SOIL LOSS ESTIMATION IN A SEMI-ARID MOUNTAINOUS CATCHMENT ENVIRONMENT, CITY OF WINDHOEK, NAMIBIA

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Abstract

More than half of the global population currently lives in urbanised areas. Consequently, a significant vegetation cover is continuously cleared as cities grow. Where surface grounds are not covered by impermeable surfaces, open soil is eroded by runoff, putting several ecological systems at risk of degradation. This study aimed at investigating the problem of soil loss in Windhoek. High amounts of soil loss are found in very low income settlements compared to high income areas. More soil loss is also found on medium slopes despite the fact that many eroded features are on gentle slopes. Grass cover plays a major role in the magnitude of soil loss. These findings are expected to be of particular interest to land managers in their bid to reduce potential environmental degradation, and also city planners, while they attempt to integrate control measures into the city's development. Any effort towards soil conservation would be highly significant, as the loss of topsoil is currently a great concern in the city.

Introduction

More than half of the world's population currently resides in urban areas, and the number is anticipated to continue rising through the process of urbanisation (Pickett, et al., 2008; Huang, et al., 2010; Haas & Ban, 2014). Urbanisation is intensified by many factors, including political instabilities and the increased effects of climate change on natural resources, leading to high rates of rural-urban migration (McLemon & Smit, 2006; Portnov & Paz, 2008). As a result of rapid population sizes in urban areas (Kötter & Friesecke, 2007; United Nations, 2012), there is a continuous demand for land for the development of settlements, accompanied by the immense necessities of infrastructures and services to cater for the population's growing socio-economic needs (Shuster, et al., 2005). Consequently, areas are cleared of vegetation

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Volume 6, Number 1, 2017 – ISSN 2026-7215

which, in turn, is replaced with impermeable surfaces, such as buildings, roads, drainage systems and pavements surfaces (Shuster, et al., 2005; Strahler, 2010). Such structures distort the water movement through the normal paths of flow. This subsequently amplifies the amount of water runoff and results in significant soil losses. Presently, the consequences of soil loss appear to be largely recognised in its contribution to soil degradation and the subsequent low levels of productivity in agricultural activities (Pimentel & Kounang, 1998; Lal, 2001; Nearing, et al., 2004; Pimentel, 2006; Fu, et al., 2009; Cantón, et al., 2011; Prasannakumar, et al., 2012).

The increases in rainfall intensity, combined with the rapid urban population growth and the increase of urban impermeable surfaces, magnify the problem of soil loss, particularly for dryland cities. Proper planning and environmental management is not only essential to ensure that urban ecosystems can cope with the high human population without imposing irreversible damages on the environment, but it is also necessary to make sure that urban centres are reasonable places to live in in the future (Pickett, et al., 2008). This implies that city planning cannot only focus on demographic and developmental aspects but it should also be inclusive of spatial problems, resulting from developmental activities, including problems of accelerated run-off and consequent soil loss. Currently, the dynamics relating to soil loss are not fully understood in urban areas (Anigbogu, 2001; Yair & Raz-Yassif, 2004; Le Roux, et al., 2008; Wei, et al., 2012).

Apart from soil loss causing soil degradation, it causes sedimentation of dams and muddy roads, and reduces ground water recharge (Shuster, et al., 2005; Guzman, 2016; Merina, Sashikkumar, Rizvana, & Adlin, 2016). This is particularly true for the City of Windhoek, Namibia. Reduction of water infiltration while the top soil is too thin, heavily affects the city water supply, as the city relies on ground water when dams do not yield sufficient water (Zhang, et al., 2004; Lahnsteiner & Lempert, 2007; Jourbert, 2008; Mapani & Schreiber, 2008). Shallow soil layers above the aquifer also make the aquifer more vulnerable to contaminations during periods of high rainfall (Gold, et al., 2001; Gray, et al., 2008; Mapani & Schreiber, 2008). Despite these observations, to our knowledge, there has not been a study that quantified the level of soil loss in Windhoek. This study therefore aimed at investigating the severity of soil loss in Windhoek. Specific objectives were to: (1) assess the influence of slopes and vegetation cover on soil loss in Windhoek, and (2) determine the areas mostly at risk of soil loss in Windhoek. Such information can be useful to local authorities for assisting them when designing proper land management and soil conservation programmes in urban centres.

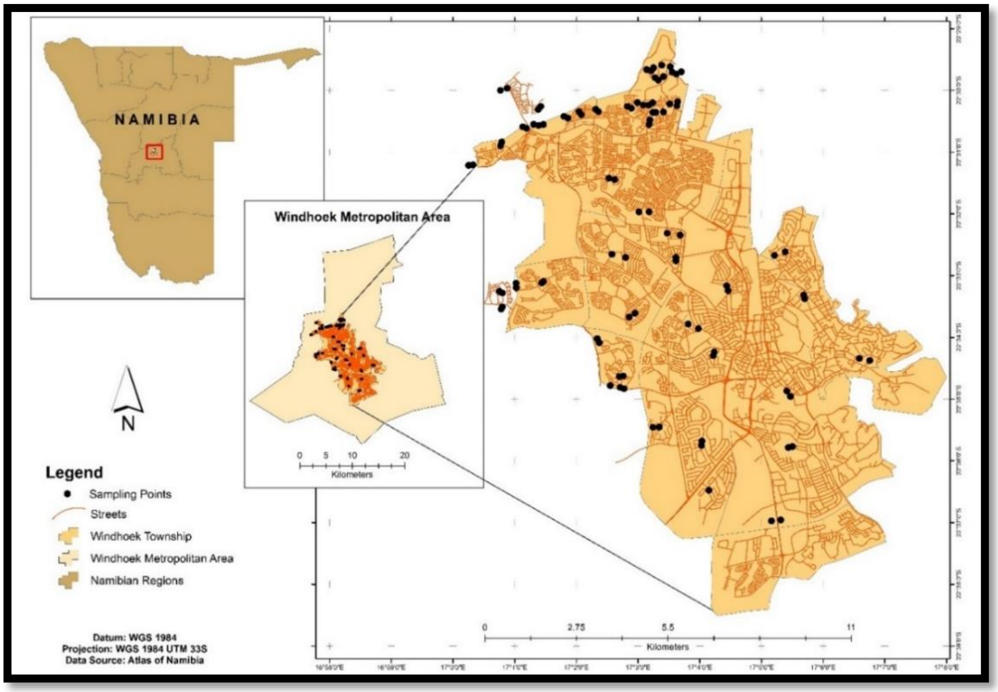


Figure 1: Study area

Materials and methods

Characterises of the study area

Windhoek is the capital city of Namibia and the only city in Namibia (Fig. 1). The city lies in a valley at about 22˚34′ 12″S, 17˚5′ 1″E, and about 1800m above sea level. It is bordered by Khomas Hochland and the Auas Mountains, which make the city a central water catchment area (Mendelsohn, et al., 2002; Ministry of Environment and Tourism, 2002; Mapani & Schreiber, 2008). Even though Windhoek lies in a valley, the topography of the area is largely made up of several size-varied hills that provide various slopes for run-off (Fig. 2a). This increases the vulnerability to water erosion of the city, and consequent soil loss. Settlements in Windhoek are spread across the catchment area. The higher income classes are located on the southeast part of the city on mostly medium and steep slopes, and they include townships, such as Eros, Klein Windhoek, Avis, Auasblick, Olympia and Academia. The middle-class settlements occupy mostly gentle slopes to flat areas in the middle part of the city, and these settlements include areas, such as Otjomuise, Khomasdal and Dorado. The low-income settlements are located mostly on medium slopes on the northwest in suburbs, such as Katutura, Goreangab, Wanaheda and Okuryangava, while the very low income areas (which are mainly the informal settlements), just like the high-income areas, are also mostly located on medium to steep slopes at the very end of Hakahana, Okuryangava, Wanaheda and Goreangab to other areas beyond the mapped townships. However, some of them are also located on gentle to medium slopes that are largely situated on stream banks. Informal settlements are described as human establishments and land uses in the urban areas that are not suitable for living, and are not expected to adhere to the standards and regulations of that particular urban area (Sietchping, 2000). The fast-growing informal areas in the city have led to a significant reduction of vegetation, because of vegetation clearance for construction and hygienic purposes (Gray, et al., 2008; Mapani & Schreiber, 2008; Greunen, 2013).

The Auas and Kuiseb Mountains are formed from metamorphosed Quartzite horizons and Schist respectively (Fig. 2b, Zhang, et al., 2004; Mapani & Schreiber, 2008; Tredoux, et al., 2009). The weathered Quartzite has soil deposits with good porosity and permeability (Murray, et al., 2000), whereas Biotite Schist covers most of Windhoek's development grounds with crystalline rocks, which are highly impermeable (Mapani & Schreiber, 2008; Tredoux, et al., 2009). The higher grounds of the city are characterised by rough, ridged rocky outcrops, while the lower areas have topsoil with gravel and sand layers that are generally thin, ranging from 1cm to less than 100cm deep (Gold, et al., 2001; Mapani & Schreiber, 2008).

The city naturally has a limited vegetation cover due to the aridity of the region where it is located (Gold, et al., 2001; Gary, et al., 2008; Greunen, 2013). Vegetation cover is dominated by *Acacia* shrubs and trees, such as *A. erubescens* and *A. hereroensis*, and short-lived annual grasses, such as *Stipagrostis* and *Enneapogon* species, with weedy herb species on the stream banks (Fig. 2c, Gold, et al., 2001). The average temperature and rainfall varies between 18 and 20˚C and 300-360mm respectively (Fig. 2d, Mendelsohn, et al., 2002). As part of the dryland region, Windhoek is expected to experience prolonged droughts and increased intensity in some rainfall events (Lahnsteiner & Lempert, 2007; Knapp, et al., 2008; IPCC, 2007).

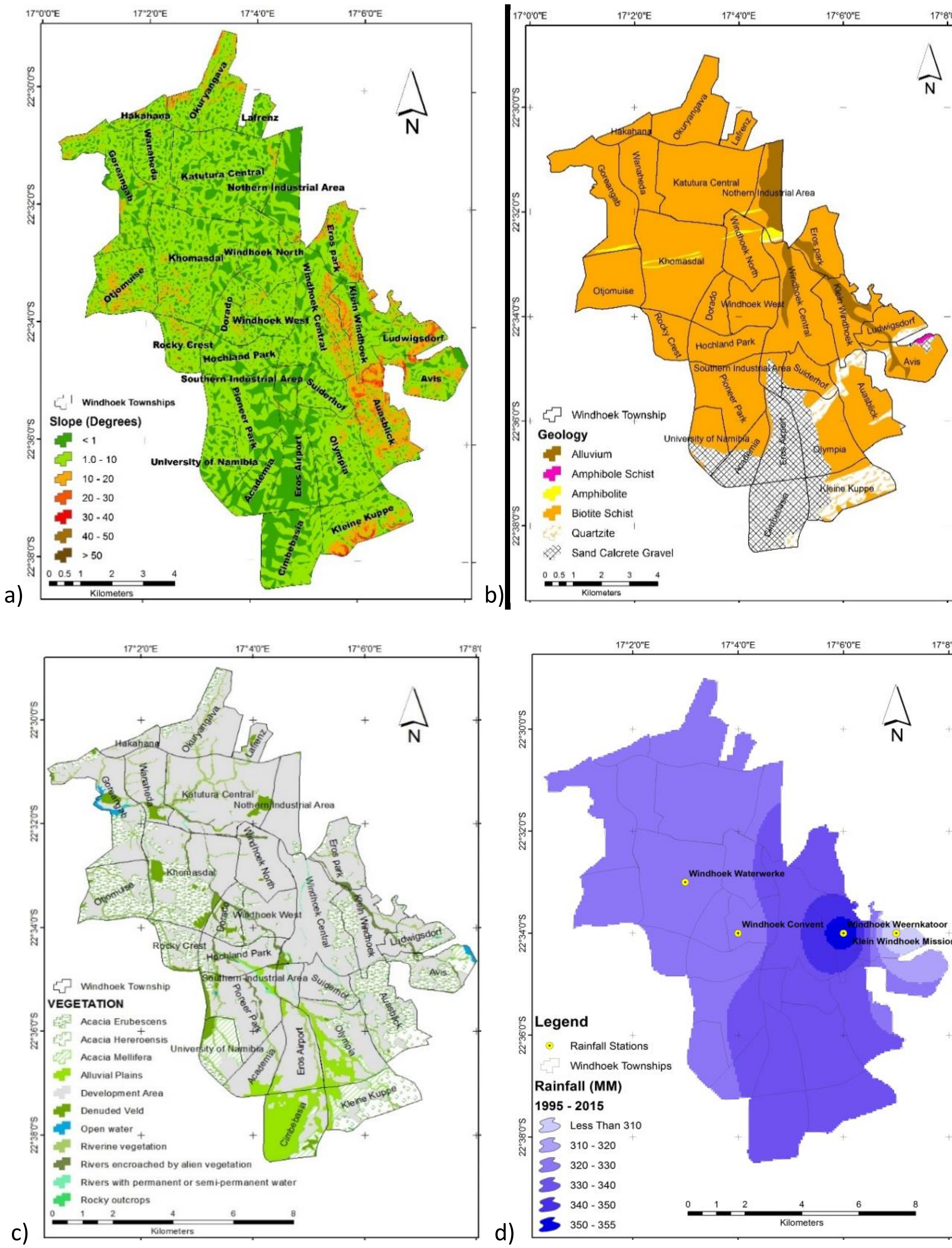


Figure Fig. 2: Topographical maps: a) slopes, b) geological material, c) vegetation cover, and d) average annual rainfall in Windhoek

Methods and sampling

The Field survey approach has been identified as one of the methods that significantly represent the real field conditions (Herweg, 1996; Evans, 2002). The present study used a field survey method to collect data on soil loss from rills and gullies across the city of Windhoek. Using snap-shot, a Google earth map, a total of 95 field sites depicting bare surfaces in the developing area of Windhoek were randomly selected, and all were surveyed. The bare surfaces were more visible in the northern part of the city than on the southern side, hence more plots were sampled on the northern side (Fig. 1). The field measurements followed the field guide of Herweg (1996). Each sampled site measured 80m x 40m, and the types of settlement in terms of average level of income were recorded, as well as the estimated vegetation cover (m^2) and slope (degrees: flat = 0, gentle = 1-20, medium = 20-45 & steep = > 45). At each site, the length, width and depth of the erosion features were measured. To calculate the total area eroded, that is, volume (amount) of soil loss (m^3) per site, the following formula was used: **[**((Width x Depth) / 2) x Length**].** This formula is for triangular prism because eroded areas are not in rectangle shapes, but are normally in triangular shapes. When width and depth had different measurements at different points, additional measurements of depth and width were taken in order to calculate the average depth or width, which was then used for the calculation and recording.

Results

Table 1 below shows the number of eroded features per estimated slopes. Gully features were few (< 10% of sites), whilst rills were in abundance (89.5%) across the 95 surveyed sites. Much of the soil loss occurred at gentle and medium slopes (99%). However, most of the bare surfaces were also not visible at steep slopes and on flat areas during the snap shots, hence few plots were sampled at these slopes. Consequently, the main emphasis was on the gentle and medium slopes, but information for the steep and flat areas is also presented.

Table1: Summary of soil loss in sampled plots across the different estimated slopes

Slope position*	**Gully count**	**Rill count**	**Total soil loss (m^3)**
Flat	0	0	0
Gentle	7	94	512.42
Medium	7	52	529.20
Steep	0	2	1.39
Total	**14**	**148**	**1043.01**
***Estimated slope position (in degrees): flat = 0, gentle = 1-20, medium = 20-45 & steep = > 45**			

Figure 3 below shows the amount of vegetation cover per slope category. Of the total vegetation cover of 2840m^2, grass contributed the majority (68%), followed by trees (20%) and grass (12%). Generally, the amount of vegetation should be higher at flat areas, but in this case only a few plots of bare surfaces were found in flat areas. The amount of each type of vegetation cover, grass, trees and shrubs at medium slopes (33%, 31% and 32%), was almost half of the amount at the gentle slopes (58%, 58% and 62%) respectively, yet more soil loss is experienced at medium slopes than at gentle slopes.

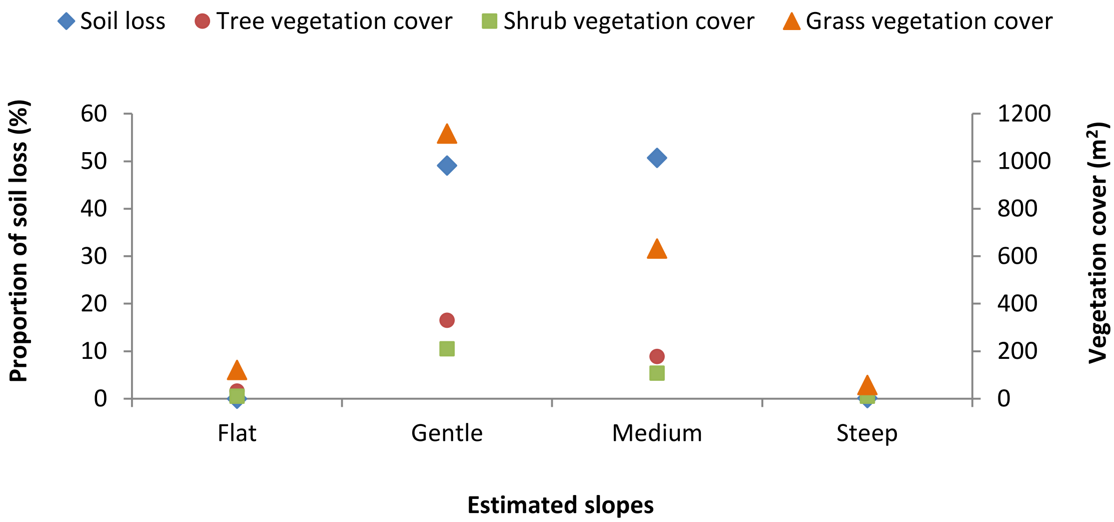
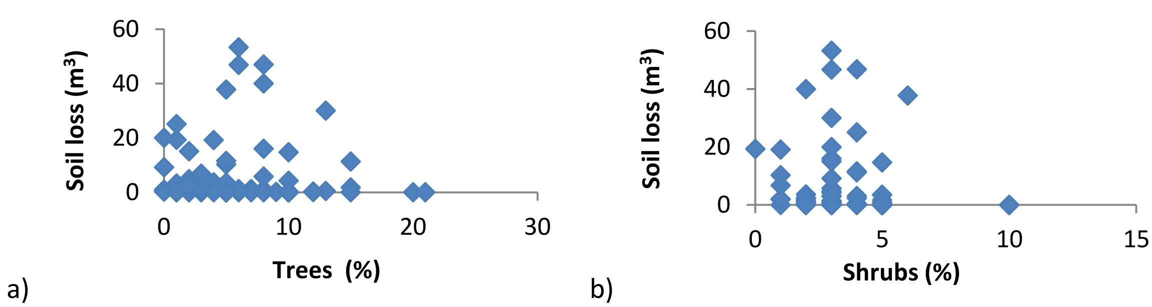
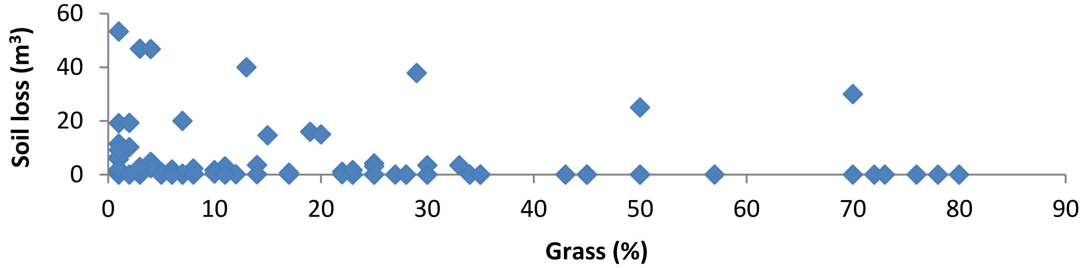


Figure 3: The influence of vegetation on soil loss at slope gradient

Despite many rills being found on gentle slopes, a higher amount of soil loss is experienced at medium slopes than on gentle slopes (Table 1). Areas eroded with approximately 40m^3 to 50m^3 amounts of soil loss had less than 10% of trees, 5% of shrubs and 30% of grass (Fig. 4). In many cases, the sites with a high amount of soil loss were located far from streams and they have rills that are associated with longer lengths (40-70 cm long).





c)

Figure 4: Vegetation cover in relation to the amount of soil loss

Soil loss varied significantly in different settlements of income levels, with the lower income areas having the highest level of soil loss (Fig. 5). This was despite them having the lowest total number of sites surveyed. Although the higher income areas or wealthier settlement areas had the highest number of surveyed sites (20% and 23%), they had the least soil loss at 10% and 1% respectively.

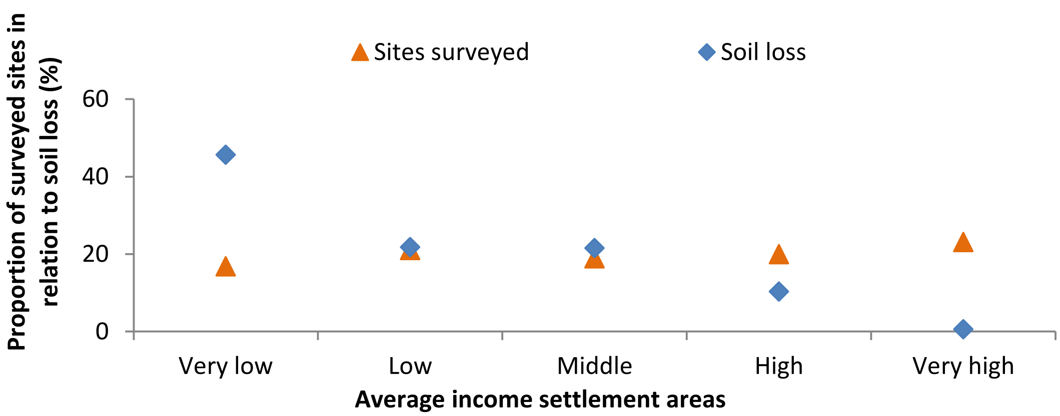


Figure 5: Soil loss in relation to settlement areas in terms of income areas

Figure 6 shows examples of typical vegetation cover in the settlements, the magnitude of vegetation cover clearance in informal settlements, and their occupation of both stream banks and slope terrains. Evidently, vegetation cover in higher income areas (Fig. 6b) is kept as much as natural areas (Fig. 6a), while the opposite is practised in the lower income areas (Fig. 6c & 6d). More open soil is also seen in longer occupied informal settlements (Fig. 6d).

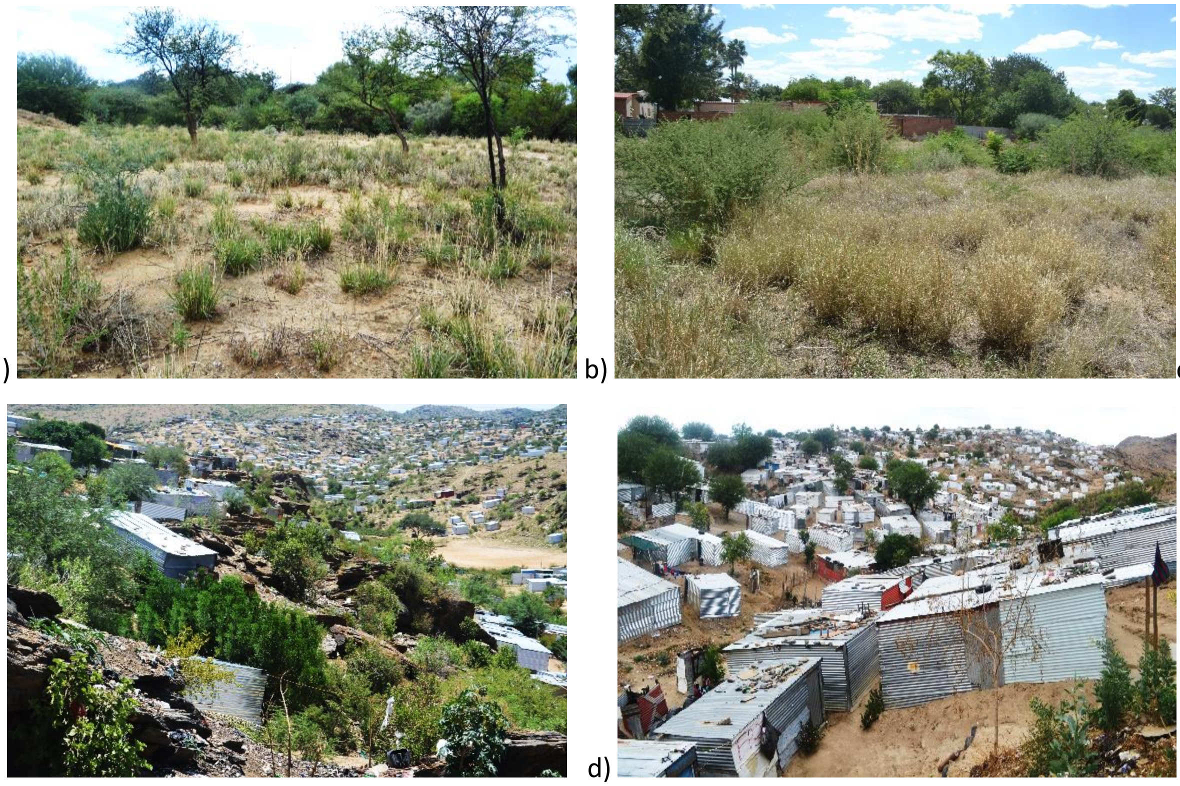


Figure 6: Typical vegetation cover in: a) unoccupied areas, b) high income settlements, c) newly occupied informal settlements, and d) informal settlements occupied for long & located on stream bank, Windhoek. Source: Author

Discussion

The amount of vegetation cover and the different slopes played a major role in the amount of soil loss. A higher amount of soil loss is experienced at medium slopes than at gentle slopes, even though many rills are found on gentle slopes. This could be attributed to the fact that most of the city's grounds are underlined by the impermeable rocks of Biotite Schist, making it more difficult for the water to erode deeply. Instead, this contributes to increased run-off (Mapani & Schreiber, 2008). Water run-off is faster and has high energy to erode significantly deeper at steeper grounds (Nearing, et al., 1999). The high number of rills at gentle slopes is attributed to the large proportion of grass vegetation cover, since the trees and shrubs are extremely limited. The energy of water run-off reduces on gentle slopes and results in broad surface flow in areas with grass vegetation cover (Gyssels, et al., 2005; Nearing, et al., 2005). Broader surface flows subsequently produce many smaller rills that are easily eroded. The high amount of grass can also be credited to the rainfall seasons, as grass grows back faster and this happens every year when the rains falls, while the trees and shrubs take longer to grow back, once cleared off. The importance of the amount and the types of vegetation cover in erosion and soil loss have also been illustrated in other studies (Zhou, et al., 2008; Mohammed & Adam, 2010), even though not specific to urban areas.

Areas of lower income are mostly at higher risks of soil loss than those of high higher income areas in Windhoek. Apart from having high amounts of vegetation cover in higher income settlements, the areas also were observed to have in place good drainage systems. The opposite was observed at residential sites of lower income groups. Vegetation cover is lacking in many lower income areas. Moreover, the settlements are located in stream banks, but lack proper drainage systems (in very low income areas). Where the systems are partially available (in low income areas), they are not well-maintained. The lack of vegetation cover means that the soil is readily available to be eroded, even when rainfall events are not intense. These reasons therefore significantly contribute to the high levels of soil loss. Therefore, poor urban communities are the most vulnerable, and they are at risk of experiencing large amounts of soil loss compared to higher income areas. This finding is alarming, considering the fact that about two thirds of Windhoek migrants settle in these areas, comprising about 60% of the population and, as a result, are densely populated (Gold, et al., 2001; Frayne, 2007; Pendleton, et al., 2014). Poor urban communities have also been reported to suffer from other environmental disasters, such as flooding (Rashid, 2000; Brouwer, et al., 2007; Douglas, et al., 2008), but not with specific reference to the risk of soil loss.

Various soil conservation measures are urgently needed in order to combat any further loss of soil. This is particularly important because the city is already concerned about the issue of a lack of top soil (Mapani & Schreiber, 2008). Aspects needing consideration for the effectiveness of soil conservation measures, need to recognise the vulnerabilities of different sites by considering both natural processes (flow of water, reducing soil loss and increasing vegetation cover) and socio-economic aspects (land use practices, social and economic developments, and financial capacity to maintain the developments). From a broader perspective, it is essential for the affected dryland cities, such as Windhoek, to consider potential solutions that reflect on issues leading to urbanisation at local, national and international levels. This is important for urban ecosystems and for circumventing land degradation, seeing that the anticipated effects of climate change, the increasing rates of urbanisation and the consequently fast growing cities, on the environment are unlikely to decline anytime soon. Moreover, this finding is of relevance, particularly because dryland regions' environments are inherently fragile and soil is vulnerable to any amount (slight or heavy) rainfall due to the limited vegetation cover (Tooth, 2002; Cornelis, 2006; Vásquez-Méndez, et al., 2011; Ligonja & Shrestha, 2015). Possible actions could include the decentralising of economic activities to rural areas, and the provision of more drought resistant agricultural products. Such arrangements would significantly reduce the need to move to urban centres, and would, consequently, reduce the fast expansion of urban areas, thereby relieving cities from economic and environmental pressures. Ecological systems would require an in-depth understanding and collective efforts in order to reverse current and potential future impacts and even disasters.

Conclusion

The study demonstrates that soil loss is a problem in Windhoek. Factors such as the level of development, building on the stream banks, the amount of vegetation cover, and the high presence of slopes (especially, the medium slopes) are found to be the main drivers of soil loss. Remarkably, grass cover appears to have the most influence on the magnitude of soil loss (as opposed to trees and shrubs). While land degradation is not linked to soil loss in this study, the two are directly associated. Therefore, given the vulnerability of the dryland regions and the continuous phenomenon of soil loss in Windhoek are most likely to be reflected on land degradation and the degradation of other ecological functions in the near future. Furthermore, failure to attend to this problem is likely to result in environmental states that might be impossible to reverse, especially when the aquifer is contaminated when the topsoil is drastically reduced by erosion. The study proposes that the city should prioritise the development of a soil loss control plan. The first step would be to develop a soil loss policy upon which a soil loss control plan can be based. Currently, legal documents which are specific to erosion and soil loss, are lacking. To provide a quicker remedy, initiatives aimed at improving the amount of vegetation cover, would be beneficial to Windhoek City. Improving the drainage system in the lower income areas, can also lessen the problem.

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