table 6-14 Responses to the question about how frequently sand movement occurred near the farms.

Sand movement	Frequency	Percent
Never	1	.3
Very rarely	27	7.8
Occasionally (once every 5 years)	99	28.8
Frequently (about once every year)	132	38.4
Very frequently (more than once every year)	85	24.7
Total	344	100.0

From Table 6.14 it can be seen that, according to the farmers observations sand movement near to their farms occurred quite frequently, with the greatest regarded frequency being once a year but with over 90% separating movement at least once every 5 years. This clearly shown that sand movement is generally quite active in the region as a whole.

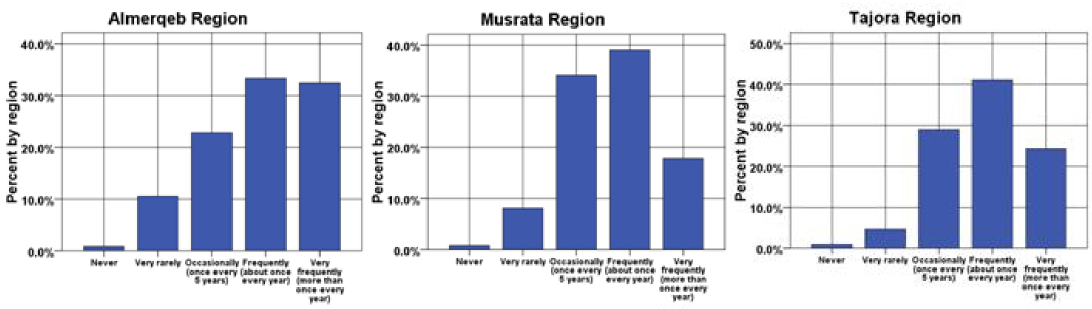


Figure 6.11 Sand movement velocities

The situation in the three different regions (Figure 6.11) shows similarity in patters in the Musrata and Tajora regions, but with a greater proportion of very frequent sand movement in the Almerqeb region. Results show that there is a general consensus in terms of amount of sand movement in the three regions; this consensus makes the results more credible, especially as they are consistent with the results of prediction formulas for sand transport rate that have been reached in the fourth chapter. A chi-square contingency table test of the data (with eight degrees of freedom) gave $x^2 = 13.177$, p = .106, which is a non- significant result. These results show that the farmers responses concerning the frequency of sand movement in this group of study did not very significantly between regions, ever thigh there were some different recorded.

6.16 Methods used to stop sand dune encroachments on the farms

Table 6-15 Methods used to stop sand dune encroachments on the farms.

Methods used	Number of farms	Percent
Afforestation	220	64.0
Physical Barriers	117	34.0
Other (e. g. removal)	7	2.0
Total	344	100.0

Table 6.15 shows the frequencies of responses and relevant percentages of methods used to stop sand dune encroachment in the farms which were studied. Afforestation was used approximately twice as often as physical barriers, and almost is other methods were used. This preference for afforestation may be due to the state financial contribution in previous years to support afforestation of mobile sand dunes, and also of method of reforestation by farmers may be less expensive in terms of effort and money compared to other methods.

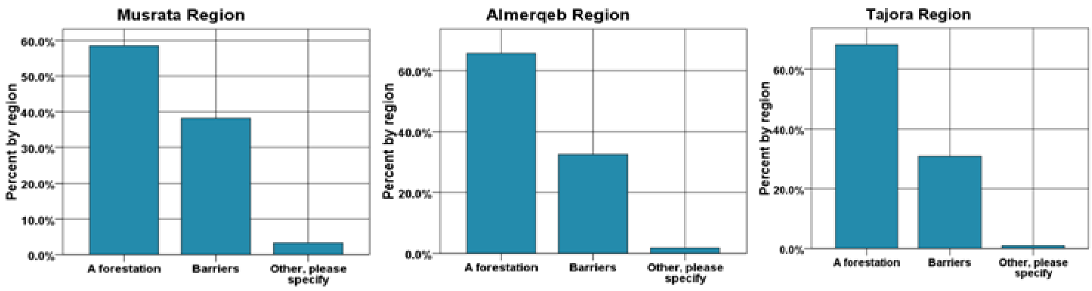


Figure 6.12 Methods used to stop sand dunes encroachments in the farms in the three regions separately.

Figure 6.12 shows that the proportions of methods used to stop sand dunes encroachment were very similar in the three regions. A chi-square contingency table test of the data (with four degrees of freedom) give x^2 = 3.541, p = .472, which is a non-significant result. Although there are slight aviations in the frequency of usage of the different methods, they are not statistically significant.

6.17 Costs of stopping sand creeping

Table 6-16 Costs of stopping sand creeping

Costs for the whole farm (per year)	Number of farms	Percent
Very little (< 250 DL)	29	8.4
Some (251-500 DL)	222	64.5
A lot (> 500 DL)	93	27.0
Total	344	100.0

DL = Libyan Dinar.

Table 6.16 shows that the percentage of farmers reporting the different level of cost needed in stopping sand creeping in the farms was particularly high for the 251-500DL-per year category. Therefore, the highest proportion of responses related to a moderate cost to the farmers to stop sand movement affecting their crops, with second most frequent responses being spending a lot of money; few farmers reported spending very little in costs. Clearly there is a notable financial outlay every year to stop sand movement within the study area.

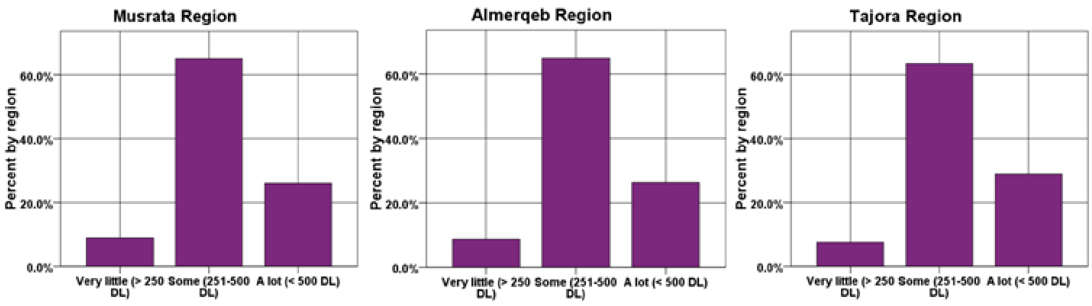


Figure 6.13 Costs of stopping sand creeping

Figure 6.13 shows that the proportion of responses concerning the level of cost for stopping sand creeping is very consistent in the three regions. A chi-square contingency table test of the data (with four degrees of freedom) = .411, p = .982, which is a non-significant result. Results show that there is a consensus about the spending cost per farm in the three regions, this convergence in the proportions, especially with the second category, is a clear signal that the agricultural land within the area was affected by the sand movement.

6.18 Discussion and conclusion

For the sake of clarity, the discussion in this chapter will be arranged into four sections, corresponding broadly to the questions which were asked to the owners of farms. It seeks to highlight the interesting issues raised by these results and to explore their significance in relation to the phenomenon of sand movement and the earlier literature. Thus, section one explores responses concerning the perception about the occurrence farming problems. Section two discusses the responses concerning the status of farms. Section three discusses the responses concerning sand movement. Section four explores the status of vegetation and damage caused by sand creep. Section five discusses the responses concerning the methods used to stop sand movement and their costs.

6.18.1 The responses concerning farming problems due to sand creep

Before discussing the first issue of this theme it is useful to point out what has been mentioned earlier, that in recent years there is a remarkable increase of land desertified within Libya, therefore exacerbating the rate with which farming problems occur, which enables farmers to see what is happening in their farms in terms of developments in desertification during their lifetimes.

Accordingly, the researcher posed the question of perception about farming problems caused by sand movement in the region. It is valuable to find out to what extent the perceptions of farmers are consistent with the widely held perception that there is a general farming problem as a result of sand encroachment. Any differences might be due to two reasons: the first one is size of local sand movement; the second reason is due to the use of methods to stop sand movement.

Land owners were asked "whether they support the view that there are farming problems as a result of the encroachment of sand, for each farm". The responses given by the land owners indicating that there were problems are consistent with those given by local authorities in their reports about the evolution of the phenomenon of sand movement and its intensity in recent years within the region (Ministry of Agriculture, Libya, 2006). This matches with the results of previous studies, which have been mentioned earlier, that there is a remarkable increase in recent years in the area of land desertified throughout Arab countries which reduces production of farmers in their areas (Ayad, 1995; Abd Elgawad, 1997).

Furthermore, many writers **(**e g. Darraz, 1995; Mastronuzzi and Sans, 2002; Wang *et al*. 2004) indicate that the phenomenon of sand movement is an important environmental problem within dry and semi dry areas. To discuss this important point, it should be noted that this phenomenon is generally already present, and thus it should be treated as a persistent problem associated with the region, but through the responses of land owners it is very clear about their perception of the evolution of this phenomenon and its impact on crops. There is a clear agreement on the part of most land owners on the existence of farming problems as a result of sand movement (Table 6.1; Figure 6.2).

However, a small minority of 4.4% of land owners expressed their disagreement with the existence of agricultural problems, suggesting that there is at least some farming land protected from the effects of sand encroachment. However, from what has been mentioned above, one can conclude that there is a considerable agreement among most land owners regarding the current farming problems in terms of sand creep. This reflects a clear view about the damages due to sand movement. Also these comments reflect to a large extent one of the environmental problems that Libya suffers from which has been mentioned in chapter 2.

6.18.2 The responses concerning the situation of farms

This section of the questionnaire included a number of points, namely the length of time farmers have worked in farms, the total farm area, the percentage of irrigated land, the type of crops grown, in addition to how the farm was created and the methods used to create it.

It is useful to point out that the results relating to the details of the farms have been embedded amongst the main important points in the design of the questionnaire, as has been done in previous studies (e. g. Oppermann, 2003). This has enabled such points to illuminate other result from the survey, for example linking the total size of the farm with the amount of irrigated land and the methods of control of sand dune movement (Al-harthy *et al.,* 2007).

In response to the question of how many years farmers had worked on farms, most replies indicated that farmers overall have considerable experience in farming, with the majority of them having worked on farms for 20 years or more (Table 6.3), as indicated in section 6.5. It is useful to identify more generally the perceptions of land owners as to their experience of farming problems, as well as their views with regard to how to control sand movement. The literature underscores the importance of the length of past experience of respondents in supporting the results which will be obtained in a survey. This fact was noted by many writers such as Al Kataly, (1988), Gafsi and Brossier, 1997, and Schonhart *et al*., (2011).

The second part of this exploration asked land owners what the total area was that they farmed. The results showed that each of the size categories suggested by the researcher was indicated by a substantial percentage of the total number of farms (for example, 40.4% of farms having an area of up to five hectares; Table 6.4, and Figure 6.4). Most of the farms in the study area range in size between 1 and 9.9 hectares. The size of farms is related to widening and narrowing of the coastal plain and the spread of sand dunes over the entire region, which limits the size of some of these farms. Most farms in the study area were not part of the agricultural projects planned by the State. This matches with what was mentioned earlier in the literature review.

The third part of this exploration asked land owners “what is the percentage of irrigated area”. The responses were in one of the categories of irrigated area suggested by the researcher (for example, 52% of farms reported irrigating three quarters or more of their area (Table 6.5). In discussing the issue of the irrigated land, one can note that there are a number of farms dependent on rains in each year (Figure 6.5). These areas of rainfed farming systems reflect to a large extent the problems that the region suffers from which have been mentioned by Libyan and Arab experts in the area of sand dune fixation (Almasoudi, 1984, Al Kataly, 1988 and Ayad, 1995), and which was addressed in chapter3.

The fourth part of this theme concerns the type of crops produced in these farms. The responses of land owners to this were mixed between four types of production (Table 6.6). Despite the importance of tree crops to deter sand movement (Ahmed, 1990), the results from the present study showed that there is a noteworthy shortage of these crops (Figure 6.6). This might be partly attributed to the financial gain of other crops; especially in this region where there is no control of agricultural institutions by the state, as well as the lack of experience of land owners in terms of maintaining the environmental system. This issue was mentioned earlier in the literature review.

In the last part of this exploration, land owners were asked how they had created their farm, and the methods they had used. The results shown in

Table 6.7, although not unanimous, indicated that 88.6% of land owners stated that there is an urgent need to create farms through removing sands in the region. This result may be due to the considerable extent of spread of sand dunes, specially the Nbugat sand of local origin in this region. This theme also questioned the methods used (primitive, latest technology and other) to create a farm. The results showed that there is an increasing use of the latest technological methods for farms to be created in the region (Figure 6.7). This means using heavy machinery and trucks in those processes.

The question that arises here is; what role might those processes play in increasing the rate of sand movement? It has been agreed by many researchers that such processes do not contribute towards environmental protection, and that conservation requires knowledge and planning (Macdonald and Johnson, 2000; Ray and Williams, 2002; Voinov and Bousquet, 2010). For example, the processes of removing sand to settle or remove it to somewhere else typically require removing the vegetation cover; this work would have an effect on local environmental through cutting off and destroying the vegetation which helps bind the soil in place.

6.18.3 The responses concerning sand movement

In this section, the exploration of sand movement has included a number of points, namely the frequency of sand movement, the timing of seasonal movement of sand, in addition to the direction in which sand dunes are located relative to the farms and the distance between farms and sand dunes.

Land owners were asked how often sand movement occurred. The responses showed a clear consensus on the part of most land owners regarding the existence of sand movement within their farms, with some differences in the extent of it. However, approximately 0.3% of land owners indicated that there was no sand movement within their farms. These results reflect to a large extent the results which were obtained earlier in chapter 4. The second issue within this theme concerns the question of in which season the sand movement was observed. The responses of land owners were mixed (Table 6.10), but with a clear increase in the amount of sand movement during the spring and autumn. This might be partly attributed to the wind speed in such seasons (chapter 3) and developments which have occurred in the extent of vegetation cover recently. Clearly there are two seasons in each year where sand movement mainly occurs, as has been mentioned in chapter 4.

In the third part of this exploration land owners were asked in what direction and at what distance were sand dunes located in relation to the farms. The land owners indicated that sand dunes were located in a variety of directions, and approximately equal numbers were located less or more than 500m away. The most important of these comments is that the sand dunes are distributed in all directions relative to the farms. This means that there is the potential for sand movement from all directions, but therefore the factors of wind speed from different directions will be crucial in determining the extent of the problem experienced by farmers, as noted by Almasoudi (1984), Al Kataly, (1988) and Wang *et al*. (2008).

In summary, one can conclude three important facts. The first one is that sand movement has been clearly observed in the whole region (Table 6.9). Secondly, sand movement has been observed to vary in both timing and frequency in different places, as noted by Bagnold (1973), Wang and Ke (1997). Thirdly the direction of sand dunes location is likely to be important in influencing sand movement into farms.

6.18.4 The responses concerning the vegetation cover and damages.

This section of the exploration has included two points, the status of vegetation and the damage caused by the creeping of sand.

Discussing the first issue of this theme it is useful to indicate the importance of the vegetation cover in the process of sand dune fixation and protect the local environment generally, as has been mentioned previously in chapter 2. Accordingly, the researcher posed the question" Do you take advantage of sand dune vegetation for grazing". The responses given by the land owners are consistent with the results of chapter 5. The above results shown in Table 6.12, although not unanimous, indicated that 88.6% of land owners stated that they exploited the vegetation, as noted by Al-Enezi *et al*. (2008). This exploitation would be in the form of grazing livestock on the available vegetation.

The second part of this exploration asked land owners “what damage is caused by the creeping of sand”. The results showed that there was notable loss of crop production due to this cause (Table 6.12). This matches with what many researchers have referred to (eg. Almasoudi, 1984 and Nhal, 1989), as has been mentioned earlier in chapter 2.

From what has been mentioned above, one can conclude that there is a considerable agreement among all land owners regarding the amount of damage of their crop production due to sand movement, of about a quarter of the crop annually. This reflects a clear view that the sand movement is a large environmental problem suffered in the study area.

6.18.5 The responses concerning the methods used to stop the sand movement and their costs.

The results showed that the land owners mostly focused on the use of afforestation to help control the sand movement in the region, with a moderate number using barriers. This is consistent with the results of previous studies (see chapter 2).

The majority of the farmers spend a moderate amount of money (251 – 500DL) each year in trying to control sand dune movement, which again is consistent with previous studies (chapter 2). As has been mentioned above, the lack of or shortage of financial resources and governmental assistance may have negative consequences and affect the level of achievements in desertification control. This fact was confirmed by a number of previous researchers who have stated that the lack of such resources affected the quality of control methods used and if such sources had been available to land owners they might have been able to present more successes in the field of desertification control. This theme has been explored by Nhal (1989), who revealed that the quality of financial resources affects the extent of achievement in desertification control.

6.18.6 Final comments

In summary, the views of land owners with regard to these themes confirm similar facts discussed by a number of authors in previous studies. For example, the Arab Centre for the Studies of Arid Zones and Dry (ACSAD, 2006) indicates in its report that the governments of Arab Countries suffer considerable economic losses due to desertification ; and Darraz, (1995) indicates that the paucity of technical capabilities, and the awareness of the local population, especially in the Maghreb countries, make it difficult to keep abreast of the latest technical developments in the field of desertification control. Furthermore, the present results are consistent with the fact that sand movement is an environmental problem afflicting many countries of the world, due to climate changes and increasing population pressure, especially in the third world countries (Xu *et al*., 2010).

These findings are important; the local authorities should contribute both the financial resources and sustainable development to address this phenomenon, so that the land owners can gain and track the latest technical methods in the field of desertification control.

Finally, all the results obtained from the questionnaire are very useful when discussing the previous results which have been obtained in chapters four and five. Also, most of these results directly support the objectives of this project. There is a broad agreement between the results of responses concerning farming problems due to sand creep and the results which have been obtained in earlier chapters. In addition, further information was obtained which can support interpretations about the results in earlier chapters regarding the size and direction of sand movement within the study area. Further discussion of these results in relation to those of all aims of investigation in this project will be given in the next chapter.

7 CHAPTER SEVEN: General discussion

7.1 Introduction

This study has used three methods to address the aims and objectives of this research, namely to assess the amount of movement of sand dunes and the impact this has on local people in NW Libya. These methods have included using an equation to predict the rate of sand dune movement, using satellite images to analyse the changing land use cover of the study area over time, and using a questionnaire to identify the damages caused by sand movement within the study area. This chapter will discuss the important points raised by the results from these three approaches, and aims to compare the results obtained from the different methods. This work will hopefully contribute to providing a good description and analysis of sand dune movement in NW Libya.

7.2 Changes in land cover categories in the study area and their implications for sand movement.

The size of the human population has an important role in increasing human pressure on land use within the region. The rate of population growth in the territory, according to the censuses of 1984, 1994, and 2004, respectively was 31.2%, 34.7% and 37.5% (GAIL, 2006). Furthermore, there were notable increases in the number of animals which were reared by the farmers in the territory over the same period, according to the general censuses of agriculture of 1984, 1994, and 2004, where the proportional increases per decade were, respectively, 19.3%, 22.5% and 24.6% (GAIL, 2006).

Undoubtedly these substantial changes have caused an increasing pressure on vegetation cover, as well as the increase in urban area with shrinking forest area, and thus this is likely to have been directly reflected in an increasing problem of sand movement within the region.

In general the type of vegetation in the study area is of the steppe type, and the forest which is present has been cultivated specifically for the stabilization of sand dunes. The steppe climate type is defined by having a semi dry weather in most months of the year, with only a low rate of rainfall and with an annual precipitation total of 260 mm. Moreover, there is evidence of a succession of drought periods where there are six dry years in every ten, with an annual maximum temperature of 28 ^{o} C and an annual minimum temperature of 13 ^{o} C, which would lead to high evapotranspiration. All of these conditions together result in a poor growth of vegetation and low species diversity.

In recent years the natural vegetation in the region had been exposed to further inappropriate and excessive exploitation. The issue of lack of or poor vegetation cover has been noted in some reports issued by (Libyan Agricultural Ministry 2007)**,** as well as being observed first hand during the fieldwork for this study. It is also worth noting the results obtained from the questionnaire in chapter 6, which have indicated that more than three-quarters of the farmers who responded to the survey are exploiting the vegetation cover for grazing of their animals (83.7%). This percentage was not very different in the two parts of the region, but the western part had a slightly higher proportion of vegetation exploitation, composed to the eastern part.

Considering the results which were obtained from analysis of satellite images in chapter 5, about the changes shown by the different categories over the whole seventeen year period (1986 – 2003), results indicated that there were decreases in percentage terms of the bare soil with sparse vegetation (-19%). This category represents most of the vegetation cover within the study area, apart from forests (which also declined). Further, by tracking the years which showed the biggest percentage drop in this category, it can be seen that almost half of the loss of area of the bare soil with sparse vegetation occurred during the first four years (1986 - 1990). It is likely that the decline in this category of vegetation cover is due to two factors. The first is limited rainfall (the length of the dry period). As noted above the rate of rainfall in the region is very limited, and was particularly low during the previous twelve months prior to taking the satellite image (from August 1985 to July 1986, the total rainfall was only 109 mm (see Table 7.1).

Table 7-1 Monthly total of rainfall (mm) in the study area during 1985 -1986

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1985	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0**	**10**	**6**	**6**	**37**
1986	**16**	**3**	**27**	**0**	**2**	**1**	**1**	**Total= 109 mm**				

The second factor is human activity, particularly overgrazing. As indicated above, the results of the questionnaire indicated the region's farmers have been using vegetation for grazing of their livestock. Thus, there is agreement between the results obtained in chapter 5 and chapter 6 about the deterioration of vegetation cover within the study area. This negative evolution of vegetation cover will lead to greater instability of old sand dunes within the region, with a large potential for the emergence of new dunes, mostly in the phase of growth. This emphasizes the growing problem of sand dunes in this region of Libya.

The large changes of farming land which were observed especially in western parts of the study area are linked to water reaching the farmers from the Great Man-Made River Project (GMMRP; Darraz, 1995). In recent years there has started to be a focus on exploitation of all lands for agriculture, including forest land and other grassland (Aljadedie, 1992, p. 235).

However, there are some slight differences in the results regarding the exploitation of vegetation cover between the two parts of the study area. In the western part the vegetation was exploited by 86.3% of land owners, while in the eastern part 79% of land owners did so (Table 6.12), this exploitation would be in the form of grazing livestock on the available vegetation. Also, this result may have relevance to the results of land cover changes found in chapter 5, where there was a slight decrease in the vegetation category within the western part over the period 1986 - 2003 (Table 5.6), while in contrast the eastern part had a positive increase in the vegetation category during the same time (Table 5.15).

The forested areas have been a significant component of the study area because much of this forest has been created for fixation of sand dunes and combating desertification within the region. However, forest areas cover less than 2% of the study area as a whole.

Furthermore the forested areas of the region have been exposed to much exploitation, with a lack of protection of it and insufficient attention given to it by the local administrations; for example, there has been an almost complete halt to re-forestation of forest which has been destroyed, or afforestation of those areas where sand dunes have appeared, since 1986 **(**Almakasbie, 2001**).** There has also been a lack of control and direct supervision which has led to forests being exposed to more cutting and weed removal (Alkorachy, 1992). The results obtained from the analysis of satellite images in chapter 5 have indicated great decreases in percentage terms in forest coverage (-67.5%) within the whole study area during the 17 year period investigated (1986 - 2003). Most decline of forested areas was during one period of nine years (1990 - 1999), during which time more than half of the forest cover in the region was lost. The process of logging of the forest is the most prominent factor contributing to this shrinking of the forest coverage in the study area (illustrated in Figure 7.1), probably contributed to by a lack of sufficient attention given to forests by the local authorities. It is possible that poor rainfall might also have contributed to decline by 1999, as the twelve months prior to taking the satellite image of 1999 (from September 1998 to August 1999), had a particularly low total rainfall of 65 mm (Table 7.2), although by itself poor rainfall probably is not responsible for the rapid decrease in forest cover observed, especially as the previous twelve months rainfall had been higher, but it would have an impact on seasonal vegetation.

Table 7-2 Monthly total of rainfall (mm) in the study area during 1998 -1999

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1998	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**0**	**11**	**24**	**30**
1999	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**Total= 65 mm**			

Figure 7.1 Shows the processes of cutting and removal of trees which have exposed the sandy forest soils in the study area (Photos by the researcher, October, 2008)

The main changes in both parts of the study area mostly concern the loss of forest, which has probably changed directly into bare soil with sparse vegetation, and also changed to sand dunes. The changes from forest cover to areas of sand dunes may happen quickly, as a direct result of the cutting and removing of a large area of forest. It is possible that the change has occurred with bare soil with sparse vegetation as an intermediate transition stage, but if so then the land cover has not remained in that category for long. The absolute change in amount of forest in the eastern area is smaller than in the western area studied (Table 5.5), but in percentage terms the loss is even greater. The great decline of forested areas has caused an increase problem of sand dune movement in the region.

Despite the negative progress which has occurred concerning forest coverage, the results obtained from the questionnaire in chapter 6 have indicated that there has been positive progress in the use of afforestation at a small scale on farms where 64% of farmers have used afforestation method to stop sand dune encroachment on the farms. The afforestation method has been used approximately twice as often as physical barriers, and almost no other methods were used. Thus, the comparison of these different results have indicated that there is a conflict between the great loss in forest area generally, and at the same time the positive process of using re-afforestation.

The disagreement between the results above can be considered in relation to the matrix of changes in land cover categories over the whole time period considered (1986 - 2003). The results of the change matrix for land cover categories show that over time forest was converted mostly to sand and farming land. However, it should be noted that there were some gains recorded from farming land changing to forest, though not quite enough to compensate the losses. The changes from forest to farming involved 2464 ha, while the changes from farming to forest involved 2376 ha which nearly offset the losses, leaving an absolute shift from forest to farming of only 87 ha. By contrast, it is worth referring to the changes relating to sand and forest categories over this period. The actual transformation from forest to sand was 1340 ha. There is apparently some re-forestation of the sand area, by

163 ha. Therefore, the great majority of the loss of forest was from its conversion to sand, whereas the losses to farming were largely offset, presumably by afforestation of farm land.

During this period it is clear that there has been increasing pressure on forest land of the area for the 18 years covered by these data. Generally, therefore, there have been on one hand climatic issues involving a succession of periods of drought, with clear increases in the number of wind days in year (see chapter 3), and a link of that with the high rates of wind speed, which will enhance sand movement, and on the other hand the destruction of protecting vegetation and a decline in the area of forest. This situation as a whole will probably have led to the significant acceleration of the problem of sand dunes movement.

7.3 Predictions and actual observations about sand movement over time

As noted in chapter 3, the origin of sediment source and its supply in the study area is an important point to help interpret the results from chapters 4, 5, and 6. Most of the deposits which cover the study area are from Quaternary sediments, including sand formations in two parts of the study area, where the sand formations in the western part belong to the recent desert sediments (dry valleys deposits), this group of sediments being related to the younger dry valleys where there is a ready availability of supply because these areas are still constantly and rapidly evolving. In contrast, the source of sand formations in the eastern part is due to marine formations resulting from the decline of sea level during the Holocene, where the fossilized formations have emerged along the shore line; therefore, sediment supply for these formations is at a low rate compared to the supplies of those formations in the western part of the study area, because the processes of erosion are very slow in such cases. In general, however, there is a plentiful sediment supply within the study area.

The sand particle size in the study area as a whole had a mean size of between 1.7 - 3 phi, 0.125 - 0.25 mm, and the grains were moderately well sorted, fewer than 6% of the particles being <63 mm in size (Table 4.4). However, the particle sizes of sand are relatively different in the two parts of the study area. The particle size of sand in the eastern part of the study area was generally greater than the size of sand in the western part, possibly due to several reasons, such as the origin and type of sand, as discussed above, and also it may be because of exposure to further movement during earlier periods, as indicated in chapter 2. For example, Muhs *et al*. (2003) and Pease *et al*. (1999) have indicated that the size of sediments was affected by the length of distance which may be travelled by those particles from the original source.

In general, the sand from the western part of the study area is finer (mean = 2 phi, 0.125 - 0.25 mm), well sorted and positively skewed, while that from the eastern part is more bimodal because there is a smaller peak within the coarse fraction size range. Such coarser components have been suggested to be due to winnowing to deposition at other sites (Asal, 1997), and this may be the case here. All sediments in the western part are from the historical formation age of the mid-Holocene, therefore these results probably indicate erosion and further deposition. In contrast, the source of sediments in the eastern part is from the sea and the results probably indicate the wind erosion rate is low.

Another important point which should be noted for further understanding of predictions and actual observations about sand movement over time is the wind speed. Through experiments conducted on the correlation between wind speed and the size of sand grains (as shown in Table 2.1), according to the results of Bagnold, for sand of size 0.25mm to be moved a wind speed from 4.5 to 6.7 meters per second is needed; this rate of wind speed has been recorded in the western part of the study area during 83 days per year. The eastern part recorded such speeds on 86 days per year (Table 4.9), a value similar to that recorded by Livingstone *et al*., (2007) who observed in Namib Desert, Namibia. Most sand grains in the study area ranged between 0.125 - 0.25mm in size. Therefore, these figures clearly indicate the potential for notable sand movement within the study area through the action of the wind, with more in the west because the grains are smaller.

There has been an upsurge of the annual frequency of wind gusts during the last few years, as seen in chapter 3 (Figure 3.15). Also there was an increasing trend of annual frequency of wind gusts during (1977 - 2008). According to Robertson-Rintoul (1990), particles of sediment which are smaller than 0.2 mm move through suspension in the air. This process can be carried out by wind gusts. Since most sand grains in the western part of the study area were approximately in the 0.2 mm size range, therefore, this type of sand grains has a considerable potential to move and stay in suspension for a long time, thus its impact is greater. However, dry land farming is also another cause of dust storms, since more than 45% of farms in the study area (Table 6.5) depend on rainfall in more than 50% of farm area, with this percentage being approximately the same in both parts of the region. These areas of rain-fed farming systems reflect to a large extent the problems that the region suffers and have been mentioned by Libyan and Arab experts in the area of sand dune fixation (Darraz, 1995) Agriculture of dry land depends on rainfall to a large extent to irrigate crops; also, ways of maintaining moisture in the soil in those areas include a period of fallow for a year after harvesting a field so that the soil can build up. These practices of agriculture make dry land susceptible to movement of particles in strong gusts of wind.

The results of predicted rates of sand transport in the whole of the study area ranged between the lowest rate expected of 0.23 g/m-1 s-1 at Naaiemah site in the eastern part, and the highest rate expected of 0.47 g/m-1 s-1 at Alawashier site in the western part. The sand in the western part of the study area had a greater predicted rate of sand transport, compared with the sand in the eastern part. The difference in sand transport predicted in the two parts may be due to the size of the sand particles and the sand density, which therefore may have given rise to differences in the value of shear velocity.

Potential sand movement is also clearly linked with the wind directions, and as illustrated in Figure 4.38, the north winds dominate the wind directions in the study area. There is a reasonably large proportion of winds which are southerly, in contrast very few from the east or west. Therefore, the prediction is for the movement of sand within the open areas generally to be north/ south, with an emphasis particularly towards the south. Although the sand is generally of larger grain size in the eastern part the prediction is that there will be a bigger problem to human activity in this area. This relates to the wind direction, because in the eastern area the sand dunes are located along the coast, and are therefore likely to move inland (to the south), whereas in the western part the sand dunes are mainly sourced from the desert to the south and are therefore less likely to move to populated areas in the north because of the majority wind direction being contrary to this.

The results of chapter 6 (Table 6.9) indicated that there is a clear consensus on the part of most farmers regarding the existence of sand movement within their farms, with some differences in the extent of it. Furthermore, the farmers observed sand movement in the seasonal periods (Table 6.10), with a clear increase in the amount of sand movement during the spring and autumn. This might be partly attributed to the wind speed in such seasons reported in chapters 3 and 4 (Figures 3. 11 and 4.32) and developments which have occurred in the extent of vegetation cover recently (see chapter 5, Table 5. 10). For both chapters 4 and 6 clearly there are two seasons in each year where sand movement mainly occurs. In summary, one can conclude two important facts. The first one is that sand movement has been clearly observed in the whole region (Tables 4.11, 5.5 and 6.9). Secondly, sand movement has been observed to vary in both timing and frequency in different places, as has been found in other studies (Bagnold 1973; Wang and Ke 1997).

In contrast, despite the disparity in the rate of overall accuracy of classification of the different sized maps which have been used, the results which were observed from the satellite images showed clearly that there were different changes in the two parts of the study area. Some findings were the same in both areas, namely that there was a significant increase in the size of sand dune cover within both east and west parts of the study area during the time period 1986 -2003, as well as for the study area as a whole, with a clear overall increase between 1986 and 2003 of 3%. Over the area as a whole, the forest category decreased substantially. While urban areas increased, presumably associated with population growth, farming land also had a great positive increase in area during the whole time period, while the bare soil with sparse vegetation category had a clear decrease in area during 1986-2003. However, these changes were not uniform across the whole of the study area, with the western and eastern parts of the area different with respect to sand dune coverage. Thus, in the eastern part sand dunes increased in area progressively over time, while in the western part the increase seen up to 1999 was largely reversed by 2003. Both areas saw a major decline in forested area, but farming areas also showed gaining in the western part but not in the east, while the reverse was true for bare soil with sparse vegetation which increased in the east but not the west.

The changes which were observed in sand dune areas within the eastern parts of the study area are larger than the predicted rates in the western part of the study area. This does not mean there is no change in the area of sand dunes within the western part, but the changes in coverage might vary in how pronounced they are at different times in the two areas, while still being significant overall. It should be remembered that the sand dunes in the western part are of desert type origin and have a plentiful supply in the region, where it is difficult to control and to stop their movement, because to do so requires an abundant vegetation cover and a relatively humid climate (Al Jadedie, 1992, p. 124), which is not the case as discussed earlier. Also, this type of sand from the desert normally shows sand movement as a regular feature, compared to the sea sand in the eastern part of the region which has a larger particle size and is in limited supply, because it needs a long time to gain an extra supply from its source (Al Emsalati, 1995). Also abundant moisture in such areas because of their proximity to the sea can help vegetation to grow on the sand more easily, which reduces movement.

Topography may be the factor which is the most important in activating erosion processes, therefore, the geological structure of the region may have a clear impact in increasing the supply of sediment. Most of the deposits which cover the study area are from Quaternary sediments. The study area mostly comprises flat plains with a low altitude, particularly in the western part of the region. This flat region includes some broad and shallow vales, with those dry valleys being the source of a lot of desert sediment supply. The Miocene hills in the eastern part are a source of only limited sediment supply. The differences in amount of sediment supply between the two parts of the region might affect the rates of sediment movement accruing into both parts (see eg. Singhvi and Porat, 2008 for an example of such differences elsewhere). However, although geological sources may account for different quantities of sand in the two parts of the region it does not explain the greater extent of sand dune change in the east.

Of particular interest is the comparison of the predicted sand movement with what was actually observed in the area from the satellite images. Although on the basis of wind direction there was more likelihood of sand dune movement impacting on humans in the eastern region, on the basis of the smaller sand grain sizes and the greater wind shear velocity it had been predicted that there would be more sand movement in the western region. The results presented in chapter 5 show greater movements in the east, however. There are probably a number of factors influencing this discrepancy. In the first place, there has been a difference in land use cover changes in the two regions: the west, perhaps because of the influence of the GMMRP, has had a much greater development of farming, whereas the east has essentially shown environmental degradation, moving from forest to bare soil and sand dunes. Even though both regions have lost a lot of forest, proportionally more was lost from the eastern region, and it is likely to be this factor that has resulted in more sand dune movement in the east. Therefore, the conclusion from this is that the effects of human influences have overridden what would have been predicted solely on the basis of the physical properties found in the two areas.

7.4 Reported impact on farmers

The responses given by the land owners are consistent with those given by local authorities in their reports about the evolution of the phenomenon of sand movement and its intensity in recent years within the region (Libyan Agricultural Ministry, 2006), and agree with the results of previous studies, that there is a remarkable increase in recent years in the area of land desertified throughout Arab countries which reduces the production of farmers in their areas (Ayad, 1995; Abd Elgawad, 1997, p.196).

Through the responses of land owners it is very clear about their perception of the evolution of this phenomenon and its impact on crops. There is a clear agreement on the part of most land owners about the existence of farming problems as a result of sand movement (Table 6.1; Figure 6.2), although with a small number (approximately 4.4%) disagreeing with this, suggesting that there is some farming land protected from the effects of sand encroachment.

The general view of farmers, from both eastern and western regions, is that sand movement is greatest during the spring and autumn. This seasonal movement is probably related to the wind speed and direction in such seasons. A further point that arises from Table 6.13 is that 83.7% of all land owners questioned stated they did exploit the vegetation on sand dunes for grazing animals. One can only conclude that there is extensive exploitation of vegetation in the study area, which will result in increasing sand movement. Considering the economic costs and losses which result from sand dune mobility, this exploitation of sand dune vegetation would appear to provide a short- term gain but a longer- term loss because of the reduced stability of the dunes which results from this action. This many differ in the two areas, as discussed in section 7.2 above.

The elements of this counterproductive trade-off have been observed before by other researchers into the over- exploitation of vegetation in the whole region (Al Jadedie, 1992, p.89). The loss due to sand encroachment has been estimated previously by Almasoudi (1984) and Nhal (1989, p.128), at about a quarter of the crop annually, which is consistent with the results found here.

Likewise, the farmers indicated that they used afforestation as the favoured method of stopping the encroachment of sand dune, despite the fact that people living in the areas are at the same time cutting down the forest which was originally planted precisely to protect against further sand encroachment. This result is consistent with what was obtained from the results of land cover conversion matrix for the whole period from 1986 and 2003. Although there was a significant decrease in forest, the forest had some grains from farming land, though not enough to compensate the losses (Table 5.9).

This control of sand movement involves farmers in at least some cost. As has been mentioned before, the lack of or shortage of financial resources and governmental assistance may have negative consequences and affect the level of achievement in desertification control. This fact has been observed previously by a number of researchers who stated that the lack of such resources affected the quality of methods used and that if such resources had been available to land owners they might have been able to be more successful in desertification control (e.g. Nhal, 1989, p.176).

In summary, the information from land owners with regard to these themes confirm similar facts discussed by a number of authors in previous studies, for example the Arab Centre for the Studies of Arid and Dry Zones (ACSAD, 2006), which indicated in its report that the governments of Arab Countries suffer considerable economic losses due to desertification ; and Darraz, (1995) who indicated that the paucity of technical capabilities, and the lack of awareness of the local population, especially in the Maghreb countries, make desertification control more difficult. The present results reinforce the fact that sand movement is an environmental problem which afflicts many countries of the world, partly due to the climate changes but especially due to increasing population pressure, and inappropriate land management, especially in a country such as Libya.

7.5 The relative influence of natural and human changes on sand movement problems

This study has focussed on an important environmental problem facing the contemporary world, represented in the phenomenon of sand dune movement in dry areas. In this study of NW Libya, the extent of the movement of sand dunes has been demonstrated, and also the extent of the damage resulting from this movement. It is clear that the problem is experienced throughout the northwest of Libya, but particularly in the eastern part of the study area there is more evidence of sand movement over the time period studied through satellite imagery. This section aims to review the evidence obtained in this study as to the extent to which the movement of sand is a result of natural processes or is caused by human influences.

The first question is whether there is any evidence of changes in natural processes over time, to account for increasing sand movement recently. Chapter 3 includes an analysis of climatic trends in the region over the period 1977-2008. The data for annual mean, annual maximum and annual minimum temperatures all show slight but non-significant increases over time. Rainfall was quite erratic in abundance in different years, which could harm vegetation, but the overall trend was not statistically significant over the time period studied. Average wind speeds showed little evidence of systematic changes over time either. Therefore there is no convincing evidence of progressive changes in these climatic variables being responsible for the increased sand dune mobility. There was, however, evidence for a statistically significant increase in the number of wind gusts over that period, which might have contributed to the greater sand movement. Overall, though, there is only limited evidence for climatic changes as being responsible for greater sand dune movement recently.

A second question is whether there are any differences in natural processes in the two parts, east and west, of the study area which could explain the different results observed there. Wind speed records (Chapter 3) showed essentially the same values in both parts, and wind directions likewise were the same. The latter point could have had a different impact in the two areas, however, because of the locations of the sand dunes in the two areas (sand in the eastern area being more likely to move to human-occupied areas than the western part). The topography and origins of sand are also different in the two areas, which would have an impact on relative amounts of sand supply. This also has influenced the sand particle sizes, which were larger in the east (Chapter 4). These last points, however, would suggest greater problems of sand in the western area, with greater sand movement predicted there. The results actually obtained (Chapter 5) on sand coverage, however, indicated greater problems in the east of the study area rather than the west. Therefore, of these parameters the only one that could be contributing to the results obtained, and overriding the predictions made based on sand size, is the location of the dunes relative to human occupancy which would indicate that the wind direction was critical.

In contrast to this consideration of the natural processes, a consideration of the evidence for human activity being responsible shows a number of relevant features. In terms of trends over time there are the changes in human population numbers (Chapter 3), loss of forest and other vegetation coverage (Chapter 5), exploitation of vegetation for grazing (Chapter 6), and the increase of agricultural land and urban development (Chapter 5). There are also notable differences in human activity in the two parts of the study area. These include greater proportional loss of forest in the east (Chapter 5), a greater increase in farming land in the west because of the GMMR project (Chapter 5), but evidence of tree planting on farm land in the west offsetting much of the general forest loss (Chapters 5 and 6). While not studied specifically in this work, there is also evidence of greater quarrying of sand to provide building materials in the east of the area. Apart from the increase in farming land in the west, which is largely offset by increased tree planting on such land, all of these points indicate an increase in human activities over time with particularly environmentally degrading activities in the eastern area.

Overall, therefore, while there could be some contribution to the problem observed in the results being caused by the natural processes of increased wind gusting and wind direction, it is likely that much the greatest contribution to the problem comes from the impact of human presence, largely arising from inappropriate land management, which has degraded the remaining vegetation cover and allowed greater sand movement, especially in the eastern part of the study area.

7.6 Conclusion

There are some important natural processes which many have contributed to changes observed in land cover over time within the study area. These processes were an increase in wind gusts over time, which wind directions lead to predictions of more problems within the eastern parts in the region. Also, rainfall patterns were such that there can be prolonged drought periods for several months (up to nine per year) and low rainfall sometimes over a period of three to five years, which could adversely affect vegetation. However, overall human activity appears to be much more important in these changes in terms of the size of population growth in the region and the reflection of that on their different activities, through the processes of encroachment on vegetation cover and forest which have been a major contributor to of sand dune fixation in the study area but are areas being degraded or lost.

In chapter 1 of this thesis, two general aims and four objectives were set for this research. From the results in chapter 4 it is clear that predictions of sand movement potential do differ for sand in different parts of the study area, largely reflecting the different sand origins. The analysis of wind speed in chapter 3 also highlights the substantial potential for movement of sand, give the particle size distribution observed. Thus objective 1 has been achieved. Objective 2 was largely met by reference to the satellite image data, which has shown notable changes in land - use coverage over time, including an increase in sand dunes (subject to the limitations of accuracy of working with remotely – sensed data). These changes do not appear to correspond well with the predictions of movement from chapter 4 (objective 3), and suggest that human activity patterns have overridden the results expected if natural processes only had been operating. Most notable were the decline in forest cover and in other land cover associated with vegetation (chapter 5). Chapter 6 has demonstrated that local farmers are impacted in various ways (objective 4) by sand movement, perhaps the most notable being that they are planting trees in an attempt at afforestation on their land to prevent sand spread, partly to offset the general loss of forest in the region that previously had been helping to reduce dune movement.

Therefore the original research hypotheses have been largely met. They have contributed to meeting the broader research aims, although there are aspects of both research aims that have not been included in the present work. Thus, while in aim 1 the extent and dynamics of sand dunes have both been addressed the aim would have been met more fully with estimations of rates of movement of dunes and their specific locations over time, so that further corroboration of the direction of movement with wind directions could have been established. Also, aim 2 has investigated the impacts on human activity with respect to farming, but not to other types of activity.

Overall, the present research has developed understanding of both the problems and the likely causes of sand movement and its impacts in this region of Libya, both features likely to be common to other areas of northern Africa and elsewhere.

7.7 Future research work

To assess the solutions to this growing problem of sand movement requires a focus on future research. These researches should be in line with the current situation and future of this problem, through the following:

1) Monitoring further change in the areas of sand dunes, through the following:

A) The use of modern satellite images for monitoring the monthly and yearly changes of sand dunes.

B) The use of recently – developed equipment to measure the size of actual sand movement (per hour or per day), for some free dunes.

2) How to enhance vegetation cover, through the following:

A) The study of the characteristics of plants which grow on the sand dunes, with investigations to be carried out for the best plants which are drought-resistant in the region, and how to establish them in degraded.

B) An analytical study to know the suitability of the sand layers content for the growth of plants and how this affects the development of plant growth in the future.

3) How to influence people to implement change in practice, through the following:

A) To conduct a detailed study of people's opinions and determine their attitudes about the reasons for human encroachment into forests and vegetation cover in general, and support the potential of local people to implement change in practice through involving them in all projects to combat sand encroachment, taking into account their needs and their views, and practical ways to support them.

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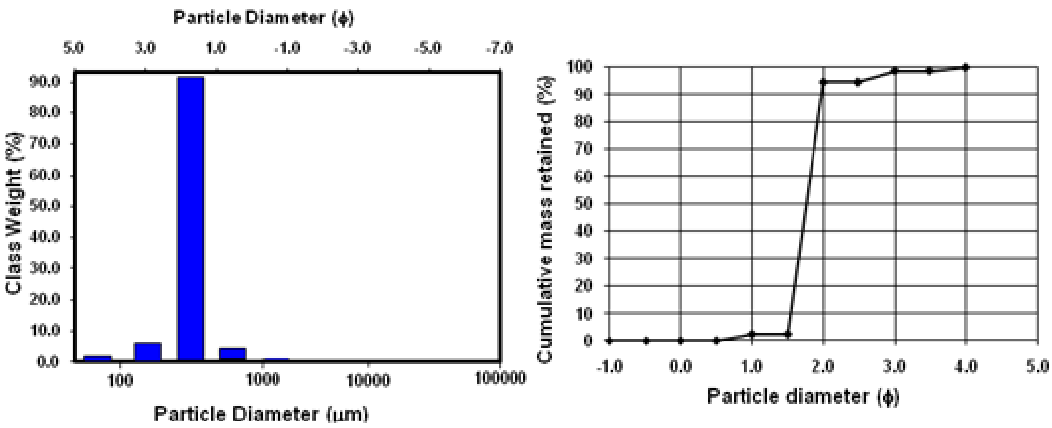
9 Appendix 1

This Appendix presents detailed results, for each sample location separately of the sand grain size analyses summarised in section 4.5.

(1) Qaser Ahmad Region N32’22“ E015’11“

Particle size analysis of the Qasser Ahmad sands revealed that particles with a diameter of between 250 µm and 500 µm diameter accounted for 92% of the tested sample. A further 4.1% of the sample occupies the size range 125 µm to 250 µm.

Figure 9.1. A. Grain size distribution, B. The cumulative frequency curve of Qaser Ahmed sand, from the eastern area of coastal sand dunes.

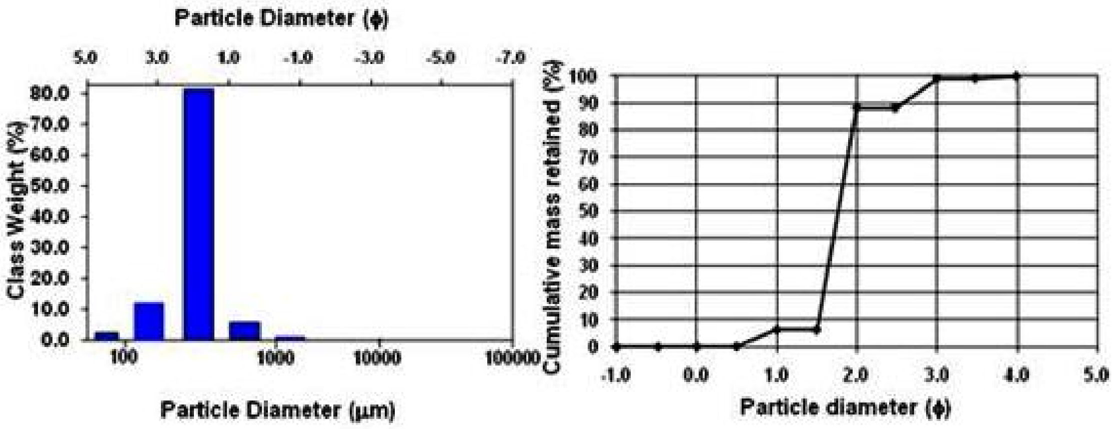


The sand particles possess a very slight positive skew, with the particle sizes in the 500 µm to 1000 µm diameter comprising only 2.4% of the sample.

(2) Aljazeera Region N32’24” E015’01”

Figure 9.2.A shows that the Aljazeera sands contain particles mainly with a diameter of between 250 µm and 500 µm diameter comprising 82% of the tested sample, and 11% of the sample occupies the size range 125 µm to 250 µm.

Figure 9.2. A. Grain size distribution, B. The cumulative frequency curve of Aljazeera sand, from the eastern area of coastal sand dunes.

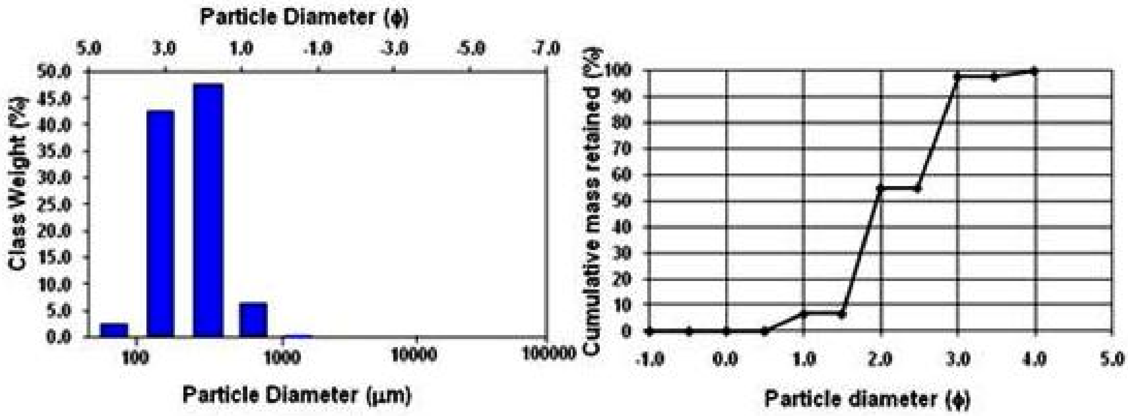


Furthermore, Figure 9.2.B. shows that the sand particles of this sample possess a slight positive skew, with a lower proportion of particles in the 500 µm to 1000 µm diameter size (only 5% of the sample) compared to the 125 - 250 µm range.

(3) Alsawawa Region N32’24” E014’59”

The Alsawawa sands were one of the samples with almost equal percentages of particles in two size categories: 48% in the 250 - 500 µm range, and 43% in the 125 - 250 µm range. A further 6.5% of the sample occupies the size range 500 - 1000 µm. Compared to most samples; these results therefore show a strong positive skew.

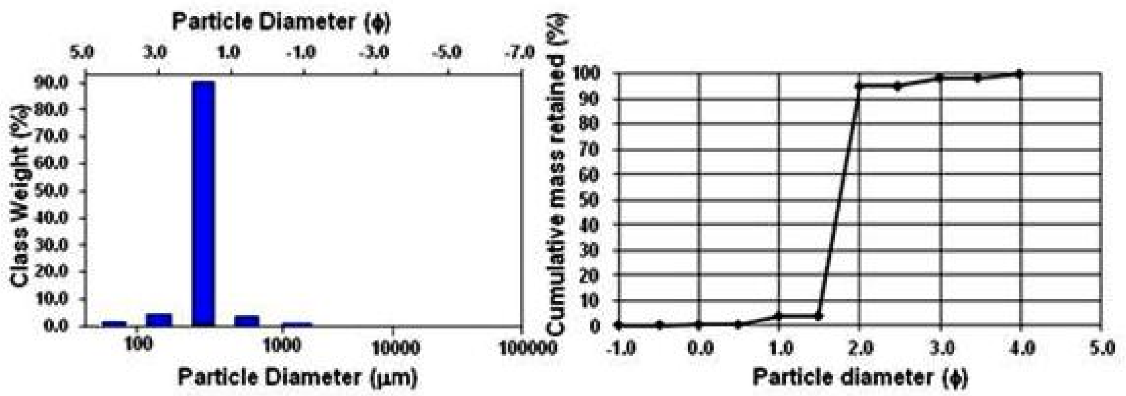
Figure 9.3. A. Grain size distribution, B. The cumulative frequency curve of Alsawawa sand, from the eastern area of coastal sand dunes, from the eastern area of coastal sand dunes.



(4) Zawiat Almahgob Region N32’23” E014’58”

90% of the particle sizes in Zawiat Almahgob sands fall into the range of between 250 µm and 500 µm diameter, as shown in Figure 9.4. A. A further 3% of the sample occupies the size range 125 µm to 250 µm, with 2% of the sample found less than 125 µm, and approximately the same proportions found in the right – hand tail larger than 500 µm. Also the sand particles possess a symmetrical distribution.

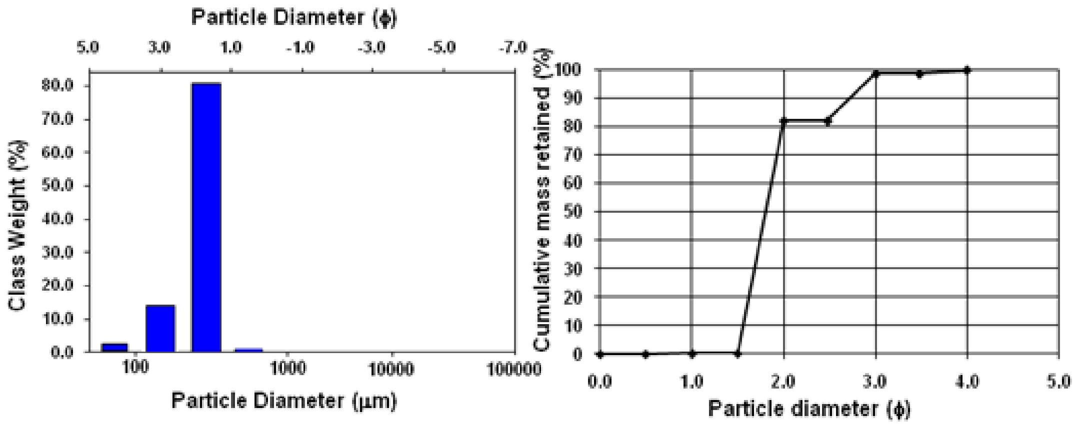
Figure 9.4. A. Grain size distribution, B. The cumulative frequency curve of Zawiat Almahgob sand, from the eastern area of coastal sand dunes.



(5) Abourwia Region N32’24” E014’56”

Particle size analysis of the Abourwia sands revealed that particles with a diameter of between 250 µm and 500 µm diameter accounted for 80% of the tested sample. A further 16% of the sample occupies the size range 125 µm to 250 µm, with 2% in the 62.5 - 125 µm band.

Figure 9.5. A. Grain size distribution, B. The cumulative frequency curve of Abourwia sand, from the eastern area of coastal sand dunes.

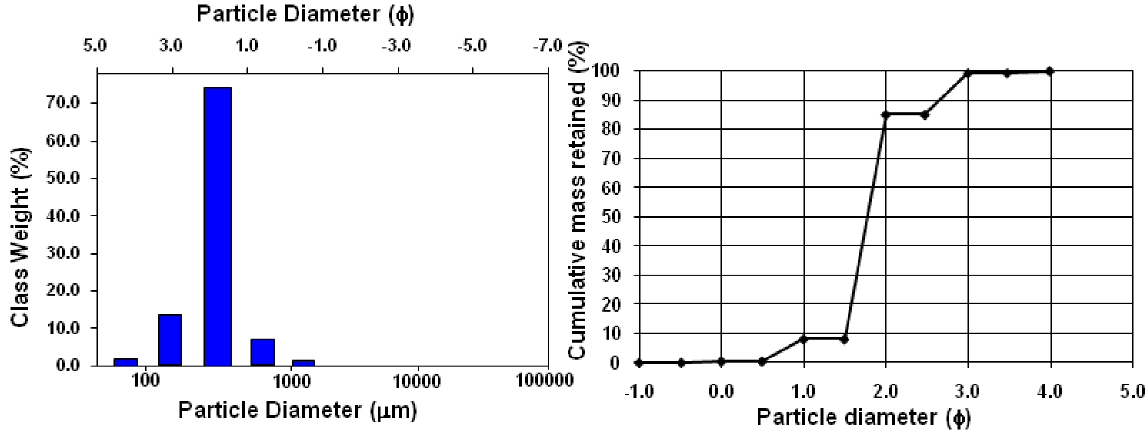


The sand particles possess a positive skew, with the particle sizes in the 500 - 1000 µm diameter category comprising only 0.8% of the sample.

(6) Zeriq Region N32’25” E014’53”

Particle size analysis of the Zeriq sands revealed that particles with a diameter of between 125 µm and 500 µm diameters accounted for 91% of the tested sample, with most of the particles in the 250 – 500 µm range. A further 8% of the sample occupies the size range 500 µm to 1000 µm. The data therefore show a slight positive skew.

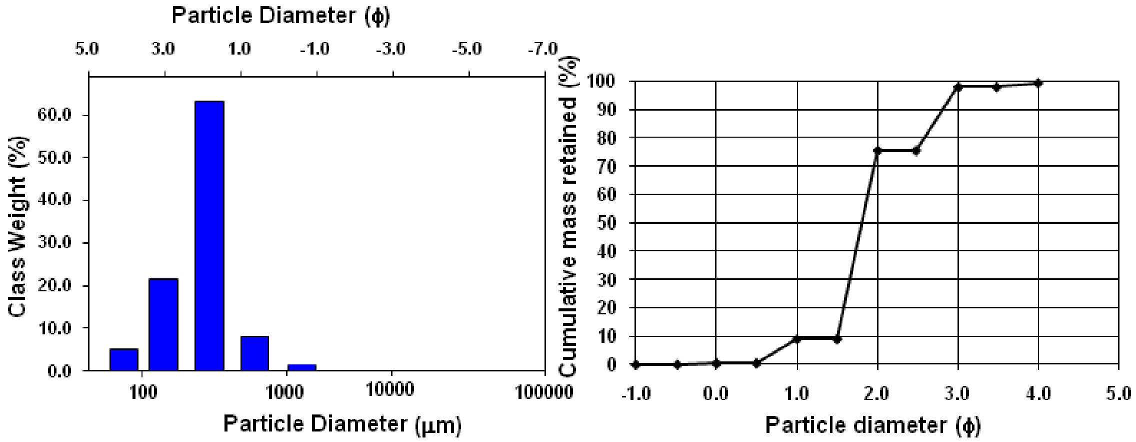
Figure 9.6. A. Grain size distribution, B. The cumulative frequency curve of Zeriq sand, from the eastern area of coastal sand dunes.



(7) Aldafniya Region N32’24” E014’50”

64% of the sand particle sizes in Aldafniya have a diameter of between 250 µm and 500 µm diameter, as shown in Figure 9.7. A. A further 22% of the sample occupies the size range 125 µm to 250 µm, with smaller amounts in the other categories. The sand particle size distribution therefore possesses a positive skew, with a smaller proportion of the larger particle sizes.

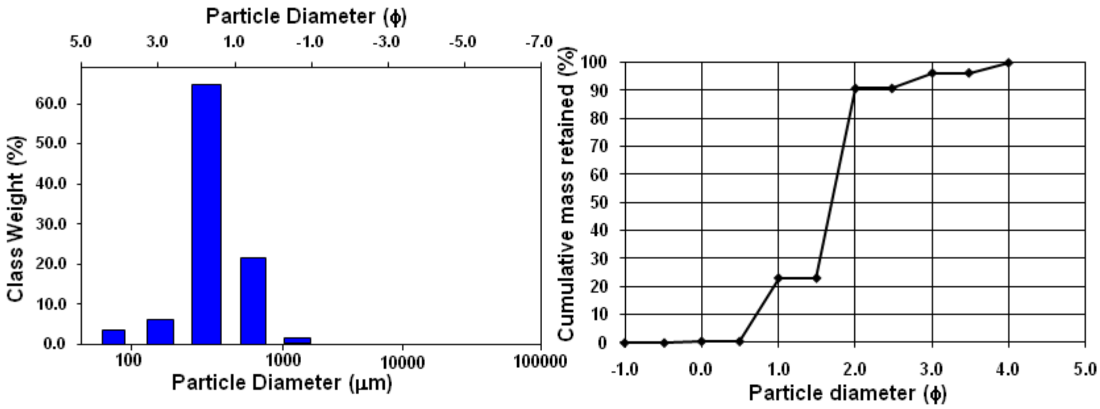
Figure 9.7. A. Grain size distribution, B. The cumulative frequency curve of Aldafniya sand, from the eastern area of coastal sand dunes.



(8) Naaiemah Region N32’27” E014’40”

Figure 9.8.A. shows a particle size distribution for the Naaiemah sands which has a negative skew: Most of the particles lie between 250 µm and 500 µm diameter (66% of the tested sample), but there are 22% in the 500 – 1000 µm range and small percentages in the other categories.

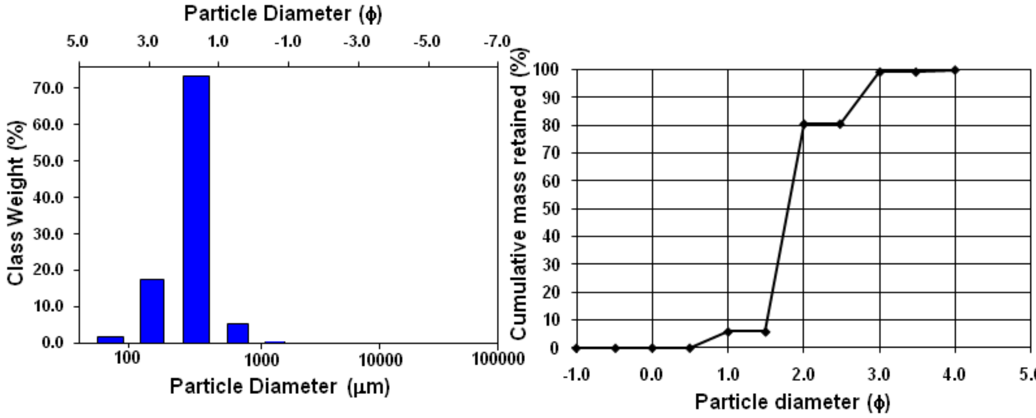
Figure 9.8. A. Grain size distribution, B. The cumulative frequency curve of Naaiemah sand, from the eastern area of coastal sand dunes.



(9) Azdo Region N32’28” E014’38”

Particle size analysis of the Azdo sands revealed the peak of 73% falling in the 250 µm to 500 µm diameter range. A further 18% of the sample occupies the size range 125 µm to 250 µm, with 5% of the sample found of between 500 and 1000 µm. The sand particles possess a positive skew.

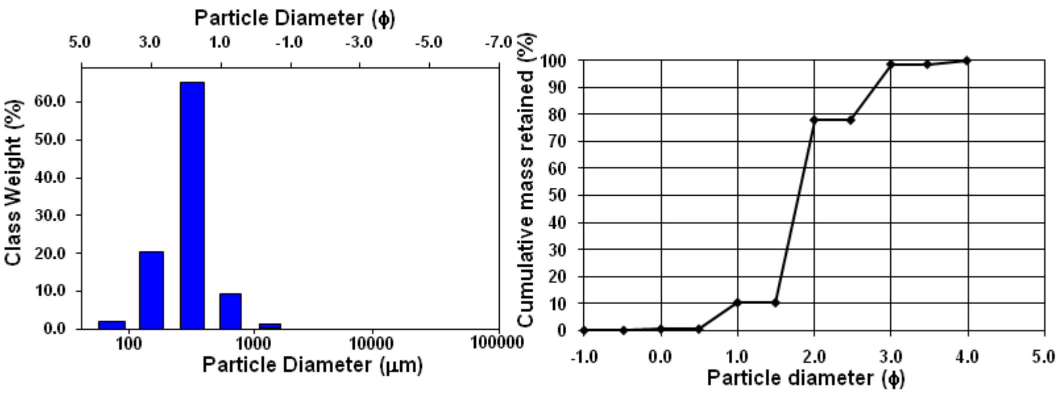
Figure 9.9. A. Grain size distribution, B. The cumulative frequency curve of Azdo sand, from the eastern area of coastal sand dunes.



(10) Aboruqiya Region N32'29" E014'36"

88% of the particle sizes in the Aboruqiya sands have a diameter of between 125 µm and 500 µm diameter, mainly between 250 and 500 µm, as shown in Figure 9.10. A. Smaller percentages were found in the other categories, particularly the 500 - 1000 µm range which contained 10%. The sand particle distribution therefore possesses a slight positive skew.

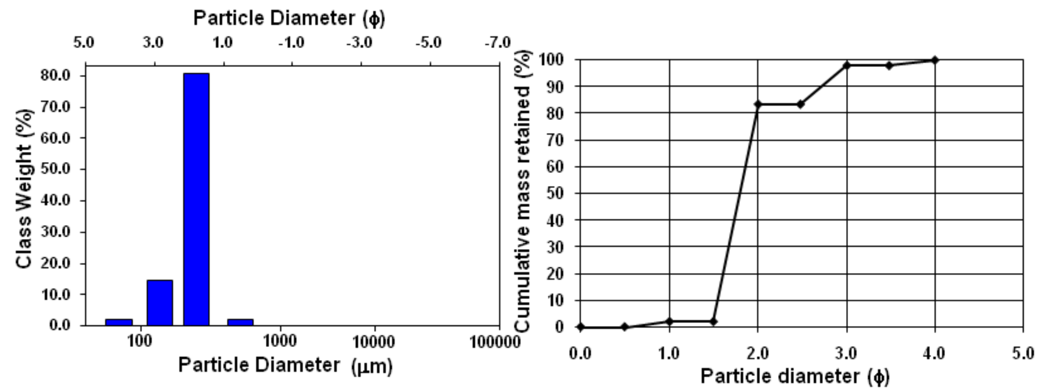
Figure 9.10. A. Grain size distribution, B. The cumulative frequency curve of Aboruqiya sand, from the eastern area of coastal sand dunes.



(11) Almontaraha Region N32'28" E014'33"

Particle size analysis of the Almontaraha sands found most particles had a diameter of between 250 µm and 500 µm diameter (80%). A further 15% of the sample occupies the size range 125 µm to 250 µm, with very little in other categories. There is therefore a slight positive skew to the distribution.

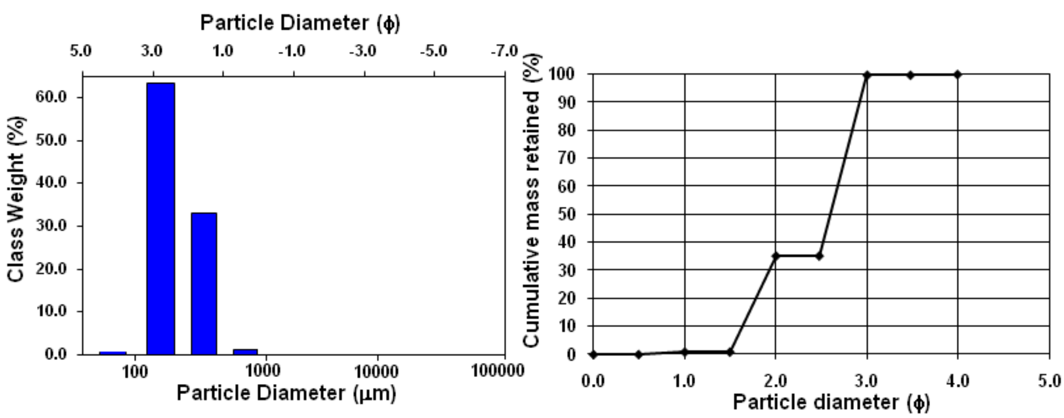
Figure 9.11. A. Grain size distribution, B. The cumulative frequency curve of Almontaraha sand, from the eastern area of coastal sand dunes.



(12) Ekaam Region N32’30” E014’30”

Particle size analysis of the Ekaam sands revealed a strong negative skew to the shape of the distribution but with the peak at a smaller size fraction than in many samples: 64% of the particles being found between 125 µm and 250 µm diameters and almost all the remainder (33%) in the 250 µm to 500 µm sizes.

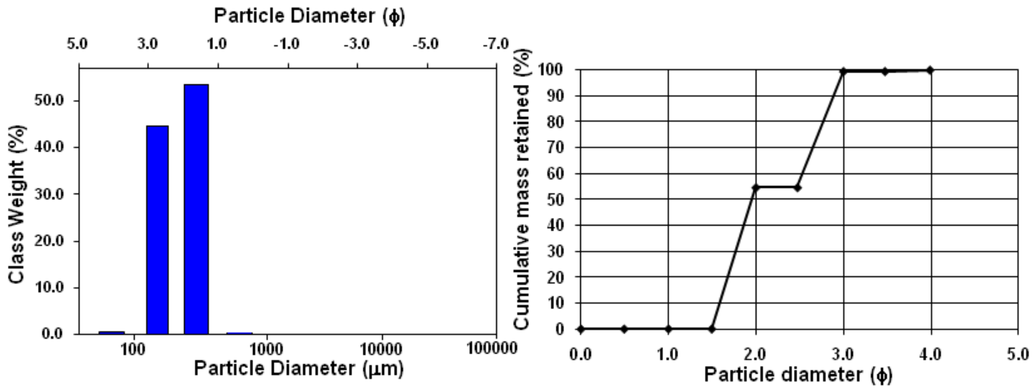
Figure 9.12. A. Grain size distribution, B. The cumulative frequency curve of Ekaam sand, from the eastern area of coastal sand dunes.



(13) Soukh Alkamies Region N32’33“ E014’25“

99% of the particles from in the Soukh Alkamies sands have a diameter of between 125 µm and 500 µm diameter, with only a slightly greater proportion in the larger size category, as shown in Figure 9.13. A.

Figure 9.13. A. Grain size distribution, B. The cumulative frequency curve of Soukh Alkamies sand, from the eastern area of coastal sand dunes.

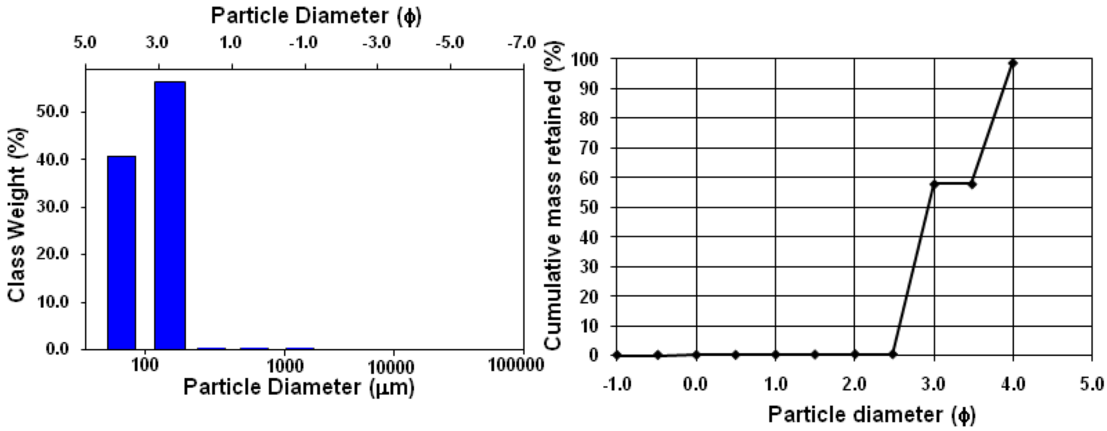


The sand particles therefore possess a significant positive skew, based on the modal category of 250 to 500 µm.

(14) Alawashier Region N32’44” E013’57”

The Alawashier sands generally consist of smaller particle sizes than many samples, with 40% in the 62.5 µm to 125 µm diameter category and 59% in the 125 µm to 250 µm range. The results show a strong positive skew.

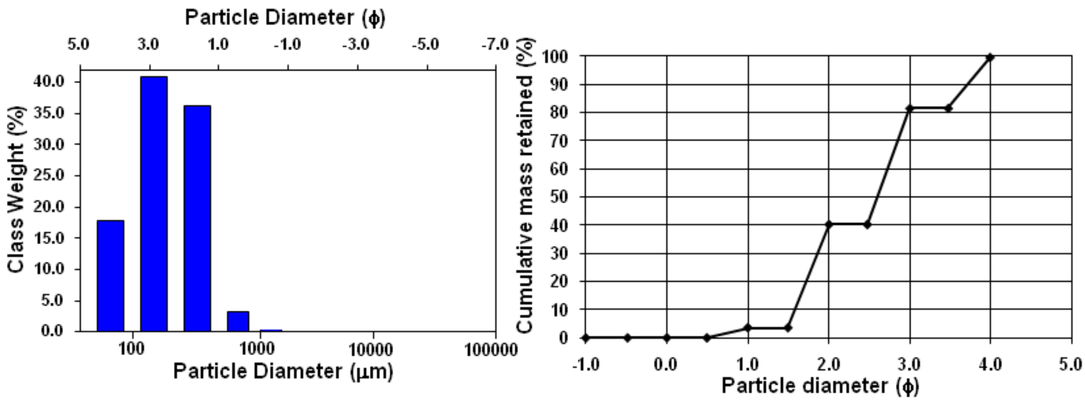
Figure 9.14. A. Grain size distribution, B. The cumulative frequency curve of Alawashier sand, from the western area of desert sand dunes.



(15) Awlaad huseen Region N32’45” E013’56”

The mix of particle size is unusually broad for the Awlaad huseen sands (Figure 9.15.A). The most common category is 125 - 250 µm (fine sand; 41%), but there are almost as many particles in the 250 - 500 µm range (36%), and a further 18% of 62.5 – 125 µm size with a small percentage in other categories. The sand particle distribution therefore shows a positive skew to small particle sizes.

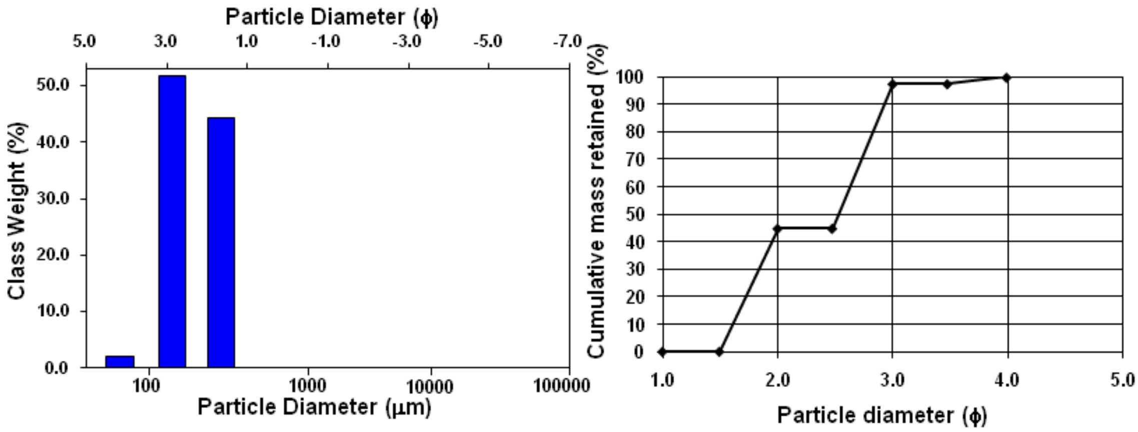
Figure 9.15. A. Grain size distribution, B. The cumulative frequency curve of Awlaad huseen sand, from the western area of desert sand dunes.



(16) Siede Amier Region N32’46” E013’51”

Particle size analysis of the Siede Amier sands revealed that particles with a diameter of between 125 µm and 500 µm diameter accounted for 98% of the tested sample, with slightly more (52%) being in the 125 – 250 µm category.

Figure 9.16. A. Grain size distribution, B. The cumulative frequency curve of Siede Amier sand, from the western area of desert sand dunes.

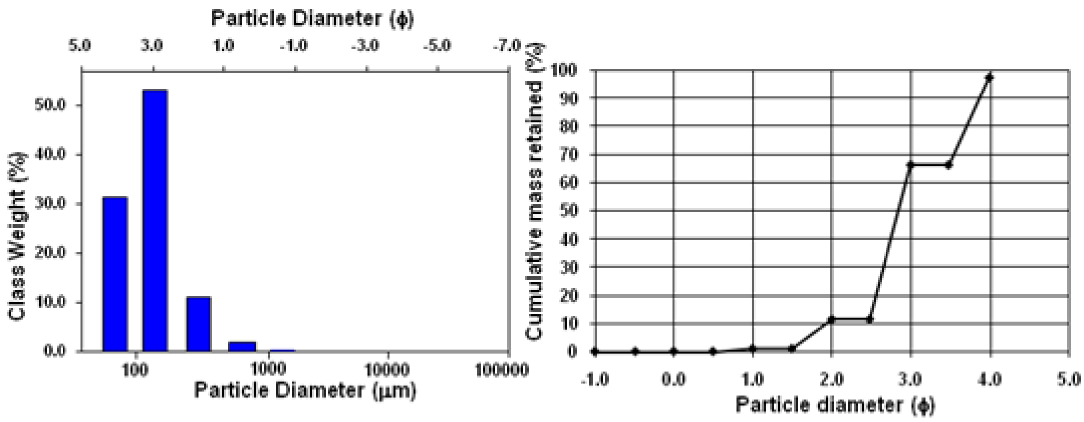


The sand particles possess a significant negative skew based on ϕ units, but with the modal category being 125µm to 250 µm, or fine sand.

(17) Alnachiea Region N32’45” E013’40”

86% of the particles in the Alnachieah sands fall into the range 62.5 - 250 µm diameter, as shown in Figure 9.17. A. The peak is in the 125 – 250 range, but the sand particles are therefore strongly positively skewed to smaller particle sizes.

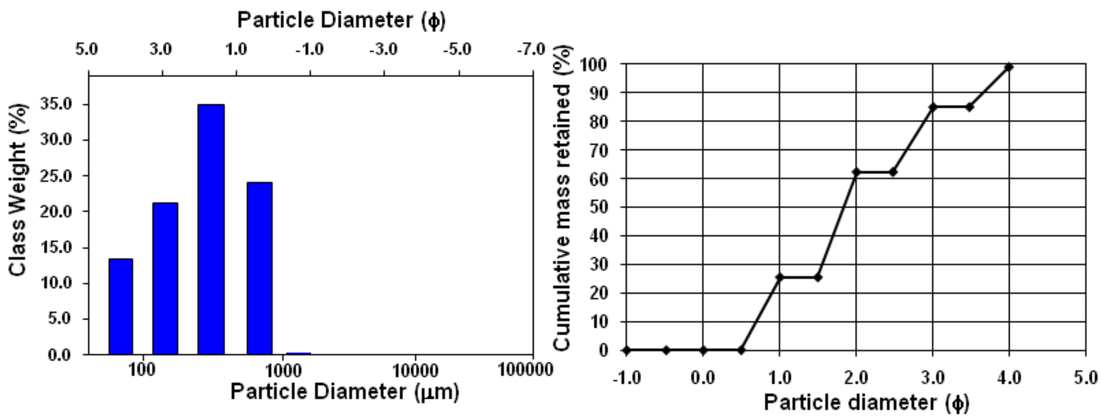
Figure 9.17. A. Grain size distribution, B. The cumulative frequency curve of Alnachiea sand, from the western area of desert sand dunes.



(18) Alkrawa Region N32’44” E013’44”

Particle size analysis of the Alkrawa sands revealed a broader spread of particle sizes, with a peak diameter of between 250 µm and 500 µm diameters accounting for 35% of the tested sample, but with 13% of the sample occupying the size range 62.5 µm to 125 µm, 21% the 125 – 250 µm range, and 25% the 250 – 500 µm range.

Figure 9.18. A. Grain size distribution, B. The cumulative frequency curve of Alkrawa sand, from the western area of desert sand dunes.

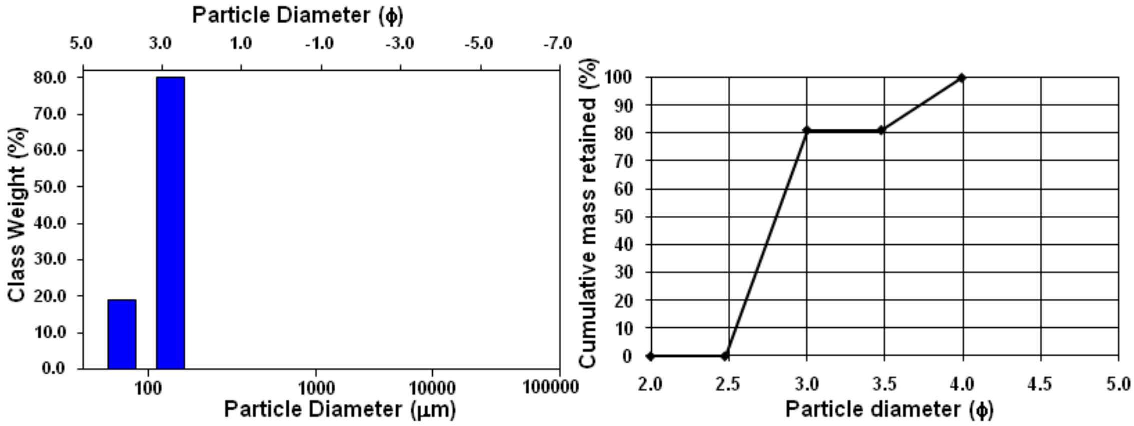


The sand particles possess a slight positive skew, despite the second most frequent size being the 250 - 1000 µm range.

(19) Al ataya Region N32'46" E013'41"

Particle size analysis of the Al Ataya sands revealed that particles with a diameter of between 125 µm and 250 µm diameter accounted for 81% of the tested sample. A further 19% of the sample occupies the size range 62.5 µm to 125 µm. There were no other sizes present. The sand particles possess a significant positive skew, and are entirely consisting of fine or very fine sand.

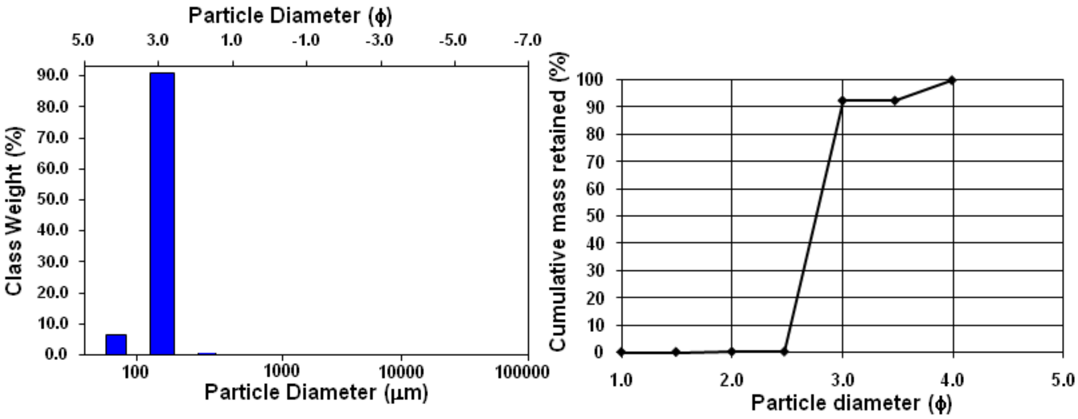
Figure 9.19. A. Grain size distribution, B. The cumulative frequency curve of Al ataya Regoin sand, from the western area of desert sand dunes.



(20) North Algaweah Region N32'45" E013'39"

Figure 9.20.A. shows that the particle size distribution of the North Algaweah sands is similar to that for the Al ataya region above, except that there is an even greater preponderance of particles in the 125 µm to 250 µm range (92%), and only 7% of the sample occupies the size range 62.5 µm to 125 µm. There is a very small representation (0.5%) in the 250 µm to 500 µm size range.

Figure 9.20. A. Grain size distribution, B. The cumulative frequency curve of Geological map of the study area North Algaweah sand, from the western area of desert sand dunes.

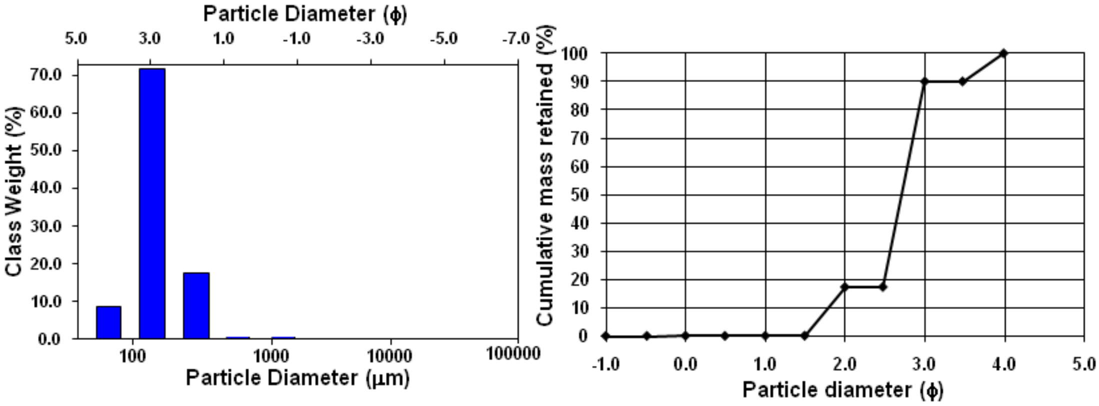


Furthermore, Figure 9.20.B. shows that the sand particles of this sample possess a slight positive skew.

(21) South Algaweah Region N32’43” E013’35”

73% of the particles in the South Algaweah sands have a diameter of between 125 µm and 250 µm diameter, as shown in Figure 4.26. A. Approximately 17% of the sample occupies the size range 250 µm to 500 µm. Also the sand particles possess a slight negative skew, with only 9.5% of the sample in the particle sizes of the 62.5 µm to 125 µm diameter category.

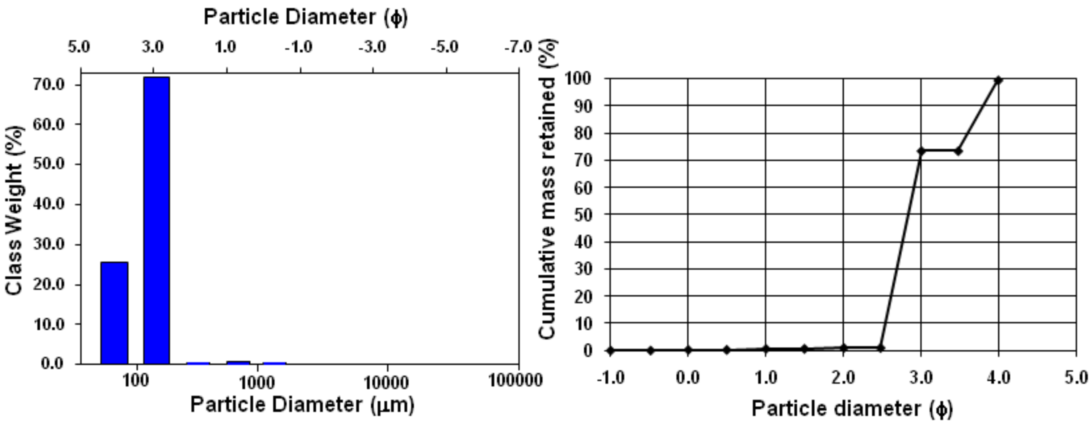
Figure 9.21. A. Grain size distribution, B. The cumulative frequency curve of South Algaweah sand, from the western area of desert sand dunes.



(22) Alwady Alsharqy Region N32’45” E013’32”

Almost all of the Alwady Alsharqy sands have a particle size of between 62.5 µm and 250 µm diameter, with 73% in the 125 µm to 250 µm range and a further 26% of the sample in the 62.5 µm to 125 µm range. The sand particles possess a significant positive skew, with the particles in the larger fractions comprising only 1% of the sample.

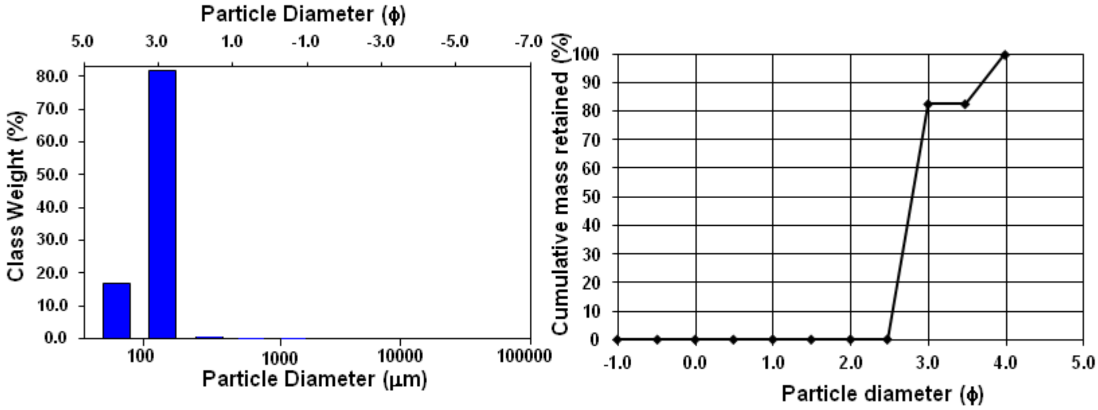
Figure 9.22. A. Grain size distribution, B. The cumulative frequency curve of Alwady Alsharqy sand, from the western area of desert sand dunes.



(23) Bear Turky Region N32’45” E013’30”

Figure 9.23.A. shows that the particle size distribution of the Bear Turky sands is similar to that of Alwady Alsharqy above, but with the particles with a diameter of between 125 µm and 250 µm diameter accounting for 82% of the tested sample, and only 17% of the sample occupying the size range 62.5 µm to 125 µm.

Figure 9.23. A. Grain size distribution, B. The cumulative frequency curve of Bear Turky sand, from the western area of desert sand dunes.

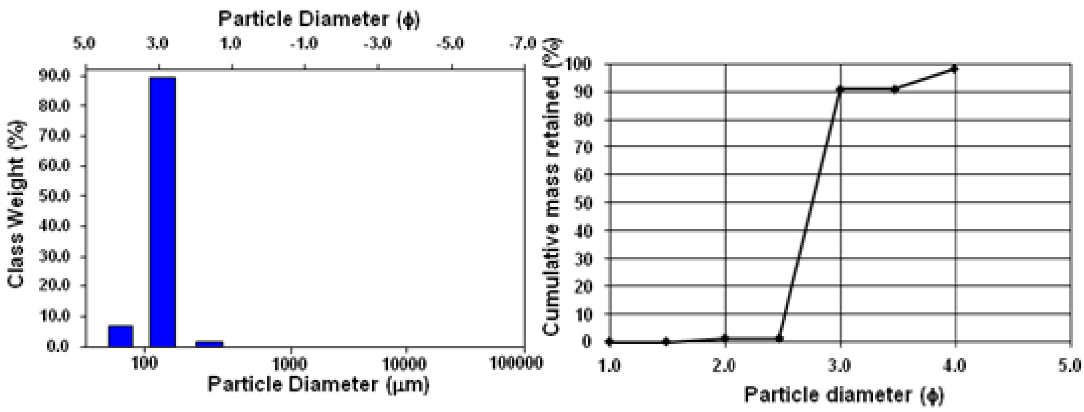


Furthermore, Figure 9.23.B. shows that the sand particles of this sample also had a slight positive skew.

(24) Wady Alrabieh Region N32’47” E013’28”

Almost all the particles of the Wady Alrabieh sands fall in the category of between 125 µm and 250 µm diameter, accounting for 90% of the tested sample. A further 8% of the sample occupies the size range 62.5 µm to 125 µm.

Figure 9.24.A. Grain size distribution, B. The cumulative frequency curve of Wady Alrabieh sand, from the western area of desert sand dunes.

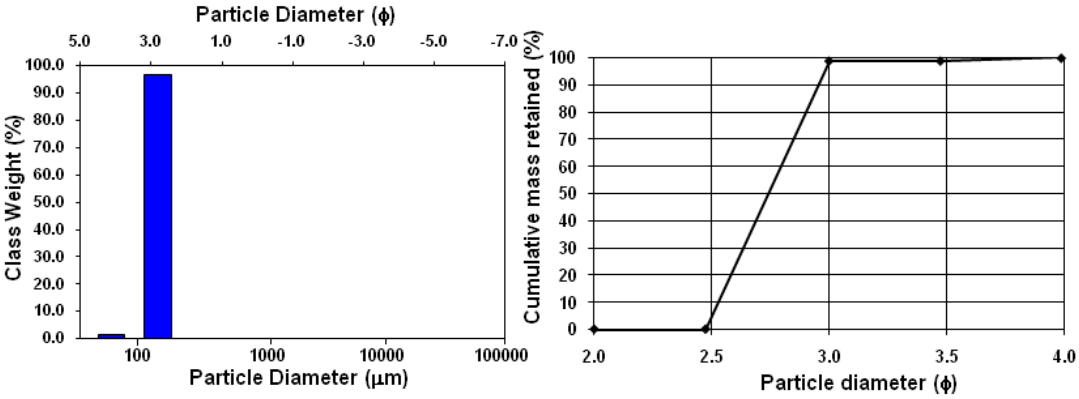


The sand particles possess a positive skew, with the particle sizes in the 500 µm to 250 µm diameter comprising only 1.5% of the sample.

(25) Alwady Alqarby Region N32’43” E013’26”

Particle size analysis of the Alwady Alqarby sands revealed that the particles with a diameter of between 125 µm and 250 µm diameter accounted for 98% of the material. The sand particles possess a very slight positive skew, because the only other particle size represented is the 62.5 µm to 100 µm range comprising only 2% of the sample.

Figure 9.25. A. Grain size distribution, B. The cumulative frequency curve of Alwady Alqarby sand, from the western area of desert sand dunes.



10 Appendix 2

A questionnaire for the land owners

I am a Libyan student studying for my PhD in England at the University of Bradford.

أخي المواطن:

ان اجابتكم عن أسئلة الاستبيان ذات قيمة كبيرة في نتائج البحث, كما أنها ستكون موضع شكرنا وتقديرنا.

عليه نأمل منكم الاجابة بكل صدق وأمانة لان اجابتكم من شأنها ان تنير لنا الطريق للوقوف على خليفات هذه المشكلة البيئية بالمنطقة.

ان هذف الدراسة علمي , والمعلومات التي تقدمونها ستستخدم في الأغراض العلمية البحثة وستراعى السرية التامة في المحافظة عليها.

As part of my research, I am collecting information from the owners of agricultural holdings through a questionnaire, which is enclosed, particularly about the movement of sand dunes in your area. I should be grateful if you could answer the questions and return the questionnaire back to me.

Your answers, which will be confidential, will be of great value to my academic research. They will not be used for any commercial, profit making or other reason.

A self addressed and stamped envelope is enclosed for the return of the completed questionnaire. Your co-operation is gratefully acknowledged with thanks.

Suliman Koja	**سليمان فرج خوجه**
PhD student	**طالب دكتوراه**
University of Bradford	**جامعة برادفورد**

استبيان خاص بأصحاب الحيازات الزراعية

A questionnaire for farm owners

Please tick only one answer for each question	**يرجي اختيار اجابة واحدة لكل سؤال من الاسئلة التالية**

Q1.	**Please specify your location**		يرجى تحديد الشعبية التى تتبعها هذه المزرعة	**س1**
	Musrata Region	☐	شعبية مصراته	
	Almergeb Region	☐	شعبية المرقب	
	Tajora Region	☐	شعبية تاجوراء	
Q2.	Approximately, what is the area of your farm (in hectares)?		يرجى تحديد مساحة المزرعة بالهكتار .	**س2**
	1-5	☐	من 1 الى 5	
	5-10	☐	من 5 الى 10	
	>10	☐	أكثر من 10	
Q3	What is the percentage of your irrigated area?		يرجى تحديد نسبة المساحة البعلية بالمزرعة.	**س3**
	<25%	☐	اقل من 25%	
	>25%<50%	☐	من 25% الى 50%	
	>50%<75%	☐	من 50% الى 75%	
	>75%	☐	اكثر من 75%	
Q4	How many years have you run this farm (in years)?		يرجى تحديد عدد سنوات عملك بهذه المزرعة	س4
	<10	☐	اقل من 10 سنوات	
	>10<20	☐	من 10 الى 20 سنه	
	>20<30	☐	من 20 الى 30 سنه	
	>30<40	☐	اكثر من 30 سنه	
Q5	Did you have to move sand to create your farm?		هل قمت بازالة كثبان رملية عند استصلاحك للمزرعة؟	**س5**
	Yes	☐	نعم	

	No	☐	لا	
Q6	What type of methods have you used in creating your farm? primitive latest technology used Other, please specify....................	 ☐ ☐ ☐	ماهي الطرق التى قمت باستخدامها في عملية الاستصلاح؟ طرق بدائية طرق علمية حديثة اي طرق اخرى	س6
Q7	What types of crops are cultivated in the farm? Legumes Fruit trees vegetables Other, please specify.....	 ☐ ☐ ☐ ☐	ماهي انواع المحاصيل التى تقومون بزراعتها داخل المزرعة بقوليات اشجار فواكه خضراوات اخرى...........	س7
Q8	How far away from your farm boundary is the nearest sand dune? Less than 500 meters More than 500 meters	 ☐ ☐	كم تبعد الكثبان رملية حاليا عن مزرعتك؟ أقل من 500 متر أكثر من 500متر	**س8**
Q9	In which direction is the nearest sand dune? North South West East All direction	 ☐ ☐ ☐ ☐ ☐	في اي اتجاه من مزرعتك توجد الكثبان الرملية شمال جنوب غرب شرق جميع الاتجاهات	س9
Q10	To what extent do you agree that the		الى اي مدى تعتقد ان الكثبان	**س10**

	current sand dunes are a problem to your farm?		الرملية التى تمت ازالتها كانت سببا في بعض المشاكل للمزرعة	
	Strongly disagree	☐	لا اوافق اطلاقا	
	Disagree	☐	لا اوافق	
	Natural	☐	تقريبا	
	Agree strongly agree	☐	اوافق بشدة	
Q11	In which of the following seasons does the sand move? (tick as many as you need)		في اي من الفصول التالية تعتقد ان الكثبان الرملية تتحرك	**س11**
	Winter	☐	فصل الشتاء	
	Spring	☐	فصل الربيع	
	Fall/autumn	☐	فصل الخريف	
	Summer	☐	فصل الصيف	
Q12	Does the movement of sand cause you:		الى اي مدى سببت حركة الكثبان الرملية لك اضرار في المحاصيل؟	س12
	Loss of more than ¼ production	☐	اكثر من 25% من الانتاج	
	Loss of between ⅛ and ¼ production	☐	من 12.5% الى 25% من الانتاج	
	Loss of less than ⅛ production	☐	اقل من 12.5% من الانتاج	
	Never	☐	لا يوجد أضرار	
Q13	Is the existing vegetation on any nearby sand dunes grazed?		هل يستغل الغطاء النباتى الموجود على الكثبان الرملية للرعي؟	س13
	Yes	☐	نعم	
	No	☐	لا	

Q14	How often does the sand move?		مامدى السرعة التى تعتقد ان الكثبان الرملية تتحرك بها؟	س14
	Never	☐	لا تتحرك اطلاقا	
	Very rarely	☐	ببطؤ شديد	
	Occasionally (once every 5 years)	☐	أحيانا (مرة كل 5 سنوات)	
	Frequently (about once every year)	☐	غالبا (مرة كل سنه)	
	Very frequently (more than once every year)	☐	تتحرك بشدة (اكثر من مرة في السنة)	
Q15	What methods do you use to stop the encroachment of sand dunes?		ماهي الطرق التى تستخدمونها لايقاف زحف الكثبان الرملية؟	**س15**
	A forestation	☐	التشجير	
	Barriers	☐	اقامة الحواجز والعوارض	
	Other, please specify.....	☐	اخرى.......	
Q16	If you have used methods to stop the encroachment of sand, how much money did you spend?		اذا قمتم بمحاولة لوقف زحف الرمال كم يمكنك تقدير التكاليف المالية لذلك؟	س16
	Very little (< 250 DL)	☐	قليلة جدا	
	Some (251 – 500 DL)	☐	متوسطة	
	A lot (> 500 DL)	☐	مكلفة جدا	

لكم كل التقدير والاحترام لمشاركتكم في تعبئة هدا الاستبيان الأمر الذي سيكون له الأثر الفعال في إثراء البحث العلمي وسعيا لإمكانية الوصول إلى انسب الطرق لمكافحة ظاهرة زحف الرمال.

الباحث الأكاديمي/ أ. سليمان فرج خوجة
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