Soil erosion – causative factors, extent and prevention

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Abstract

A short overview is given of the extent of soil erosion (both wind and water erosion) in Namibia. The different types of erosion, as well as severity classifications, are explained using the definitions used by SOTER.

The factors contributing to erosion, viz. rainfall energy, rainfall interception by vegetation, slopes and soil types, are discussed with examples.

A few telltale signs of erosion are discussed and illustrated, and the negative effect of erosion on the production of natural vegetation highlighted. A few preventative measures for especially sheet erosion are listed.

Introduction

Soil degradation in Namibia is not a spectacular phenomenon. It is inconspicuous and insidious. It manifests itself as nutrient depletion, hardpan formation and surface sealing. Wind, sheet, rill and gully erosion do occur, but are not perceived as major problems compared to the inherently poor physical and chemical properties of Namibia's soils and the overwhelming aridity of the country. Therefore, very few people realise that erosion is a problem in Namibia. (Coetzee 1999).

However, erosion does occur. During the past few years' field work for the Vegetation Survey project (Strohbach & Sheuyange 1999), observations have been made about the type and severity of erosion. Although the data do not yet cover the whole country, the results give a good indication of just how widespread the problem of erosion is (Table 1). Wind erosion is especially a problem in the southern Kalahari (Figure 1), whilst sheet erosion has been observed widespread (Figure 2).

Table 1: Number of sites with observed erosion.

No erosion	56	6.8%
Slight sheet erosion	323	39.2%
Moderate sheet erosion	273	33.1%
severe sheet erosion	80	9.7%
extreme sheet erosion	8	1.0%
Rill erosion	10	1.2%
Wind erosion:	74	9.0%
Number of plots:	824	

As can be seen from Table 1, only 6.8% of the observed sites did not show any sign of erosion, whilst the extreme cases of erosion, being rill erosion and extreme sheet erosion, were only observed on 1.2% and 1.0 % of the plots, respectively. Erosion, albeit often only slight to moderate in degree, is thus happening in over 90 % of our country!

Types of erosion

In the SOTER methodology (FAO 1993) the following types of erosion are recognised:

- Water erosion: sheet, rill, gully and tunnel erosion
- Wind erosion, shifting sand
- Water, wind and salt deposition

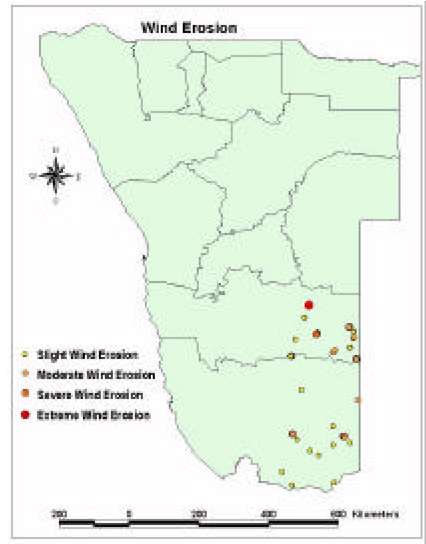

Figure 1: Map indicating the occurrence of wind erosion in the country. (Map prepared by the Agro-Ecological Zoning programme, MAWRD, from data from Strohbach & Sheuyange 1999)

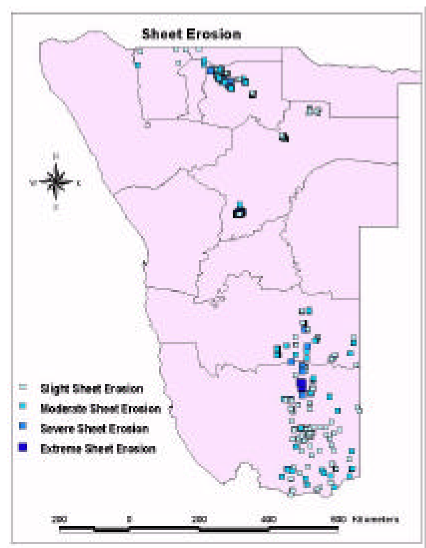

Figure 2: Map indicating the occurrence of sheet erosion in the country. (Map prepared by the Agro-Ecological Zoning programme, MAWRD, from data from Strohbach & Sheuyange 1999)

Sheet erosion is the erosion of the surface soil layers over a large area. This type of erosion is the start of erosion and often not easily recognised, as no telltale rills are formed (Figure 3). The next step is rill erosion, were small channels are formed (Figure 4). As these channels grow bigger, typical gullies are formed (Figure 5). Eventually the gullies result in gully landscapes or badlands. These are often associated with Lesotho and the Eastern Cape in the southern African context, but are also found in Namibia (Figure 6). Tunnel erosion is a phenomenon in which the topsoil is very stable, whilst the lower soil horizons are highly erodible, and often exposed. With water-logging, the subsoil layers wash away, leaving hollows / tunnels into which the topsoil sinks. This form of erosion is also often associated with high rainfall areas and heavy frost areas.

A distinction is made between straight forward wind erosion, where the topsoil is taken away by the action of wind (Figure 7) and shifting sands, where (desert) plains are alternating covered/ uncovered by sand sheets.

All types of erosion result also into deposition (or sedimentation) of the soils removed. Deposition often happens in locations fairly remote from the origin of these soils.

The degrees of erosion are defined by SOTER as follows:

- Slight erosion: Some evidence of loss of surface horizons. Original biofunctions largely intact.

Figure 3: Severe sheet erosion in the Okahandja district (1999). Note: no rills are visible yet (Photo: B. Strohbach).

Figure 4: The first rills become visible with severe erosion. (Okahandja district, 1999) (Photo: B. Strohbach)

Figure 5: Rills become gullies .... (Okahandja district, 1999) (Photo: B. Strohbach)

Figure 6: .... which result in badlands. (Opuwo district, 1998)

Figure 7: A typical example of wind erosion in the southern Kalahari (Mariental district, 1999). This tree's roots are expose for about 1 m. *(Photo: B. Strohbach)*

- Moderate erosion: Clear evidence of removal of surface horizons. Original biofunctions partly destroyed.
- Severe erosion: Surface horizons completely removed, with subsurface horizons exposed. Original biofunctions largely destroyed.
- Extreme erosion: Substantial removal of deeper subsurface horizon (badlands). Complete destruction of original biofunctions.

Factors contributing to erosion

Water erosion occurs when raindrops hit the ground and dislodge soil particles from the soil, and then these dislodged soil particles wash away and in the process dislodge and remove further soil particles. The amount of erosion is thus a function of the following four factors: the rainfall energy, the vegetative cover, the length and steepness of the slope and the type of soil (Stocking 1987).

The rainfall energy

The rainfall energy is the energy which falling raindrops have then impacting with the soil. This energy is a product of the mass (i.e., the size) of the drop as well as the speed at impact. The higher the origin of the drop, the higher its impact speed. The bigger the drops, and thus the 'harder' the rainfall event, the more energy is released to the soil (Stocking 1987). Namibia has generally very 'hard' rainfall associated with our tropical thunderstorms compared to the eastern part of the subcontinent. The more rain per annum, the more energy is released onto the soil per annum. Thus, a high rainfall area has an inherent higher risk of erosion than a lower rainfall area.

As an example: a 'normal' raindrop of about 2 mm diameter will fall with a terminal velocity of 6.4 m/sec (Smith & Wischmeier 1962). Using the regression formula of Bisal (1960)[1] it can be calculated that this drop will dislodge approximately 2.35 g of soil on impact on a sandy loam (typical for the Okahandja and Otjiwarongo districts) (Figure 8).

A bigger drop of 3 mm diameter will fall with a terminal velocity of 7.8 m/sec and will dislodge 4.7 g of soil on the same soil type. During heavy rains, with an average drop size of 4 mm diameter, each drop will fall with a terminal velocity of 8.6 m/sec and will dislodge as much as 7.2 g of soil!

Another example: On the same soils, devoid of vegetation and on fairly flat slopes, some 1.10 t/ha soil will be washed away in a season with only 250 mm of rainfall. In a season like this year with say 500 mm rainfall, an estimated 12.72 t/ha will be washed away from the same site (using SLEMSA (Stocking 1987) as guideline).

Rainfall Interception

The rainfall energy is intercepted by the vegetation cover. A rain

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[1] According to Bisal (1960), the amount of soil splashed away can be calculated as follows:

$$E = K*d*v^{1.4}$$

where E is the amount of soil lost through splashing (g)
K is the soil erodibility factor (0.087 for loamy sand)
d is the diameter of the raindrop
v is the terminal velocity (i.e. the velocity at impact) of the raindrop

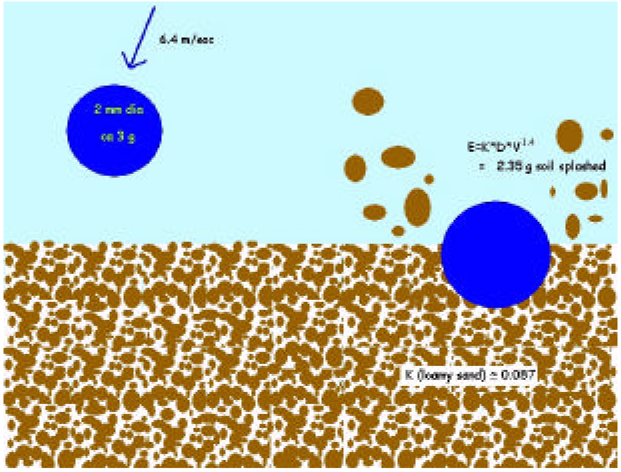

Figure 8: Schematic representation of the events when a raindrop hits the ground.

drop falling onto a leaf will burst

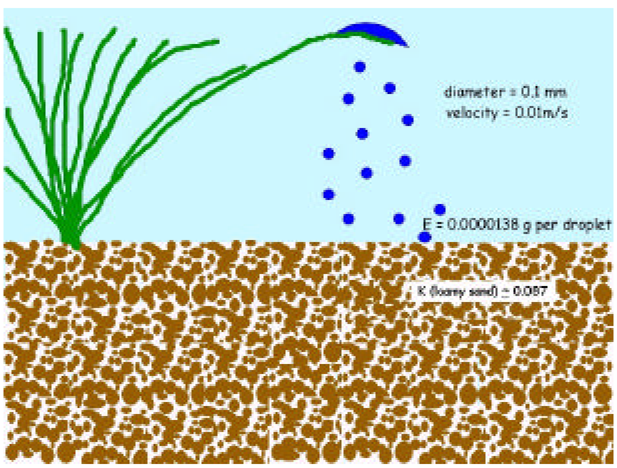

Figure 9: Schematic representation of the interception effect of plants on rainfall.

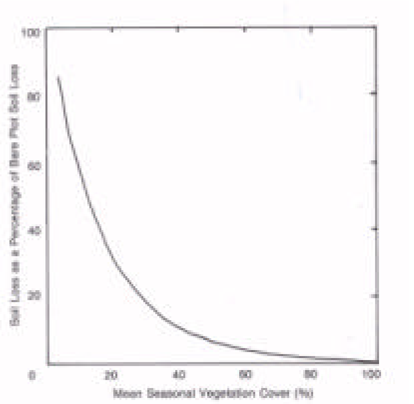

Figure 10: The effect of vegetation cover on the soil loss ratio: the lower the vegetative cover, the higher is the loss (as compared to loss from bare soil) (after Stocking 1994).

into numerous tiny droplets, which (a) do not have the same mass as the original drop, and (b) do have only a short distance to fall – thus not attaining the same terminal velocity as a raindrop falling from the clouds.

As example: the 2 mm diameter drop hits a plant and bursts into numerous small droplets, each about 0.1 mm in diameter. These droplets will scarcely attain a terminal velocity of 0.01 m/sec when hitting the soil. Such a drop will only be able to dislodge 0.0000138 g of soil, less than the weight of a sand grain. The total effect of the original drop is thus reduced to 0.014 g of soil dislodged (or 0.05 % of the effect of the original drop) (Figure 9).

The density of the vegetation cover is thus of importance – more so than the basal cover (Figure 10 after Stocking 1994). The crown cover of the vegetation is highly responsive to rainfall and can easily form a dense cover during the rain season. On the other side of the coin, the crown cover of the vegetation of Namibia is as drastically reduced after the growing season. Towards the end of the dry season, Strohbach *et al.* (1996) have shown the vegetative cover not to exceed 30 % - over half of the country has a vegetative cover of less than 20 % in October (Figure 11). This means that the vegetation cover is at it lowest at the onset of the first rains – and as we all know, the first rains are often hard rains. **The protection the vegetation offers to our soils is thus at a minimum at the onset of the rainy season.**

During a ‘normal’ year with 300 mm or rain, some 2.09 t/ha soil will be washed away from bare soil, whilst only some 0.104 t/ha soil will be washed away from soil covered by vegetation (ca 50 % cover) (using the same soil types and slopes as before). During a high rainfall year (500 mm), 50 % covered soil will erode to about 0.634 t/ha, compared to the loss from bare soil of 12.72 t/ha.

In the same light a tree-dominated vegetation does not protect the soil as effectively from erosion as lower grass cover. Raindrops are caught in the tree canopies and combine to form bigger, heavier drops. A drop of 6 mm diameter falling (only) 3 m will attain a terminal velocity of 9 m/sec and will thus dislodge as much as 11.31 g of soil! Evidence of this phenomenon has been seen in forests (planted for erosion control!) in Brazil and in Zimbabwe (Stocking 1994) as well as in Lesotho (personal observation). Bush encroachment is thus **not** a blessing in disguise, as it does not prevent erosion. It could rather have the effect of accelerating erosion!

Slope length and steepness

After dislodging the soil particles from the soil surface, these particles have to be transported in order for erosion to take place. Gravity is the driving force: The **steeper the slope**, the faster the water can move. The faster water

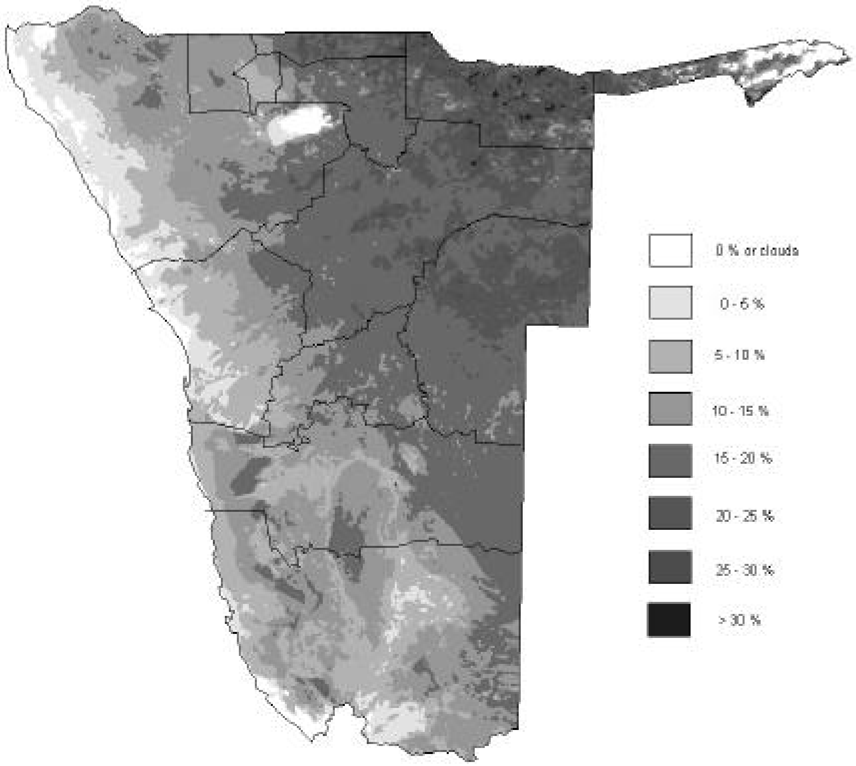

Figure 11: The estimated vegetative cover in Namibia at the end of the dry season (after Strohbach et al. *1996)*

moves, the more soil particles it can take along, and the more additional soil particles can be dislodged. The steeper the countryside, the more erosion will take place.

Obstructions along the slope will impede the flow of the water. Litter, branches, logs, stone, contours – all will slow down the flowing water and thus reduce the amount of soil particles the flowing water takes along. The **longer the (uninterrupted) slope**, the more the erosion caused by flowing water.

An example: the main path to the house is 1000 m long on a gentle slope of about 5 % (approx. 3°). As it is the main driveway, it is uncovered and most properly also compacted. If you don't put in contours, you will lose 16.55 t/ha in an average rain year (300mm). If you put a contour every 100 m, you will lose (only) 5.23 t/ha during the same year!

Erodibility of the soil[2]

Finally, the soil type, and especially the chemical and physical properties of the soil type, determine the ease with which soil particles are removed from the soil body. A major factor is the ease with which water is absorbed into the soil, as well as the bonding of the soil particles.

Coarse sand particles present enough spaces for water to infiltrate. Finer sand and silt particles provide less interparticle spaces and by way of compaction reduce their ability to take up water. This makes fine sandy and loamy soils more erodible than coarse sands (like the Kalahari sands).

The structure of the soil is a function of the cementing forces between soil particles. Sandy soils have little or no structure; this is an indication that no binding forces exist between the soil particles. Such soils are thus inherently very erodible.

Clay particles on the other hand are the smallest particles of all and are strongly bound together by colloidal forces, making dislodging of particles extremely difficult. Clay soils often have a strong, massive structure - think of the blocks and prisms of vertisols. Because of this, clay soils are very stable to erosion.

Extremely erodible are sodic soils, i.e., soils with an excess of sodium ions – or a "brackish" soil. Although seemingly hard and with massive structure in the dry state, exactly these cementing forces are disrupted by sodium ions, meaning that the soil particles will float apart as soon as water is added to the soil – truly a highly erodible soil!

Signs of soil erosion

Erosion is commonly associated with gullies or donga's. However, this is the ultimate product of erosion. Wind and water erosion both start off with limited

[2] The Soil Erodibility Factor (the K-factor in Footnote 1 and many other erosion-related formulas) can be calculated with the following regression formula (Wischmeier & Smith 1978, as quoted in Lal & Elliot 1994):

$$K = 2.8*10^{-7}*M^{1.14}(12-a)+4.3*10^{-3}(b-2)+3.3*10^{-3}(c-3)$$

where M is the particle size parameter (% silt + % fine sand) * (100 - % clay)
a is the % organic matter
b s the soil structure code (1: very fine granular; 2: fine granular; 3: medium or coarse granular; 4: blocky, platy or massive)
c is the soil profile permeability class (1: rapid; 2: moderate to rapid; 3: moderate; 4: slow to moderate; 5: slow; 6: very slow)

Figure 12: Air bubbles are cemented into the crust of soils just below the soil surface by a thin clay layer. These air bubbles prevent the infiltration of water into the soils and thus create an arid soil climate. (Photo: B. Strohbach, Okahandja district, 1999)

movement of the lose topsoil – with wind erosion a dune-like ripple effect is seen, whilst water erosion is evident by flowing patterns on the soil surface.

Plants always germinate at or near the soil surface, with the roots developing below the soil surface. When these roots become exposed it is a sure sign of moderate to severe sheet erosion. At this stage, no obvious rills are visible that one would associate with serious erosion. Another sure sign of erosion is the formation of pedestals – small stones, leaves, pieces of wood, etc. protect the soil directly below from the raindrop impact. With time, the soil washes away around these objects, leaving them on little pedestals – about 1 or 2 cm, maybe up to 5 cm high.

Often plants are seen to grow on little hills. This can be either the effect of sheet erosion washing away the soil around the plant, but as often the sign of material deposited against the plant base by wind- or water erosion.

Soil surface capping is often associated with erosion. The impact force of the raindrops compacts the soil surface to various degrees and thickness'. Surface capping results in impeded water infiltration, meaning that more water will run off. The greater water mass running off will also increase erosion due to the abrasive power of the running water. Clay bubbles (Volk & Geyger 1970) (Figure 12) are often associated with soil capping: In soils with a favourable mixture of sands and clay minerals, clay bubbles form just below the soil surface. These clay bubbles are initially formed as the infiltrating water replaces the air in the dry soil. The air bubbles are covered with a layer of clay, which prevents these air bubbles to escape from the soil surface. During the next downpour, these accumulated air bubbles below the soil surface prevent further infiltration of water (Volk & Geyger 1970). Clay bubbles can easily be observed below stones embedded in the soil surface.

The appearance of first rills and then later gully's or donga's is a sign that erosion is well advanced.

Soil erosion vs. production

The obvious effect of soil erosion is the loss of topsoil. But how does it effect the productivity of the land?

Vegetative cover is the main protection of the soil. It has also been shown that bush encroachment is a result of the reduction in grass cover (Walter 1971; Knoop & Walker 1985; Strohbach 1990). Essentially the grasses compete with trees and shrubs for soil moisture. As the grasses are relatively fast growing, and use water from the topsoil, they can out-compete shrubs for their water supply. As soon as the grass layer is reduced however, more water reaches the shrub roots, and bush encroachment can start.

As the grass cover is reduced, the soil becomes exposed to rain, wind and sun. Soil erosion removes the topsoil, and also often results in surface capping. The capping of the soil surfaces poses a problem to seedlings – the soil surface is too hard for them to emerge. The hard soil surface also means that water infiltration is reduced (often drastically so, if clay bubbles are present) thus, reducing the amount of soil moisture available for plants. The exceptions are the trees and shrubs – due to their funnel-shaped growth form, they can collect rainwater, and by means of stem flow, provide water to their own root zone.

Nutrient mineralization, especially nitrogen mineralization, takes place in the top layers of the soil. Soil nitrogen is a very unstable, yet highly important for plant growth. Nitrogen (as part of the air) is primarily bound into nitrates by micro-organisms in the topsoil. As it is very unstable, these compounds tend to disintegrate into ammonia, which is very volatile. Exposed soil is inherently hotter and drier than soil covered with grass, meaning that the nitrates are more easily disintegrating and the nitrogen is thus more easily lost from the soil. This also contributes to lower production (Schlesinger *et al.*

1990), which again will lead to increased soil erosion during the next rainfall event / season!

Prevention of erosion

A number of methods are available to combat erosion – especially gully erosion. However, the real challenge lies in the prevention and combating of sheet and wind erosion.

- Prevent overgrazing – the grass cover is the best protection you can have against erosion.
- Know your soils – use sensitive soils cautiously, and as conservatively as possible!
- Then combating bush encroachment, – use the branches as barriers to soil flow. Either scatter the branches at random, or pack them in lines parallel to the slope contours.
- Stabilise roads and tracks by building contours / humps.

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