Assessment and Mapping of Wind Erosion in Northeast Butana Area

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الملخص

اجريت دراسة في أربعة مواقع في الجزء الشرقي من سهل يطنابة في المنطقة الممتدة من شمال شرق سريان الخلاف الجديد الزراعي (مواقع رقم 1 إلى الحديد الشمالية لمنطقة نهر عطبرة) 4. إن الهدف الرئيسي للدراسة هو تدبير وتخريج مناحي التعبير الزراعية الأربعة والتي يتألف منها العرض التربوي والمنطقة الحالية والخطوة وتغيير الخطوة الناتجة عن التساقط من الرياح الزراعية والعوامل المساندة. تشمل الدراسة أيضا اختيار عدة طرق ومواقع مستخدمة في دراسة التعبير الزراعي، لتقديم معرفة معتمدة واسعة استجابة في منظور الرياح الزراعية. استخدمت هذه الدراسة توقعات الرياح وتقييمات الاستشعار على بالإضافة إلى التموذج الرياضي التجاري "Woodruff and Siddoways"

عند استخدام موتری نسبة التغطية بالكثبان و الحصى اوضحت الدراسة أن مواقع التعبير رقم 3، 2، 1، والمتمثلة في المنطقة الممتدة من الأطراف الشمالية لمشروعة حلفا الجديده الزراعي حتى جنوب قرية بانغير تعاني من حالة تعرض خفنه. اوضحت النتائج عند استخدام مؤشر نسبة التغطية بالكثبان في موقع التعبير رقم 4، والمتمثلة في المنطقة الممتدة من بانغير حتى الحديد الشمالية لديوانة نهر عطبرة، تعاني من حالة تعرض شديد جدا، بينما فشل مؤشر نسبة التغطية بالحصى في تصنيف الكثبان الزراعية لخلوها من الحصى. اوضح استخدام تقييمات الاستشعار عن بعد، المتمثلة في الصور الجوية وصور الارتفاع الصناعي، ان حالة التعبير متواضعة في المواقع الأربعة.

تم تقدير معدل التعبير باستخدام مصائد رملية راسية واقبالة. اوضحت التحاليل الإحصائية وجود زيادة طردية في معدل التعبير الزراعي في الاتجاه شمالي حيث وجد ان 78% من مجمل التعبير تم بموجب التعبير رقم 3، 4. اوضحت النتائج كذلك عن وجود علاقة عكسية بين شدة التعبير والارتفاع عن سطح الأرض حيث وجد ان 79% من مجمل كميات الريب المتجسدة بالمصائد تم ارتفاع يصل الى قد واحد من سطح الأرض. اوضحت الدراسة أيضا زيادة شدة التعبير بسبب عامل من شهر ديسمبر حتى يونيو (بداية ونهاية فترة التعبير) مما يوضح قوة اثر الرياح الجنوبية رغم قصر امدها.

أوضحت نتائج القياسات المباشرة وجود شدة تعبيرية مرتفعة جدا في كل المواقع عدا الموقع رقم واحد لحثة بمشروعة تغلق الجديده من الرياح الجنوبية. أعطت كل من المؤشر المعتمد على تقييمات الاستشعار عن بعد ومؤشر الموجز التعبيري تقديرات أقل من تلك المعتمدة على القياس المباشر. اكدت الدراسة اختلاف الوحدات المرسومة باستخدام تقييمات الاستشعار عن بعد في شدة التعبير.

بينت النتائج ان موقع التعبير رقم 1 يعاني من خطورة متواضعة من جراء التعبير الزراعي بينما يواجه موقع التعبير رقم 2 و 3 خطوة عالية. أما الموقع رقم 4 تواجهه عالية جدا. يكم السبب الرئيسي للخطورة في زيادة الكثافة الحيوانية عن حمولة المرعى حيث وجد ان الكثافة الحيوانية بالمنطقة فوق عن حمولة المرعى.
Abstract

A study was conducted in four sites representing Northeast Butana extending from the northern border of New Hlafa Agricultural Scheme (site 1) to the northern fringes of River Atbara Locality (Site 4). The objectives were to assess and map wind erosion. The four aspects of wind erosion namely status, rate, inherent risk and hazard of desertification caused by wind erosion in the area were studied. Also to test different methods and indicators used in estimation of wind erosion to develop tools and methods that are quantifiable, simple and locally adapted. The main methods used were direct measurement, remote sensing techniques and the parametric model developed by Woodruff and Siddoways (1965).

Using percent cover of dunes/hummocks and that of gravels as indicators, sites 1, 2 and 3 were slightly affected by wind erosion. The status of wind erosion was very high at site 4 when percent cover by dunes/hummocks was used as an indicator. However, the indicator of percentage coverage by gravels failed in rating status at the dunes as they were free of gravels. However, using remote sensing technique the status of wind erosion in the four sites was moderate.

Statistical analysis on the data collected by vertical and horizontal traps showed progressive northward increase in intensity of wind erosion (IWE). In site 3 and site 4, 78% of the total sand movement took place. The results also revealed existence of inverse relation between IWE and elevation above the ground level. It was found that 79% of the total collected sand was within one 0.3 m above the ground surface. The results, in general, showed increase in IWE from December to June. Although the southerly wind prevailing in summer is of shorter duration, it had a profound effect on wind erosion. Compared to the direct measurement the indicators based on remote sensing technique and that based on the parametric model under-estimated the IWE. However, by using remote sensing technique land units with different IWE could be delineated.

The study showed that site 1 had moderate hazard of desertification caused by wind erosion. Sites 2 and 3 had high while site 4 had very high hazard of desertification caused by wind erosion. The main cause of the hazard was overstocking. Animal density in the area was found to be more than twice the carrying capacity.
DEDICATION

To my wife and children for their patience and support
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CHAPTER ONE

INTRODUCTION

Rapid increases in the world population increases demand on food, fiber and fuel. To meet this demand increasing land are cultivated more intensively, and more marginal land are brought into production. However, soil is nonrenewable (in human life scale) and is a limited resource. Land has to be carefully managed if productivity has to be sustained or increased, otherwise various processes of soil degradation will inevitably occur. International community, (UNCOD, 1977) recognized desertification as a major ecological problem. The Conference recommended preparation of status of desertification map to provide warning of adverse trend and identification of problem areas.

The basic causes of desertification are climatic variation, human activity and climate change. Some authors looked upon desertification as a natural phenomenon that occur as dry phase alternating with wet phase in geological time scale i.e. The world is facing a climate change rather than anthropogenic desertification (Glantz, 1977; Hellden, 1998). Others (Kirkby and Carsson, 1972; Rap et al., 1976) regard it as a consequence of misuse of the environment. The main causes are reflected on the widely accepted UNCED (1992) definition of desertification as “Land degradation in arid, semi arid and dry sub humid areas resulting from various factors including climatic variation and human activity”. The main desertification processes include degradation of vegetation, wind and water erosion and salinization. These processes are natural but they may be accelerated by human activities such as overgrazing,
deforestation, over-cultivation and incidence of fire. The prominent consequences of desertification include poverty, famines, social conflicts and mass migration. From 1997 to 2020 some 60 million people are expected to move out from desertified areas in the Sub-Saharan Africa (FAO, 2002).

In the Sudan although desertification is recognized as a central constraint to sustainable development in the dry lands of the country, detailed information about the magnitude of the problem is meager and has been evaluated in general qualitative term. Inaccessibility of the affected areas, financial limitations and lack of standardized methodologies applicable under Sudan conditions are among the major factors that constrain research efforts to assess, map and monitor desertification. There is need for generating precise quantitative data on the status, rate, risk and hazard caused by the determinative processes in each ecosystem in the Sudan to formulate appropriate plans to combat desertification.

The arid zone of the country has a vital economic importance for 10.8 millions (38.9 percent) of the total human population inhabiting this zone (UNSO, 1997). Natural vegetation of short grass and sparse thorn scrub provide a period of good grazing for sheep, goats and camels. Ayoub (1998) estimated that the total area affected by wind erosion in the arid zone is 20 m ha compared to 5.8 m ha, and 1.2 m ha in hyper arid and semi-arid zones, respectively. Clark et al. (1997) found that in sub Saharan Africa below latitude 15 °N, independently of the soil type, wind erosivity was not enough to generate significant amount of aerosols. Above this zone it was seven times larger.
The Sudan government addressed the problem of desertification in response to the recommendations of UNCOD (1977) by formulating "Guideline of the national plan for combating drought and desertification" NDDU (1991). One of the recommendations made was assessment of the natural resources and building of Geographical Information System (GIS) to assist in storage, analysis and retrieval of information related to the natural resources.

North east Butana, falling in arid region of the country, is characterized by fragile ecosystem. Water balance deficit prevails due to higher evapotranspiration than effective rainfall. In addition the scanty vegetation and presence of weathered products of the Nubian sandstone furnished good condition for the wind to act freely. Moreover uncontrolled open grazing system is adopted whereby unspecified numbers of flocks of sheep, goats and camels roam the area. The area is, however, preferred by the herders because it is free of diseases such as foot and mouth disease. In addition pastoralists use this area to avoid traffic-ability problems of the clay plain during the rainy season. Moreover the study area also owes its importance for its location bordering New Halfa Agricultural Scheme which has a marked contribution to the economy of the country. Invasion of the scheme by drifting sand if it is not checked in early stages will have serious economic consequences. It may be more serious than the problem of “Miskeet” tree invasion. Some signs of accelerated wind erosion were observed in the area. For example most of the semi nomads who had been living in Goz Ragab village, close to Atbra river, after invasion of their land by sand dunes, migrated with their herds in New Halfa Agricultural Scheme. Also the majority of the semi-nomads who inhabited the plain north of the Scheme settled at the border of the Scheme.
Concentration of the livestock has led to many conflicts between the herders and the farmers. Frequently the local authorities were forced to send representatives of security to manage the conflicts. In spite of the economic importance of the area detailed information on the status and trends of wind erosion is lacking. There is urgent need for information about state and trends of the main processes of desertification working in the area as a prerequisite for planning purpose. Advances in information technology provided considerable opportunity in data acquisition, storage analysis and retrieval of information related to the natural resources. Hellden (1982) concluded that remote sensing technique when integrated with geographic information system (GIS) and implemented with modern field data collection methods based on satellite aided global position system (GPS) provide important tools to support assessment and monitoring approach.

The present study was undertaken to achieve the following objectives:

1. To conduct quantitative investigations on the status, rate, inherent risk and hazard of wind erosion in North East Butana area.
2. To develop and test quantitative, applicable and reproducible methods to assess wind erosion.
3. To develop a data base on wind erosion capable of integrating with other land resource management systems.
CHAPTER TWO

Literature Review

2.1 Extent and Intensity of Wind Erosion

Detailed data about wind erosion is meager and concentrated mainly in western Sudan. Generally wind erosion is tackled under the context of desertification in a qualitative term.

Warning about soil degradation in the Sudan was first raised by Kennedy-Cooke (1944). The warning was based on existence of three zones or climatic belt in the per-Saharan region. A zone of desert, which is the ultimate stage and nothing can be done to ameliorate conditions. The second is a zone of instability where slight disturbance (natural or human induced) may produce considerable change in the sensitive ecological balance leading to the enlargement of desert at the expense of the instable zone. The third zone is stable where permanent vegetation destruction is unlikely as the vegetation is restored subsequently when the pressure is released. They considered the whole country as instable except the extreme northern parts. Stebbing (1937) studied marginal land in West Africa. He forwarded historical evidences such as rock-paints, fossil remains and infilling of “wadis” with sand, at the time of
study, and concluded that the study period was one of the greatest aridity. In response to Stebbing’s work Anglo-French Forestry Commission set up investigation by Falconer on expansion of the desert margin to the south. However, Falconer (1938) could neither find evidences for desertification and soil erosion nor climatic change. He claimed that most of Stebbing’s arguments were based upon former pluvial period, irrelevant to the contemporary landscape.

One of the most widely cited references about desert encroachment in the Sudan was by Lamprey (1988). During a month, he led a team using a plane and vehicles and made ten crosses of the climatic boundary between latitudes 13° and 19° N in Northern Kordufan and Northern Darfur states and Nile valley. Although they stated that in the course of a month reconnaissance it was not possible to make more than a preliminary assessment of the situation, they presented the following evidences for ecologic decline in the Northern Kordufan and Northern Darfur. First by comparing position of the boundary drawn between sub desert scrub and the grass land with the position drawn by Harrison and Jackson (1958), he claimed that the boundary had shifted south by an average of about 90 to 100 km in 17 years (1958-75). The second evidence was that in Northern Kordufan particularly in Hamrat EL Wuz and Kheiran areas loose sand had accumulated over formerly consolidated terrain. The third evidence was that the observed high mortality of gum producing Acacia Senegal woodland. He stated “the northern limit of growth of this species appears to be shifting south”. He continued “Near Mezrub there are signs of progressive abandonment of agriculture particularly where sand encroachment had taken place”. From the foregoing it’s clear that the level of the study was preliminary assessment based mainly on observation rather than detailed and precise quantitative measurements. Therefore the level of the
survey and the method used made it subject to a wide margin of error in evaluating state and rate of desert creep. Secondly Harrison and Jackson carried out their survey in the fifties when the condition was wet while Lamprey made his preliminary assessment in 1975 which was one of the severe drought periods. More over Hellden (1988) pointed out that Harrison and Jackson’s desert boundary followed 75 mm isohyets while that of Lamprey followed 100 mm isohyets and the large shift might be due to difference in their concepts related to dry land boundary.

Hellden (1988) studying desertification in Northern Kordufan compared stratification based on Landsat MSS (FCC) recorded Nov 1972 with corresponding stratification based on Landsat MSS 5 and RBV imagery recorded Jan. 1979. The boundary between semi desert bushes with no or very scanty vegetation cover and grass land with more or less vegetation cover were drawn. The images were in original scale of one to one million. He concluded that he could not identify any significant change in the boundaries between 1972 and 1979. In southern parts of Kheiran, using air photos from 1962, Landsat MSS data recorded in October 1972, January 1973 and January 1979 he found (on the contrary to Lamprey) no southward dune encroachment. Moreover, he pointed out that the EL Tawil basin had been under irrigated cultivation ever since the beginning of the 19th century and still not buried by sand. Finally he concluded that there was no creation of long-lasting desert like condition, during 1962-1979 periods in the area. He reported, however, a severe drought impact on crop yield and natural vegetation during the Sahelian drought 1964-1974. The impact of the drought, according to him, was short lasting followed by fast land productivity recovery. From the above one can note the followings: First contrary to Lamprey his reference images were recorded in 1972 which was one of severe
drought periods, while the other set were recorded in 1979 which was wet. Secondly due to the scale limitations as well as resolution limitations encountered with the images used one can hardly expect variation within the time laps of seven years (1972-79). Thirdly, he used vegetation cover as an indicator of desertification even though it’s a poor indicator under conditions of low vegetation cover (FAO/UNEP/UNESCO, 1979). Annual vegetation cover reflects the condition of the preceding rainy season rather than the state of desertification.

Salih (1995) found that the total area affected by desertification in the Sudan amount to 50.5 percent of the country. According to Mustafa and Saeed (2004) wind erosion affected 27 out of 64 million hectares of the degraded land in the country. Dregne (1985) reported that in the Sudan about 198 million hectares of rangeland and 26 million hectares of rain fed cropland and 0.25 million of irrigated land were affected by desertification.

Tucker et al. (1991) used a satellite-derived vegetation index to map interannual changes of vegetation cover in the Sahel zone over eleven years of observations (1980 – 1990) and reported an average advance or retreat of Saharan-Sahelian boundary (200 mm precipitation isoline) as follows:

<table>
<thead>
<tr>
<th>Year</th>
<th>Advance/Retreat</th>
<th>Distance (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>Advance</td>
<td>+55</td>
</tr>
<tr>
<td>1981</td>
<td>Advance</td>
<td>+77</td>
</tr>
<tr>
<td>1982</td>
<td>Advance</td>
<td>+11</td>
</tr>
<tr>
<td>1983</td>
<td>Advance</td>
<td>+99</td>
</tr>
<tr>
<td>1984</td>
<td>Retreat</td>
<td>-110</td>
</tr>
<tr>
<td>1985</td>
<td>Retreat</td>
<td>-33</td>
</tr>
<tr>
<td>1986</td>
<td>Advance</td>
<td>+55</td>
</tr>
<tr>
<td>1987</td>
<td>Retreat</td>
<td>-100</td>
</tr>
<tr>
<td>1988</td>
<td>Advance</td>
<td>+44</td>
</tr>
</tbody>
</table>
From these figures they concluded that the mean position in 1990 was thus about 130 km south of its position in 1980. The above figures, however, reflect climate variation rather than climate change.

Trilsbach (1984) extracted a desertification map covering Sudan from the desertification map of the world produced by FAO/UNESCO/WMO in 1977. The extracted map showed that the whole of the Sudan faces hazard of desertification except the true desert in the north and the wet area of the south and along Ethiopian borders. With reference to the map the study area fell under very high risk of desertification. He analyzed, numerous case studies and concluded that cause and effect of desertification were site specific varying from place to other. Akhter (1994) presented a desertification map for Butana. According to her the study area was very severely affected by desertification.

Hagendorn et al. (1977) made a survey of literature on dune formation and reported that rate of barchans migration had been reported from 8 to 47 meters per annum. He stated that the highest figure had been reported for Peru. In Saudi Arabia, Gilani (1997) reported that sand dune movement reached ten meters per year while in Qatar it reached eight meters per year. Rizgalla, et al. (1999) found that potential wind erosion in a bare field 2 kilometers north of El-Obeid (Western Sudan Agricultural Research field) 66.7 t/ha/yr. In Dammokia, 30 km east of El-Obeid, it was 93.9 t/ha/yr. In fenced fallow field in Banno, 20 km south of El-Obeid, the potential wind erosion was 1.2 t/ha/yr.
Farah (2003) estimated the potential wind erosion in south and east of Khartoum by 1.25 t/ha/an. In North Khartoum it was 1.75 t/ha/yr.

2.2 Causes of wind erosion

There are many theories for the causes of desertification in general and wind erosion in particular. Some authors attributed desertification to climate change that happens naturally in a geologic scale with little interference of human activities in the process (Glantz, 1977; Hellden, 1998). One of the main causes of climate change is variation in the received solar radiation, due to variation in the earth rotation and passage around the sun or to the disturbance of the earth crust, (Williams, 1982). This leads to disturbance of the complex global ecosystem, with modification in circulation of air and water, redistribution of the atmospheric pressure and thermal change, casting its effect on the biotic environment (biosphere).

Others attributed it to human associated activities (Kirkby and Carson, 1972; Nelson, 1990). The radiation passing through the earth atmosphere may be modified (reflected, deflected or absorbed) associated with variation in concentration of the particulates such as dust, and carbon dioxide, due to vegetation stripping or industrial activities. Due to the sensitivity of mass and energy balance apparently small change (even nondeductible) in one or more components of the global ecosystem may result in a dramatic change in another. If vegetation is stripped by overgrazing, deforestation or uncontrolled fire albedo increases thereby lowering the surface temperature, cooling
atmosphere and promoting Hadley cell subsidence above the subtropical deserts of the world, (Charney, 1975). According to Charlson and Wigly (1994), Industrial aerosols, which are mainly in the northern hemisphere, also reflect solar radiation back into the space.

2.3 Effect of wind erosion

Wind erosion has a severe impact on both environment and soil productivity. The affected countries are under a risk of famines and civilian unrest, (Abdell Jalil 1980). Soil erosion reduces crop productivity through many ways. One of the most serious effects is on soil water relation. Wind erosion reduces soil water holding capacity subjecting crops to frequent and severe water stress. The reduction of soil water capacity is due to the reduction of the rooting depth caused by removal of top soil or by changing soil texture as by removal of fine material from the top soil leaving the soil course textured, (Dregne, 1990).

One of the most cited adverse effects is reduction of soil fertility. The transported soil particles remove attached nutrients exposing generally infertile subsoil or leaving behind coarse textured skeletal soil material. Many workers (Gaber, 1998; Larney et al., 1998; Boon et al., 1998) indicated that wind erosion resulted in decrease of organic matter, nitrogen, phosphorous, and potassium. Addition of fertilizers to compensate the lost nutrients increases the cost of production. Larney, et al. (1999) found that concentration of the surface applied herbicides was higher in wind eroded sediments than in the surface soil. The result demonstrates the potential hazards of wind transported herbicides and its associated implications upon offsite areas and water quality.
Soil erosion causes also degradation of soil structure promoting surface ceiling and crusting with the consequence of reduced seedling emergency and infiltration (Leonard and Johnson, 1987). Soil erosion normally occurs in non-uniform pattern leading to non-uniform topography requiring different management strategies. Different doses of fertilizers have to be applied at different sites and times. This leads to devaluation of the land (Singh et al., 1992).

When dust particles fall on plant leaves they mask sunlight and reduce photosynthesis important for dry matter production. Also when dust particles of the same sizes of the stomata fall on leaves they may plug stomata or keep them open all through affecting the gaseous exchange of the leaves. Significant damage to young crops and pasture occurs by sand blasting and burial by drifting sands lowering marketability of vegetables as asparagus and lettuce. More over sand bury infrastructures such as roads, railway lines, fences and channels and increases cost of maintenance. Further more wind erosion aids in spread of weed seeds and disease. Udas et al. (1997) estimated that offsite cost due to wind erosion was much higher than on-site cost.

Few studies were carried out to determine the effect of wind erosion on yield in quantitative term. The main reason is that it is difficult to screen contribution of wind erosion from many variables that affect crop production. However, there are some studies that related yields of certain crops to soil thickness. Lyles (1977) made rough estimates of yield reduction per millimeter of top soil loss for limited range of fine texture soils in USA. He found the reduction to be 10 kg/ha for corn and 8 kg/ha for wheat, soybeans, grain sorghum and oats. He concluded that the data were too sparse to extrapolate across soils, climate and type of erosion. Abrasive injuries have
been reported for some crops such as winter wheat by Armbrust et al. (1974b) and green beans by Bubenzer and Weis (1974).

The principal off site environmental impact is due to the disruption of the global carbon cycle (Lal and Kimble, 1998). The direct effect on the human is that when dust is inhaled it causes many health problems such as asthma, (Williams and Young 1999). It also reduces visibility, (Leys, 2003) causing traffic hazards.

2.4 Wind erosion mechanics
Soil erosion by wind occurs when the force of wind is sufficient to detach and carry soil particles. The process involves three distinct types of movements.

2.4.1 Saltation
When strong wind passes over loose, dry, smooth, bare or nearly bare soil surface, it exert force on particles by its impact. It also exerts a drag on particles exposed to it because of the viscosity of the air passing over the grain surface. A third effect follows from increasing wind velocity with height. Such increase causes pressure gradient (Bernoulli Effect) and consequently particles tend to rise pushed from below (Williams, 1982). This process is referred to as saltation.

On the account of rapid spinning of the grain, the air near the grain surface is carried with it. On the upper side the air is moving in the same direction of wind while on the lower side the air moves against the wind direction. The air velocity at any point is made up of two components, one due to the wind and the other to the spinning of the grain. On the upper side these components
have the same direction, whereas below they have opposite directions. Thus the velocity is greater at the top surface than the bottom. According to Bernoulli theorem the pressure is decreased at the top and increased at the bottom and the grains tend to rise, (Chepil, 1945). When soil particles are shot into the air, they tend to rise almost vertically at $75^0$ to $90^0$ reaching heights depending on wind velocity and grain characteristics. However, field and tunnel measurements indicated that most of soil movement by saltation was below a height of one foot. As the particles enter faster wind the spin slows down. Having lost their upward impulse and because of the force of gravity they descend at an accelerating velocity. Photographs showed that the inclined path of the falling grains is almost straight line striking the ground surface in remarkably constant angle irrespective of the height reached. This angle ranges between $6^0$ and $12^0$ according to Chepil (1961) and $10^0$ to $16^0$ according to Bagnold (1941). The latter attributed the constant angle to the balance between the gravity and forward velocity as both of them increase with height. When particles hit the ground they may rebound into the air conserving its momentum. Alternatively, the impact of the particles on the surface of loose material may be sufficient to cause other particles to move, which without this assistance may not be able to move with wind alone. Another alternative is that the momentum may be dissipated by abrading aggregates on striking the aggregates from behind.

2.4.2 Surface creep
Soil particles larger than 0.5 mm in diameter (0.5 – 3 mm diameter) are generally too heavy to be lifted by wind. They are pushed along the ground surface. The kinetic energy of relatively strong wind is needed to initiate
surface creep (called fluid threshold). However surface creep can also be caused by the aid of energy received from saltating particles (impact threshold). The descending soil particles strike the larger grains adding energy to them, similar to a pair of billiard balls. The impact velocity of the saltating grains is sufficient to impart movement of larger soil particles.

2.4.3 Suspension.
When saltating particles hit soils of dust size (smaller than 0.1 mm in diameter) they are kicked high into the air. Due to their large specific area they stay in suspension and are carried a long distance, some times thousands of kilometers (Chepil, 1945). Suspended materials remain in the air as the upward eddy current is more than terminal velocity of fall, determined by grain size, shape and density (Bagnold, 1941). The impact velocity of the saltating grains is sufficient to impart movement of dust particles.

2.5 Factors affecting wind erosion
The rate of wind erosion depends on many factors and their interactions pertaining to the process. The contribution of each factor can be positive or negative. Chepil (1945a) started his investigations on applied wind erosion by specifying thirteen important factors and divided them into three groups: the first included the velocity, turbulence, density and viscosity of the air. The second group included roughness, cover, obstructions, temperature and topographic features of the ground. The third group included soil structure as affected by organic matter, lime content, texture and moisture content. Wilson and Cook (1980) grouped the factors affecting wind erosion into soil erodibility and wind erosivity factors. They stated that stability of the structural unit against abrasion, which determines erodibility of soils in the field, are
principally determined by soil water, texture, organic matter, and disaggregating processes such as calcium carbonates, freeze-thaw activity and harrowing. He divided erosivity factor into two main categories: Those related to nature of atmospheric flow and those related to the main constraints on that flow, surface roughness. With respect to wind erosivity, Chepil et al. (1962) suggested the following.

\[ WE = \sum_{j=0}^{15} \sum_{i=1}^{12} u_i^3 f_i \]

Where: \( WE \) = wind erosivity caused by all wind velocity groups in all directions.

\( U_{ij} \) = mean wind velocity above a threshold velocity in the \( i \)th velocity group for the \( j \)th direction.

\( f_{ij} \) = duration of the wind velocity in the \( i \)th velocity group and \( j \)th direction expressed as fraction of all observations in the \( j \)th direction within the \( i \)th velocity group.

\( J = 0 \) = east direction (E), \( j = 1 \) = ENE and so on.

For the factors that make constraints on the flow, he recognized five roughness elements, these were: vegetation height and density, clods and non-erodible elements, ridges, field shelter belts and local change in topography. Woodruff and Siddoway (1956) listed eleven primary variables governing wind erosion. These were: Soil erodibility, knoll erodibility, surface crust stability, soil ridge roughness, wind velocity, surface soil moisture, distance across field, sheltered distance, in addition to the quantity, kind and orientation of the vegetative cover. It is clear that Chepil started his work based on the biotic factors of wind erosion, while Willson and Cook added
vegetation as a factor, whereas Woodruff and Siddoway added human factor represented by ridging and shelterbelt.

Wind erosion can be looked upon as result of adverse effect of climate and living organisms on soils, modified by relief through time. Hence the main factors affecting wind erosion are: Climate mainly wind velocity and temperature; soil mainly texture, structure and moisture; living organisms include natural vegetation and human activities (due to the difference in mode of action, biotic factor will be divided into natural vegetation and human factor); relief and time.

2.5.1 Climate

The most important climatic factor is the force of wind. Wind erosivity depends on wind speed and duration. Bagnold (1941) found that the soil movement varies directly as the cube of wind velocity. Zachar (1982) presented a table (Table 2.1) showing threshold wind velocity in relation to the grain size.

Table 2.1  Threshold wind velocity (m/s) in relation to grain diameter

<table>
<thead>
<tr>
<th>Grain diameter, mm</th>
<th>0.01</th>
<th>0.1</th>
<th>0.25</th>
<th>1.0</th>
<th>1.5</th>
<th>2.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initiation of movement</td>
<td>3.65</td>
<td>3.83</td>
<td>4.57</td>
<td>6.62</td>
<td>7.65</td>
<td>8.57</td>
</tr>
<tr>
<td>Starts to rise</td>
<td>3.72</td>
<td>5.41</td>
<td>6.60</td>
<td>10.71</td>
<td>13.41</td>
<td>16.25</td>
</tr>
</tbody>
</table>

The table indicates that soil particles can move even at gentle breeze, Beaufort scale of wind force (Bf) 3. Under Bf number 4 sand particles of the size 0.5
start to move. Chepil (1945) used the following index to estimate climatic aggressivity:

\[ C = \frac{V^3}{2.9 (PE)^2} \]

Where \( V \) = wind speed and \( PE \) = the precipitation effectiveness of Thornthwait.

Range of particle size transported decreases with height and the height reached depend on the shape of the particles. The height reached increases with sphericity (Williams, 1964).

According to Bagnold (1941) amount of sand movement (q) depends upon the mean grain diameter (d), the degree of the uniformity of the grain size, and the drag velocity (\( V^* \)) of the wind. Introducing an empirical coefficient C, the actual measured rate of sand movement is given by the expression

\[ q = C \sqrt{\frac{d}{D}} \cdot \rho V^3 \]

Where:

d is the grain diameter of the sand in question

D is a standard grain diameter of 0.25 mm

C is a coefficient having the following values:

1.5 for nearly uniform sand

1.8 for naturally graded sand

2.8 for sand of a very wide range of grain size
\( \rho \) is density of the fluid (air)

\( g \) is gravitational constant

\( \frac{\rho}{g} = 1.25 \times 10^{-6} \)

Chepil (1957) attributed the down-wind increase in the quantity of material transported to many causes. First to the progressive increase in number of grain impact (higher frequency of impact) due to increase in supply of erodible material by abrasion. In addition the incoming materials are generally more erodible than that in the upwind. Moreover, particles are trapped in depressions weakening their surface roughness and increasing the rate of transport. Chepil (1959) found that the distance from the point of initiation to saturated flow as approximately the same for all levels of erosive wind but varies with soil erodibility. This distance ranged between 65 meters for most erodible soils to 1960 meters for the least erodible soils

2.5.2 Soil factor

Soils show some kind of resistance to wind force by reducing its kinetic energy. Soil erodibility depends mainly on its texture, structure and the moisture content.

2.5.2.1 Texture

Soil texture can affect many other soil properties especially those related to soil moisture and fertility. Simmons and Dotzenko (1974) found significant correlation between soil texture, organic matter content, 15-bar moisture percentage, cation exchange capacity with percentage of erodible dry soil fraction in some erodible eastern Colorado soils. Chepil (1955) found that in
general the higher the proportion of silt and clay in a soil, the greater the production of clods and the lower is soil erodibility. He also found that clods showing a high degree of stability consisted of mixture containing 20 – 30 percent clay, 40 – 50 percent silt.

Chepel (1945b) presented the following table (Table 2.2) showing relation between soil erodibility classes and dominant grain size.

Table 2.2 Relation between soil erodibility and dominant grain diameter (Chepil 1945b)

<table>
<thead>
<tr>
<th>Erodibility</th>
<th>Threshold velocity (m/s)</th>
<th>Dominant grain diameter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high</td>
<td>3 - 4</td>
<td>0.15-0.1</td>
</tr>
<tr>
<td>High</td>
<td>4 - 5.5</td>
<td>0.5 - 0.15 and 0.1 - 0.05</td>
</tr>
<tr>
<td>Moderate</td>
<td>5.5 - 7</td>
<td>0.5 – 1 and 0.05 - 0.01</td>
</tr>
<tr>
<td>Low</td>
<td>7 - 10</td>
<td>1 – 2 and 0.01 – 0.005</td>
</tr>
<tr>
<td>Very low</td>
<td>&gt; 10</td>
<td>&gt; 2 and &lt; 0.005</td>
</tr>
</tbody>
</table>

2.5.2.2 Structure
Soil structure depends on the content of organic matter and other cementing agents as calcium carbonates, silica and iron oxides. The stronger bond between the particles is generally associated with cementing materials. The more stable the structure the more it can withstand erosion. The amount of soil eroded by wind varies directly with the ratio of erodible to non-erodible
fraction in the soil surface layer. Soil aggregates and primary particles greater than 0.84 mm diameter are generally considered non-erodible (Woodruf and Siddoway, 1965). In general all factors that promote the formation of aggregates $>0.84$ reduce soil erodibility and hence wind erosion.

### 2.5.2.3 Moisture
Dryness of the soil is normally associated with the wind. Chepil (1956) conducting his experiment in a wind tunnel, found that wind erosion is a function of the cohesive force of adsorbed water films surrounding the soil particles. He found erodibility decreased with each successive increment of moisture from one-third equivalent to 15-atmosphere percentage. Above 15-atmosphere percentage a relatively great increase in wind velocity is required to produce movement of soil. However, Wiggs et al. (2002) conducted field experiment verified existence of a wind speed specific moisture threshold for the initiation of saltation activity. He found that this threshold lies within a range of 4 – 6 % which, according to him, is in excess of critical moisture contents specified in wind tunnel investigations.

Sabir and Babaker (1997) studied effect of water content on wind erosion of four Moroccan soils using 0, 2, 4, 8 % moisture. They found that soil erodibility decreased with increase in soil humidity and attributed it to increase in cohesive force between soil particles.

### 2.5.3 Vegetation
Vegetation dead or alive slows down wind velocity at the ground surface reducing its ability to dislodge soil particles. Also plant roots give strength to the soil (Williams, 1982). Effect of vegetation depends on the type, height, density and distribution (Agricultural Bureau of South Australia, 2002). Also
Frances and Thornes (1990) found that wind erosion was inversely related to density and duration of vegetation cover.

### 2.5.4 Human activity

Human activity can cause, intensify or ameliorate the process of wind erosion. Human induced erosion is made by adverse modification of the other factors. Climate modification, for example, may take place by activities leading to increase of albedo, as by vegetation stripping and pollution. Destruction of soil structure takes place by soil cultivation. Vegetation cover may deteriorate by overgrazing, deforestation and improper crop management. Rate of wind erosion under natural vegetation is generally low. Upon cultivation the rate changes dramatically. However conservation technology, as implementation of minimum tillage reduces wind erosion (Oldman et al., 1990). Microtopography is modified by ridging.

### 2.5.5 Topography

Topographic relief retard wind flow and concentrate it at the sides. Chepil et al. (1964) showed that soil loss increased with increase of slope and distance towards the top of a knoll for windward slope less than 150 meters length. Wind tunnel simulation experiment of mountain dunes by Liu-Xian et al. (1999) showed that the pressure coefficient on the windward slope increased with increase of wind velocity, strike angle and slope angle.

In micro scale natural surface projection and other non-erodible fractions such as random gravels provide direct cover and protect the erodible grains underneath and adjacent. Particle size, shape and distribution of the non-erodible fractions are the main elements that affect entrainment of sand.
particles. The condition at which the non-erodible fraction is just sufficient to prevent soil movement is called by Chepil and Woodruff (1963), critical surface barrier ratio. It is defined as ratio of the distance between the non-erodible barriers divided by the height of the barriers.

2.5.6 Time
Importance of the time factor in wind erosion lies on the fact that all the above mentioned factors work in a time frame. As the time of operation of a factor that promote wind erosion increases, wind erosion increases.

2.6 Estimation of wind erosion
Wind erosion can be assessed using the following methods: Direct observation and measurement; use of remote sensing technique and parametric models.

2.6.1 Direct measurement.
It is the main reliable method of data collection. It can serve as ground check to verify results obtained by remote sensing technique or modeling. Surveys are often based on direct measurement using diagnostic criteria or indicators. The results of direct measurement can be synthesized as maps, tables or other form of representation.

Measurements of wind erosion can be conducted in the field or in simulated conditions. Field measurements are generally more reliable, but due to spatial and temporal variation and so many interactions that involved in the process, it is very difficult to determine the main causes of wind erosion or examine the process under work.

2.6.1.1 Wind tunnels
Experiments designed for explanation are best undertaken in the laboratory where the effect of many factors can be controlled (FAO/UNEP/UNESCO, 1979). However field confirmation is required to verify the results. Almost all the basic studies in wind erosion have been carried out in the laboratory using wind tunnels. Wind is supplied by a vacuum or compressor through the tunnel. Realistic wind profile is produced only in the test section. The value of the tunnel depends on the length of this section. Numerous studies were carried by Bagnold (1941) to understand the dynamics of sand movement. He tested his hypothesis under controlled condition of wind tunnel and field observation and measurement. Chepil (1945a, 1945b, 1950, and 1956) building on Bagnolds findings tried to identify quantitatively the factors that affect soil erosion by wind. Wind tunnels have been used also by Koolen (1976) to study the effect of low growing plant. Moreover they are used in testing and calibrating sand traps.

2.6.1.2 Field measurement
Various types of traps are used to catch moving sand in a band of unit width. There are two types of traps; horizontal traps and vertical traps.

(i) Horizontal traps:

A horizontal trap consists of a trough set in the ground parallel to the direction of the wind with the lid at the same level with the ground surface. Some times the traps are divided into compartments so that rolling and saltating particles fall into the different compartments according to their length of hop (Morgan, 1995). Horizontal traps have the advantage of minimum interference with the wind but a considerable length is required to collect a representative sample
depending on the length of hop. The other drawback is that, as they are fixed, they cannot be easily reoriented when wind direction change.

(ii) Vertical traps:

Consists of a series of boxes placed one above the other so as to collect all of the moving particles at different heights. Back pressure causes deflection of the wind from the catcher. This is prevented by adjusting the ratio of the inlet and outlet to permit free flow of the air. There are different types of traps. Fixed types were used by Bagnold (1941) and Horrikawa and Shen (1960). Nickling and Neuman, (1997) used wedge-shaped aeolian sediment trap. A rotating type was used by Janssen and Terzlaff (1991). It consist of a narrow capture tube leading into wide vertical tube where wind blown materials are settled out falling into a tray mounted on top of balance. The weight of the material is weighed automatically. By fixing the catcher to a wind vane the apparatus rotates so that the capture always faces the wind. Similarly Bauer and Namikas (1998) designed and field tested what they called “a new tibbing-bucket” assembly for Aeolian sand traps. Spaan an Abeele (1991) developed, an automatically recording sensor called a “saltiphone’. The saltating activity is detected by means of a microphone drum that response to the impact of saltating grains. The frequency of the impulses, which are proportional to the number of impacts, are read out

2.6.2 Use of remote sensing technique

Remote sensing can be broadly defined as collection of information about an object or phenomenon without being in physical contact with it (Sabins, 1978).

Since last decade remote sensing has been increasingly used in data collection about location, availability and changing condition of natural resources.
Application of remote sensing in natural resource investigations depends on the fact that every feature in the nature is unique in reflection or emittance of the electromagnetic radiations. Consequently information about the physical (size, shape, area, etc) and chemical properties of this surface can be extracted by measurement of the reflected or emitted radiation using special kind of sensors.

Scientists studied the interrelationship between the spectral responses of the features and their physical and chemical properties with laboratory instruments. Thomas et al. (1986) concluded that large scale photographs can be used reliably to determine the volume of the soil lost in the study area. Also Dymond and Hicks (1986) applied photo interpretation technique to obtain volumetric measurement of erosion in mountainous catchments to the most part of New Zealand and found it sufficient. Navone (1998) investigated the effectiveness of the Landsat images in differentiating among degrees of wind erosion in three different sites. The results showed that wind erosion was detectable in the three sites. Hoffer (1967) stated that in general soils were characterized by high spectral response in the thermal infra red, and rather low response in the reflective infra red, and varied response in the visible portion of the spectrum.

The main advantage of remote sensing is that it provides a repeated and relatively inexpensive mean of data collection. This is particularly important for developing countries where generally data are non available or of poor quality. It may be the only source of historical data. In case of national and regional level and other extensive studies is the only practical method. The synoptic view permits accurate delineation of physiographic boundaries. More over the repetitive coverage enable monitoring changes of the natural
resources. Further more the multi spectral capability of the satellite images enhance discrimination of the different features. The main limitations, however, are that: because land satellite portrays only surface reflectance properties, subsurface properties such as soil horizonation can not be measured directly. Only it can be inferred reasonably when subsurface variation is reflected on the surface. Krislof and Zachar (1971) noted that identification of soil series was not possible because surface and subsurface properties differentiate series. Also different objects or phenomena having the same reflectance characteristics may be grouped together though they are different. A water body, for example, and rock out crops composed of dark minerals may be registered as dark tone. High experience and local reference level are required for interpretation of remote sensing documents. Auxiliary data and field verification are necessary for verification.

In Sudan data acquisition using remote sensing technique is widely used. Soil Survey Administration used photo-interpretation coupled with field verification in most of semi detailed studies carried out during feasibility studies of the main agricultural schemes in New Halfa, Guneid, Rahad, Suki, and Kinana. They also applied satellite imageries in compilation of exploratory soil maps of the mapped states. Many other authors, Salih (1983) used remote sensing technique in land evaluation; Hamid (2000) in modeling land use; EL Hag (1983), Akhtar and Mensching (1994) used Satellite imageries in assessment of desertification.

2.6.3 Assessment using parametric models
At present there is no widely accepted model for predicting wind erosion. However the following generalized formula is used widely (FAO/UNEP/UNESCO, 1979).

\[ D = f(C, S, T, V, L, M) \]

In which \( D \) is Soil degradation, \( C \) is Climatic aggressivity factor, \( S \) is Soil factor, \( T \) is Topographic factor, \( V \) is Natural vegetation factor, \( L \) is land use factor, and \( M \) is Management factor.

Solving of the equation gives a numerical indicator of rate of wind erosion. Since the values assigned to each factor is only approximate in our present state of knowledge the final result give indication of the magnitude of the problem.

Woodruff and Siddoway (1965) published an equation known as a wind erosion equation (WEQ). The amount of soil erosion, \( E \), was evaluated in terms of equivalent variables. It can be expressed as:

\[ E = f(I', K', C', L', V') \]

Where \( I' \) is a soil erodibility index, \( K' \) is a soil ridge roughness factor, \( C' \) is a climatic factor, \( L' \) is field length along the prevailing wind erosion direction, and \( V' \) is equivalent quantity of vegetative cover. The five equivalent variables are obtained by grouping some and converting others of the eleven primary variables known to govern wind erodibility. The equation is designed to serve the two fold purpose of providing a tool to (i) determine the potential erosion from a particular field, and (ii) determine what field conditions of the soil cloddiness, roughness, vegetative cover, sheltering by barriers, or width and orientation of field are necessary to reduce potential erosion to a tolerable
amount. The main drawback of the equation is that standard condition refers to conditions at Garden City, Kanasas as they were during 1956 – 1957.

As a follow-up to the recommendations of United Nation Conference on Desertification (UNCOD, 1977), UNEP and FAO jointly developed a provisional methodology for assessment and mapping of desertification, (FAO/UNEP, 1984). The main feature of the system is incorporation of quantifiable anthropogenic factors to the natural factors leading to desertification. The major natural or induced determinative processes that were considered are: degradation of the vegetative cover, water erosion, wind erosion, salinization. The subordinate processes include, reduction in organic matter, soil crusting and compaction and accumulation of substances toxic to plants or animals. For each process the aspects considered were; Status; rate; inherent risk and hazard of desertification. The severity of desertification was graded as slight, moderate, severe and very severe.

The methodology was reviewed in Kenya (1987). The initial evaluation concluded that the method could only be used in local and plot level. Grades of the aspects were expanded to include non-affected class.

Babikir et al. (1994) proposed a methodology for assessment and mapping desertification in Sudan. The methodology is an adapted version of that of FAO/UNEP (1984).
CHAPTER THREE

Materials and Methods

3.1 Experimental area

3.1.1 Location.
The experiment was undertaken in Northeast Butana, in an area covering about 2000 square Kilometers (Fig. 3.1). It stretches from the northern borders of New Halfa Agricultural Scheme (Lat. 15° 50′ N) northwards till the boundary of Kassala state with the Nile state (Lat. 16° 20′ N). Lat. 35° 8′ E bounded the western border, while River Atbara sub tend the eastern boundary. Four sites were selected for detailed investigations. They were located within the following grid references.

Site no. 1: Lat. 15° 54′ 36.8″ N; Long. 35° 26′ 34.4″ E
Site no. 2: Lat. 15° 59′ 87.9″ N; Long. 35° 23′ 16.4″ E
Site no. 3: Lat. 16° 06′ 29.4″ N; Long. 35° 21′ 49.3″ E
Site no. 4: Lat. 16° 14′ 42.5″ N; Long. 35° 22′ 56.3″ E

3.1.2 Geology and Geomorphology:

The main geologic formation comprises pre-Cambrian Basement Complex of mainly igneous rocks that outcrops in few places such as Jebel (hill) El Muhandad, Jebel El Areed, Jebel EL Hilab, and Jebel El Diri. In the northern side of the study area the basement comple