Institute of Biochemistry and Biology

Department of Plant Ecology and Nature Conservation

An Ecohydrological Impact Assessment in Urban Areas: Urban Water Erosion in Windhoek, Namibia.

Publication-based dissertation submitted to the Faculty of Mathematics and Natural Sciences at the University of Potsdam, Germany,

for the degree of Doctor of Natural Sciences (Der. rer. nat.) in “Ecology”

Rosemary Ndawapeka Shikangalah

Potsdam, September 2016

Table of Contents

Abstract

Over the last decades, the world's population has been growing at a faster rate, resulting in increased urbanisation, especially in developing countries. More than half of the global population currently lives in urbanised areas with an increasing tendency. The growth of cities results in a significant loss of vegetation cover, soil compaction and sealing of the soil surface which in turn results in high surface runoff during high-intensity storms and causes the problem of accelerated soil water erosion on streets and building grounds. Accelerated soil water erosion is a serious environmental problem in cities as it gives rise to the contamination of aquatic bodies, reduction of ground water recharge and increase in land degradation, and also results in damages to urban infrastructures, including drainage systems, houses and roads. Understanding the problem of water erosion in urban settings is essential for the sustainable planning and management of cities prone to water erosion. However, in spite of the vast existence of scientific literature on water erosion in rural regions, a concrete understanding of the underlying dynamics of urban erosion still remains inadequate for the urban dryland environments.

This study aimed at assessing water erosion and the associated socio-environmental determinants in a typical dryland urban area and used the city of Windhoek, Namibia, as a case study. The study used a multidisciplinary approach to assess the problem of water erosion. This included an in depth literature review on current research approaches and challenges of urban erosion, a field survey method for the quantification of the spatial extent of urban erosion in the dryland city of Windhoek, and face to face interviews by using semi-structured questionnaires to analyse the perceptions of stakeholders on urban erosion.

The review revealed that around 64% of the literatures reviewed were conducted in the developed world, and very few researches were carried out in regions with extreme climate, including dryland regions. Furthermore, the applied methods for erosion quantification and monitoring are not inclusive of urban typical features and they are not specific for urban areas. The reviewed literature also lacked aspects aimed at addressing the issues of climate change and policies regarding erosion in cities. In a field study, the spatial extent and severity of an urban dryland city, Windhoek, was quantified and the results show that nearly 56% of the city is affected by water erosion showing signs of accelerated erosion in the form of rills and gullies, which occurred mainly in the underdeveloped, informal and semi-formal areas of the city.

Factors influencing the extent of erosion in Windhoek included vegetation cover and type, socio-urban factors and to a lesser extent slope estimates. A comparison of an interpolated field survey erosion map with a conventional erosion assessment tool (the Universal Soil Loss Equation) depicted a large deviation in spatial patterns, which underlines the inappropriateness of traditional non-urban erosion tools to urban settings and emphasises the need to develop new erosion assessment and management methods for urban environments. It was concluded that measures for controlling water erosion in the city need to be site-specific as the extent of erosion varied largely across the city.

The study also analysed the perceptions and understanding of stakeholders of urban water erosion in Windhoek, by interviewing 41 stakeholders using semi-structured questionnaires. The analysis addressed their understanding of water erosion dynamics, their perceptions with regards to the causes and the seriousness of erosion damages, and their attitudes towards the responsibilities for urban erosion. The results indicated that there is less awareness of the process as a phenomenon, instead there is more awareness of erosion damages and the factors contributing to the damages. About 69% of the stakeholders considered erosion damages to be ranging from moderate to very serious. However, there were notable disparities between the private householders and public authority groups. The study further found that the stakeholders have no clear understanding of their responsibilities towards the management of the control measures and payment for the damages. The private householders and local authority sectors pointed fingers at each other for the responsibilities for erosion damage payments and for putting up prevention measures. The reluctance to take responsibility could create a predicament for areas affected, specifically in the informal settlements where land management is not carried out by the local authority and land is not owned by the occupants.

The study concluded that in order to combat urban erosion, it is crucial to understand diverse dynamics aggravating the process of urbanisation from different scales. Accordingly, the study suggests that there is an urgent need for the development of urban-specific approaches that aim at: (a) incorporating the diverse socio-economic-environmental aspects influencing erosion, (b) scientifically improving natural cycles that influence water storages and nutrients for plants in urbanised dryland areas in order to increase the amount of vegetation cover, (c) making use of high resolution satellite images to improve the adopted methods for assessing urban erosion, (d) developing water erosion policies, and (e) continuously monitoring the impact of erosion and the influencing processes from local, national and international levels.

Zusammenfassung

In den letzten Jahrzehnten ist die Erdbevölkerung mit großer Geschwindigkeit gewachsen. Das hatte eine verstärkte Urbanisierung zur Folge, insbesondere in den Entwicklungsländern. Zurzeit lebt über die Hälfte der globalen Bevölkerung in Stadtgebieten, mit steigender Tendenz. Städtewachstum geht mit einem signifikanten Verlust von Vegetationsbedeckung, sowie mit Bodenverdichtung und -versiegelung einher. Diese Faktoren führen bei Starkregenereignissen zu einem hohen Oberflächenabfluss, und zu Problemen durch beschleunigte wasserbedingte Bodenerosion in Straßen und auf Baugelände. In Städten ist eine beschleunigte wasserbedingte Bodenerosion ist ein ernstzunehmendes Umweltproblem, denn sie verursacht eine Verschmutzung der Gewässer, eine verminderte Grundwasserneubildung und erhöhte Landdegradierung. Darüber hinaus kommt es zu erosionsbedingten Schäden in der städtischen Infrastruktur, inklusive der Entwässerungssysteme, sowie an Häusern und Straßen. Für ein nachhaltiges Planen und Management von erosionsanfälligen Städten ist es von essentieller Bedeutung, die Probleme der Wassererosion in städtischen Gebieten zu verstehen. Trotz der großen Anzahl wissenschaftlicher Studien über Wassererosion in ländlichen Gegenden bleibt unser Verständnis der zu Grunde liegenden Erosionsdynamiken in urbanen Trockengebieten unzureichend.

Diese Studie zielt darauf ab, Wassererosion, sowie die dazu beitragenden sozio-ökologischen Faktoren, in einem typischen urbanen Trockengebiet zu erfassen. Hierzu wurde ein fachübergreifender Ansatz am Fallbeispiel der Stadt Windhoek, Namibia, gewählt. Die Arbeit umfasst eine detaillierte Literaturanalyse der aktuellen Forschungsansätze zur urbanen Wassererosion und den damit verbundenen Herausforderungen. Außerdem wurde eine feldstudienbasierte Methode entwickelt, mit der das Ausmaß der Wassererosion in der Stadt Windhoek quantifiziert und räumlich erfasst wurde. Schließlich wurden persönliche Befragungen mit halbstrukturierten Fragebögen durchgeführt, um die Wahrnehmung der verschiedenen Interessenvertreter zum Thema Erosion in Stadtgebieten zu analysieren.

Die Literaturanalyse hat gezeigt, dass 64% der untersuchten Studien in der entwickelten Welt durchgeführt wurden und nur sehr wenige Regionen mit extremen Klimabedingungen, einschließlich Trockengebieten, untersucht wurden. Hinzu kommt, dass die verwendeten Methoden zur Erosionsquantifizierung und -beobachtung die für urbane Gebiete typischen Merkmale nicht beinhalten und dafür auch nicht ausgerichtet sind. Des Weiteren mangelt es

der untersuchten Literatur an Ansätzen, die den Einfluss des Klimawandels und politische Aspekte in Bezug auf Erosion in Stadtgebieten thematisieren.

In einer Feldstudie wurde das Ausmaß von Wassererosion in der trocken gelegenen Stadt Windhoek quantifiziert und räumlich erfasst. Beinahe 56% der Stadt waren von Wassererosion betroffen und wiesen Anzeichen beschleunigter Erosion in Form von Rinnen und Rillen auf. Letztere traten vor allem in den unterentwickelten, informellen und semi-formellen Stadtgebieten auf. Das Ausmaß der Erosion in Windhoek wurde unter anderem von der Vegetationsbedeckung und dem Vegetationstyp, von sozial-urbanen Faktoren, und zu einem geringeren Grad von dem geschätzten Gefälle bestimmt. Der Vergleich einer interpolierten feldstudienbasierten Erosionskarte mit Ergebnissen, die auf einer konventionellen Methode zur Erosionserfassung (der Allgemeinen Bodenabtragsgleichung (ABAG)) basieren, ergab eine starke Abweichung in den räumlichen Mustern. Das verdeutlicht die Unzulänglichkeit einer direkten Übertragung von traditionellen nicht-urbanen Methoden zur Erosionserfassung auf ein urbanes Umfeld und betont die Notwendigkeit, neue Methoden sowohl zur Erfassung als auch zum Management von Erosion für urbane Gebiete zu entwickeln. Aus der großen Variabilität des Erosionsausmaßes innerhalb der Stadt lässt sich folgern, dass Methoden zur Kontrolle von Wassererosion in Städten standortspezifisch sein sollten.

Anhand von halbstrukturierten Fragebögen wurde in einem weiteren Teil der Arbeit die Wahrnehmung und das Verständnis der unterschiedlichen Interessenvertreter zum Thema urbane Wassererosion in Windhoek untersucht. Insgesamt wurden 41 Interessenvertreter zu ihrem Verständnis der Wassererosionsdynamiken, zu ihrer Wahrnehmung in Bezug auf mögliche Ursachen und zum Ausmaß der Erosionsschäden, sowie zu ihrer Einstellung zur Verantwortlichkeit für die Erosion in der Stadt befragt. Die Ergebnisse deuten darauf hin, dass es eine geringe Wahrnehmung für das Phänomen der Erosion als Prozess gibt, dafür aber eine im Vergleich erhöhte Wahrnehmung der Erosionsschäden und der Faktoren, die zu den Schäden beitragen. Ungefähr 69% der Interessenvertreter stuften die Erosionsschäden als moderat bis sehr ernsthaft ein. Dabei gab es erkennbare Differenzen zwischen der Gruppe der privaten Haushalte und der der öffentlichen Behörden. Des Weiteren hat die Untersuchung ergeben, dass die Interessenvertreter kein klares Verständnis ihrer Verantwortung in Bezug auf das Management der Kontrollmaßnahmen, sowie ihrer finanziellen Verantwortung für die Schäden haben. Die privaten Haushalte und die örtlichen Behörden wiesen sich gegenseitig die Zahlungsverantwortung für die Erosionsschäden und für vorbeugende Maßnahmen zu. Der

Unwille der einzelnen Akteure, Verantwortung zu übernehmen, könnte eine Zwickmühle für die betroffenen Gebiete werden. Dies gilt insbesondere für die informellen Siedlungen, in denen von den örtlichen Behörden kein Landmanagement durchgeführt wird, das Land aber auch nicht Eigentum der Bewohnern ist.

Abschließend hat die Studie ergeben, dass es für eine effektive Erosionsbekämpfung in der Stadt von ausschlaggebender Bedeutung ist, die verschiedenen, den Prozess der Urbanisierung auf negative Weise verstärkenden Dynamiken, auf ihren unterschiedlichen Skalen zu verstehen. Auf Grundlage der hier präsentierten Ergebnisse wird eine Entwicklung speziell auf Stadtgebiete ausgerichteter Ansätze mit folgenden Zielen dringend nahegelegt: (a) Einer Integration von diversen sozio-ökonomisch-ökologischen Aspekten, die sich auf Erosion auswirken; (b) Einer wissenschaftlich begründeten Verbesserung der natürlichen Kreisläufe, die sich positiv auf die Wasserspeicherung im Boden und die Nährstoffverfügbarkeit für Pflanzen auswirken, um dadurch einen höheren Vegetationsbedeckungsgrad zu erreichen; (c) Der Nutzung hoch aufgelöster Satellitendaten, um die Methoden zur Erosionserfassung für urbane Gebiete zu verbessern; (d) Der Entwicklung politischer Maßnahmen zur Bekämpfung von Wassererosion, und (e) Einer kontinuierlichen Beobachtung der Auswirkungen von Erosion und der zu Grunde liegenden Prozesse auf lokaler, nationaler und internationaler Ebene.

Chapter One

General Introduction

1.1 Contemporary challenges of urban water erosion

Soil erosion is a frequently observed phenomenon in urban areas, but comparably little erosion research has been carried out in these areas. This can be largely attributed to the fact that at present, urban managers appear to have not recognised water erosion as a problem. This consequently leads to failure to realise the importance of investigating this pressing topic and accordingly address the possible causes and consequences. As one city manager stated when asked to comment on water erosion: “We do not have a problem of water erosion in Windhoek”. This was stated in spite of evidence for water erosion problems in the literature and countless visible erosion features in the city (Fig. 1), predominantly in areas that are inhabited. Urban water erosion causes damages to houses and roads, clogs drainage systems, contaminates and deposits silt in reservoirs while also reducing the ground water recharge and resulting in degradation of ecological functions (Gaffield et al. 2003; Shuster et al. 2005; Merz et al. 2010; Strahler 2010; Bong et al. 2011; Wei et al. 2012). These problems consequently affect the well-being of the public’s livelihoods, the development of the city and the ecological health state of urban ecosystems in ways that are not easily reversed.

Currently, more than half of the world’s population is residing in urban areas and further increase is anticipated through urbanisation (Pickett et al. 2008; Huang et al. 2010; Haas and Ban 2014). Urbanisation is intensified by many factors, including political instabilities and the increased effects of climate change on the natural resources, leading to high rates in rural-urban migration (McLemon and Smit 2006; Portnov and Paz 2008). As a result of rapid population growth in urban areas (Kötter and Friesecke 2007; United Nations 2012), there is a continuous demand of land for settlements development, accompanied by the immense necessities of infrastructures and services to cater for the population’s growing socio-economic needs (Shuster et al. 2005). Consequently, massive of vegetation cover are continuously cleared off the land surface and replaced with the impermeable surfaces such as buildings, roads, drainage systems and pavements surfaces (Shuster et al. 2005; Strahler 2010). Such structures restrict the movements of water to particular flow paths. This subsequently amplify the amount of water runoff and accelerate water erosion, leading to the numerous problems in urban areas. However, presently water erosion appears to be largely recognised for its contribution to soil degradation and the succeeding low productivity in agricultural activities (Pimentel and Kounang 1998; Lal 2001; Nearing et al. 2004; Pimentel 2006; Fu et al. 2009; Cantón et al. 2011; Prasannakumar et al. 2012).

a)  b) 

c)  d) 

Figure 1: Examples of water erosion evidence in Windhoek: a) rill features, b) a gully feature, c) damages to the road, and d) damages to the house. Source: Shikangalah RN.

1. 2 Contextualizing water erosion perspectives

Erosion mostly occurs in dryland climatic regions. Dryland covers more than 40% of the global land and is home to more than 30% of the world's population (Verón et al. 2006; Reynolds et al. 2007; Feng and Fu 2013). These regions are persistently affected by soil water erosion due to the scarcity of vegetation cover, prolonged drought and intense rainfall events (Tooth 2000; Vásquez-Méndez et al. 2011; Ligonja and Shrestha 2013). Soil erosion is a process of detachment, transportation and deposition of soil materials by wind or water (Morgen 1995; Lal 2001; Aksoy and Kavvas 2005; Vreiling 2006). Where water is the agent, soil is exposed to raindrops, and this results in the removal of topsoil which consequently forms soil erosion features (Pimentel and Kounang 1998; Le Roux et al. 2008). Billions of hectares in various climatic regions have been affected by water erosion (Pimentel and Kounang 1998; Ananda and Herath 2003). While this has been true mostly for agricultural areas, the phenomenon has increasingly become a problem for urban environments, as urban areas become common centres for the rapid population growth.

The anticipated increase of the rainfall intensity combined with the rapid urban population growth and the increase of urban impermeable surfaces undoubtedly amplify the problem of water erosion, especially for dryland cities. Proper planning and environmental management is not only essential to ensure that urban ecosystems can cope with the high 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 the future (Pickett et al. 2008). This implies that city planning cannot only focus on demographic and developmental aspects but the planning and the management should be inclusive of spatial problems resulting from developmental activities, including problems of water erosion. Currently, the dynamics of water erosion are inadequately studied and barely understood in urban areas (Anigbogu 2001; Yair and Raz-Yassif 2004; Le Roux et al. 2008; Wei et al. 2012).

1.3 Current research needs on urban erosion

Owing to the above reasons, there is a need for urban specific research schemes for water erosion, including scale-crossing monitoring, experiments and modelling to provide cities with risk assessments that can serve as a basis and a core factor to erosion related socio-economic environmental activities, decision-making and policy improvement. As such, specific investigations on urban water erosion have been carried out and published worldwide (Rowntree et al. 1991; Fan and Li 2004; Colosimo and Wilcock 2007; Bong et al. 2011; Spencer et al. 2011; Mukundan et al. 2013; Omon and Ogheneruemusua 2014). However, to date an overview is still lacking. An overview is urgently needed to provide a concise synopsis of the investigations that had been carried out and outline the major gaps in research areas, thereby providing a foundation for more focused future actions of urban investigations.

Due to the completely different land-use features and the diverse land cover of urban areas such as built-up land, standard methods of sampling such as erosion pins (Jimoh 2001), erosion plots or rainfall experiments alone might not make practical conclusions for such varied spaces of urban settlements (Rejman et al. 1998; Bryan 2000; Miyata et al. 2010). An understanding of the spatial extent of water erosion is a fundamental key for city planners and land managers to reduce water erosion and the possible resultant damages. To understand the pattering and impact of urban soil erosion, not only the standard parameters such as slope and vegetation cover (Pimentel and Kounang 1998) need to be quantified as typically applied in agricultural fields, but also other parameters describing the specific socio-spatial structure and the visible damage of erosion to houses, roads and other infrastructures within the different urban settlements. Approaches for the quantification of soil erosion such as the traditional Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978) are mainly developed for agricultural environments and then adapted for urban settings. Currently, it is not clear if they are practical for assessing urban erosion risks.

Since water erosion is accelerated by human activities, an understanding of the dynamics and functions of the society should be a significant aspect of planning and managing water erosion in urban areas. Therefore, to effectively minimise water erosion, urban managers should not only seek to understand the environmental aspects but they should also integrate aspects of the society that inhabit the system (Agle et al. 1999; Cordono et al. 2004; Mitter et al. 2014). However, presently the perceptions of stakeholders are hardly incorporated in studying urban soil erosion (Reidsma et al. 2010). The views of local communities could provide opportunities for land managers to understand how best applicable and adaptable erosion measures can be designed for urban societies (Amsalu and de Graaff 2006; Mitter et al. 2014).

1.4 The aim of the study

Assessments of water erosion risks are needed to contribute to the facilitation and prioritisation of the city planning and management for soil conservation and other related urban development activities. This could significantly reduce the amount of finance the cities would spend on maintaining the infrastructures that might have been impacted by erosion. This research study is aimed at assessing the problem of water erosion and the associated socio-environmental determinants in a dryland urban area. Specifically, it assess the problem of urban water erosion in relation to the areas of different income classes, types of settlements, vegetation cover and slopeness of the area. To achieve the aim, three main objectives were identified:

1) to provide an in-depth literature review of urban water erosion,
2) to quantify a real extent of water erosion in a dryland city, and
3) to analyse the perceptions of the local communities on urban water erosion.

Objective 2 and 3 were carried out in one dryland city, Windhoek, Namibia.

1.5 Study area

Windhoek is the capital city of Namibia and it is used as a case study in this study. The city lies in a valley at about 22° 34′ 12″ S, 17° 5′ 1″ E and about 1800 m above sea level. It is also bordered by Khomas Hochland and Auas Mountains (Fig. 2a), which makes it a central watershed area for the mountains (Mendelsohn et al. 2002; Uni-Koeln 2003; Mapani and 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 the slope for water erosion (Fig. 2b). Furthermore, owing to the abundant slopes in the city, the area is covered with several tributaries that flows to the northwest of the city (Fig. 2c).

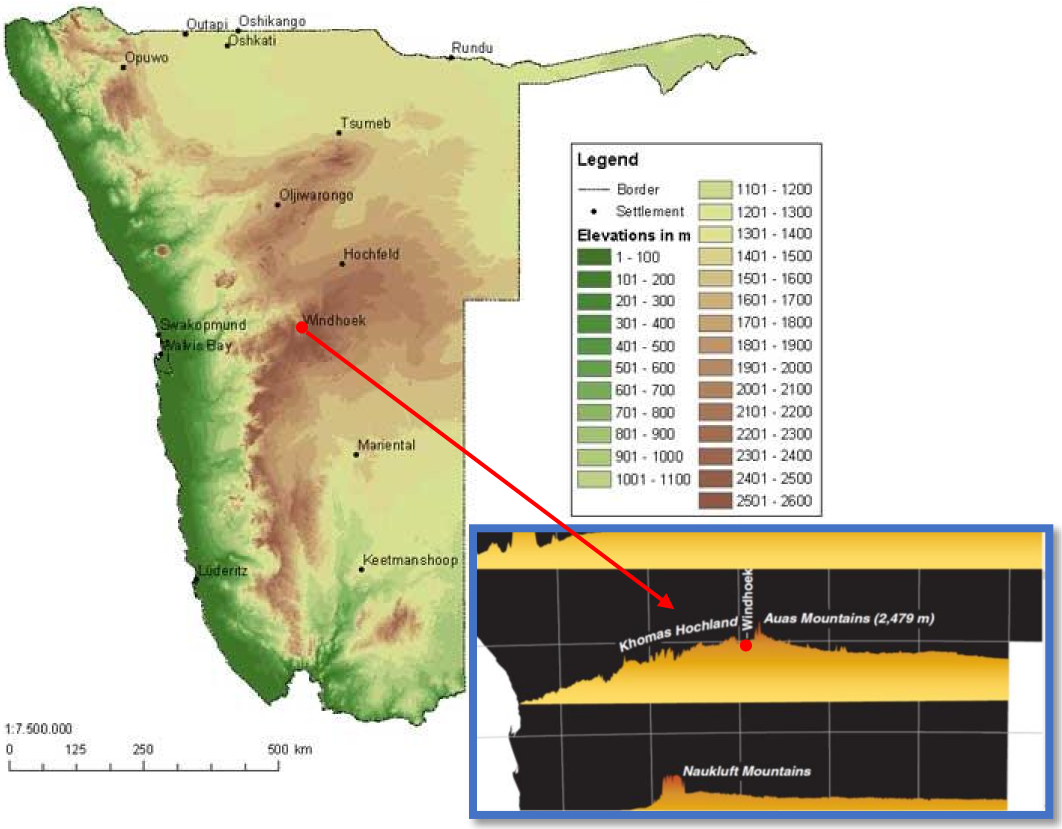


Figure 2a: Elevation and reliefs surrounding Windhoek. Source: Mendelsohn et al. 2002 (Insert for an altitude profile showing a cross-section at Windhoek); Uni-Koeln 2003 (Main map).

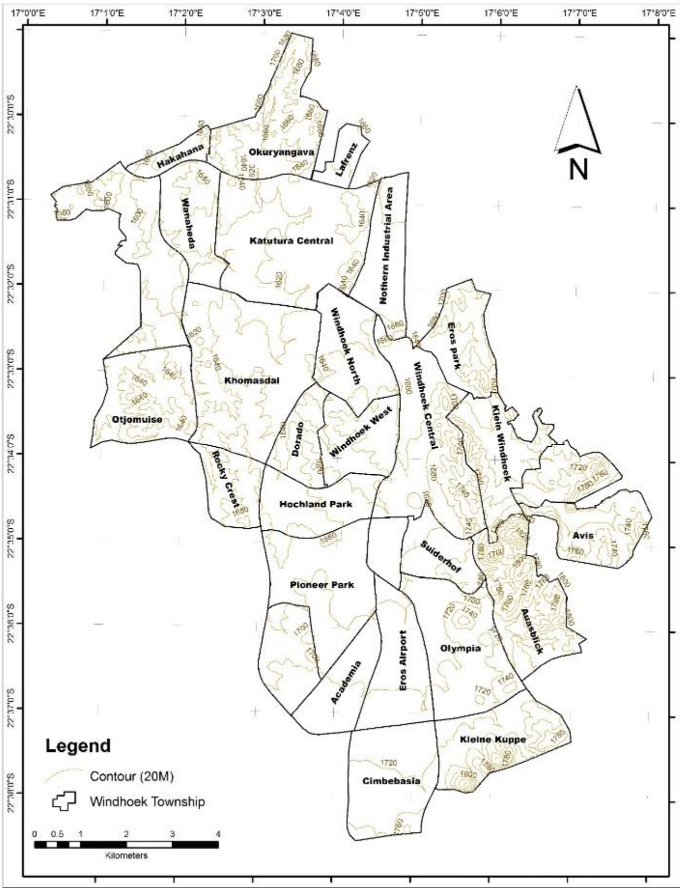


Figure 2b: The topography of Windhoek townships. Source: City of Windhoek 2010.

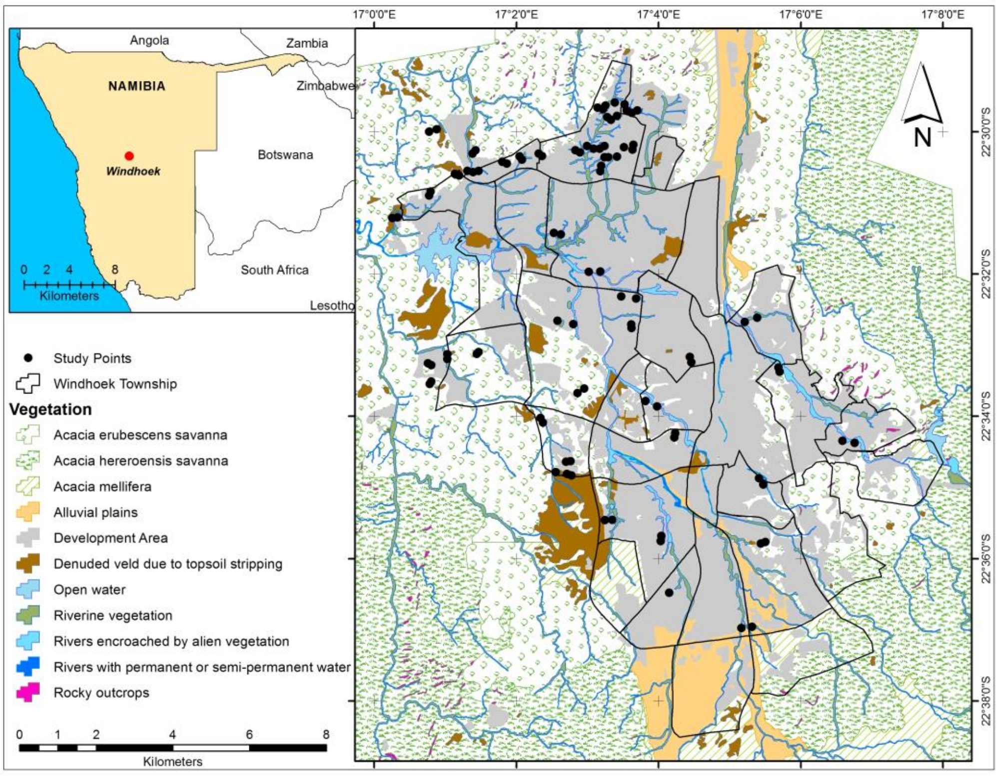


Figure 2c: Study site and tributaries of the city. Source: City of Windhoek 2010.

The city's annual average temperature varies between 18 - 20 ˚C and annual average rainfall ranges between 300 - 350mm (Mendelsohn et al. 2002). The hottest month of summer is December (Fig. 3), with an average temperature of 24°C while the lowest temperature is experienced in July. The city has more months for summer than winter, and only three months of good rainfall. This means the city is characterised by longer drier periods than any other seasons. As part of a dryland country in the southern Africa, the city is further predicted to go under significant climate changes marked by increasing temperatures, drought and increased intensity in some rainfall events (Lahnsteiner and Lempert 2007; Knapp et al. 2008; IPCC 2013).

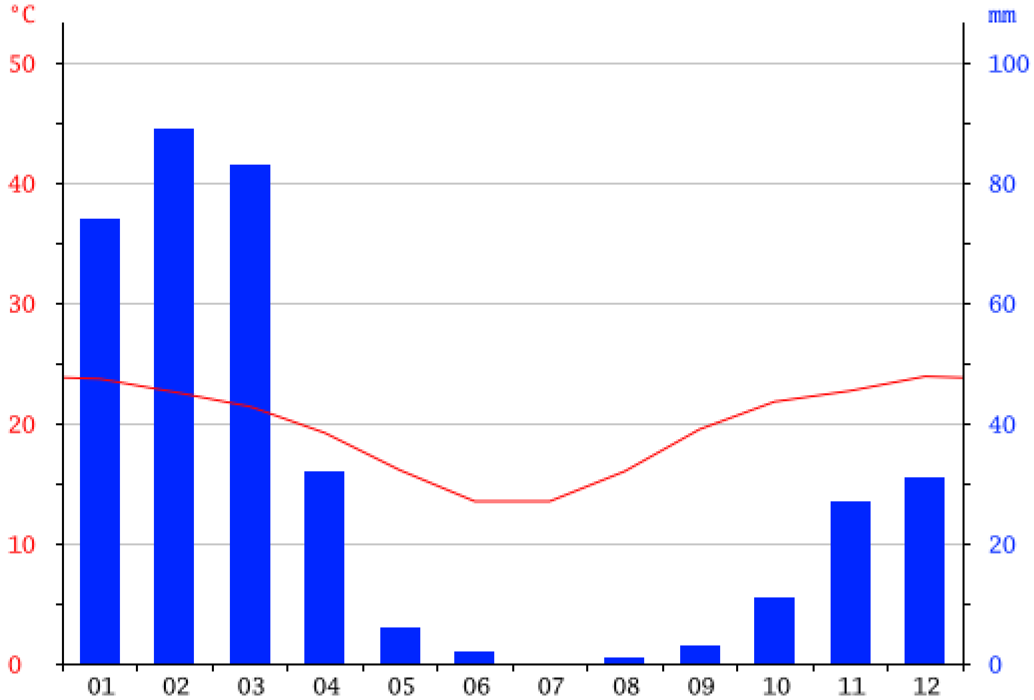


Figure 3: Average monthly temperatures (˚C) & precipitation (mm) in Windhoek. Source: Climate-data.org 2012.

Vegetation cover is mainly dominated by acacia trees, shrubs and short lived grass (Fig. 4a & b; Gold et al. 2001; Gray et al. 2008). Even though vegetation cover is naturally limited due to aridity, much of the available vegetation is intentionally cleared for housing constructions, hygienic purposes and fire wood (Harper and Maritz 1998; Gold et al. 2001; Labbe et al. 2006). This leaves the soil unprotected from rain drops, making the soil susceptible to water erosion. Added to that is the fact that the city has a thin layer of topsoil (Gold et al. 2001; Mendlesohn et al. 2002; Mapani and Schreiber 2008), which makes it easy to expose the underneath geological material once the top soil is eroded away, specifically on the slopes (Fig. 4c & d). The city's ground is predominantly made up Biotite Schist geological materials, which increases surface runoff and contribute to the risk of erosion since the materials are mostly impermeable rocks (Mapani and Schreiber 2008; Tredoux et al. 2009).

a)  b) 

c)  d) 

Figure 4. Examples of typical: (a & b) vegetation cover in unoccupied areas, (c & d) Biotite Schist outcrops in Windhoek. Source: Shikangalah RN.

Namibia is part of the developing countries where millions of people move to urban centres each year (Cordono et al. 2004; Huang et al. 2010). The city is located in the central part of the country (Fig. 2c), which makes it easier to travel there, Windhoek is also the centre of attraction for economic activities (Mapani and Schreiber 2008). Furthermore, Windhoek is the only city in Namibia and as such, the city offers more than 50% of the country's manufacturing activities, nearly 80 % of the finance and business services (Pendlton et al. 2012). Currently, Windhoek is home to 15% of the country's total population of 2.1 million (National Planning Commission 2012). About 60% of Windhoek population are migrants and more than 60% of the migrants settle in the low income areas of the city (Frayne 2007; Pendleton et al. 2014). Many of these areas are predominantly characterised by steep terrain, informal settlements, and are densely populated (Gold et al. 2001; Pendleton et al. 2014). Informal settlements are described as human establishments and land use of the urban areas that are not suitable and are not expected to adhere to the standards and regulations of that particular urban areas (Sietchping 2000). Figure 5a & b shows examples of an old and new informal settlements in steep terrains and depicts the clearance of vegetation cover in the former settlement in Windhoek. The fast growing population in the city leads to over clearing of the already limited vegetation cover and results in recurrent water erosion problems (Gray et al. 2008; Mapani and Schreiber 2008; Greunen 2013).

a)

b)

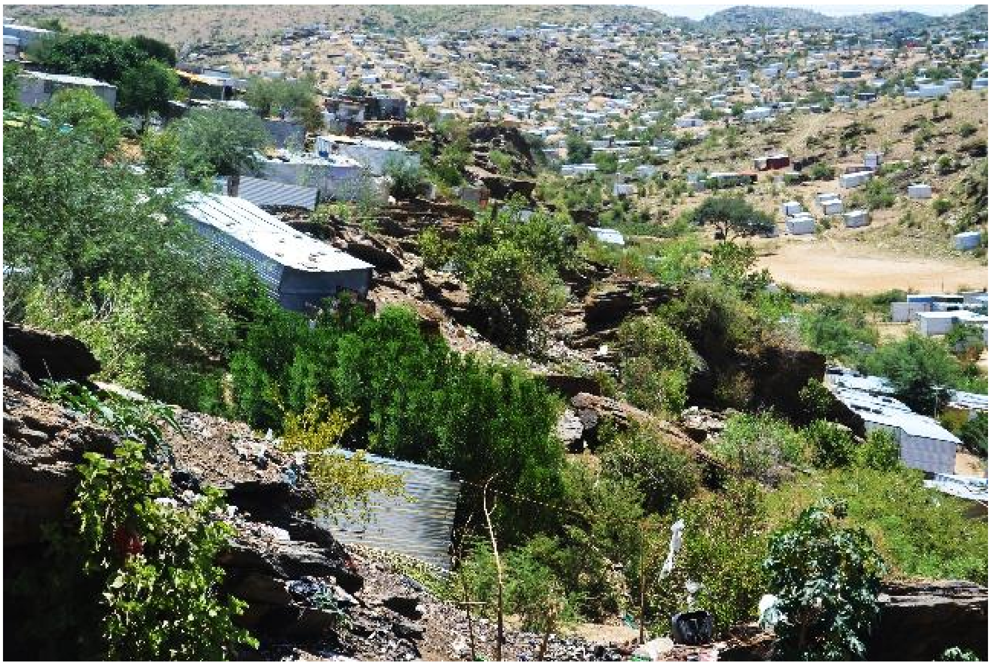


Figure 5. Typical informal settlements in steep slopes, Windhoek: a) longer occupied area, b) newer occupied area. Source: Shikangalah RN.

Apart from the damages to infrastructures, water erosion poses the following threats to the city: (i) erosion transports sediments and pollutants to dams and other aquatic bodies (Mapani and Schreiber 2008; Greunen 2013); (ii) the resultant loss of soil reduces water infiltration when the top soil is too less to store water, affecting the recharge of the ground water system on which the city heavily relies on for water supply when the dams do not yield enough (Zhang et al. 2004; Lahnsteiner and Lempert 2007; Jourbert 2008; Mapani and Schreiber 2008); (iii) soil loss also contributes to the current problem of shallow soil layers above the aquifer, making the aquifer more vulnerable to contaminations during high rainfall events (Gold et al. 2001; Gray et al. 2008; Mapani and Schreiber 2008); and (iv) eroded topsoil leads to reduced soil productivity, contributing to the existing state of land degradation (Bertram and Broman 1999).

The inadequacy of scientific studies on water erosion could hamper the city's planning for erosion control measures. Furthermore, an understanding of water erosion risks under the impact of fast urban environmental change is crucial for land management and future conditions of urban ecosystems. The vulnerability of dryland climate combined with accelerated water erosion in Windhoek could also lead to an environmental state that might be difficult or even impossible to reverse if not urgently addressed, especially on the aquifers.

1.6 The objectives of the study and the structure of the thesis

The thesis is structured in five main chapters (Fig. 6). Chapter one (this chapter), provides the general background of accelerated urban water erosion, a description of the study area, the aim and objectives of the thesis. Each objective generates its own method, subsequent results and findings, and is presented as a chapter of which each manuscript was submitted to a journal (chapter 2, 3 & 4). Consequently, parts of chapter 2, 3 & 4 are written as fist person plural because the papers are co-authored and submitted as such to the journals. Chapter two addresses the first objective of providing an in-depth literature review. Chapter three addresses the second objective of quantifying a real extent of water erosion by focusing on methods used to provide evidence for urban erosion in a typical dryland city while chapter four addresses the third objective, analysing the views of the stakeholders in respect to urban water erosion. The links are provided as bridges between these three main chapters (chapters 2, 3 & 4) addressing the objectives. The last chapter (chapter five) of the thesis presents the overall discussion, future perspectives and provides the overall conclusions derived from this study.

In chapter one of the thesis, I have introduced the reader to the problem of soil water erosion in urban areas, with regard to the damages. I have also described what is known about water erosion as an environmental process and the link to urban planning and land management. Forming the main chapter is the current research need for urban erosion in spite of the existing literature of erosion in rural areas. Furthermore, I described the study area in terms of the physical land features, climate and the growing population of the city. A description of the study aim and objectives are provided at the end.

In chapter two of the thesis, I carry out an in-depth review of researches on urban water erosion. Urban soil erosion is assessed distinctively different from the typical soil erosion on agricultural fields. The need to understand the interactive and influencing factors that play the main role in erosion processes under the urban settings is compelling. The underlying water erosion dynamics and the consequent impacts are however highly complex and investigations have been carried out in efforts to understand urban water erosion (Paterson et al. 1993; Jimoh 2001; Sathler et al. 2005; Tamim et al. 2012; Khosrokhani and Pradhan, 2013). Yet, an overview of what have been investigated so far is still lacking. The review determines the major gaps and provides grounds for future actions. As such, the following objectives are set for the review:

(1) to identify the regions and focal points investigated on urban water erosion,
(2) to outline the approaches applied in the investigations of urban water erosion,
(3) to determine the major gaps in researches of water erosion in urban settings, and
(4) to illustrate key challenges in current and future actions for urban erosion.

This chapter has been published as: Shikangalah RN, Jeltsch F, Blaum N, Mueller EN. 2016. A Review on Urban Water Erosion. Journal for Studies in Humanities and Social Sciences: 5 (1), 163 -178.

In chapter three of the thesis, I concentrate on methodological aspects to provide quantitative evidence for water erosion in a dryland urban areas. Hence, here I quantify a real extent of water erosion in Windhoek, Namibia. This is significantly important considering the continuous urbanisation (Cohen 2006; Huang et al. 2010; Duranton 2015) and the persistence of water erosion in drylands (Tooth 2000; Cornelis 2006; Vásquez-Méndez et al. 2011; Ligonja and Shrestha 2013). A field survey method is used to show the pattering of water erosion. This method allows the study to incorporate the socio-spatial structure parameter, depicting the potential influence it has on the impacts of water erosion in urban settings. The specific objectives are:

(1) to assess the extent and severity of water erosion in relation to urban socio-environmental characteristics,
(2) to interpolate the extent and severity of erosion, hence the spatial distribution,
(3) to compare the erosion map derived from the field survey data with an erosion risk map derived using a traditional erosion quantification tool approach (Universal Soil Loss Equation). The latter is the most widely used tool in assessing the potential of water erosion, especially in rural areas (Erdogan et al. 2007; Ozcan et al. 2008; Kinnell 2010).

This chapter is submitted to the journal and is under review as: Shikangalah RN, Paton EN, Jeltsch F, Blaum N. 2016. Quantification of a Real Extent of Soil Erosion in a Dryland Urban Area: An example of Windhoek, Namibia. Cities and the Environment Journal.

In chapter four, I focus on analysing the stakeholders' perception on urban water erosion. The perceptions of stakeholders are not commonly incorporated in studying soil erosion (Reidsma et al. 2010). However, the views of local communities provide opportunities for land managers to understand how best applicable and adaptable erosion measures can be designed for the communties (Amsalu and de Graaff 2006 Heitz et al. 2009; Mutekanga et al. 2013; Mitter et al. 2014). Semi-structured questionnaires are used to carry out face to face interviews with the stakeholders. The objectives formulated are aimed at:

(1) determining the stakeholders' awareness on the severity of soil erosion,
(2) examining the perceived responsibilities of erosion damages and prevention measures,
(3) determining the stakeholders' understanding of water erosion phenomenon.

This chapter is submitted as: Shikangalah RN, Paton EN, Jeltsch F. 2016. An Analysis of Stakeholders' Perceptions on Urban Water Erosion, Windhoek, Namibia. Journal of Urban Ecosystem.

In the last chapter (chapter five), I first discuss the key findings and their implications for urban water erosion, especially for urban drylands. I further provide prospective for the future researches and draw conclusion with regard to the needs for managing water erosion in cities. The chapter also provide possible next step for the Windhoek.

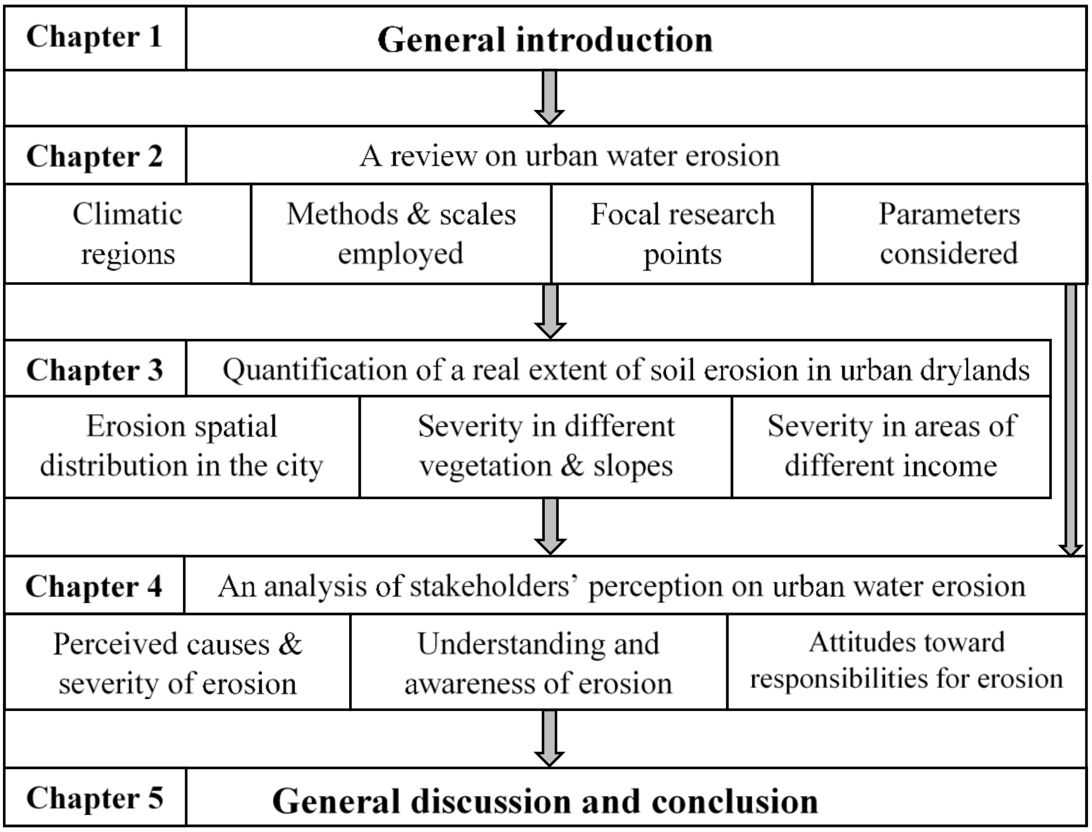


Figure 6: A schematic of the study outline and summary of the chapters

Chapter Two

A Review on Urban Soil Water Erosion

Abstract

Accelerated soil water erosion is one of the major global environmental problems that adversely affect both rural and urban areas. While many investigations have been initiated to efficiently understand and effectively manage water erosion problems in agricultural areas, specific knowledge on urban water erosion is less pronounced. This paper aims at providing an overview of the extent at which erosion dynamics and processes have been explored in urban areas. Based on the last decade's publications, the majority (64%) of studies were conducted in the developed world, mostly in humid subtropical and humid continental climate regions. Furthermore, researchers largely concentrated on offsite erosion, focusing on contaminated sediments and on stream erosion. The employed methods were mostly traditional approaches (81% of all articles) compared to modern methods of remote sensing and modelling. This review identified some limitations in the methods employed and gaps in focal research topics and urban-specific management strategies. In particular, this paper argues that approaches oriented towards minimizing the risks from water erosion in urban areas are urgently needed. The review findings are expected to be of interest to researchers, urban planners and environmental related managers.

Published as:

Shikangalah RN, Jeltsch F, Blaum N, Mueller EN. 2016. A Review on Urban Water Erosion. J. Stud. Humanit. Soc. Sci. 5: 163 - 178.

2.1 Background

Erosion is generally defined as the removal of materials from the earth surface by erosive agents such as wind and water (Morgan, 1995; Aksoy & Kavvas, 2005). Thereby, ‘removal’ includes the transport and deposit of the eroded sediments and solutes at a new location (Vrieling, 2006). In most systems, erosion is a natural process that has continuously occurred since the earliest age of geological times in history, shaping landscapes, moulding landforms, and creating mountain valleys, hills, pediment slopes, alluvial fans, deltas and floodplains (Sundborg & Rapp, 1986). Human land use clearly impacts soil erosion that is significantly escalated in the last couple of decades consequential to the rapid population growth and diverse human activities (Cantón et al., 2011). Currently, the accelerated soil erosion is one of the most serious global problems contributing to land degradation (Lal, 2001; Vrieling, 2006). It is estimated that around 2 billion ha of total land area has been affected by soil degradation as a result of human activities (Pimentel & Kounang, 1998; Lal, 2001), including arid, semiarid and humid environments (e.g. Booth & Henshaw, 2001; Aksoy & Kavvas, 2005; Fu et al., 2009; Ibotoye & Eludoyin, 2010; Cantón et al., 2011).

Soil erosion problems are generally related to agricultural practices in tropical and semi-arid countries (Nearing, Pruski & O’Neal, 2004; Prasannakumar, Vijith, Abinod & Geetha, 2012). Around 450 hundred million ha of the world’s arable land was found to be unproductive by mid 1990s and an estimated of 10 million ha of cropland are abandoned each year by agricultural use due to soil erosion (Pimentel, 2006). Soil erosion, however, is not only important in agriculture but has also become an important phenomenon in urban environments. As a result of the rapid population growth, the continuous demand for more settlement land and the unavoidable removal of vegetation coupled with the changes in climate in particular aggravate soil erosion by water in agricultural as well as in urban environments. Recent projections assume that by 2050 approx. 70 % of the world populations will be living in urban areas (Kötter & Friesecke, 2007; United Nations, 2012). This urbanization process is further accelerated by climatic changes. Especially in many dryland areas, the increased risk of droughts and soil erosion, and the related vulnerability of natural resources lead to an increasing rural - urban migration (McLeman & Smit, 2006; Portnov & Paz, 2008). At this point, the second phase of land conversion from both native land and agricultural land to impermeable urban surfaces continues at an alarming rate (Allan, Erickson, & Fay, 1997). The accompanying socio-economic needs of the growing urban population require constant infrastructure development, thus constant urban surface alteration and growth to cater for the population needs and demands (Shuster, Bonta, Thurston, Warnemuende, & Smith, 2005). Increasing urban populations are evidently associated with an increase in sealing of permeable surfaces (Shuster et al., 2005; Strahler, 2010). The impervious surfaces include road networks, buildings, canalization of drainage systems, pavements and other concrete-like surfaces. Such surface changes do not only impact the kinetics of chemical soil reactions and gas diffusion but also modify water movements (Scalenghe & Marsan, 2009; Strahler, 2010). As such, the movements of water get more restricted to specific flow paths where the amount of water runoff is amplified and water erosion is accelerated. Accordingly, the accelerated water erosion leads to considerable urban problems such as (a) damages to bridges, roads, buildings, and other structures through high speed of water erosion and / or flooding (Merz, Kreibich, Schwarze, & Thieken, 2010); (b) clogging of drainages systems, muddy roads and reduction of water storage capacity in reservoirs with deposited sediments. The latter leads to either channel diversion or cut off and in the process contributes to flash flooding (Bong, Lau, & Ghani, 201; Wei, Chen, Yang, Fu, & Sun, 2012); (c) the transportation of pollutions and contaminations into drinking water supplies which threatens public health (Gaffield, Goo, Richards, & Jackson, 2003); (d) the reduction of the ground water recharges (Shuster et al., 2005); (e) degradation of critical urban ecological functions (Strahler, 2010), and (f) the contribution to climate change by releasing carbon into the atmosphere from eroded areas (Gaiser, Stahr, Billen, & Mohammed, 2008).

Predicted changes in rainfall regimes (e.g. increasing high-intensity precipitation events) in combination with the enormous urban population growth and the related massive conversion of land to impermeable surfaces certainly magnifies the risks of urban flooding and water erosion. However, the related urban-specific erosion effects and the consequent underlying erosion dynamics are highly complex, given that they are influenced by a range of interacting factors that are inadequately studied and are hardly understood (Anigbogu, 2001; Yair & Raz-Yassif, 2004; Wei et al., 2012). Thus, there is a need to design urban specific research schemes for water erosion and flooding, including scale-crossing monitoring, experiments and modelling, ultimately improving the planning for and management of urban areas. As such, worldwide several specific investigations on urban water erosion have been published. However, until now, an urgently required overview of this important research topic is still missing.

This paper aims at providing an overview on the extent to which urban soil water erosion matters have been covered in literature over the last two decades. Specifically we intend to 1) identify the regions covered and focal areas of previous research on urban water erosion, 2) outline the approaches applied in assessing, quantifying, predicting and managing urban erosion, 3) determine the major gaps in studying water erosion in urban settings and, 4) illustrate key challenges in current and future comprehension and managing of urban erosion.

2.2 Material and methods

We searched the ISI Web of Knowledge and Google scholar for publications between 1991 and March 2014 focusing on soil water erosion processes in urban environments. To ensure that only articles directly linked to this topic were included, we conducted a title search using a set of selected keywords. Specifically, the search included the following terms: soil erosion, water erosion, sediment transportations, and sediment deposition, in combination with urban (including urbanization and urbanized), city or cities. In this initial search 34 *accessible* publications by the researcher at a time, matched our literature search criteria. In addition, we went further into the literature and searched into the related and cited articles which yielded 44 more *accessible* publications, giving a total of 78 publications on which our analyses were based.

In a first step, we examined and analyzed the climatic and geographical regions where the studies were carried out and the scales (spatial and temporal) that were considered. Subsequently, we categorized the published studies according to their apparent research focus, i.e. (i) key causes and impacts of erosion, (ii) types of contaminations carried by erosion, (iii) method development for erosion assessment, (iv) sediment movements (i.e. sediment transportation and deposition) and (v) erosion control. Within these categories we further analyzed the specific types of erosion explored, the different methods engaged in the studies and lastly the consideration of specific environmental factors influencing erosion.

2.3 Results

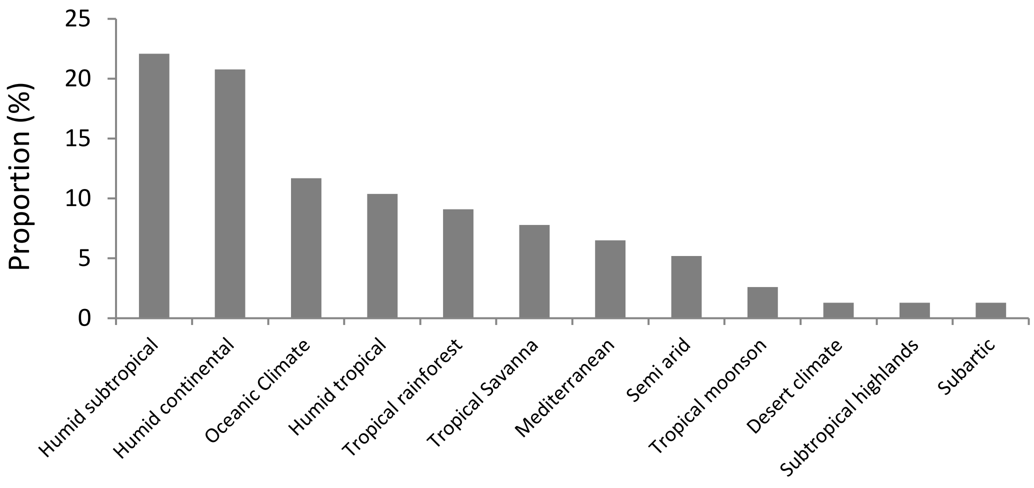


Figure 1. The proportion of publications in specific climate regions

The majority of urban water erosion studies were conducted in climate regions of the developed world (Fig. 1). Within these areas, the highest number of studies was from North America (42%), mainly from humid subtropical climate regions (e.g. North Carolina: Paterson et al. 1993, or Newack: Ludwig & Lannuzzi, 2005) and from humid continental climates (e.g. Ontario: Eyles & Meriano, 2010, or Maryland: Colosimo & Wilcock, 2007). This was followed by studies from Europe (19%), primarily covering oceanic climate regions (e.g. Cantabria, Spain: Zafra, Temprano, & Tejero, 2008) or Mediterranean climate (e.g. Italy: Bretzel, Benvenuti, & Pistelli, 2014). The least explored continent of the developed world was Australia with only 3% of all studies (e.g. Brisbane: Brown & Chanson, 2012). In the developing world, most studies were conducted in Asia (16%), with the majority carried out in humid continental climate (e.g. Korea: Moon, Lee, & Yoon, 1994; China: Zhao & Li, 2013). Overall, only 12% of the studies took place in Africa, mostly in Nigeria (e.g. Jimoh, 2001; Ehiorobo & Audu, 2012; Omon & Oisasoje, 2012), and only 9% in South America, with a focus on Brazil (e.g. Franz, Makeschin, Weiβ, & Lorz, 2014). Interestingly, drier climate regions appear to have received rather limited attention regarding erosion in urban areas. Apart from the semi-arid region (5% of the studies), desert and subarctic regions were only addressed by a single publication each (desert: Parker, 2000; subarctic: Fan & Li, 2004).

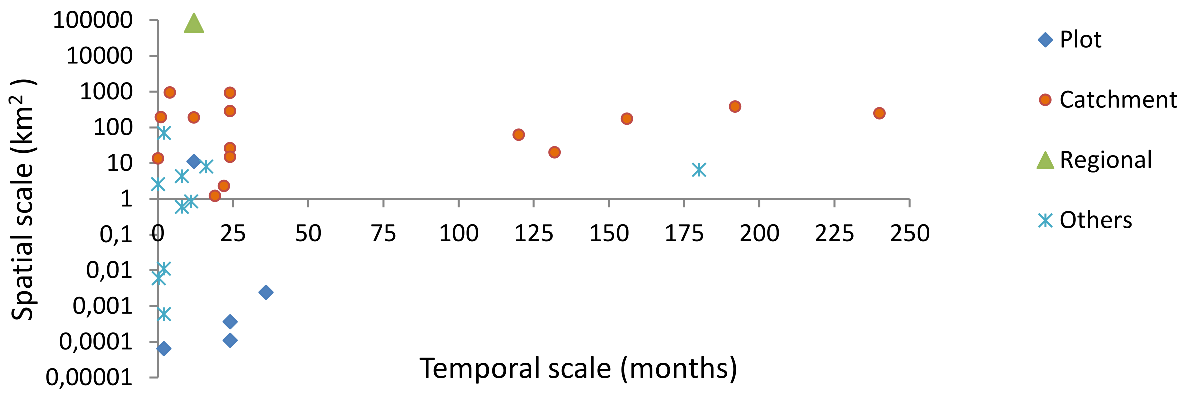


Figure 2. Distribution of scales employed. *Although often scales overlap, a 'plot' scale ranges from areas of 0.01m² to 10 000m², a 'catchment' scale ranges from less than 1km² to several hundreds of km² while a 'regional' scale refers to areas larger than a catchment (Wei et al., 2012). 'Others' includes distance measures and areas such as 'distance to a road', 'beach stretch', 'lagoon', or 'city area'.*

Most of the studies (48%) of urban water erosion were conducted at the catchment scale (Fig. 2), focusing primarily on aspects related to soil loss control (e.g. Stroosnijder, 2005). This includes research on the sources (Nelson & Booth, 2002; Poleto, Merten, & Minella, 2009), spatial distribution and quantification of various sediments (Rowntree et al., 1991; Franz et al., 2014), and related long term soil losses (Ehiorobo & Audu, 2012). In contrast, relatively few publications (16%) addressed the plot scale (e.g. Bazzoffi, Pellegrini, Rochini, Morandi & Grasselli, 1998; Osorio & De Oña, 2006; Greenstein et al., 2014) and only one publication focused on a regional scale other than catchment (i.e. a loess plateau region in china: Hu, Zhi-mao, & Jun-ping, 2001). However, 32% of the publications fell under the unspecific category "others" covering a broad variety of scales (e.g. Hu et al., 2001; Jimoh, 2005; Zhao, Li, Wang, & Tian, 2010; Ehiorobo & Audu, 2012). From a temporal perspective, many studies (i.e. 81%) covered a time span of less than 25 months, with 29% of studies only spanning one year or less. Longer time spans were typically related to monitoring activities (e.g. Colosimo & Wilcock, 2007; Kelderman, 2012) and providing overviews of existing observed erosion dynamics (e.g. Balamurugan, 1991; Booth & Henshaw, 2001). Only half of the reviewed publications included sufficient information on spatial and temporal scales to be integrated in Fig. 2. The reviewed studies mainly addressed erosion induced damages resulting mostly from heavy rainfall events and poor planning, thus associated with local flooding, gully formation and debris flow (Rowntree, Natsaba, & Weaver, 1991; Gupta & Ahmad, 1999; Berger, McArdell, & Schluneger, 2011). The spatial extents of these damages occur at micro-, meso- and macro scale. At micro scales, the damage extended to single unit properties within a settlement, especially during flooding (e.g. Taş, Tas, Durak, & Atanur, 2013). At meso scales, studies focus on sediment movements and contaminations affecting drainage systems and river channels (e.g. Moon et al., 1994; Taylor & Owens, 2009). At macro scales, larger units at coastlines, such as lagoons and beaches are studied. In particular, contaminations from transport activities and industrial areas that affect lagoons and coastal estuaries or the effect of eroded sediments that damage municipal or private properties at larger scales (e.g. Jiménez, Gracia, Váldemoro, Mendoza, & Sanchez-Arcillo, 2011).

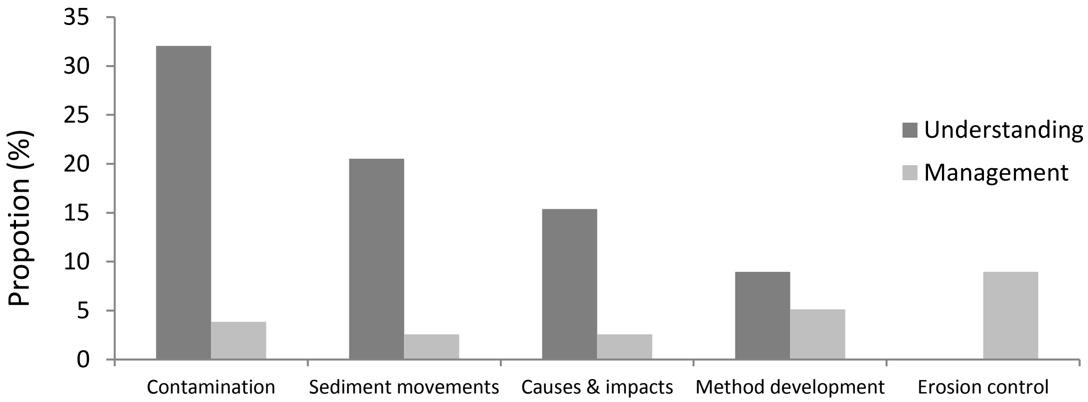


Figure 3. Focal research topics addressed in the publications

Overall, the reviewed research focused more on offsite erosion (e.g. flooding, contamination, sediment fluxes, river adjustments) than on the onsite effects of erosion (e.g. erosion rate, soil loss, landform development). The highest number of studies addressed contamination (36%) as a focal research topic, followed by sediment movement (i.e. transportation and deposition) (23%), and the causes and impacts of erosion (18%). Less attention was paid to the development of methods (14%) and to erosion control (9%). Except from studies directly addressing erosion control, most studies were more oriented towards a basic understanding (77%) than towards management issues (23%). Moreover, studies aiming at the management erosion level hardly considered the causes and the impacts of erosion or the movements of the eroded sediments. On the other hand, studies aiming at understanding focused more on contamination compared to any other subjects and did not consider the erosion control at all.

Sources of contamination were largely traced back to anthropogenic activities, including domestic effluents (Horowitz, 2009), output from sewage works (Carter, Owens, Walling, & Leeks, 2003), and automobiles activities (Sutherland & Tolosa, 2000). Contaminations accumulated in different water bodies including reservoirs (Wildi et al., 2004) and estuaries (e.g. Ludwig & Lannuzzi, 2005). Specific agents that were detected included metals such as Calcium (Ca), Copper (Cu), Lead (Pb) and Zinc (Zn) (Irvine, Drake, & James, 1992; Estébe, Boudries, Mouchel, & Thévenot, 1997; Parker, 2000; Jartun, Ottesen, Steinnes, & Volden, 2008) and organic contaminants such as Dichlorodiphenyl Trichloroethane (DDT), Polycyclic Aromatic Hydrocarbon (PAH) and Polychlorinated Biphenyls (PCBs) (Walker, Walker, Mcnutt, & Mash, 1999; Greenstein et al., 2014).

Studies focusing on fluxed sediments identified types of surfaces as a main influencing factor, which varied highly among urban areas. For example in Rio Grande do Sul (Brazil), the percentage of sediments yield varied from paved surface (46%), to unpaved surfaces (23%) and stream channels (3%) (Poleto et al., 2009). Similar variation occurred in Seattle (Washington, United State of America (USA)), where sediments originated from landslide areas (40%), channel banks (20%), or road surfaces (15%) (Nelson & Booth, 2002). In Maseru (Lesotho) construction sites produced in averagely 85% of sediments, whereas gulling walls contributed 10% and agricultural areas adding another 5% (Franz et al., 2014). Also soil losses related to erosion strongly differed among sites. For example, gully erosion was found to be responsible for soil loss up to 3,57m^3/m^2 in Benin, while observed losses in China were up to 2, 24m^3/m^2 and up to 2,11m^3/m^2 in Spain (Ehiorobo & Audu, 2012).

Reported causes for erosion were primarily from the stream banks being changed (adjusted or enlarged) as urban development areas expand (Fan & Li, 2004; Colosimo & Wilcock, 2007). Other causes were attributed to high rainfall events, that in combination with a lack of proper planning of infrastructures led to sediment accumulation in water bodies and to debris flow. This combined water, sediment and debris flood subsequently destroyed bridges and culverts while also forming prominent features such as rills and gullies (Ibitoye & Eludoyin, 2010). The formation of gullies further depends on the soil type (e.g. clay or silting sand gravel) since it strongly influenced soil wetness and thus erodibility (e.g. Omon & Oisasoje, 2012).

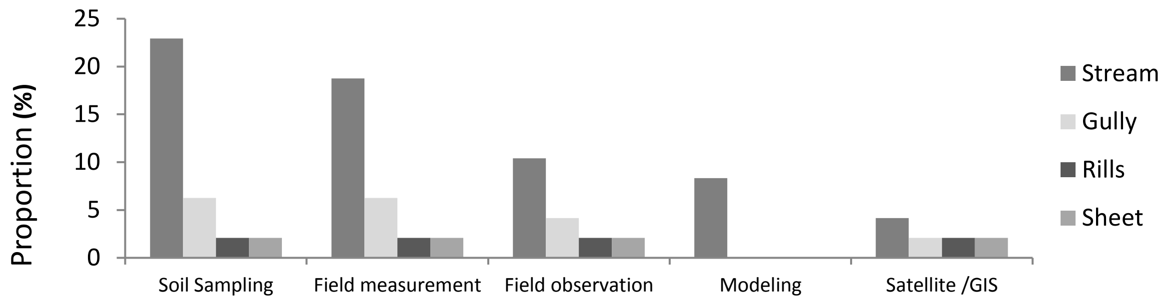


Figure 4. Methods and types of urban erosion researched

The type of erosion studied primarily included late stages of erosion, i.e. stream erosion (65%) and gully erosion (19%). As such, only limited attention was paid to the newly formed erosion of rills (8%) and sheet erosion (8%). Most approaches employed traditional field methods (81.3%; e.g. soil sampling, field measurements and observations) (Fig. 4). Modeling was mostly applied to stream erosion and storm water runoff while the use of Remote Sensing (RS) and Geographical Information System (GIS) was largely restricted the detection of erosion related to land use (Tamim, Pallu, Wunas, & Baja, 2012; Khosrokhani & Pradhan, 2013; Vaz & Bowman, 2013). Models used include 'USLE' for soil loss (Mukundan et al., 2013), 'CREAMS', 'KENTUCKY' and 'MIKE' for sediments transportation (Irvine et al., 1992; Deletic, 2005; Spencer, Droppo, He, Grapentine, & Exall, 2011), and 'FEFLOW' for ground water flow (Eyles & Meriano, 2010). Additional model applications using 'ISWMS', 'PDF', 'DWSM' and 'SWAT' concentrated mostly on modeling storm water runoff (Allen, Arnold, & Skipwith, 2002; Fan & Li, 2004; Harris & Adams, 2006; Zhang, Zhang, Hu, Lie, & Li, 2013). Only one publication was based on laboratory experiments, aimed at understanding the processes of sediment transport in runoff over grass (Deletic, 2005).

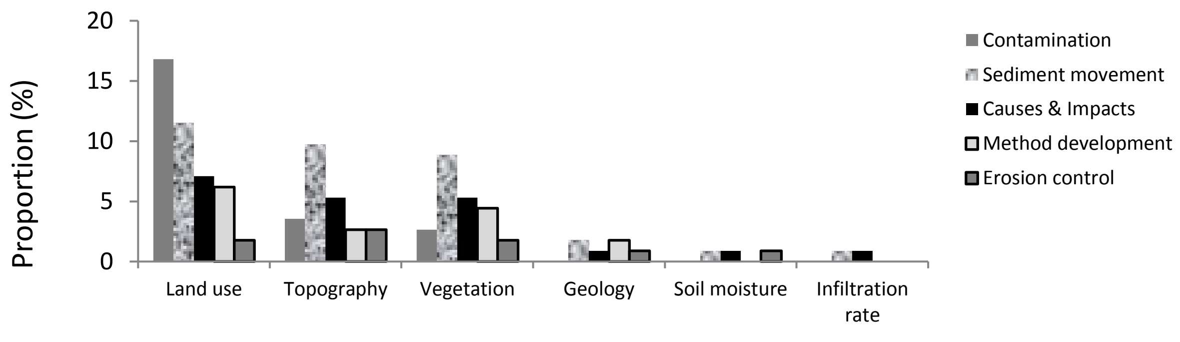


Figure 5. Key factors considered in erosion studies in relation to focal research areas

The most frequently considered influencing factors in the reviewed soil erosion studies include land use (43%), topography (24%) and vegetation cover (23%) (Fig.5). Surprisingly, the important soil-related factors influencing erosion (i.e. geology, soil moisture and infiltration rate) were only rarely or not at all considered, independent from the focal research topic of the study. Examples of studies that had not considered the related soil properties included investigations on urbanized watersheds (e.g. Colosimo & Wilcock, 2007), contaminated sediments (e.g. Tao et al., 2010; Kelderman, 2012) and coastal erosion (e.g. Jiménez et al., 2011). Furthermore, only a limited number of studies linked land use and erosion control though this link is probably crucial for future erosion risk management.

As for managing urban water erosion, studies were overall very case specific and only few general themes could be identified. One of them was the use of cost effective materials for erosion control, e.g. natural materials. For example, in Betim (Brazil), straw blankets were successfully applied for controlling gully erosion (De Brito Galvão, Pereira, Coelho, Pereira, & Coelho, 2010). In contrast, in the City of Gaza waste material was used to control coastal erosion. But, despite of the materials being viable and cheap, they were also found to be a potential cause for ground and surface water pollution (Al-Agha, 2000). Similarly, in Italy and Spain, compost was used to control runoff and soil erosion. In Italy, the compost increased the bulky density by $0.08 Mgm^{-3}$ as a result of its inert fraction content (Bazzoffi et al., 1998). For Spain, it was reported that soil loss was reduced by compost-mediated runoff control up to 94% (Ros, Garcia, & Hernandez, 2001). Three other publications discussed the subject of erosion control. Two of them addressed erosion programs in North Carolina, where one study assessed the public and private costs and benefits associated with urban erosion and sediment control (Paterson et al., 1993). It established that the urban householders were willing to pay up to around $14.2 million to maintain and control erosion and sediment pollution. The other study examined the use of cohesive and cooperative approaches to control erosion and sediment pollution (Burby, 1995). The study concluded that for the programs to be successful in managing erosion and control the sediment pollution a more coercive approach would be required. In particular, this would include improving staffing, applying severe sanctions when standards are violated and offering incentives to improve the cooperation between levels of governments (Burby, 1995). The third publication on erosion control dealt with specific protection measures such as adding sand at the Spanish Mediterranean coast (Jiménez et al., 2011).

2.4 Discussion

2.4.1 Distributions of water erosion studies across the continents and climate zones

Most extreme climate regions (i.e. semi-arid, arid or desert regions) are located in the developing world, especially in Africa and Asia. In comparison to other climatic regions (e.g. humid), these regions can be more susceptible to problems of water erosion due to observed and predicted changes in precipitation distributions (Reich, Eswaran, & Beinroth, 2001). In particular, an overall reduction of average annual precipitation in these areas is often accompanied by less but more intense rainfall events leading to increased erosion risks (Nearing et al., 2004; World Meteological Organization, 2005). Furthermore, the majorities of cities in Africa and Asia are experiencing rapid population growth, brought about by the dramatic increase of urbanization due to global warming and reduction of annual precipitation (Portnov & Paz, 2008; United Nations, 2012). Despite this high relevance, the developing regions, and more especially Africa, have to date received very limited attention regarding urban water erosion studies. This holds, though Africa experienced the highest contributions to soil erosion through land use change in the last decades (Yang, Kanae, Oki, Koike, & Musiake, 2003). Also, soil erosions are estimated to be increasing up to 50% in Africa (as well as in Australia) by the year 2090 (Yang et al., 2003). In particular, the obvious lack of research in urban areas of the developing world should be a major source of concern as soil erosion intensity is generally closely linked to patterns of population density distribution (Silveira, 2002). Thus, the urban poor living in high population density areas are likely to suffer the most severe consequences of increasing erosion risks.

2.4.2 Temporal and spatial scales

Unlike in agricultural and other areas where researchers have concentrated more on sheet and rill erosion processes at plot scale (Poesen, Nachtergaele, Verstraeten, & Valentin, 2003), research on urban water erosion largely focused on stream and gully erosion at catchment scale (Fig. 2 and 4). This focus on visible large scale effects instead of indicative smaller-scale erosion impacts suggests that erosion problems in urban areas only come to public attention at advanced stages when their alarming consequences have become obvious.

Clearly, the proper understanding of soil water erosion processes requires the explicit consideration of different spatial and temporal scales (Renschler & Harbor, 2002; Cantón, et al., 2011; Wei et al., 2012). Long-term and large-scale studies are necessary for monitoring consequences of and changes in soil erosion processes, while small-scale studies of shorter duration are important for identifying underlying mechanisms and local drivers (Renschler & Harbor, 2002). However, many urban water erosion investigations have only lasted for less than two years (Fig. 2). Also, despite the importance of providing regional information to policymakers (Wei at al., 2012), only one of the publications on urban areas were carried out at a regional scale. This stands in contrast to non-urban areas where water erosion studies at regional scale have received ample attention since the 1990s (De Vente, Poesen, Verstraeten, Van Rompaey, & Govers, 2008).

2.4.3 Research approaches

Interestingly, modern methods in erosion research such as satellite based studies, GIS and computer modeling are only relatively sparsely used in relation to urban erosion (Fig. 4). This is unexpected since, for example, high resolution sensors such IKONOS, ASTER and Quick Bird are highly suitable for identifying early processes and impacts of erosion (Vrieling, 2006) and can be used to inform the management and policymakers well in advance. Also, current approaches in erosion modeling lack a clear focus on the specifics of urban areas. For instance, the widely used Universal Soil Loss Equation (USLE) model was developed for conservation planning as an assessment tool for predicting long term annual averages of soil loss (Nearing, 1998; Nearing et al., 2005). Despite the various modifications to the model (e.g. the incorporation of process-based equations (Prasannakumar et al., 2012)), its current limitations reduce the applicability to urban settings. This includes the model's restriction to small areas (Nearing et al., 2005), and its limitation in estimating the distribution of soil loss or runoff volumes (Nearing, 1998). Furthermore, expanding urban environments are highly variable, especially along vulnerable areas like streams. Addressing this variability would require further refinement of the model or the integration of new approaches. Similar concerns in terms of applicability apply also to the CREAMS model (Aksy & Kavvas, 2005). Even though it has been adjusted for urban environment (e.g. Irvine, Perrelli, Ngoen-Klan, & Droppo, 2009), the model assumes soil topography and land use to be uniform (Merritt, Letcher, & Jakeman, 2003), which clearly is not the case in urban context. Also well-established models such as MIKE (Spencer et al., 2011) and SWAT (Zhang et al., 2013) are not able to cover all relevant aspects of urban soil erosion. However, they can be applied to specific scenarios. For example, the MIKE model can be used for analyzing storm-based events though it ignores bank erosion processes (Merritt et al., 2003) which are vital during flooding in urban watershed areas. In contrast, the SWAT model can help to predict long term erosion yield but it is not suitable for analyzing severe storm events (Borah & Bera, 2003). This is problematic since such events are critical in urban areas often leading to flash flooding, which especially occurs in areas with inefficient drainage systems.

Overall, though current models disregard some of the important factors for urban environment, the integration of various modeling approaches appear to be a suitable answer to current challenges in urban water erosion. In either case, a close linkage of models to monitoring data is required to solve the inherent problem of insufficient model parameterization and testing (Merritt et al., 2003).

2.4.4 Focal factors and processes

The specific approach applied clearly determines the influencing factors considered. Fig. 5 shows that surface geology, soil moisture and infiltration are the least considered factors in urban water erosion investigations, despite the fact that related parameters greatly influence the understanding and accuracy of predictions of soil water erosion (Western et al., 2004). For example, improved understanding of soil properties' sensitivity to degradation has been identified as a key to early warning in water erosion risks (Luleva, Werff, Meer, & Jetten, 2012). More particularly, understanding the effects of surface geology on water erosion is important because some parent materials such as limestone and sandstone are more easily eroded than others (Kosmas, Gerontidis, Marathianou, 2000). Also, soil permeability largely depends on the surface geology which impacts soil development (Jencso & McGlynn, 2011). Permeability together with actual soil moisture largely determines how much water can infiltrate. Hence, they also influence surface water erosion and the related amount of soil loss and transport (Qiu, Fu, Wang, & Chen, 2003). The inadequacy of current knowledge regarding the linkage between soil moisture and its influencing environmental factors (Qiu et al., 2003; Feng, Zhao, Qiu, Zhao, & Zhong, 2013) combined with the lack of long term observation largely hampers the calibration and validation of conceptual and physical-based model approaches of erosion (Venkatesh, Lakshman, Purandara, & Reddy, 2011). The lack of such in-depth understanding of underlying processes implies that the more complex dynamics of urban water erosion is only insufficiently resolved. This clearly also hampers the management of erosion risks in urban areas.

2.4.5 Challenges in managing water erosion in urban settings

Urban sectors, including planning, engineering, education and health, typically have inadequate measures to cope with urban water erosion impacts, especially during extreme rainfall events. The related risks can have severe consequences given the fact that more than 50% of the world's populations are currently living in urban areas with an observed ongoing increase in urbanization (Kates & Parris, 2003; Seto, Guneralp, & Hutyra, 2012). Consequent damages to society and to critical environmental systems can be nearly irreversible. Yet, erosion control was the least investigated aspect in the current research on urban water erosion (Fig. 3).

The few applied erosion management approaches in urban areas used materials that are either environmental friendly (waste, compost and straw blankets sewn with recycled plastic threads) or consist of cheap materials (construction waste, white metal waste and tires). While overall all tested approaches had achieved their specific aims, the use of cheap materials suffered from the challenge of balancing the tradeoff between benefit (immediate condensed public health hazard and less economic strain) and producing new environmental problems. For example, steel within concrete waste corrodes at a very high rate as it reacts with sea water and the use of tire wastes eventually degrades and contributes to environmental pollution (Bazzoffi et al., 1998). Both results can be very hazardous to the public health and the environmental systems, and even deadly to aquatic life. Similarly to the inland urban areas, the challenge in managing coastal erosion is also resulting from the massive expansion of urban land use at coastlines (Vaz & Bowman, 2013). Added to that is inadequate hazard zone buffers, poor planning of land use and development of inappropriate erosion measures (Adelekan, 2010; Vaz & Bowman, 2013). The increasing anthropogenic pressure on coastal areas further worsens existing (natural) erosion problems, affecting infrastructures and also reducing beach capacity for recreation (Lizárraga-Arciniega, Appendini-Albretchsen, & Fitcher, 2001). Natural storm erosion makes managing coastal erosion even more complicated than managing inland urban areas. Therefore, especially at the coast sound environmental policies are essential for production of strong and long lasting management measures.

2.5 Conclusion

A key challenge in understanding and managing urban water erosion is the rapid growth of urban areas and the related ongoing change of the physical environment. Consequent effects on water erosion might be even greater than effects caused by climate change (Slaymaker, 2001). This review identifies existing gaps in research on key influencing factors in urban water erosion, a limitation in current methods employed, and a missing focus on management strategies that are oriented towards risk minimization. To start with, only very few erosion experiments were carried out at the plot scale and almost none at the regional scale. While research at the plot scale is very important to better understand basic processes, information gathered at regional scales is crucial for management and policy advice. Furthermore, even though managing strategies are generally based on polices, the role of policies in managing erosion risks is hardly addressed. Also socioeconomic factors such as the level of education, the level of income, land availability, and the type of housing were not considered in current studies on urban water erosion. The lack of such data is problematic since they could help to improve the specifics of future management strategies, and the development of suitable policies. In addition, none of the studies reviewed explicitly addressed the important issue of climate change for urban areas, even though the expected increase in the intensity of rainfall events will likely increase current threats in urban water erosion. Possible reasons for these different shortcomings clearly include the complexity and dynamics of urban water erosion processes, but also the high costs involved in the necessary detailed scale-crossing and interdisciplinary studies. Furthermore, though any effort to conserve soil and its ecological functions is based on the state condition of the soil, the reviewed studies did not address the extent of eroded area in urban areas. Understanding the extent of which urban areas have been affected is profoundly significant for soil management and maintaining a quality urban ecosystem. Finally, management solutions in the reviewed literature hardly included the stakeholders' understanding and perceptions of water erosion, even though such information can be very instrumental in developing applicable solutions for the affected communities.

To conclude, urban-specific interdisciplinary studies are urgently needed, that (i) systematically explore all underlying factors and drivers that influence erosional processes across scales, (ii) careful evaluate the applicability of different approaches adapted, (iii) better integrate modern approaches such as remote sensing, GIS and urban-specific process-based computer modeling. Further, more research should be oriented towards (iv) the detection of early erosion risk signals, (v) exploration for reinforcement of environmental policies, (vi) a better integration of socio-economic factors for urban planning, (vii) a critical examination of the extent of eroded area in urban settings, oriented towards long-term management strategies to reduce water erosion risks, and (viii) a stakeholder analysis in urban areas, focusing in understanding the views and perceptions of the local communities with regard to water erosion.

2.6 References

Adelekan, I. O. (2010). Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria. *Environment and Urbanization*, 22(2), 433–450. doi:10.1177/0956247810380141

Aksoy, H., & Kavvas, M. L. (2005). A review of hillslope and watershed scale erosion and sediment transport models. *Catena*, 64(2-3), 247–271. doi:10.1016/j.catena.2005.08.008

Al-Agha, M. R. (2000). Access to the coast and erosion control: use of wastes on local engineering works in the coast of Gaza City. *Environmental Geology*, 39(3-4), 405–410. doi:10.1007/s002540050021

Allan, J. D., Erickson, D. L., & Fay, J. (1997). The influence of catchment land use on stream integrity across multiple spatial scales. *Freshwater Biology*, 37(1), 149–161. doi:10.1046/j.1365-2427.1997.d01-546.x

Allen, P. M., Arnold, J. & Skipwith, W. (2002). Erodibility of Urban Bedrock and Alluvial Channels, North Texas1. *JAWRA Journal of the …*, 38(5), 1477–1492. doi:10.1111/j.1752-1688.2002.tb04360.x

Anigbogu, N. A. (2001). The Reciprocal Relationship Between Construction and Soil Erosion. *Journal of Environmental Science*, 4(2), 55–59.

Balamurugan, G., & Lumpur, K. (1991). Sedimemt Balance and Delivery in a Humid tropical Urban River Basin: The Kelang River, Malaysia. *Catena*, 18, 271–287.

Bazzoffi, P., Pellegrini, S., Rocchini, A., Morandi, M., & Grasselli, O. (1998). The effect of urban refuse compost and different tractor tyres on soil physical properties, soil erosion and maize yield. Soil & Tillage Research, 48, 275–286.

Berger, C., McArdell, B. W., & Schlunegger, F. (2011). Direct measurement of channel erosion by debris flows, Illgraben, Switzerland. *Journal of Geophysical Research: Earth Surface*, 116(1), 1–18. doi:10.1029/2010JF001722

Bong, C. H. ., Lau, T. L. L., & Ghani, A. A. (2011). Sediment deposition characteristics of urban concrete drains in Kuching. In *Managing Rivers in the 21st Century: Sustainable Solutions for Global Crisis of Flooding, Pollution and Water Scarcity* (pp. 712 –720).

Booth, D. B., & Henshaw, P. C. (2001). Rates of channel erosion in small urban streams. *Water Science and Application*, 1–21. doi:10.1029/WS002p0017

Borah, D. K., & Bera, M. (2003). Watershed-scale hydrologic and nonpoint-source pollution models: review of mathematical bases. *American Society of Agricultural Engineers*, 46(6), 1553–1566. Retrieved from http://www.isws.illinois.edu/iswsdocs/journals/TransASAE46-6-1553-1566.pdf

Bretzel, F., Benvenuti, S., & Pistelli, L. (2014). Metal contamination in urban street sediment in Pisa (Italy) can affect the production of antioxidant metabolites in Taraxacum officinale Weber. *Environmental Science and Pollution Research*, 21(3), 2325–2333. doi:10.1007/s11356-013-2147-2

Brown, R., & Chanson, H. (2012). Suspended sediment properties and suspended sediment flux estimates in an inundated urban environment during a major flood event. *Water Resources Research*, 48(11). doi:10.1029/2012WR012381

Burby, R. J. (1995). Coercive versus cooperative pollution control: Comparative study of state programs to reduce erosion and sedimentation pollution in urban areas. *Environmental Management*, 19(3), 359–370. doi:10.1007/BF02471978

Cantón, Y., Solé-Benet, A., De Vente, J., Boix-Fayos, C., Calvo-Cases, A., Asensio, C., & Puigdefábregas, J. (2011). A review of runoff generation and soil erosion across scales in semiarid south-eastern Spain. *Journal of Arid Environments*, 75(12), 1254–1261. doi:10.1016/j.jaridenv.2011.03.004

Carter, J., Owens, P. N., Walling, D. E., & Leeks, G. J. L. (2003). Fingerprinting suspended sediment sources in a large urban river system. *The Science of the Total Environment*, 314-316(03), 513–534. doi:10.1016/S0048-9697(03)00071-8

Colosimo, M. F., & Wilcock, P. R. (2007). Alluvial Sedimentation and Erosion in an urbanizing wtershed, Gwynns Falls, Maryland. *Journal of The American Water Resources Association*, 43(2).

De Brito Galvão, T. C., Pereira, A. R., Coelho, A. T., Pereira, P. R., & Coelho, J. F. T. (2011). Straw Blankets Sewn With Recycled Plastic Threads for Erosion and Urban Sediments Control. *Geotechnical and Geological Engineering*, 29(1), 49–55. doi:10.1007/s10706-010-9371-z

De Oña, J., & Osorio, F. (2006). Using waste to reduce slope erosion on road embankments. *Proceedings of the ICE - Transport*, 159(1), 15–24. doi:10.1680/tran.2006.159.1.15

De Vente, J., Poesen, J., Verstraeten, G., Van Rompaey, A., & Govers, G. (2008). Spatially distributed modelling of soil erosion and sediment yield at regional scales in Spain. *Global and Planetary Change*, 60(3-4), 393–415. doi:10.1016/j.gloplacha.2007.05.002

Deletic, A. (2005). Sediment transport in urban runoff over grassed areas. *Journal of Hydrology,* 301(1-4), 108–122. doi:10.1016/j.jhydrol.2004.06.023

Ehiorobo, J. O., & Audu, H. A. P. (2012). Monitoring of Gully Erosion in an Urban Area Using Geoinformation Technology. *Scholarlink Reseacrh Institute of Journals*, 3(2), 270–275.

Estèbe, A., Boudries, H., Mouchel, J. M., & Thévenot, D. R. (1997). Urban runoff impacts on particulate metal and hydrocarbon concentrations in river Seine: Suspended solid and sediment transport. *Water Science and Technology*, 36(8-9), 185–193. doi:10.1016/S0273-1223(97)00600-8

Eyles, N., & Meriano, M. (2010). Road-impacted sediment and water in a Lake Ontario watershed and lagoon, City of Pickering, Ontario, Canada: An example of urban basin analysis. *Sedimentary Geology*, 224(1-4), 15–28. doi:10.1016/j.sedgeo.2009.12.004

Fan, C., & Li, J. (2004). A modelling analysis of urban stormwater flow regimes and their implication for stream erosion. *Water Quality Research Journal of Canada*, 39(4), 356–361.

Feng, Q., Zhao, W., Qiu, Y., Zhao, M., & Zhong, L. (2013). Spatial Heterogeneity of Soil Moisture and the Scale Variability of Its Influencing Factors: A Case Study in the Loess Plateau of China. *Water*, 5(3), 1226–1242. doi:10.3390/w5031226

Franz, C., Makeschin, F., Weiß, H., & Lorz, C. (2014). Sediments in urban river basins: Identification of sediment sources within the Lago Paranoá catchment, Brasilia DF, Brazil - using the fingerprint approach. *Science of the Total Environment*, 466-467, 513–523. doi:10.1016/j.scitotenv.2013.07.056

Fu, B.-J., Wang, Y.-F., Lu, Y.-H., He, C.-S., Chen, L.-D., & Song, C.-J. (2009). The effects of land-use combinations on soil erosion: a case study in the Loess Plateau of China. *Progress in Physical Geography*, 33(6), 793–804. doi:10.1177/0309133309350264

Gaffield, S. J., Goo, R. L., Richards, L. A., & Jackson, R. J. (2003). Public Health Effects of Inadequately Managed Stormwater Runoff. *American Journal of Public Health*, 93(9), 1527–1533. doi:10.2105/AJPH.93.9.1527

Gaiser, T., Stahr, K., Billen, N., & Mohammad, M. (2008). Modeling carbon sequestration under zero tillage at the regional scale. I. The effect of soil erosion. *Ecological Modelling*, 218(1-2), 110–120. doi:10.1016/j.ecolmodel.2008.06.025

Greenstein, D. J., Bay, S. M., Young, D. L., Asato, S., Maruya, K., & Lao, W. (2014). The use of sediment toxicity identification evaluation methods to evaluate clean up targets in an urban estuary. *Integrated Environmental Assessment and Management*, 10(2), 260–8. doi:10.1002/ieam.1512

Gupta, A., & Ahmad, R. (1999). Urban steeplands in the tropics: An environment of accelerated erosion. *GeoJournal*, 49(2), 143–150. doi:10.1023/A:1007099806210

Harris, J. A., & Adams, B. J. (2006). Probabilistic assessment of urban runoff erosion potential. *Canadian Journal of Civil Engineering*, 33(3), 307–318. doi:10.1139/l05-114

Horowitz, A. J. (2009). Monitoring suspended sediments and associated chemical constituents in urban environments: Lessons from the city of Atlanta, Georgia, USA water quality monitoring program. *Journal of Soils and Sediments*, 9(4), 342–363. doi:10.1007/s11368-009-0092-y

Hu, S., Zhi-mao, G., & Jun-ping, Y. (2001). The impacts of urbanization on soil erosion in the Loess Plateau region. *Journal of Geographical Sciences*, 11(3), 282–290. doi:10.1007/BF02892311

Ibitoye, M., & Eludoyin, A. (2010). Urban Growth and Development of Soil Erosion in Part of Humid Region in Southwest Nigeria. In *Facing the Challenges - Building Capacity*. Retrieved from http://www.researchgate.net/publication/236861826

Irvine, K. N., Drake, J. J., & James, W. (1992). Particulate trace element concentrations and loadings associated with erosion of pervious urban land. *Environmental Technology*, 13(3), 221–237. doi:10.1080/09593339209385148

Irvine, K. N., Perrelli, M. F., Ngoen-Klan, R., & Droppo, I. G. (2009). Metal levels in street sediment from an industrial city: Spatial trends, chemical fractionation, and management implication. *Journal of Soils and Sediments*, 9(4), 328–341. doi:10.1007/s11368-009-0098-5

Jartun, M., Ottesen, R. T., Steinnes, E., & Volden, T. (2008). Runoff of particle bound pollutants from urban impervious surfaces studied by analysis of sediments from stormwater traps. *Science of the Total Environment*, 396(2-3), 147–163. doi:10.1016/j.scitotenv.2008.02.002

Jencso, K. G., & McGlynn, B. L. (2011). Hierarchical controls on runoff generation: Topographically driven hydrologic connectivity, geology, and vegetation. Water Resources Research, 47(11), 1–16. doi:10.1029/2011WR010666

Jiménez, J. A., Gracia, V., Valdemoro, H. I., Mendoza, E. T., & Sánchez-Arcilla, A. (2011). Managing erosion-induced problems in NW Mediterranean urban beaches. *Ocean and Coastal Management*, 54(12), 907–918. doi:10.1016/j.ocecoaman.2011.05.003

Jimoh, H. I. (2001). Erosion studies in a Nigerian city: A methodological approach. Environmentalist, 21(2), 97–101. doi:10.1023/A:1010663826050

Jimoh, H. I. (2005). Tropical Rainfall Events on Erosion Rates Ina Rapidly Developing Urban Area in Nigeria. *Singapore Journal of Tropical Geography*, 26(1), 74–81. doi:10.1111/j.0129-7619.2005.00205.x

Kates, R. W., & Parris, T. M. (2003). Long-term trends and a sustainability transition. *Proceedings of the National Academy of Sciences of the United States of America*, 100(14), 8062–8067. doi:10.1073/pnas.1231331100

Kelderman, P. (2012). Sediment pollution, transport, and abatement measures in the city canals of Delft, the Netherlands. *Water, Air, and Soil Pollution*, 223(7), 4627–4645. doi:10.1007/s11270-012-1223-4

Khosrokhani, M., & Pradhan, B. (2013). Spatio-temporal assessment of soil erosion at Kuala Lumpur metropolitan city using remote sensing data and GIS. *Geomatics, Natural Hazards and Risk*, 5(3), 252–270. doi:10.1080/19475705.2013.794164

Kosmas, C., Gerontidis, S., & Marathianou, M. (2000). The effect of land use change on soils and vegetation over various lithological formations on Lesvos (Greece). *Catena*, 40(1), 51–68. doi:10.1016/S0341-8162(99)00064-8

Kötter, T., & Friesecke, F. (2007). *Developing urban Indicators for Managing Mega Cities*.

Lal, R. (2001). Soil degradation by water erosion. Land Degradation & Development, 539, 519–539.

Lizárraga-Arciniega, R., Appendini-Albretchsen, C., & Fitcher, D. (2001). Planning for beach ersoion: A case study, Playas de Rosarito, B.C. Mexico. *Journal of Coastal Research*, 17(3), 636–644.

Ludwig, D. F., & Iannuzzi, T. J. (2005). Incremental ecological exposure risks from contaminated sediments in an urban estuarine river. *Integrated Environmental Assessment and Management*, 1(4), 374–390. doi:10.1002/ieam.5630010407

Luleva, M. I., Werff, H. Van Der, Meer, F. Van Der, & Jetten, V. (2012). Gaps and Opportunities in the Use of Remote Sensing for Soil Erosion. Chemistry: *Bulgarian Journal of Science Education*, 21(5), 748–764.

McLeman, R., & Smit, B. (2006). Migration as an adaptation to climate change. *Climatic Change*, 76(1-2), 31–53. doi:10.1007/s10584-005-9000-7

Merritt, W. S., Letcher, R. A., & Jakeman, A. J. (2003). A review of erosion and sediment transport models. *Environmental Modelling and Software*, 18(8-9), 761–799. doi:10.1016/S1364-8152(03)00078-1

Merz, B., Kreibich, H., Schwarze, R., & Thieken, A. (2010). Review article "assessment of economic flood damage." *Natural Hazards and Earth System Science*, 10(8), 1697–1724. doi:10.5194/nhess-10-1697-2010

Moon, C. H., Lee, Y. S., & Yoon, T. H. (1994). Variation of trace Cu, Pb and Zn in sediment and water of an urban stream resulting from domestic effluents. *Water Research*, 28(4), 985–991. doi:10.1016/0043-1354(94)90108-2

Morgan, R.P.C. (1995). *Soil Erosion and Conservation*. (2nd ed). England: Longman Group, Ltd

Mukundan, R., Pradhanang, S. M., Schneiderman, E. M., Pierson, D. C., Anandhi, A., Zion, M. S., Steenhuis, T. S. (2013). Suspended sediment source areas and future climate impact on soil erosion and sediment yield in a New York City water supply watershed, USA. *Geomorphology*, 183, 110–119. doi:10.1016/j.geomorph.2012.06.021

Nearing, M. A. (1998). Why soil erosion models over-predict small soil losses and under-predict large soil losses. *Catena*, 32(1), 15–22. doi:10.1016/S0341-8162(97)00052-0

Nearing, M. A., Jetten, V., Baffaut, C., Cerdan, O., Couturier, A., Hernandez, M., Van Oost, K. (2005). Modeling response of soil erosion and runoff to changes in precipitation and cover. *Catena*, 61(2-3 SPEC. ISS.), 131–154. doi:10.1016/j.catena.2005.03.007

Nearing, M. A., Pruski, F. F., & O'Neal, M. R. (2004). Expected climate change impacts on soil erosion rates - A review.pdf. *Journal of Soil and Water Conservation*, 59(1), 43 -50.

Nelson, E. J., & Booth, D. B. (2002). Sediment sources in an urbanizing, mixed land-use watershed. *Journal of Hydrology*, 264(1-4), 51–68. doi:10.1016/S0022-1694(02)00059-8

Omon, E. J., & Oisasoje, O. M. (2012). Aspects of f Gully Erosion in Benin City, Edo State, Nigeria. www.iiste.org.

Osorio, F., & De Oña, J. (2006). Using compost from urban solid waste to prevent erosion in road embankments. *Journal of Environmental Science and Health. Part A, Toxic/hazardous Substances & Environmental Engineering*, 41(10), 2311–2327. doi:10.1080/10934520600873134

Parker, J. T. C. (2000). Chemical Characteristics of Urban Stormwater Sediments and Implications for Environmental Management, Maricopa County, Arizona. *Environmental Management*, 26(1), 99–115. doi:10.1007/s002670010074

Paterson, R. G., Luger, M. I., Burby, R. J., Kaiser, E. J., Malcom, H. R., & Beard, A. C. (1993). Costs and benefits of urban erosion and sediment control: The North Carolina experience. *Environmental Management*, 17(2), 167–178. doi:10.1007/BF02394687

Pimentel, D. (2006). Soil erosion: A food and environmental threat. *Environment, Development and Sustainability*, 8(1), 119–137. doi:10.1007/s10668-005-1262-8

Pimentel, D., & Kounang, N. (1998). Ecology of Soil Erosion in Ecosystems. *Ecosystems*, 1(5), 416–426. doi:10.1007/s100219900035

Poesen, J., Nachtergaele, J., Verstraeten, G., & Valentin, C. (2003). Gully erosion and environmental change: Importance and research needs. *Catena*, 50(2-4), 91–133. doi:10.1016/S0341-8162(02)00143-1

Poleto, C., Merten, G. H., & Minella, J. P. (2009). The identification of sediment sources in a small urban watershed in southern Brazil: an application of sediment fingerprinting. *Environmental Technology*, 30(11), 1145–1153. doi:10.1080/09593330903112154

Portnov, B. A., & Paz, S. A. (2008). Climate Change and Urbanization in Arid Regions. *Annals of Arid Zone*, 47(3 & 4), 1–15.

Prasannakumar, V., Vijith, H., Abinod, S., & Geetha, N. (2012). Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. *Geoscience Frontiers*, 3(2), 209–215. doi:10.1016/j.gsf.2011.11.003

Qiu, Y., Fu, B., Wang, J., & Chen, L. (2003). Spatiotemporal prediction of soil moisture content using multiple-linear regression in a small catchment of the Loess Plateau, China. *Catena*, 54(1-2), 173–195. doi:10.1016/S0341-8162(03)00064-X

Reich, P., Eswaran, H., & Beinroth, F. (2001). Global Dimensions of Vulnerability to Wind and Water Erosion. *Sustaining the Global Farm*, 838–846.

Renschler, C. S., & Harbor, J. (2002). Soil erosion assessment tools from point to regional scales: the role of geomorphologists in land management research and implementation. *Geomorphology*, 47(2-4), 189–209. doi:10.1016/S0169-555X(02)00082-X

Ros, M., Garcia, C., & Hernandez, T. (2001). The use of urban organic wastes in the control of erosion in a semiarid Mediterranean soil. *Soil Use and Management*, 17(4), 292–293. doi:10.1111/j.1475-2743.2001.tb00041.x

Rowntree, K. M., Natsaba, M. M., & Weaver, A. V. B. (1991). Changing Patterns of Erosion in a Peri-Urban Catchment, Maseru, Lesotho. In *Sediment and Stream Water Quality in a Changing Environment: Treds and Explaination*. (pp. 93 -102).

Scalenghe, R., & Marsan, F. A. (2009). The anthropogenic sealing of soils in urban areas. *Landscape and Urban Planning*, 90(1-2), 1–10. doi:10.1016/j.landurbplan.2008.10.011

Seto, K. C., Guneralp, B., & Hutyra, L. R. (2012). Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools. In *Proceedings of the National Academy of Sciences* (Vol. 109, pp. 16083–16088). doi:10.1073/pnas.1211658109

Shuster, W. D., Bonta, J., Thurston, H., Warnemuende, E., & Smith, D. R. (2005). Impacts of impervious surface on watershed hydrology: A review. *Urban Water Journal*, 2(4), 263–275. doi:10.1080/15730620500386529

Silveira, A. L. L. (2002). Problems of modern urban drainage in developing countries. *Water Science and Technology*. Retrieved from http://www.iwaponline.com/wst/04507/wst045070031.htm

Slaymaker, O. (2001). Why so much concern about climate change and so little attention to land use change ? Human domination of Earth's ecosystems at the global scale The subtly reflexive relationship between climate and human activity. *The Canadian Geographer*, 45(1), 71–78.

Spencer, K. L., Droppo, I. G., He, C., Grapentine, L., & Exall, K. (2011). A novel tracer technique for the assessment of fine sediment dynamics in urban water management systems. *Water Research*, 45(8), 2595–2606. doi:10.1016/j.watres.2011.02.012

Strahle, A.H. (2010). *Introducing Physical Geography*. (5th ed). Chichester: John Wiley & Sons

Stroosnijder, L. (2005). Measurement of erosion: Is it possible? *Catena*, 64(2-3), 162–173. doi:10.1016/j.catena.2005.08.004

Sundborg, A., & Rapp, A. (2014). Erosion and Sedimentation by water: Problems and Prospects. *Springer*, 15(4), 215–225.

Sutherland, R. A., & Tolosa, C. A. (2000). Multi-element analysis of road-deposited sediment in an urban drainage basin, Honolulu, Hawaii. *Environmental Pollution*, 110(3), 483–495. doi:10.1016/S0269-7491(99)00311-5

Tamim, A., Pallu, S., Wunas, S., & Baja, dan S. (2012). Soil Erosion in the Urban Catchment Area of Baubau City, Indonesia. *International Journal of Engineering and Innovative Techology* (IJEIT), 2(6), 421–425.

Tao, J., Huggins, D., Welker, G., Dias, J. R., Ingersoll, C. G., & Murowchick, J. B. (2010). Sediment contamination of residential streams in the metropolitan Kansas City area, USA: Part I. distribution of polycyclic aromatic hydrocarbon and pesticide-related compounds. *Archives of Environmental Contamination and Toxicology*, 59(3), 352–369. doi:10.1007/s00244-010-9497-2

Tas, M., Tas, N., Durak, S., & Atanur, G. (2013). Flood disaster vulnerability in informal settlements in Bursa, Turkey. *Environment and Urbanization*, 25(2), 443–463. doi:10.1177/0956247813501134

Taylor, K. G., & Owens, P. N. (2009). Sediments in urban river basins: A review of sediment-contaminant dynamics in an environmental system conditioned by human activities. *Journal of Soils and Sediments*, 9(4), 281–303. doi:10.1007/s11368-009-0103-z

United Nations. (2012). *World Urbanization Prospects: The 2011 Revision*. Retrieved from http://esa.un.org/unpd/wpp/ppt/CSIS/WUP_2011_CSIS_4.pdf

Vaz, E., & Bowman, L. (2013). An Application for Regional Coastal Erosion Processes in Urban Areas: A Case Study of the Golden Horseshoe in Canada. *Land*, 2(4), 595–608. doi:10.3390/land2040595

Venkatesh, B., Lakshman, N., Purandara, B. K., & Reddy, V. B. (2011). Analysis of observed soil moisture patterns under different land covers in Western Ghats, India. *Journal of Hydrology*, 397(3-4), 281–294. doi:10.1016/j.jhydrol.2010.12.006

Vrieling, A. (2006). Satellite remote sensing for water erosion assessment: A review. *Catena*, 65(1), 2–18. doi:10.1016/j.catena.2005.10.005

Walker, W. J., Mcnutt, R. P., & Mash, C. K. (1999). The Potential Contribution of Urban Runoff to Surface Sediments of the Passaic River: Source and Chemical Characteristics. *Chemosphere*, 38(2).

Wei, W., Chen, L., Yang, L., Fu, B., & Sun, R. (2012). Spatial scale effects of water erosion dynamics: Complexities, variabilities, and uncertainties. *Chinese Geographical Science*, 22(2), 127–143. doi:10.1007/s11769-012-0524-2

Western, A. W., Zhou, S. L., Grayson, R. B., McMahon, T., Blöschl, G., & Wilson, D. J. (2004). Spatial correlation of soil moisture in small catchments and its relationship to dominant spatial hydrological processes. *Journal of Hydrology*, 286(1-4), 113–134. doi:10.1016/j.jhydrol.2003.09.014

Wildi, W., Dominik, J., Loizeau, J. L., Thomas, R. L., Favarger, P. Y., Haller, L., … Peytremann, C. (2004). River, reservoir and lake sediment contamination by heavy metals downstream from urban areas of Switzerland. *Lakes and Reservoirs: Research and Management*, 9(1), 75–87. doi:10.1111/j.1440-1770.2004.00236.x

World Meteological Organisation. (2005). *Climate and Land Degradation*, 20(989), 1-34.

Yair, A., & Raz-Yassif, N. (2004). Hydrological processes in a small arid catchment: Scale effects of rainfall and slope length. *Geomorphology*, 61(1-2), 155–169. doi:10.1016/j.geomorph.2003.12.003

Yang, D., Kanae, S., Oki, T., Koike, T., & Musiake, K. (2003). Global potential soil erosion with reference to land use and climate changes. *Hydrological Processes*, 17(14), 2913–2928. doi:10.1002/hyp.1441

Zafra, C., Temprano, J., & Tejero, I. (2008). Particle size distribution of accumulated sediments on an urban road in rainy weather. *Environmental Technology*, 29(5), 571–582. doi:10.1080/09593330801983532

Zhang, X., Zhang, X., Hu, S., Liu, T., & Li, G. (2013). Runoff and sediment modeling in a peri-urban artificial landscape: Case study of Olympic Forest Park in Beijing. *Journal of Hydrology*, 485, 126–138. doi:10.1016/j.jhydrol.2012.01.038

Zhao, H., & Li, X. (2013). Risk assessment of metals in road-deposited sediment along an urban-rural gradient. *Environmental Pollution*, 174, 297–304. doi:10.1016/j.envpol.2012.12.009

Zhao, H., Li, X., Wang, X., & Tian, D. (2010). Grain size distribution of road-deposited sediment and its contribution to heavy metal pollution in urban runoff in Beijing, China. *Journal of Hazardous Materials*, 183(1-3), 203–210. doi:10.1016/j.jhazmat.2010.07.012

Link to chapter three

The preceding chapter presented the literature review on urban water erosion. The findings showed that regions (drylands) with extreme climatic conditions are neglected and some areas, in particular Africa, have not been sufficiently researched. Researchers have largely concentrated on offsite erosion, focusing on contaminated sediments and on-stream erosion. Furthermore, none of the studies reviewed clearly addressed the important issue of climate change for urban areas or considered the aspects of socio-economic factors in assessing urban water erosion, even though such issues can escalate the threat of water erosion. Lastly, most of the approaches used were found to have been borrowed from agricultural studies and some might not always be suited to urban environments. Chapter three focuses on the quantification of the real extent of water erosion to provide evidence of water erosion problems in dryland urban areas. It interpolates the percentages of excessive erosion to provide the spatial distribution. The study also assesses the applicability of the adapted agricultural tool (USLE) which is commonly used for urban areas (Pradhan et al. 2011; Khosrokhani and Pradhan 2013; Leh et al. 2013). The study further assesses the impact of water erosion in different urban socio-spatial structures, and in relation to vegetation as well the slope of the area.

Chapter Three

Quantification of a Real Extent of Soil Erosion in Dryland Urban Areas: An Example of Windhoek, Namibia

Abstract

Soil erosion is one of the main global environmental problems. Soil erosion is mostly studied for rural regions in dryland settings, whereas only a few studies on the areal extent, pattering and severity of soil erosion exist in urban settings. This study aimed at mapping and quantifying the extent and severity of water erosion in a dryland city (Windhoek in Namibia) using a snap-shot field survey approach. The results show that nearly 56% of the city is affected by water erosion, showing signs of accelerated erosion in the form of rills and gullies which occurred mainly in the underdeveloped, informal and semi-formal areas of the city. Factors influencing the extent of erosion in Windhoek included vegetation cover and type, socio-urban factors and to a lesser extent slope estimates. A comparison of an interpolated field survey erosion map with a conventional erosion assessment tool (the Universal Soil Loss Equation) depicted a large deviation in spatial patterns, which underlines the inapplicability of traditional non-urban erosion tools to urban settings and emphasises the need to develop new erosion assessment and management methods for urban environments. It was concluded that measures for controlling water erosion in the city need to be site-specific as the extent of erosion varied largely across the city.

Submitted as:

Shikangalah RN, Paton EN, Jeltsch F. 2016. Quantification of a Real Extent of Soil Erosion in a Dryland Urban Area: An example of Windhoek, Namibia. Cities and the Environment Journal.

3.1 Introduction

Accelerated soil water erosion is one of the major global environmental problems that particularly affect regions within arid and semi-arid climate zones, where the environments and soils are fragile (Tooth 2000; Vásquez-Méndez et al. 2011). Due to water limitations during extended dry periods, vegetation is typically sparse, thus it is not able to protect the soil surface from the frequently occurring high-intensity rainfall storms, particularly at the onset of the rainfall seasons (Cornelis 2006; Ligonja and Shrestha 2013).

Soil erosion is normally studied and managed for rural regions, as it has adverse impacts on soil fertility and agricultural yields and for regional water management, for example through obstructions of stream channels, degradation of water quality and reservoir sedimentation. Much less frequently, soil erosion is studied for urban settings; even though the adverse impacts can be as severe as for rural regions and these effects include damages to buildings, yards, parking lots and roads. The main effects include the destabilisation of eroded land and clogging of canals and drainage systems due to the transportation of eroded soil materials (Sutherland and Tolosa 2000; Harris and Adams 2006). Specifically, rill networks and gullies are the immediate signs of excessive soil erosion by water these mainly consist of open, incised and unstable channels. Here, we refer to gullies if the channel is more than 0.5m deep and to rills when otherwise smaller (Gábris et al. 2003; Poesen et al. 2003). Rills and gullies occur where surface water flow has become trapped in a small concentrated stream and it begins to erode channels in the ground surface. The rill and gully networks destabilise any urban infrastructure in their immediate surroundings, and this might reduce access to and on properties and it might also cause damages to underground utilities such as communication cables, pipes and power cables. Rills and gullies are also an indicator for the increasingly spreading occurrence of erosion, as once more and more subsoil material is exposed, the infiltration capacity of the soils become reduced, resulting in the generation of even more overland flow and soil erosion (Bryan 2000; Perroy et al. 2010).

a)  b) 

Figure 1: Photographs on: a) Rills, b) Gullies with damages to road. Source: Shikangalah RN.

Until lately, urban soil erosion has played a tangential role in the perception of soil scientists, who mainly study erosion processes related to agricultural production, and likewise in the perception of urban planners, who do not think of erosion as being part of their competency (Shikangalah et al. 2016). A recent review by Shikangalah et al. (2016) on urban erosion studies showed that most urban studies focused on offsite erosion (for example effects of sediment fluxes in urban channel networks (Nelson and Booth 2002; Poleto et al. 2009) and attached metal or organic contaminants (Jartun et al. 2008; Greestein et al. 2014)) in contrast to the onsite effects of erosion (for example soil loss, rill and gully formations in different urban areas (Ibitoye and Eludoyin 2010; Ehiorobo and Audu 2012). Study regions of urban erosion were mostly located within temperate zones of the developed world; whereas only a small number of studies exist which have studied urban soil erosion for dryland settings and only a few of those studies were carried out in Africa, mostly in Nigeria (for example Jimoh 2001; Ehiorobo and Audu 2012; Omon and Oisasoje 2012). This account is surprising, as one would expect more serious problems with soil erosion in the water-limited urban environments than in the temperate ones.

Field surveys on the occurrence of excessive erosion in the forms of rills and gullies require a different set-up than erosion surveys carried out for rural settings. Due to the completely different land-uses of built-up areas, standard methods of sampling such as erosion pins (Jimoh 2001), erosion plots or rainfall experiments (Rejman et al. 1998; Bryan, 2000; Miyata et al. 2010) are not applicable on the private courtyards and the public paths and spaces of settlements. To understand the pattering and impact of urban soil erosion, not only standard parameters such as slope, vegetation cover and type (Pimentel and Kounang 1998) need to be quantified, but also other parameters describing the specific socio-spatial structure and the visible damage of erosion to houses, roads and other infrastructures within a settlement. To our knowledge, no standard sampling protocol exists to meet this objective.

Other ways of quantifying soil erosion include modelling approaches, for example using the traditional Universal Soil Loss Equation (USLE) after Wischmeier and Smith (1978). However, the equation was likewise developed for rural settings and it is not clear if the USLE approach is transferrable to reproduce and analyse urban erosion risk. Knowledge on the spatial extent of erosion is a fundamental key to control soil erosion and to reduce or prevent damages that occur due to rills and gullies within residential areas of cities which are especially prone to erosion (Figure 1). This study aimed to apply and test methods to quantify the extent and severity of soil erosion for different types of settlements within Windhoek, the capital of Namibia, which experiences a pronounced arid to semi-arid climate. The specific objectives are: (1) to assess the extent and severity of soil erosion in the form of rills and gullies and the resulting damage to urban infrastructure in relation to vegetation cover, types, slope characteristics and urban socio-spatial structure, (2) to interpolate the extent and severity of erosion to the spatial distribution of the Windhoek Metropolitan Area, and (3) to compare the erosion map derived from the field survey data with an erosion risk map derived using a traditional erosion quantification tool approach (Universal Soil Loss Equation) to assess the applicability of the latter approach for urban settings. The study is valuable for urban structural planning, land management and soil conservation in Windhoek and for other similar urbanized areas in dryland regions.

3.2 Materials and Methods

3.2.1 Location and characteristics of the study area

Windhoek is the capital city of Namibia, one of the most arid countries in Sub-Saharan Africa (Lahnsteiner and Lempert 2007; Greunen 2013) and is prone to recurrent droughts and flooding and soil erosion during the rainy season. The city is home to 15% of the country's population (National Planning Commission 2012; Pendleton et al. 2014). Rapid urban growth and tremendous pressure from building developments combined with environmental vulnerabilities have resulted in environmental problems related to soil erosion (Mapani and Schreiber 2008; Greunen 2013). Hotspots of soil erosion such as visible rills have been observed across the city

(Gray et al. 2008; Greunen 2013), affecting private and public housing and infrastructure. As yet, no estimates on the spatial extent of soil erosion are available.

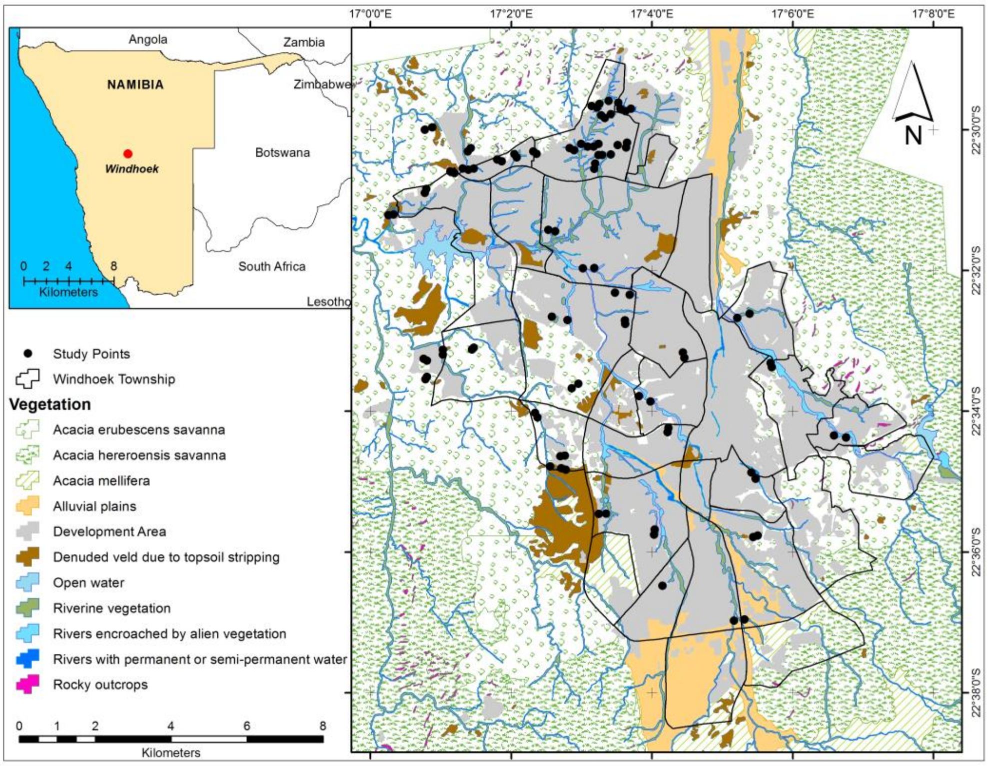


Figure 2: Location of study site within the Windhoek Metropolitan Area of Namibia with its vegetation and land-use characteristics. Source: City of Windhoek 2010.

Windhoek is located in central Namibia, about 22° 34′ 12″ S, 17° 5′ 1″ E and at ca. 1800 m altitude. The current population is around 322,500 with a national growth rate of 0.67 % (Namibia Demographics Profile 2014). In the central Metropolitan area, slopes are generally very low, whereas high slopes can be found in most sub-urban regions towards the north, west and south (Figure 3a). The average annual temperature ranges from 18 to 20°C while the annual average rainfall ranges between 300 and 350 mm (Mendelsohn et al. 2002). The city is surrounded by the Auas and Kuiseb Mountains formed from metamorphosed Quartzite horizons and Schist, respectively (Figure 3b, Zhang et al. 2004; Mapani and 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 development grounds with crystalline rocks which are highly impermeable (see Figure 3b for geological maps, Mapani and Schreiber 2008; Tredoux et al. 2009). Typical for arid to semi-arid climatic conditions, vegetation cover is very scarce in Windhoek. The city's natural vegetation is mainly dominated by shrubs and *Acacia* trees, such as *A. erubescens* and *A. hereroensis*, and short lived grasses, such as *Stipagrostis* and *Enneapogon* species, with weedy herb species on the riverbeds (Gold et al. 2001, also compare figure 2). Parks and gardens are very few and where available, they are dominated by turfgrass.

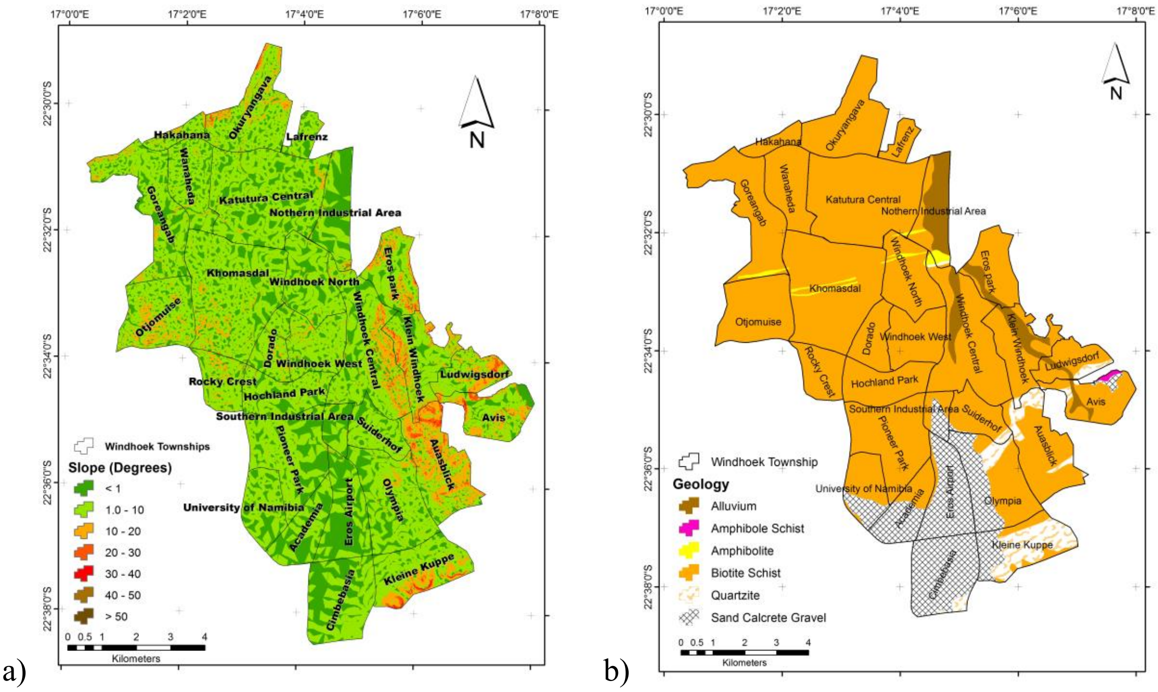


Figure 3: (a) Slope distribution in degree, (b) Geological map of the Metropolitan Area of Windhoek. Source: City of Windhoek 2010.

3.2.2 Sampling design for the quantification of urban soil erosion

No standardised sampling protocol currently exists for the quantification of urban soil erosion. Soil erosion is normally quantified for rural regions where the sizes of agricultural fields or the riverine patterns of small meso-scale catchments are the dominant features for the set-up of the sampling design. As this scheme is not applicable to the entirely different layout of the urban landscape, we developed a simple snap-shot sampling scheme which allowed us to sample across the Metropolitan area and, at the same time, allowed a plot-scale quantification of typical erosion features. During February and March of 2015, a total of 95 sites were surveyed with sampling locations distributed over the city area as depicted in Figure 2. The field sites were selected randomly (with one to two replica in each neighbourhood) from pre-defined regions that resemble typical assemblies of buildings, bare areas, footpaths and roads. Sites were located in the formal settlements of the wealthier parts of the city (dominantly in the central to southern parts) and within semi-formal and informal settlements (dominantly in the northern parts of the city). The informal settlements are areas where groups of housing units have been constructed on land that the occupants have no legal claim to or are not in compliance with current planning and building regulations. Socio-spatial information on the type of settlement and income class of the settlement were recorded qualitatively (Table 1).

Table 1: Parameters of the snap-shot field sampling for the quantification of urban soil erosion on 40 m x 80 m plots for the Metropolitan Area of Windhoek

Erosion parameters	**Explanation**
1. Gully (m) length, width and depth 2. Rill (m) length, width and depth	Parameters were used to estimate the extent of erosion (m^2) in sampled plots
Soil and terrain parameters	**Explanation**
1. Types of soil dominating the surface 2. Types of slopes at different degrees	Dominant topsoil group: stone, gravel, sand or clay Slope groups (in degrees): flat = 0, gentle = 1 - 20, medium = 20 - 45, steep = > 45
Parameters for surface cover	**Explanation**
1. Vegetation (%) o Trees , Grass	Vegetation locations of individual trees and shrubs and areas covered with grass were marked on each survey sheet
Parameters related to erosion damage	**Explanation**
1. Damage (%)	Assessment of total damages to various structures such as to houses or streets in sampled plots
Parameters on urban socio-spatial structure	**Explanation**
1. Types of settlements 2. Types of income groups	The assessed areas were first divided into three general types of settlements: formal, semi-formal and informal To see the results at a finer scale, the city was again divided into five different average income groups: very low income, low, middle, high and very high income groups

The sampling plot size was set to 40 m x 80 m modelled after the size of agricultural field plots, which was at the same time thought to be large enough to contain typical urban features (such as individual houses and court yards) as well as vegetation patches and erosion forms. Table 1 summarises the parameters which were sampled to enable an assessment on the extent and severity of soil erosion in relation to vegetation cover, types and slope characteristics and socioeconomic groups. Specific emphasis was placed on the detailed survey of erosion gullies and rills, as they are the typical signs of excessive soil erosion by water. The survey included the assessment of their distribution, length and width for each plot. When smaller rills joined a main gully, the rill feature was measured from the starting point up to the convergence point and the main gully was measured separately. Although erosion features were mostly homogenous, in few cases when features had different levels of width or depth at different points, more measurements were carried out and the average was recorded (Herweg 1996). From the measurements, the total area eroded (m^2) for a plot was calculated simply by multiplying the total lengths with the total widths of the rills and gullies (Bewket and Sterk 2003).

In the absence of official maps that could be used for the classification of the different income groups and types of settlements, areas were classified based on the knowledge of the municipal officers (personal communication) and of the authors, as well as observation during the field work. The income groups were based on the general average income classification while the types of settlements were based on the land tenure. Semi-formal settlements are areas with legal land tenure but attract a lot of low income people (Soliman 1996) who occupy the open land with their shacks or corrugated iron houses. The informal settlements are home to people who do not have any legal rights to stay on the grounds (Wakhungu et al. 2010; UN-Habitat 2015). While the semi-formal settlements are mostly inhabited by people from the low income group, some few areas also belong to the medium income group. The formal settlements are inhabited also partly by people of the low and medium income group, and all of the high and very high income groups.

3.2.3 Spatial analysis of urban erosion extent and patterns

For each plot, the spatial extent of excessive erosion in the form of rills or gullies was estimated in percentage of the area of the 40 m x 80 m plots. The standard extrapolation toolbox of the ArcGIS software (ESRI, version 9) was employed to interpolate the percentage area affected by excessive erosion to the entire study area within the Municipal of Windhoek using the Inverse Distance Weighting (IDW), Spline and Natural Neighbour methods (Bartier and Keller 1996; Kurtzman and Kadmon 1999; Kravchenko 2003; Karydas et al. 2009; Guo et al. 2010; Chen and Liu 2012).

Besides the spatial field-survey estimates of excessive erosion, soil risk for the Windhoek Metropolitan Area was also calculated with the traditional Universal Soil Loss Equation (USLE) after Wischmeier and Smith (1978). In the USLE equation, erosion is seen as a multiplier of rainfall erosivity (the R factor, which equals the potential rainfall energy); this multiplies the resistance of the environment, which comprises K (soil erodibility), LS (the topographical or slope and length factor), C (plant cover or land-use and farming techniques) and P (erosion control practices) (see for example Ma et al. 2003; Bilaşco et al. 2009; Schönbrodt et al. 2010; Tamim et al. 2012). Since it is a multiplier, if one factor tends towards zero, erosion will tend towards zero. The USLE is normally employed for rural areas, but parameterisation data are available for settlements and urban settings. The LS was derived from a Digital Elevation Model (DEM) of Windhoek with a spatial resolution of 5 m. The calculation procedure of the LS factor followed the procedure of Hui et al. (2010), Arekhi et al. (2012) and Farhan et al. (2013) and it employed the ArcHydro extension of ArcGIS (ESRI, Version 9). In the calculation of the R factor, the modified Fournier index (F) was set directly proportional to the mean annual precipitation (Kenneth and Freimund 1994; Yu and Rosewell 1996) of 350 mm for Windhoek (Mendelsohn et al. 2002). Due to the availability of only one official meteorology station in the city, the spatial distribution of R was assumed as uniform across the city. The C factor for land-use was set equal to 1 for urban landscapes with barely any vegetation cover (after Gold et al. 2001; Pandey et al. 2007; Dabral et al. 2008) in semi-arid climates for the entire city area (Greunen 2013). As no coherent measure for soil conservation exists (neglecting the rare prevention lines of sand bags and tyres on private properties), the P factor for erosion control practices was set to 1 (for example Kuok et al. 2013, Catani et al. 2014). In the absence of a soil map, the K factor was set to 0.7 for the underlying Schist geological material (for example Gitas et al. 2009; Karydas et al. 2013) that gave rise to crystalline rocks with mostly gravel - sand topsoil in Windhoek (Mapani and Schreiber 2008).

3.3 Results

3.3.1 Analysis of the effects of slope, vegetation and socio-spatial structure on urban erosion

The snap-shot sampling on urban soil erosion for the Metropolitan Area of Windhoek confirmed the extensive occurrence of soil erosion by water in its most severe forms (rills and gullies). Rill and gully erosion occurred across the entire city centre, but their magnitude differed considerably between different plots. Erosion features in the form of rills and gullies which are normally associated with accelerated erosion occur in around 45 % of the sampled field plots (accelerated erosion was assumed if rill and gully erosion cover an area larger than 10 m^2 per plot); damages to streets and houses occur in around 13 % of the plots - figure 4). Table 2 shows that the affected areas can reach up to a maximal value of 283 m^2 (8.8 %) (for the 40 m x 80 m plots) with an average of 25 m^2 and a large standard deviation of 43 m^2. Gullies are erosion features deeper than 0.5 m, while rills have depths of less than 0.5 m and N* indicates the number of plots where attributes were detected.

Table 2: Summary statistics of the urban soil erosion field survey of sampled 95 plots

Descriptive Statistics					
Attributes	**N***	**Minimum**	**Maximum**	**Mean**	**Std. Deviation**
Gullies total length (m)	10	3.0	40.0	18.70	11.38
Gullies total width (m)	10	0.4	4.0	1.94	1.31
Gullies total area (m^2)	10	1.5	160.0	42.53	46.25
Gullies total area (%)	10	0.4	37.6	10.00	10.87
Rills total length (m)	60	2.0	85.0	24.52	18.23
Rills total width (m)	60	0.2	4.1	0.98	0.71
Rills total area (m^2)	60	0.4	282.9	32.47	46.84
Rills total area (%)	60	0.02	14.5	1.67	2.40
Total eroded area (m^2)	63	0.4	282.9	37.68	48.83
Total eroded area (%)	63	0.2	11.9	1.59	2.06
Total bare surface eroded (%)	63	0.03	31.3	2.91	4.80
Total vegetation cover (%)	95	3.0	90.0	29.86	23.54
Tree cover (%)	88	1.0	21.0	6.49	4.30
Shrub cover (%)	94	1.0	10.0	3.62	1.70
Grass cover (%)	95	1.0	80.0	20.31	21.14

The average area affected by accelerated erosion in percentage is 1.59 % rather low, (ranging up to a maximum value of 11.9 %), but it has to be kept in mind that the occurrence of rills and gullies is already a warning signal of excessive erosion whose appearance indicates the occurrence of extended erosion of adjacent slopes during heavy rainstorm events.

As vegetation and slope are two of the most relevant parameters affecting soil erosion, erosion occurrence was assessed as a function of slope estimates and vegetation cover both in relative terms (Figure 4, % of plots that are affected) and absolute terms (boxplot presentation of % of plot area covered with erosion features). As a normal process, large vegetation cover and small slope result in decreased erosion, and small vegetation cover and large slope in accelerated erosion. The field results clearly reflect the effect of vegetation cover: 64 % of plots with up to 20 % vegetation cover are affected by erosion, but only 14 % of plots have vegetation cover ranging between 80 - 100% (as depicted in Figure 4b). The effect of slope on erosion is not so clear as accelerated erosion occurred mainly in plots with gentle and medium slopes, but not in plots with steep slopes (although only three plots had steep slopes, as it is not a common characteristic in the city). Figures 4 a & b show the distribution of plot areas affected by erosion both in absolute terms (m^2 area cover per plot) and % terms (% area of each 3200 m^2 plot) in a boxplot representation. A larger outlier exists for the gentle slope (nearly 300 m^2 or 9 %, respectively), the medians of affected areas with gentle and steep slopes are relatively low (8.4 and 7.5 m^2 or 0.3 and 0.2 %), whereas the plots with the medium slope show a larger median of 15.1 m^2 (0.5 %) and the largest spread between the first and third quartile.

For the following result description, only the % area with erosion cover (rather than m^2 values for the 3200 m^2 plots) will be discussed as they are thought to be more meaningful when the actual erosion cover is up scaled to the entire city extent. Although these percentages might appear to be relatively small, the presence of signs of excessive erosion (i.e. rills and gullies) suggests large actual rates erosion in the direct vicinity. Moreover, even if the % values are rather small, the actual extent (in m^2) is still sizeable as it renders the affected land useless for any urban infrastructures such as buildings, parking or work area.

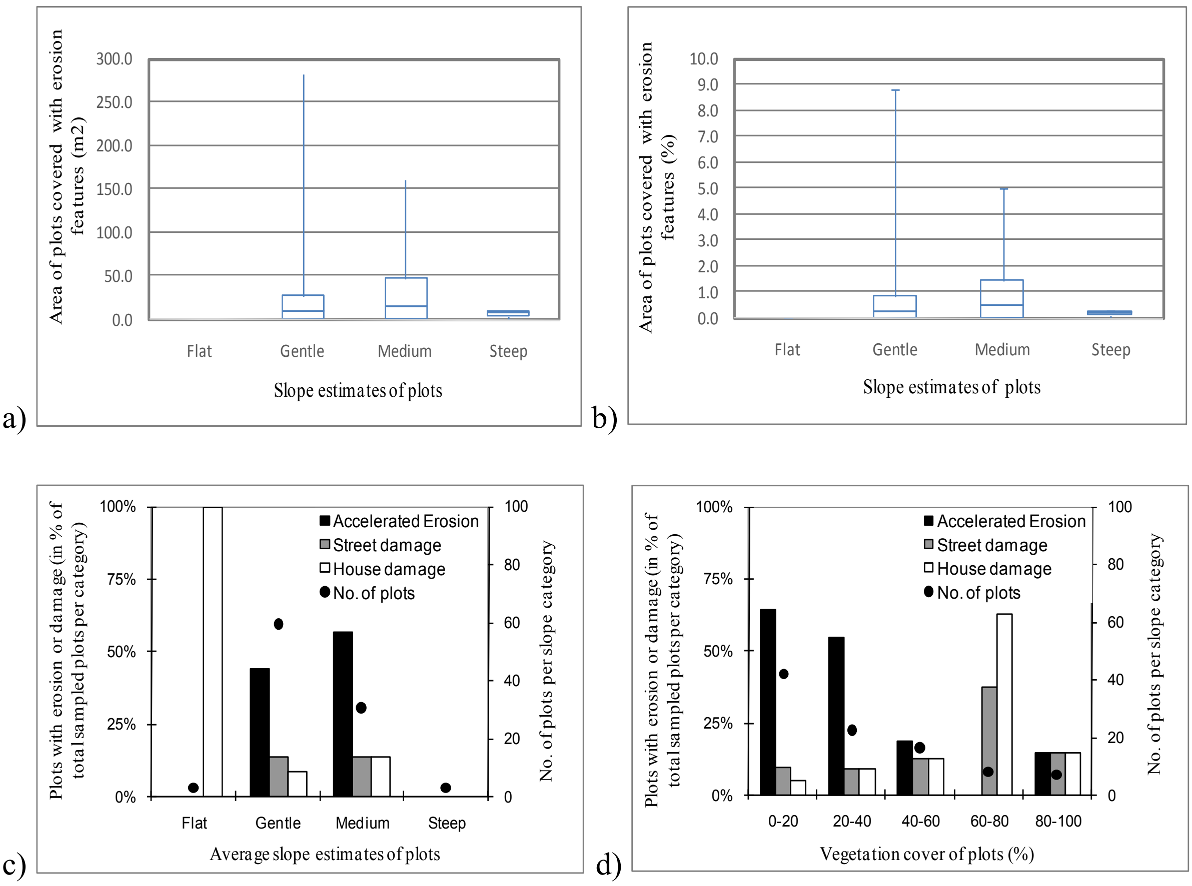
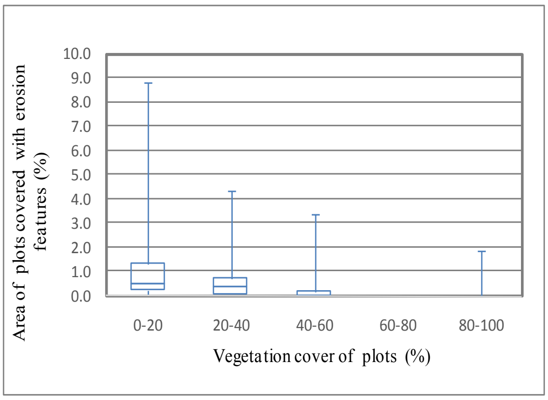
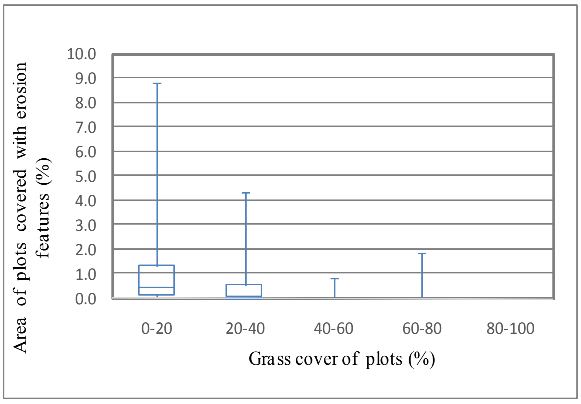


Figure 4: Occurrence of accelerated erosion as a function of slope estimates and vegetation cover in: a) absolute terms and b) percentage terms, c &d) street and house damages attributed to erosion

The amount of vegetation cover in Windhoek is generally limited due to factors such as the arid climate of the country. The vegetation cover of the plots is generally low with an average cover of around 30 %, mostly composed of grass (in average 20 %) with a very considerable smaller average coverage of trees and shrubs (Table 2). Figure 5 shows the distribution in percentages of the plot areas affected by accelerated erosion as a function of grass and tree cover. Plots with grass cover smaller than 20 % showed widespread erosion while plots with grass cover smaller than 40 % showed no erosion, and no erosion was detected for plots with larger grass cover. Erosion also declined with increasing tree cover (with no or very little erosion for plots covered by more than 10 %), however, trees are with an average cover of 6 % (Table 2) not considered to be a dominant factor in erosion occurrence.

a) 

b) 

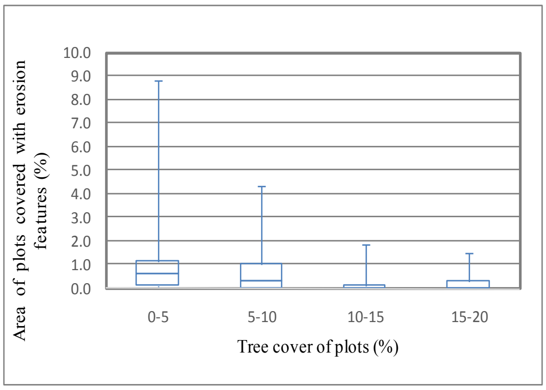
c) 

Figure 5: Plot areas affected by accelerated erosion (rills and gullies) as a function of: a) total vegetation cover, b) grass cover and c) tree cover

Erosion occurrences were also analysed as a function of settlements and income classes as shown in Figure 6a and Figure 6b, as it was presumed that the degree of vegetation cover, erosion occurrence and socio-spatial factors were interlinked. The majority of plots within informal and semi-formal areas were affected by erosion (75% and 68 %), whereas only 24 % of plots within formal settlements showed signs of accelerated erosion. Street and house damages occurred mainly in informal areas (44% and 50% of plots within informal settlements,

Figure 6). Categorising erosion occurrences as a function of income classes result in a similar but more detailed picture. Plots within areas of very low to low income classes are affected above-average, whereas within areas of high to very high income classes they showed little erosion. Large erosion occurrences were also detected for medium income classes which are partly within the formal and semi-formal settlement areas.

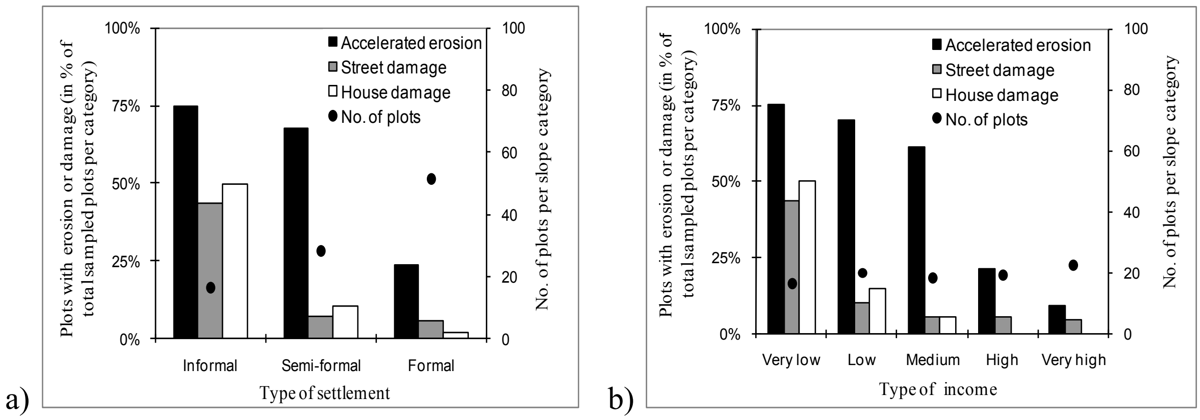


Figure 6: Occurrence of accelerated erosion, street or house damages attributed to erosion as a function of: a) settlements and b) income type

Figure 7 illustrates the relationship between vegetation cover and socio-spatial factors. Vegetation cover was highest in the formal settlements with high to very high income resulting in low percentages of areas affected by erosion and vice versa for informal settlements as well as of very low to low income areas. The semi-formal settlements did not fit into this pattern as they showed the lowest vegetation cover and significant erosion (but not as high as the informal ones).

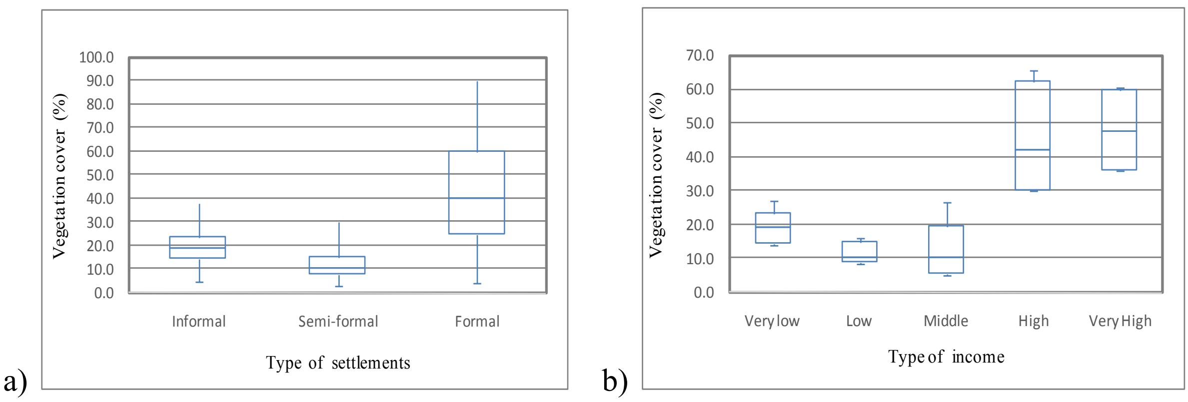


Figure 7: Vegetation cover of field plots as a function of: a) type of settlements and b) income classes

3.3.2 Spatial analysis of urban soil water erosion in Windhoek

The results of the 95 - plot field survey were interpolated with the Inverse-Distance-Weighting method (see section 2.3) to obtain the first insight into the spatial distribution of erosion-affected areas within the Metropolitan Area of Windhoek (Figure 8a). According to the interpolation results, around 56% of the city is affected by some signs of accelerated soil erosion (with an average of more than 0.3 % of the surface showing significant signs of accelerated erosion in the form of gullies or rills). Soil erosion is most severe in the northern and north-western borders of the city, especially in Lafrenz, Okuryangava, Hakahana, Goreangab, Otjomuise and Rocky Crest. The interpolation map shows low to very low erosion for the central, southern and western areas. The spatial distribution of erosion occurrence mirrors the spatial vegetation cover distribution; plots with limited vegetation cover are located mainly in the northwest part of the city while those with higher vegetation cover are in the central part to the southern east part of the city.

Table 3: Extent of soil erosion in Windhoek derived from the snap-shot sampling

Categories	Range of % area covered by rills and gullies erosion per total bare surface of the surveyed plots (%)	Corresponding city area (%)
Minimal	0 - 0.3	43.4
Low	0.3 – 1	20.8
Moderate	1 – 5	33.6
High	5 – 10	2.1
Very high	10 – 15	0.05
Extreme high	> 15	0.03

The spatial distribution obtained by using the USLE model gives a divergent picture of soil erosion occurrence and pattering in comparison to the field results. According to the USLE model (Figure 8b), 1.4% of Windhoek experienced an annual soil loss occurrence ranging between 0.06 - 0.5 ton/ha/yr mainly in the south-eastern part of the city, such as in areas of Kleine Kuppe, Auasblick, Ludwigsdorf and Windhoek Central whereas approximately 3.8% of city experienced soil loss ranging between 0.03 - 0.06 ton/ha/yr in areas such as Avis, Windhoek West, Rocky Crest, Dorado, Khomasdal, Hakahana and Okulyangava. According to the USLE model results, the rest of Windhoek (94.8%) city experiences extremely low soil loss of less than 0.03 ton/ha/yr.

Table 4: Soil loss in Windhoek derived from the USLE approach

Categories	Range of soil loss (ton/ha/year)	Corresponding city area (%)
Minimal	0 - 0.007	70.55
Low	0.007 - 0.03	24.28
Moderate	0.03 - 0.06	3.80
High	0.06 - 0.1	1.03
Very high	0.1 - 0.5	0.34

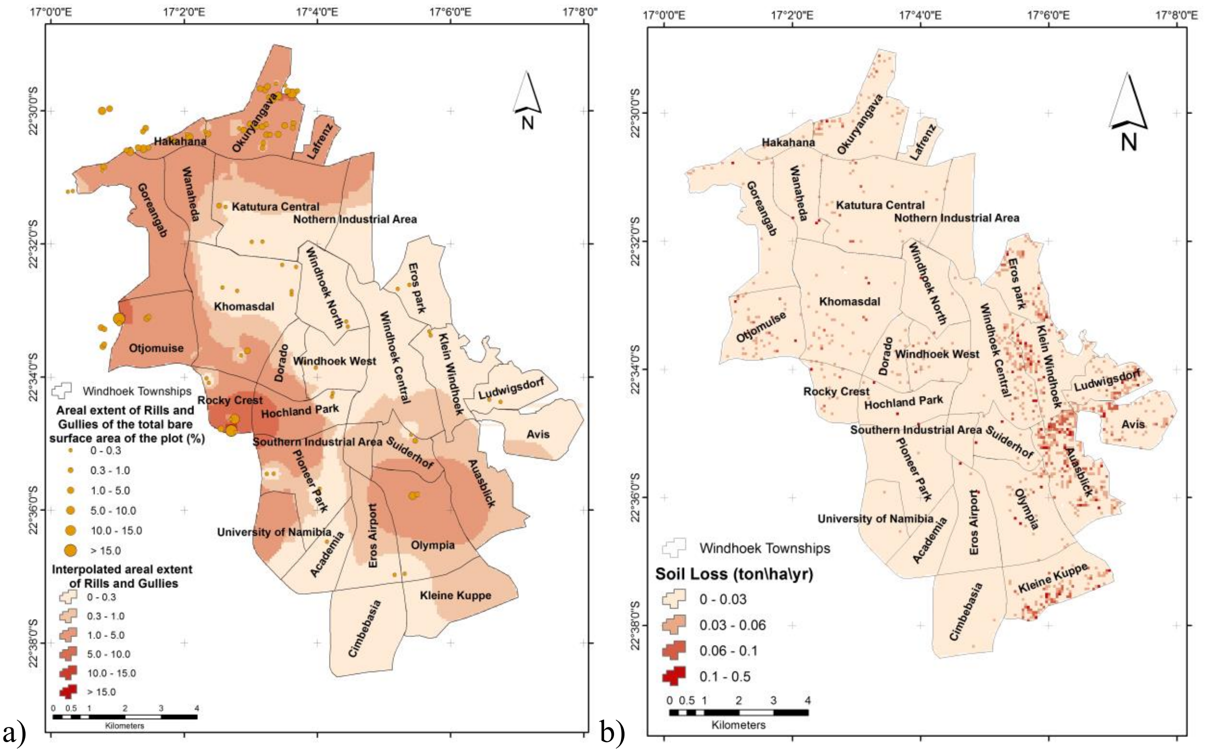


Figure 8: Spatial erosion estimates: a) Interpolation map of the field snap-shot sampling, b) USLE annual soil loss for the Metropolitan Area of Windhoek

3.4 Discussion

3.4.1 Factors influencing water erosion and the implication for management in Windhoek

The field campaign showed that erosion in its accelerated form such as rills and gullies is widespread throughout the city of Windhoek. Windhoek is largely covered with impermeable crystalline rocks of Biotite Schist (Mapani and Schreiber 2008; Tredoux et al. 2009) which is likely to increase runoff and promote the risk of erosion, if more and more subsoil material is exposed.

The variation of erosion appeared to be more strongly associated with the vegetation cover and different land management choice as a function of income class and less by slope factors. The areas most affected by erosion are characterised by very low, low or medium income classes which are spread over all settlement types. Apart from the low vegetation cover, the high frequency of erosion damages in the very low, low and medium class can be directly linked to inadequate or lack of adequate drainage systems and poor land management. Vegetation cover is likely to be reduced by the intentional clearance of vegetation, either to use the wood or simply to make the yards look tidier (Harper and Maritz 1998; Gold et al. 2001; Labbe et al. 2006). We hypothesise, that dwellers are not aware that this clearance has adverse effects on the state of their land.

In contrast, the high to very high income areas had the smallest occurrence of erosion and the highest amount of vegetation cover; in these townships, trimmed gardens are more common and within the means of the land owners. Large erosion occurs for plots associated with the medium income classes, which are equally located in semi-formal and formal regions of the city. This finding suggests that potential future management plans should not only consider the settlement type, but other socio-spatial factors such as the income class for the organisation of potential prevention schemes. Proper planning and sound land management strategies are very vital for minimizing urban erosion, especially when water erosion is ranked one of the most significant forms of land degradation (Valentin et al. 2005; Tamim et al. 2012; Kairis et al. 2013), particularly in semi-arid areas (Ayoub 1998; Cantón et al. 2011).

3.4.2 A comparison of the field survey erosion map to the USLE soil loss risk map

A comparison of the interpolated field survey erosion map with the results of soil loss estimates using the USLE model showed significant differences regarding the severity and spatial patterns of erosion obtained by the two methods, and this put a large question mark at the applicability of the USLE model in urban settings.

Despite the USLE method being criticized for either under or over predicting erosion rates (Evans 2002), it remains one of the most widely used method and it is a globally applicable means to estimate erosion risk patterns (Erdogan et al. 2007; Ozcan et al. 2008; Kinnell 2010). The USLE method estimates erosion risks in terms of annual soil loss per area, which is not directly comparable to the field survey estimates which focused on signs of severe soil erosion by estimating their percentage area per plot. Both erosion estimates were assumed to give relatively similar trends on locations and the severity of erosion.

However, as Figure 8a compared to 8b shows, the two methods showed opposing if not contradicting trends in the occurrence and severity of erosion across the Windhoek city area. Firstly, the USLE map gives very low rates of soil erosion for the entire study area (up to 0.5 tons/hectare/year). Following Wall et al. (2002), soil erosion can be considered moderate to values of up to 22 tons/hectare/year. The USLE approach does not detect any considerable occurrence of soil loss in the northern and north-western borders of the study area, whereas the field study has found excessive signs of soil erosion there. On the contrary, the USLE equation predicted increased soil erosion in parts of the central and eastern regions of the study area where no or very little soil erosion was found during the field survey (although not many sampling plots were located in that region points) and did not reproduce the large erosion in the northern and western part. Instead, the USLE approach mainly reproduces the spatial structure of slope (as was depicted in Figure a), as this is a dominant factor in the USLE model equation, but according to our field results, slope was not found to be a dominant factor for erosion in Windhoek. The comparison therefore shows that USLE is not applicable to an urban setting such as Windhoek, mainly due to two reasons: urban types of vegetation cover such as gardens and urban green surrounding footpaths and streets are not implemented in the USLE approach; and the management practice of urban green (such as intentional clearance) as a function of socio-spatial factors is not considered, although it plays a significant role in the urban soil erosion occurrence in the study area.

3.5 Conclusion

The fundamental key for the successful management of urban soil erosion is to understand the dominant contributing factors which appear to be significantly different for urban erosion in comparison to rural erosion. The extent of water erosion in Windhoek appears to be more strongly associated with vegetation cover and different land management choice as a function of income class rather than by topographic slope and this might lead to the inappropriate planning of control measures when approached in terms of settlement type. While income-group class is not a common attribute for the quantification of soil erosion outside cities, it played a significant role to assess the severity and pattering of soil erosion in Windhoek metropolitan areas. Significantly more erosion was found in settlements with lower income in comparison to higher income areas. This observed variation is directly linked to land management particularly with reference to the vegetation cover of gardens, yards and foot path vicinities, which were found to be significantly lower within lower income areas. The results show that nearly 56 % of the city is affected by water erosion, thus showing signs of accelerated erosion in the forms of rills and gullies which occurred mainly in the underdeveloped, informal and semi-formal areas of the city. Furthermore, a grass cover of more than 40 % was associated with much less erosion, whereas the presence of trees and shrubs appeared to have not much influence on the occurrence of erosion.

Our results strongly suggest the need for site-specific erosion control measures in the various townships of Windhoek. The produced soil erosion map indicates most severe erosion signs in the northwest (where lower income areas are allocated) compared to the central and southeast part (location of higher income classes). The contrasting results of the widely-used erosion modelling tool (USLE) strongly suggest that this (for rural areas) widely used approach is less suitable for urban settings, it ignores the small-scale differences in vegetation covers which are highly linked to the different land management practices. This result emphasises the need to develop new erosion assessment and management methods specifically for urban environments. However, both approaches can still be useful for different purposes. The USLE estimations can be used to highlight areas of potential erosion vulnerability which are related to the slope and provide rapid results prior to the development or land occupation of sub-urban areas. In addition, field survey approaches are indispensable for providing detailed information of water erosion under field conditions at finer scales and after land occupation.

The mapping of the extent of erosion in Windhoek was the first of its kind, as before no sampling protocol existed that would guide soil erosion mapping over an entire city area in a dryland setting. In spite of the limited number of plots assessed, the resulting map is thought to become a valuable tool for guiding land use and soil management plans, as it clearly distinguishes high and low risk erosion zones. The study demonstrated that soil water erosion is a problem in Windhoek and probably in other urban areas in dryland zones. However, more work is required to quantify secondary damages of water soil erosion on houses, roads, drainage systems and other city infrastructure. Furthermore, there appears to be no awareness of the severity of soil erosion as the city managers declined the fact that there is an occurrence of water erosion in Windhoek. We therefore call for studies that try to understand the perceptions of the local population and authorities of the relevance of soil erosion in terms of land and city management.

3.6 References

Arekhi, S., Bolourani, A. D., Shabani, A., Fathizad, H., & Ahamdyasbchin, S. (2012). Mapping soil erosion and sediment yield susceptibility using RUSLE, remote sensing and GIS (case study: Cham Gardalan watershed, Iran). Advances in Environmental Biology, 6(1), 109–124.

Ayoub, A. T. (1998). Extent, severity and causative factors of land degradation in the Sudan. Journal of Arid Environments, 38(3), 397–409. doi:10.1006/jare.1997.0346

Bartier, P. M., & Keller, C. P. (1996). Multivariate interpolation to incorporate thematic surface data using inverse distance weighting (IDW). Computers and Geosciences, 22(7), 795–799. doi:10.1016/0098-3004(96)00021-0

Bewket, W., & Sterk, G. (2003). Assessment of soil erosion in cultivated fields using a survey methodology for rills in the Chemoga watershed, Ethiopia. Agriculture, Ecosystems and Environment, 97(1-3), 81–93. doi:10.1016/S0167-8809(03)00127-0

Bilaşco, Ş., Horvath, C. P. C., Sorocovschi, V., & Oncu, M. (2009). Implementation of the USLE model using GIS techniques. Case study the Someşean plateau. Carpathian Journal of Earth and Environmental Sciences, 4(2), 123–132.

Bryan, R. B. (2000). Soil erodibility and processes of water erosion on hillslope. Geomorphology, 32(3-4), 385–415. doi:10.1016/S0169-555X(99)00105-1

Cantón, Y., Solé-Benet, A., De Vente, J., Boix-Fayos, C., Calvo-Cases, A., Asensio, C., & Puigdefábregas, J. (2011). A review of runoff generation and soil erosion across scales in semiarid south-eastern Spain. Journal of Arid Environments, 75(12), 1254–1261. doi:10.1016/j.jaridenv.2011.03.004

Catani, F., Kukavicic, M., & Paoli, C. (2014). GIS and Remote Sensing Technologies for the Assessment of Soil Erosion Hazard in the Mediterranean Island Landscapes. International Journal of Remote Sensing and GIS, 3(1), 699–712.

Chen, F. W., & Liu, C. W. (2012). Estimation of the spatial rainfall distribution using inverse distance weighting (IDW) in the middle of Taiwan. Paddy and Water Environment, 10(3), 209–222. doi:10.1007/s10333-012-0319-1

City of Windhoek (2010), Municipality of Windhoek, Namibia.

Cornelis, W. M. (2006). Hydroclimatology of wind erosion in arid and semiarid environments. in Dryland ecohydrology, Chapter 9. Dryland Ecohydrology, DOdorico and A. Porporato (eds.), 141-159. Springer, Netherlands.

Dabral, P. P., Baithuri, N., & Pandey, A. (2008). Soil erosion assessment in a hilly catchment of North Eastern India using USLE, GIS and remote sensing. Water Resources Management, 22(12), 1783–1798. doi:10.1007/s11269-008-9253-9

Ehiorobo, J. O., Audu, H. A. P., & Author, C. (2012). Monitoring of Gully Erosion in an Urban Area Using Geoinformation Technology. Scholarlink Reseacrh Institute of Journals, 3(2), 270–275.

Erdogan, E. H., Erpul, G., & Bayramin, I. (2007). Use of USLE/GIS methodology for predicting soil loss in a semiarid agricultural watershed. Environmental Monitoring and Assessment, 131(1-3), 153–161. doi:10.1007/s10661-006-9464-6

Evans, R. (2002). An alternative way to assess water erosion of cultivated land - Field-based measurements: And analysis of some results. Applied Geography, 22(2), 187–208. doi:10.1016/S0143-6228(02)00004-8

Farhan, Y., Zregat, D., & Farhan, I. (2013). Spatial Estimation of Soil Erosion Risk Using RUSLE Approach, RS , and GIS Techniques : A Case Study of Kufranja Watershed, Northern Jordan. Journal of Water Resource and Protection, 5(December), 1247–1261. doi:10.4236/jwarp.2013.512134

Gábris, G., Kertész, Á., & Zámbó, L. (2003). Land use change and gully formation over the last 200 years in a hilly catchment. Catena, 50(2-4), 151–164. doi:10.1016/S0341-8162(02)00141-8

Gitas, I. Z., Douros, K., Minakou, C., & Silleos, G. N. (2009). Multi-Temporal Soil Erosion Risk Assessment in N. Chalkidiki Using a Modified Usle Raster Model. EARSeL eProceedings, 8(5), 40–52. Retrieved from http://eproceedings.org/static/vol08_1/08_1_gitas1.pdf

Gold, J., Muller, A., & Mitlin, D. (2001). The principles of local agenda 21 in Windhoek: Collective Action and the Urban Poor. Urban Environmental Action Plans and Local Agenda 21 (Vol. 9). London. doi:10.1007/s00418-001-0362-2

Gray, M., Keating, J., Moody, J., Swan, D., & Keating, J. (2008). Erosion Control in Otjomuise, Namibia.

Greenstein, D. J., Bay, S. M., Young, D. L., Asato, S., Maruya, K. A., & Lao, W. (2014). The use of sediment toxicity identification evaluation methods to evaluate clean up targets in an urban estuary. Integrated Environmental Assessment and Management, 10(2), 260–8. doi:10.1002/ieam.1512

Greunen, S. (2013). Assessing the Resilience of Windhoek on the road to re-defining sustainability. 20th General Assembly and Conference of the Commonwealth Association of Architects, 1–12.

Guo, Q., Li, W., Yu, H., & Alvarez, O. (2010). Effects of topographic variability and Lidar sampling density on several DEM interpolation methods. Photogrammetric Engineering & Remote Sensing, 76(6), 701–712.

Harris, J. A., & Adams, B. J. (2006). Probabilistic assessment of urban runoff erosion potential. Canadian Journal of Civil Engineering, 33(3), 307–318. doi:10.1139/l05-114

Herweg, K. (1996). Field manual for assessment of current erosion damage. University of Berne.

Hui, L., Xiaoling, C., Lim, K. J., Xiaobin, C., & Sagong, M. (2010). Assessment of soil erosion and sediment yield in Liao watershed, Jiangxi Province, China, Using USLE, GIS, and RS. Journal of Earth Science, 21(6), 941–953. doi:10.1007/s12583-010-0147-4

Ibitoye, M., & Eludoyin, A. (2010). Urban Growth and Development of Soil Erosion in Part of Humid Region in Southwest Nigeria. In Facing the Challenges - Building Capacity (pp. 11–16). Retrieved from http://www.researchgate.net/publication/236861826

Jartun, M., Ottesen, R. T., Steinnes, E., & Volden, T. (2008). Runoff of particle bound pollutants from urban impervious surfaces studied by analysis of sediments from stormwater traps. Science of the Total Environment, 396(2-3), 147–163. doi:10.1016/j.scitotenv.2008.02.002

Jimoh, H. I. (2001). Erosion studies in a Nigerian city: A methodological approach. Environmentalist, 21(2), 97–101. doi:10.1023/A:1010663826050

Kairis, O., Karavitis, C., Kounalaki, A., Salvati, L., & Kosmas, C. (2013). The effect of land management practices on soil erosion and land desertification in an olive grove. Soil Use and Management, 29(4), 597–606. doi:10.1111/sum.12074

Karydas, C. G., Gitas, I. Z., Koutsogiannaki, E., & Lydakis-simantiris, N. (2009). Evaluation of Spatial Interpolation Techniques for Mapping Agricultural Topsoil Properties in Crete. EARSeL eProceedings, 26–39.

Karydas, C., Petriolis, M., & Manakos, I. (2013). Evaluating Alternative Methods of Soil Erodibility Mapping in the Mediterranean Island of Crete. Agriculture, 3(3), 362–380. doi:10.3390/agriculture3030362

Kenneth, R., & Freimund, J. (1994). Using monthy precipitation data to estimate R-factor in the revised USLE. Journal of Hydrology.

Kinnell, P. I. A. (2010). Event soil loss, runoff and the Universal Soil Loss Equation family of models: A review. Journal of Hydrology, 385(1-4), 384–397. doi:10.1016/j.jhydrol.2010.01.024

Kravchenko, A. N. (2003). Influence of Spatial Structure on Accuracy of Interpolation Methods. Soil Science Society of America Journal, 67(5), 1564. doi:10.2136/sssaj2003.1564

Kuok, K. K. K., Mah, D. Y. S., & Chiu, P. C. (2013). Evaluation of C and P factors in universal soil loss equation on trapping sediment: case study of Santubong River. Journal of Water Resource and Protection, 5(December), 1149–1154. doi:10.4236/jwarp.2013.512121

Kurtzman, D., & Kadmon, R. (1999). Mapping of temperature variables in Israel: A comparison of different interpolation methods. Climate Research, 13(1), 33–43. doi:10.3354/cr013033

Lahnsteiner, J., & Lempert, G. (2007). Water management in Windhoek, Namibia. Water Science and Technology, 55(1-2), 441–448. doi:10.2166/wst.2007.022

Ligonja, P. J., & Shrestha, R. P. (2013). Soil Erosion Assessment in Kondoa Eroded Area in Tanzania Using Universal Soil Loss Equation, Geographic Information Systems and Socioeconomic Approach. Land Degradation & Development, 379(April 2013), n/a–n/a. doi:10.1002/ldr.2215

Ma, J. W., Xue, Y., Ma, C. F., & Wang, Z. G. (2003). A data fusion approach for soil erosion monitoring in the Upper Yangtze River Basin of China based on Universal Soil Loss Equation (USLE) model. International Journal of Remote Sensing, 24(23), 4777–4789. doi:10.1080/0143116021000056028

Mapani, B. S., & Schreiber, U. (2008). Management of city aquifers from anthropogenic activities: Example of the Windhoek aquifer, Namibia. Physics and Chemistry of the Earth, 33(8-13), 674–686. doi:10.1016/j.pce.2008.06.030

Mendelsohn, J., Jarvis, A., Roberts, C., & Robertson, T. (2002). Atlas of Namibia: A portrait of the land and its people. New Africa Books (Pty) Ltd.

Miyata, S., Kosugi, K., Nishi, Y., Gomi, T., Sidle, R. C., & Mizuyama, T. (2010). Spatial pattern of infiltration rate and its effect on hydrological processes in a small headwater catchment. Hydrological Processes, 24, 535 – 549. doi:10.1002/hyp.7549

Murray E.C., Tredoux, G. & Van Der Merww, B. (2000). Enhancing Water resources: testing the Viability of Artificiaal groundwater Recharge. In WISA 2000 Biennial Conference, Sun City, South Africa, 28 May to 1 June 2000 (Vol. 1998, pp. 1–9). South Africa.

Namibia Demographic Profile (2014), Retrieved: 29/10/2015 http://www.indexmundi.com/namibia/demographics_profile.html

National Planning Commission. (2012). Namibia 2011 Population and Housing Census Results. Windhoek, Namibia.

Nelson, E. J., & Booth, D. B. (2002). Sediment sources in an urbanizing, mixed land-use watershed. Journal of Hydrology, 264(1-4), 51–68. doi:10.1016/S0022-1694(02)00059-8

Omon, E. J., & Oisasoje, O. M. (2012). Aspects of f Gully Erosion in Benin City, Edo State, Nigeria. www.iiste.org.

Ozcan, A. U., Erpul, G., Basaran, M., & Erdogan, H. E. (2008). Use of USLE/GIS technology integrated with geostatistics to assess soil erosion risk in different land uses of Indagi Mountain Pass - Cankiri, Turkey. Environmental Geology, 53(8), 1731–1741. doi:10.1007/s00254-007-0779-6

Pandey, A., Chowdary, V. M., & Mal, B. C. (2007). Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS and remote sensing. Water Resources Management, 21(4), 729–746. doi:10.1007/s11269-006-9061-z

Pendleton, W., Crush, J., & Nickanor, N. (2014). Migrant Windhoek: Rural-Urban Migration and Food Security in Namibia. Urban Forum, 1–15. doi:10.1007/s12132-014-9220-x

Perroy, R. L., Bookhagen, B., Asner, G. P., & Chadwick, O. A. (2010). Geomorphology Comparison of gully erosion estimates using airborne and ground-based LiDAR on Santa Cruz Island, California. Geomorphology, 118(3-4), 288–300. doi:10.1016/j.geomorph.2010.01.009

Pimentel, D., & Kounang, N. (1998). Ecology of Soil Erosion in Ecosystems. Ecosystems, 1(5), 416–426. doi:10.1007/s100219900035

Poesen, J., Nachtergaele, J., Verstraeten, G., & Valentin, C. (2003). Gully erosion and environmental change : importance and research needs. Catena, 50, 91–133.

Poleto, C., Merten, G. H., & Minella, J. P. (2009). The identification of sediment sources in a small urban watershed in southern Brazil: an application of sediment fingerprinting. Environmental Technology, 30(11), 1145–1153. doi:10.1080/09593330903112154

Rejman, J., Turski, R., & Paluszek, J. (1998). Spatial and temporal variations in erodibility of loess soil. Soil and Tillage Research, 46(1-2), 61–68. doi:10.1016/S0167-1987(97)00085-8

Schönbrodt, S., Saumer, P., Behrens, T., Seeber, C., & Scholten, T. (2010). Assessing the USLE crop and management factor C for soil erosion modeling in a large mountainous watershed in Central China. Journal of Earth Science, 21(6), 835–845. doi:10.1007/s12583-010-0135-8

Shikangalah, R.N., Jeltsch, F., Blaum, N., & Mueller, E.N. (2016). A Review on Urban Water

Erosion. Journal of Studies in Humanities and Social Sciences 5: 163 - 178.

Soliman, M. (1996). Legitimizing informal housing: accommodating low-income groups in Alexandria, Egypt. Environment and Urbanization, 8(1), 183–194. doi:10.1177/095624789600800116

Sutherland, R. A., & Tolosa, C. A. (2000). Multi-element analysis of road-deposited sediment in an urban drainage basin, Honolulu, Hawaii. Environmental Pollution, 110(3), 483–495. doi:10.1016/S0269-7491(99)00311-5

Tamim, A., Pallu, S., & Wunas, S. (2012). Soil Erosion in the Urban Catchment Area of Baubau City, Indonesia. International Journal of Engineering and Innovative Techology (IJEIT), 2(6), 421–425.

Tooth, S. (2000). Process, form and change in dryland rivers: A review of recent research. Earth Science Reviews, 51(1-4), 67–107. doi:10.1016/S0012-8252(00)00014-3

Tredoux, G., Van Der Merwe, B., & Peters, I. (2009). Artificial recharge of the Windhoek aquifer, Namibia: water quality considerations. Boletin Geologico Y Minero, 120(2), 269–278.

UN - Habitat. (2015). Habitat III Issue Papers 22 – Informal Settlements. United Nations Conference on Housing and Sustainable Urban Development (Vol. 22). New York.

Valentin, C., Poesen, J., & Li, Y. (2005). Gully erosion: Impacts, factors and control. Catena, 63(2-3), 132–153. doi:10.1016/j.catena.2005.06.001

Vásquez-Méndez, R., Ventura-Ramos, E., & Domínguez-Cortázar, M. A. (2011). Soil Erosion Processes in Soil Erosion Processes in Semi-Arid Areas : The Importance of Native Vegetation. INTECH Open Access Publisher (Vol. 1).

Wakhungu, J., Huggins, C., Nyukuri, E., & Lumumba, J. (2010). Approaches to Informal Settlements in Africa: Experiences from Kigali and Nairobi.

Wall, G. J., Coote, D. R., Pringle, E. A., & Shleton, I. J. (2002). RUSLE-CAN: Équation universelle révisée des pertes de sol pour application au Canada. Manuel pour l'évaluation des pertes de sol causées par l'érosion hydrique au Canada. Canada.

Wischmeier, W. H & Smith D.D. (1978) Prediction of rainfall erosion losses: A guide to conservation, agricultural handbook 537. Planning, Science and education Administration, US Department of Agriculture, Washington, DC, 58.

Yu, B., & Rosewell, C. J. (1996). A robust estimators of the R-reaction for the Universal Soil Loss Eequation. Transactions of the ASAE. Retrieved from http://cat.inist.fr/?aModele=afficheN&cpsidt=3060764

Zhang, J., Murray, R., & Tredoux, G. (2004). Regional Fractured Aquifer Modelling using Telescopic Mesh Refinement (TMR) Method. Proceedings of the 2004 Water Institute of Southern Africa (WISA) Biennial Conference, (May), 351–359. Retrieved from http://www.waterinformation.co.za/literature/files/084.pdf

Link to chapter four

Chapter three showed the spatial extent of water erosion in a dryland urban area. Around 56% of Windhoek city is affected by water erosion. Results derived from the field survey and from the USLE method were compared and they were found to be generally contradicting each other. This is mainly because the USLE is highly linked to the slopes and it fails to consider the various small pockets and typical assemblies of urban structure. The severity of water erosion is mainly associated with vegetation cover and the different choices of land management, depending in areas of income class. The lower income areas were found to be more affected than the higher income areas. This necessitated the need for an understanding of the perceptions of the local communities from different income groups and different sectors. Understanding the communities' perceptions of water erosion was also not part of the focal point of the reviewed literature in chapter two, even though such an analysis is claimed to be very informative for applicable solutions (Amsalu and de Graaff 2006; Mitter et al. 2014). Chapter four analysed the perceptions and views of the stakeholders on urban water erosion in Windhoek. The study addressed three main areas: their understanding of water erosion; their perceptions with regards to the causes and to the seriousness of erosion damages; and the attitudes towards the responsibilities for water erosion.

Chapter Four

An Analysis of Stakeholders' Perceptions on Urban Water Erosion, Windhoek, Namibia

Abstract

This study aimed at understanding the perceptions of stakeholders on urban water erosion in a dryland city, by interviewing 41 stakeholders using semi-structured questionnaires. Stakeholders' perceptions were analysed by addressing their understanding of water erosion dynamics, their perceptions with regards to the causes and the seriousness of erosion damages, and their attitudes towards the responsibilities for urban erosion. The results indicated that there is limited awareness of the process as a phenomenon; instead there is more awareness of erosion damages and the factors contributing to the damages. Around 69% of the stakeholders considered erosion damages to be moderate to very serious. However, there were notable disparities between the private householders and public authority groups. The study further showed that the stakeholders have no clear understanding of their responsibilities towards the management of the control measures and payment for the damages. This knowledge is fundamental for urban planning and the crafting of policies to plan, design and manage erosion control measures.

Submitted as:

Shikangalah RN, Paton EN, Jeltsch F. 2016. An Analysis of Stakeholders' Perceptions on Urban Water Erosion, Windhoek, Namibia. Journal of Urban Ecosystem

4.1 Background

Soil erosion is one of the major contributing factors to land degradation worldwide. The continuous increase in global population and the consequent use of vast lands intensifies the process of soil erosion (Pimentel and Kounang 1998; Pimentel 2006; Cantón et al. 2011). For decades this problem was mostly recognised as a challenge for agricultural areas (Lal 1998; Nearing et al. 2004; Garcia-Ruiz 2010; Prasannakumar et al. 2012). However, this phenomenon has increasingly become a prevalent challenge in urban environments as these areas are becoming increasingly densely populated. Currently, more than half of the world's population lives in urban areas and the number is expected to further increase (Pickett et al. 2008; Huang et al. 2010; Haas and Ban 2014). The demand for more land to cater for infrastructure development and other social and economic activities of humans reduces the urban pervious surfaces; thereby restricting water to specific flow paths and increasing surface overland flow which often results in accelerated water erosion (Merz et al. 2010; Strahler 2010; Cantón et al. 2011). The consequences of urban erosion have a major impact on both the urban environment and infrastructures (Sutherland and Tolosa 2000; Harris and Adam 2006). Such consequences include the blocking of sewerage systems, damages to houses and streets, transport contaminations and the pollution of water bodies such as dams and aquifers (Gaffield et al. 2003; Aksoy and Kavvas 2005; Shuster et al. 2005; Bong et al. 2011).

The study of water erosion dynamics in urban areas is based on environmental attributes such as land use, topology, and vegetation cover (Shikangalah et al. 2016). Since water erosion is accelerated by human activities, understanding the perceptions of communities affected by erosion processes should be a fundamental key for developing prevention and control measures of water erosion damages. Unfortunately, consultations with the affected communities are not commonly included in studies which deal with the impacts of water erosion (Reidsma et al. 2010). On the contrary, such consultative efforts are essential for developing more practical and consensus solutions (Mitter et al. 2014; Lange et al. 2015). The lack of inclusion of the affected communities in the studies explains why policy interventions often fail (Mutekanga et al. 2013). To overcome this shortfall, some studies on water erosion are increasingly employing stakeholder analysis methodologies to develop effective solutions (Reed 2008; Stanghellini and Collentine 2008). This, however, has been carried out mainly for agricultural environments (Izazola et al. 1998; Evans 2002; Okoba and de Graaff 2005; Heitz et al. 2009; Zegeye et al. 2010) but such studies have hardly explored urban areas. Yet engaging the affected communities helps to understand the behaviour that influences the total environmental system

(Agle et al. 1999; Cordono et al. 2004). This contributes to the generation of applicable solutions for reducing erosion risks (Heitz et al. 2009; Mutekanga et al. 2013; Mitter et al. 2014), particularly for the design of control measures (Amsalu and de Graaff 2006).

Until recently, urban water erosion has been largely studied in temperate climatic regions and very few studies have addressed urban erosion in dryland regions, particularly in Africa (Shikangalah et al. 2016). This holds true despite the high rate of urbanisation in developing countries (Cohen 2006; Huang et al. 2010; Duranton 2015) and the susceptibility of dryland regions to urban water erosion (Tooth 2000; Cornelis 2006; Vásquez-Méndez et al. 2011; Ligonja and Shrestha 2013). However, a recent study of the real extent of urban water erosion features in Namibia's capital city, Windhoek, demonstrated that soil erosion is indeed a serious problem in the city, where around 56% of the city area was found to be affected, and erosion was strongly associated with vegetation cover and land management (Shikangalah et al. submitted). Although understanding of the stakeholders' perception is one of the gaps in urban water erosion studies, the aim of this study originated however from several contradictory messages which the researchers got from both private land owners and public officers during a fieldwork campaign in 2015 for the quantification of the erosion features (Shikangalah et al. submitted). A number of stakeholders could not acknowledge the mere existence of any soil erosion damages, even though severe damages at communal and private infrastructure were evident. This therefore justified the need for further investigations into the underlying factors which influence water erosion, in particular with the aim to understand the communities' views rather than focussing more on the environmental aspects. Failure to appreciate the linkages between the understanding of the communities (including both private and public actors) and urban soil erosion might prevent the development of appropriate environmental policies and land management guidelines. Consequently, this study was aimed at understanding the perceptions and level of awareness of soil erosion occurrences and its damages through a consideration of different stakeholder groups from a dryland city, Windhoek, Namibia.

The researchers hypothesised that there is probably little awareness of the phenomenon of soil erosion across all sectors of stakeholders (land owners, authorities, companies), up to the degree that there is denial of erosion occurrences, especially in the group of decision-makers and implementers of management guidelines. However the researchers expected higher levels of awareness of a certain type of damage on houses, yards, paths, parking lots and roads, such as rills, gullies and cracks on houses. The researchers also believed that the understanding of soil erosion and its underlying mechanisms are very patchy and site-specific. And thirdly, the researchers hypothesized that there is no clear understanding on who is responsible for the implementation of erosion prevention control measures (e.g. house owners or city authorities), which is particularly pronounced for inhabitants of informal settlements. We envisaged that the stakeholder groups will not accept responsibilities regarding prevention control and payments for damages (i.e. the house owners group will state that it is the responsibility of the municipality group, and vice-versa). To test these ideas, objectives were formulated which aimed at: (1) determining the stakeholders' awareness on the severity and locations of soil erosion; (2) examining the perceived responsibilities for damages and prevention measures within the different groups of stakeholders; and (3) determining the stakeholders' understanding and prior knowledge of natural processes and landscape features that result in water erosion.

4.2 Material and methods

4.2.1 Study context

This case study is based in Windhoek, the capital city of Namibia in Southern Africa. Being the only city in the country, Windhoek is the centre of attraction for economic related aspects and it accommodates migrants from both rural areas and other smaller urban areas. Consequently, the city is now home for about 15% of the Namibian population (National Planning Commission 2012; Pendleton et al. 2014), with a population growth rate of 5% (Fray 2007; Lahnsteiner and Lempert 2007; Pendleton et al. 2014). Windhoek is a dryland city that is affected by water erosion as a result of climatic conditions and land use pressure from urban developments (Gray et al. 2008; Mapani and Schreiber 2008; Greunen 2013; Shikangalah et al. submitted). Although the scarcity of vegetation cover is a result of dryland conditions, the clearance of vegetation for housing constructions (Fig.1), and the use of timber and firewood exacerbates the susceptibility of the soil to water erosion, especially in the informal settlements (Labbe et al. 2006).

a) b)

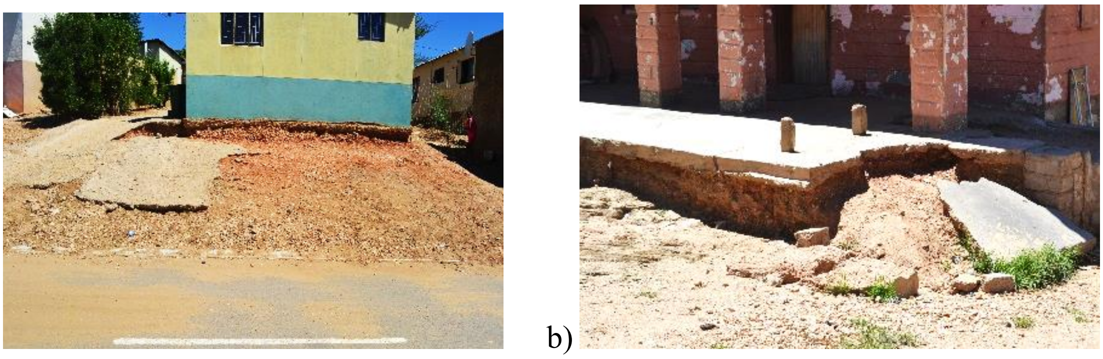


Fig. 1 Examples of erosion damages to houses. Source: Shikangalah RN.

4.2.2 Data collection and analysis

The target stakeholder groups of this study included: (1) the decision makers from local authorities (i.e. government officials from the Ministry of Agriculture, Water and Forestry, the Ministry of Environment and Tourism, and the Ministry of Regional and Local Government, Housing and Rural Development; officials of the Windhoek municipality from various sections such as environmental management, storm water, Geographical Information System (GIS), urban planning and disaster management section; the politicians (i.e. councillors of the high, middle and low income constituencies); (2) the private householders as members of the local community that own properties from formal and informal settlements; (3) developers sector (e.g. personnel from constructing companies): and (4) other sectors (Table 1). The informal settlements are described as areas where people settle without legal rights of ownership (Wakhungu et al. 2010; UN-Habitat 2015).

Table 1 Stakeholder sectors and the distribution across the groups represented

Stakeholders sectors	**Represented groups (**66% males, 34% female**)**	**Stakeholders interviewed**	
		Total number (41)	**Percentage (%)**
Public authorities	Municipal officers Government officers Councillors (politicians)	7 6 3	**39**
Private households	Households from low-income areas Households from middle-income areas Households from high-income areas	5 5 5	**37**
Developers	Private construction companies	5	**12**
Others	NGO (UN-Habitat) Private company (Namwater) Academics	1 1 3	**12**

A total of 41 stakeholders were interviewed face to face using semi structured questionnaires. The instrument allowed the exploration of emergent themes and ideas during the interview (Heitz et al. 2009; Galletta 2013). It further allowed flexibility, professional viewpoints and also enabled the respondents to reflect on the issues adequately (Lange et al. 2015). A snowball method was used to identify the stakeholders. In this method, the participants are generally identified through a chain-referral sampling as recommended by the participants who are contacted first and so forth (Heckathorn 2011). The use of a snowball approach eases the process of identifying the relevant stakeholders, thereby reducing time constraints and reducing the bias in identifying the specific samples of stakeholders for the analysis (Varvasovszky and Brugha 2000; Prell et al. 2009). The data collection was conducted over two months in 2015 (October and November). A number of topics were covered to address the stated research objectives on stakeholders' awareness, perception of responsibilities and stakeholders' understanding of erosion analysis. Table 2 provides the topics and a summary of the main questions.

Table 2 Areas of enquiry, topics and main questions

Areas of enquiry	Topics	Main questions
Stakeholders' awareness	• Risk of erosion in Windhoek • Most affected areas • Seriousness of damages	• How do you rank the risk for erosion to occur in Windhoek? • Which areas are most affected and why? • Do you think that these damages are serious or not?
Perception for responsibilities of damages and prevention measures	• Payment for damages • Suggestions for tackling the damages • Payment for prevention measures • Responsibility for prevention measures • Suggestions on prevention measures • Challenges of controlling	• Who do you think should pay for the damage caused by erosion? • Would you have any suggestions on how to tackle the problem with the damages? • Who should pay for prevention measures? • Who do you think is responsible for the prevention measures and why? • What do you suggest the responsible people for prevention measures should do? • What are the biggest challenges in controlling erosion?
Stakeholders' understanding of water erosion dynamics	• Contributing factors • Role played by factors	• Do you think these factors contribute to erosion? • In which way do they play a role in erosion?

Interviews lasted between 15 and 30 minutes and they were recorded and then transcribed. The transcripts were then coded to form categories (Galletta 2013; Magnusson and Marecek 2015). Short phrases were formulated first from the participants' answers and then further refined to produce more specific or more focused codes (tags). To ensure that all content was captured, transcribed and coded correctly, the researchers repeatedly went back to the initial answers and at times to the recordings. The codes were then grouped into four main analytical categories that were guided by the objectives of the research. Categories include stakeholders': (1) awareness of water erosion; (2) experiences with the damages; (3) perceptions towards responsibilities with regards to damage: (4) perceptions towards responsibilities for prevention measures: (5) understanding influencing factors: and (6) perceptions of the influencing factors. The succeeding result section is presented in accordance with these analytical categories.

4.3 Results

The analysis yielded three analytical categories to which the stakeholders' statements were allocated: (i) awareness of soil erosion: (ii) perceptions regarding responsibility: and (iii) their understanding of the underlying processes of soil erosion.

4.3.1 Assessment of the stakeholders' awareness of soil erosion

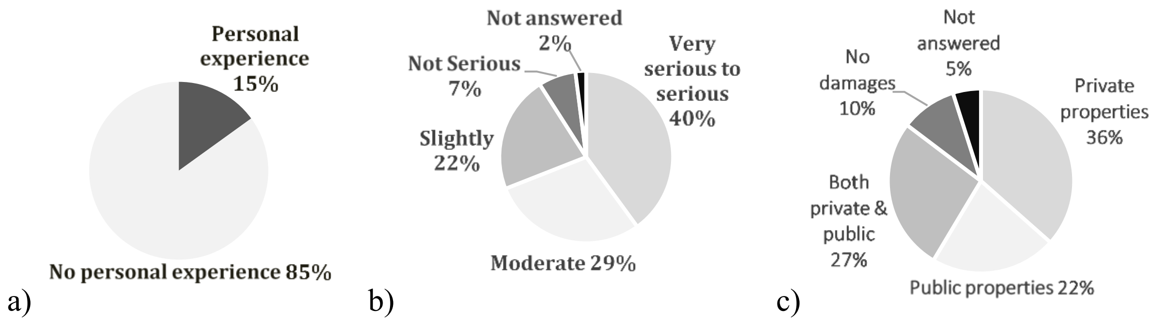


Fig. 2 Results of stakeholders views regarding their: (a) personal experience with erosion damages: (b) perceived seriousness of erosion damages: and (c) where most damages are seen in Windhoek

The interviewees displayed an ambivalent awareness of the extent and significance of soil erosion. Whereas the majority of the interviewees said that they did not have direct experiences with erosion damages (Fig. 2a), 69 % of the interviewees considered the damages due to erosion to be moderately serious to very serious (Fig. 2b). The highest level of significance (very serious to serious) was expressed mostly (58%) by private households; only 24% of the public authority sector supported this view while the opposite percentage expressed for the moderate level. In contrast, 29% of the interviewees indicated that the damages are less serious with 22% indicating “slightly serious” and 7% indicating “not serious”. This was expressed by five developers, three private householders and four public authority respondents. People from this latter group even entirely denied the existence of water erosion as a problem for the City of Windhoek. As one interviewee stated (councillor); “As far as I know we do not have any experience in connection with water erosion problems or anything like that …; there is no report on that whatsoever”. Another interviewee stated (municipality group); “I am in this field for a long time now and there are no problems resulting from water erosion”. Lastly, up to 36% indicated that most of the damages are seen on private properties and only 22% indicated the existence of the phenomenon on public properties (Fig. 2c).

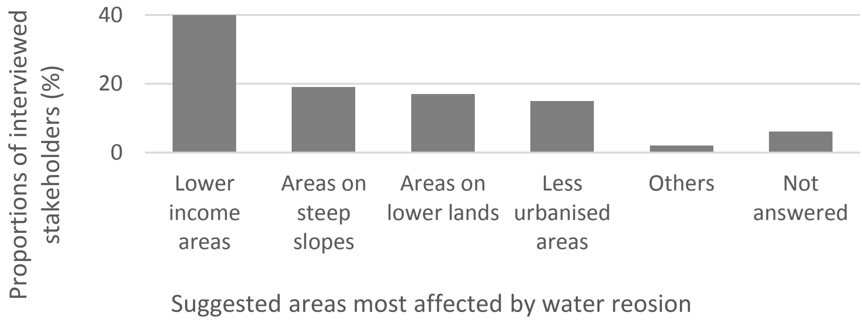


Fig. 3 Results of stakeholders’ interviews on the types of areas that are thought to be affected most by water erosion in Windhoek

Regarding the whereabouts of erosion (Fig. 3), up to 40% of the respondents thought that most of the affected sites are situated in low income settlements, including locations of informal settlements in areas such as Okulyangava and Wanaheda (Fig. 8). The stakeholders indicated that the occurrence of erosion in these settlements was due to inadequate infrastructures, lack of basic services and the usage of low quality building materials in low income settlements. Added to that is the 15% of the respondents who thought that the urbanised areas will be more affected, thus referring to the damages again. Additional reasons indicated include factors such as poor ground conditions and little vegetation cover. One stakeholder (from the municipality group) stated that: “In these areas, they don’t have trees, there is nothing binding the soil”. Other reasons included the lack of planning and land management, and also that the houses were built in valleys and river banks. Considering the areas that the stakeholders pointed out and the reasons given, it shows that both 40% and 15% respondent groups know erosion in terms of the damages.

A total of 36% of the stakeholders thought that the affected areas are located within certain slope ranges. About 19% suggested that the cause is that of steep slopes, which include townships of Kleine Kuppe, Ludwigsdorf, Klein Windhoek, Avis and Ausblick, where runoff generation is presumably high (Fig. 8). In contrast, 17% thought that the most affected areas are in lower lands in townships such as Otjomuise, Goreangab and the western parts of Windhoek where larger amounts of headwater catchment accumulate. Whereas the former thought of erosion in terms of the slope, the later thought of it in terms of where water accumulates. This is corroborated by one of the interviewees who said that; "All the water from the higher parts ends up in these areas" and another stated that "There are more river beds and more water ends there". Both groups therefore showed that they have some knowledge of water erosion in terms of the process of the phenomenon. Overall, according to the responses about the most affected areas, it was demonstrated that the majority (up to 55%) of the stakeholders know about the damages caused by erosion rather than the erosion process itself.

4.3.2 Perceptions regarding the responsibilities of damages and prevention measures

Many stakeholders perceived the damages of water erosion as very serious to moderately serious (Fig. 2a). With such seriousness of the damages, the question of responsibilities was prompted with regards to the payments for the damages and to the implementation of preventative measures. This section highlights the views of the stakeholders with regards to the question as to who should be accountable for such responsibilities.

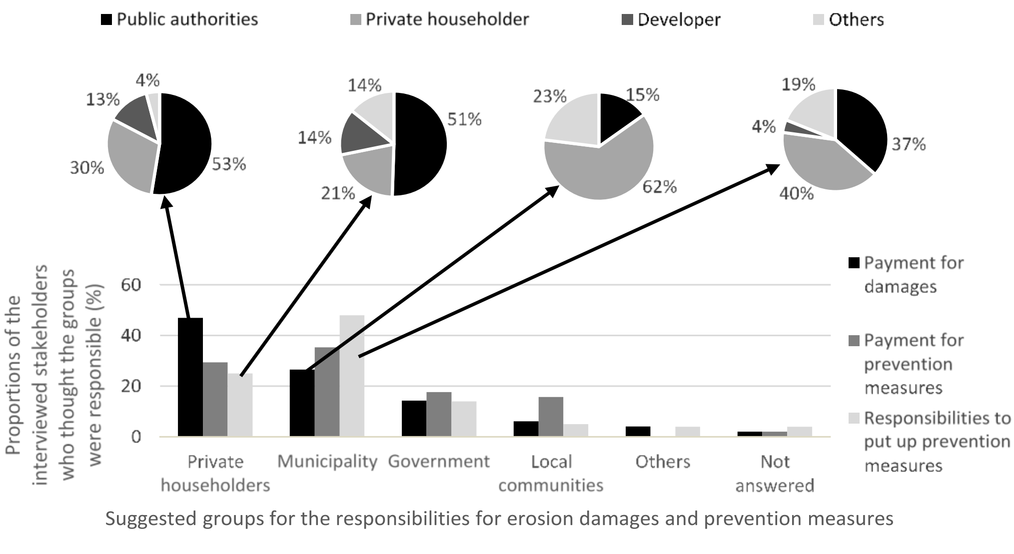


Fig. 4 Groups which were held responsible for erosion damages and prevention measures; the pie graphs shows the percentages of the 4 stakeholder sectors who held this opinion

The interviewees generally felt that mostly the private households are to be held responsible for the payments of erosion damages (Fig. 4). The reasoning came down to the fact that they own the properties or the piece of land affected. However, fewer interviewees stated that the private households are responsible for paying or putting up prevention measures. Here, the majority (48%) stated that the municipalities should be responsible for putting up prevention measures. However, there was no clear picture as to who should be paying for those. For putting the responsibility to the municipality, the reasoning was related to the views that the municipality is responsible for city planning, for servicing the land and streets, that they are overall in control of the city and that they own the city, hence owning all the land. Some stakeholders indicated that it is the municipality's responsibility rather than the private householders as the latter have already paid for erosion control as part of the municipal bills that they pay on a monthly basis. The two groups represented the private householders and the municipal group (public authority sector), and the interviewees demonstrated that each sector actually prefers the other sector to be the responsible sector. The pie graphs above show that the majority that chose the private householders to be the responsible group were the stakeholders from the public authority sector. On the other hand, the majority that chose the municipality were from the private householders sector. Interestingly, almost no developers indicated that the municipality is to be held responsible. Overall, this shows that there is a lot of disagreement between the groups with regards to the payment of the damages and the implementation of prevention measures. In spite of these disagreements, each group suggested itself for the payment of the prevention measures (Fig. 4). From the public authority sector, one interviewee stated that "The municipality only provides services; it does not have its own money. The residents provide the revenue, so they should be the ones paying." Another interviewee stated that "The damages are caused by natural causes and the municipality is not responsible for natural causes". While from the private householders one interviewee stated that the "Municipality should service everything, it is under their control"; and another stated that "Since people pay services to the municipality, any damages that occur even within the individual yards, the municipality must attend to it".

4.3.3 Assessment of the stakeholders' understanding of soil erosion processes

The majority of the stakeholders know the process of water erosion in terms of the damages caused by erosion, as only a few pointed out areas such as steep slopes are possibly the most affected (section 3.1). This section therefore analyses their understanding of the water erosion process.

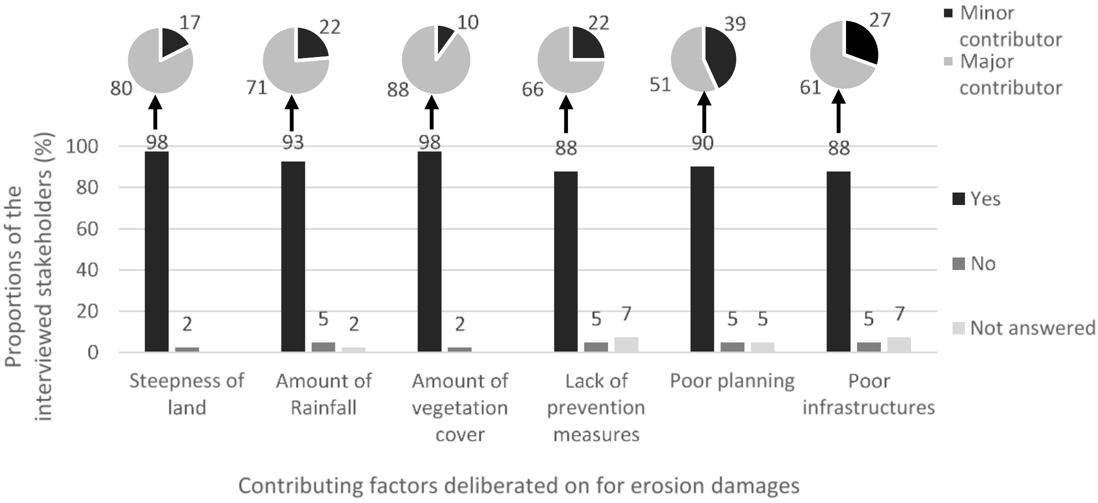
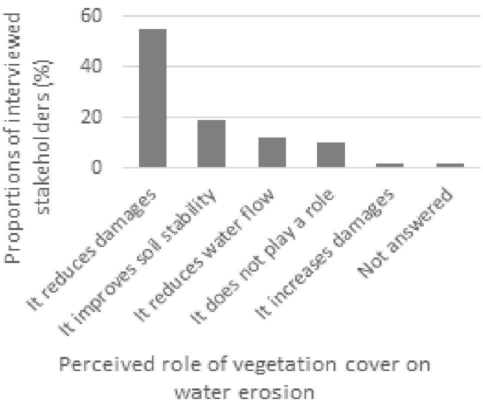
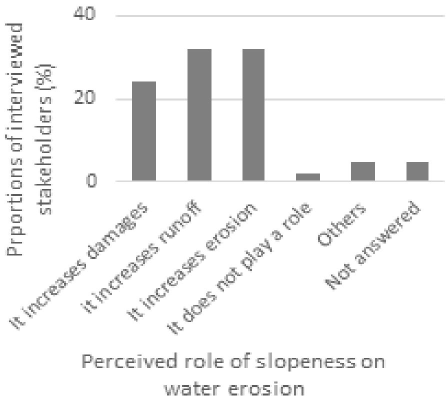


Fig. 5 Understanding of soil erosion in terms of contributing factors. The pie graphs illustrate the percentage (%) in relation to whether stakeholders considered the factors to be minor or major contributing factors

The stakeholders were asked to indicate whether factors including the steepness of the land, the amount of rainfall and of vegetation cover, the lack of prevention measures, poor planning and poor infrastructure contribute to erosion damages or not. These factors are the most critical factors influencing the process of water erosion (Bryan 2000; Lal 2001). The majority of the interviewed stakeholders agreed that these factors contribute to erosion damages (Fig. 5). The respondents additionally specify further contributing factors, mainly, roads being gravel, too many squatter camps, houses built on hills and on the water courses, places being underdeveloped, and lack of boundary walls to block the water. Clearly these factors support those provided to them (Fig. 5). The pie graphs show that the stakeholders generally understand that the highest contributing factors are the amount of vegetation and the steep slopes, while poor infrastructure and poor planning were considered slightly less. Overall, it shows that natural factors are understood to be major contributing factors to erosion damages in Windhoek than the management related factors.



a)



b)

Fig. 6 Perceived role of: a) vegetation cover, b) slope of the land on water erosion

Figure 6 above shows the perceptions of the stakeholders with regards to the role of vegetation cover and steep slopes on water erosion. For vegetation cover, the majority simply indicated that it reduces erosion damages resulting from erosion (Fig. 6a). However, a smaller percentage appeared to have more detailed knowledge as they indicated that it improves soil stability, while others referred to its stability to reduce water flow. In addition, three private householders and one councillor indicated that the amount of vegetation cover does not play any role in erosion, whereas one developer indicated that the high amount of vegetation cover actually increases the damages. With regards to the slopes, the majority of the stakeholders indicated that a large slope increases erosion damages, runoff and erosion (Fig. 6b). These results also show that there is a positive perception of the role of vegetation cover and the slope, with only a few stakeholders responding negatively. Vegetation is often removed to clear for constructions. While in formal settlements vegetation cover is allowed to recover (Fig. 7), in informal settlements it is mostly cleared off for general hygienic purposes and due to the heavy use of fire wood (Labbe et al. 2006).

a)  b) 

Fig. 7 Typical vegetation cover in settlements: a) informal, b) formal. Source: Shikangalah RN.

It should be noted that for this section of understanding the process of water erosion, the researchers provided choices because they did not want to compel the people or to make them feel uncomfortable if direct questions about their knowledge were asked. However, it was felt that the outcome could have been slightly different if the researchers had not provided the choices. At the beginning of the interviews, some of the stakeholders had even asked the interviewer to explain what water erosion / soil erosion was and they appeared to realise the process only when the possible damages were mentioned. Furthermore, no further factor were provided by the stakeholders themselves, since the list of choices ended openly for them to specify additional factors.

4.4 Discussion

In an attempt to understand the problem of urban water erosion in urban dryland communities, this research aimed at exploring how urban local communities perceived water erosion, the contributing factors and related damages. The three hypotheses are discussed in turn below.

i) Little awareness of soil erosion as a phenomenon across all sectors of stakeholders?

The study demonstrated that there is little awareness among stakeholders about water erosion as a phenomenon but the awareness is more in terms of the identified damages. This is demonstrated by the fact that the majority (55%) of the stakeholders pointed out that urbanised areas and low income areas are the most affected areas. This is further supported by their explanations which were mainly according to how infrastructure might have increased the damages in those areas. Only 36% of the stakeholders indicated that suburbs with higher levels of slopes or areas where water accumulates are affected the most, indicating their knowledge of the phenomenon. A recent study by Shikangalah et al. (submitted) indicated that areas located on higher parts of hills such as Kleine Kuppe and Ludwigsdorf could potentially have been eroded more today if good land management practices were not in place (Fig. 8). The map below (Fig. 8) shows a spatial distribution of water erosion and this map was derived from a recent field survey data by the present researchers. The map corresponds with the majority's indication of the most affected are as those representing lower income locations. According to the stakeholders, the reasons why the most affected areas are in lower income locations include the fact that there is insufficient infrastructure, lack of services and the use of low quality building materials. The low quality building materials make structures to be unable to withstand the high lateral loads due to erosion, especially in the informal settlements of Windhoek where shacks are built from cheap and recycled materials (Labbe et al. 2006).

The stakeholders' awareness is mainly associated with the damages as the researchers had predicted. Additionally, the study demonstrated that there is a notable disparity between stakeholders with regards to the level of perceptions about the seriousness of the damages: whereas private householders considered the erosion damages as serious, the decision-makers regarded the same damage to be only moderate. The perceptions of the private householders might be influenced by their direct observation within the community. Likewise, the perceptions of the public authorities can be attributed to the fact that erosion falls outside their mandate as the city currently lacks a policy aimed at addressing the problem of water erosion.

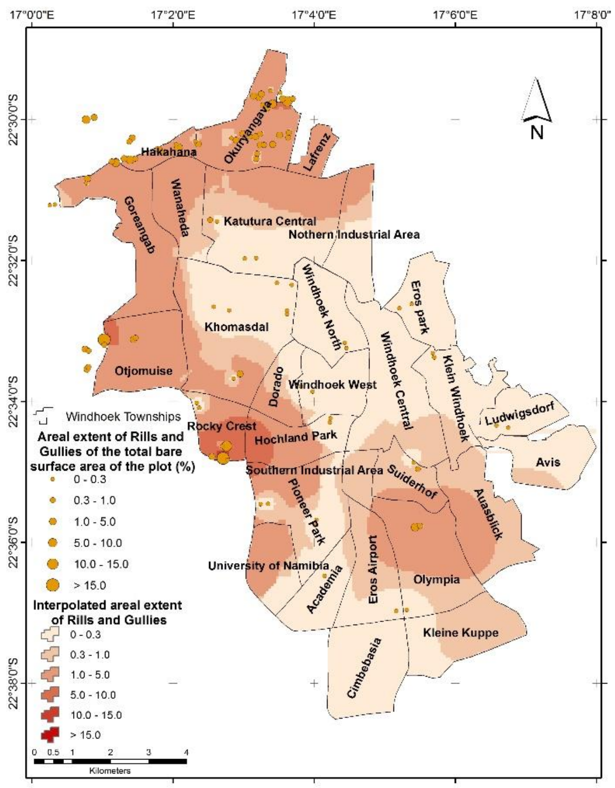


Fig. 8 Spatial distribution of erosion in Windhoek (Adapted from Shikangalah et al. submitted)

ii) Is an understanding of erosion's underlying mechanism processes patchy and site specific?

Contrary to the researchers' expectations, the study demonstrated that there is a coherent understanding of factors contributing to water erosion and the stakeholders are fairly cognisant of the role of vegetation cover and steep slopes in controlling water erosion. Vegetation cover is well documented as a parameter that reduces the risk of soil erosion (Vrieling et al. 2008;

Zhou et al. 2008; Zhongming et al. 2010; Wang et al. 2012), with at least a minimum of 40% grass cover needed to reduce erosion in dryland cities (Gutierrez and Hernandez 1996; Podwojewski et al. 2011; Shikangalah et al. submitted). The stakeholders' understanding corresponds with the forgoing scholars. The majority stated that more vegetation reduces erosion and it improves soil stability; while the steep slopes increase runoff, erosion and the associated damages. However, even though the stakeholders understood the importance of vegetation cover, currently not many initiatives are directed towards improving vegetation cover in the most affected areas. Instead, vegetation cover is currently being cleared off on the stream banks by the local and central government in an attempt to reduce criminal activities such as robbery, and it is usually also cleared by many householders for hygienic purposes in their backyards. Although the data were not enough to properly establish this assumption, it appears that vegetation cover is however commonly grown in the back yards of the houses in the low density suburbs for aesthetic purposes and also as a symbol of status, to show that one can afford the cost of the irrigation water and the labour involved in maintaining it.

iii) No clear understanding of the responsibilities for water erosion prevention measures?

Stakeholder participation is increasingly becoming a fundamental aspect for managing environmental resources (Stanghellini and Colletnine 2008). Yet despite the fact that the city of Windhoek is highly affected by water erosion (Shikangalah et al. submitted), this study shows that the stakeholders are not willing to take responsibility to address the problem. The interviewed stakeholders recognised the public authorities (such as city managers) and private householders (such as property owners) as entities responsible for payments and the implementation of prevention measures of erosion damages. However, each of these sectors shifted the responsibility to each other. This current attitude is likely to create a dilemma for the city, especially for the informal settlements where land is normally occupied illegally and the settlements are not part of the plans or land management of the local public authorities. In order to successfully manage environmental problems locally, there is a need for the stakeholders to recognise the problem, the importance of their own individual roles, and to collectively protect their local environment (United Nations 2011; Sennesa et al. 2012).

The question that might be asked therefore is, who should really be responsible for addressing the problem of water erosion in Windhoek? Many natural hazards (such as earthquakes, flooding and mudslides) in urban areas are the responsibility of the local governments (Uitto

1998; Cho et al. 2001; Tas et al. 2013), including soil erosion (Paterson et al. 1993; Burby 1995; Lizairraga-Arciniegat et al. 2001). However, in Windhoek it appears that the responsibility is clearer for the high income areas, while in other suburbs the priorities of providing basic needs such as infrastructures like domestic water provision precede the importance of addressing water erosion. In the informal settlements, addressing the problem of land tenure might be a higher priority for the local government compared to erosion.

4.5 Conclusion

This study demonstrated that there is a high level of awareness of the damages caused by urban soil erosion (severe for household and moderate for public authority), but that urban soil erosion itself is not considered a phenomenon which needs to be considered in an urban management context. In order to minimise the problem of water erosion, there is a need for the society to recognise the phenomenon, to clearly see the linkages between the damages and the phenomenon, and to set up appropriate management and prevention schemes. This is equally important for the developers and the politicians who are actively involved in city development. An increased awareness is also important for the people in the informal settlement areas where planning and management is lacking or not existent. Such an initiative will prove advantageous in terms of safeguarding their properties while also serving as a function of protecting the environment. Lastly, though water erosion might not be easy to change, the issue is very important considering the amount of the damage it causes. The study therefore recommends further studies aimed at analysing the economic impacts of damages and the possible prevention measures, as well as the influence of other aspects such as the period of property ownership on the attitudes and perceptions of stakeholders towards soil erosion.

4.6 References

Agle BR, Mitchell RK (1999) Who Matters to CEOs ? An Investigation of Stakeholder Attributes and Salience, Corporate Performance, and CEO Values. Acad. Manag. J 42:507–525

Aksoy H, Kavvas ML (2005) A review of hillslope and watershed scale erosion and sediment transport models. Catena 64:247–271

Amsalu A, de Graaff J (2006) Farmers' views of soil erosion problems and their conservation knowledge at Beressa watershed, central highlands of Ethiopia. Agric. Human Values 23:99–108

Bong CH, Lau TLL, Ghani AA (2011) Sediment deposition characteristics of urban concrete drains in Kuching. In: Managing Rivers in the 21st Century: Sustainable Solutions for Global Crisis of Flooding, Pollution and Water Scarcity, pp 712 –720

Bryan RB (2000) Soil erodibility and processes of water erosion on hillslope. Geomorphology 32:385–415

Burby RJ (1995) Coercive versus cooperative pollution control: Comparative study of state programs to reduce erosion and sedimentation pollution in urban areas. Environ. Manage 19:359–370

Cantón Y, Solé-Benet A, De Vente J, Boix-Fayos C, Calvo-Cases A, Asensio C, Puigdefábregas J (2011) A review of runoff generation and soil erosion across scales in semiarid south-eastern Spain. J. Arid Environ 75:1254–1261

Cho S, Gordon P, Moore II JE, Richardson HW, Shinozuka M, Chang S (2001) Integrating Transportation Network and Regional Economic Models to Estimate the Costs of a Large Urban Earthquake. J. Reg. Sci 41:39–65

Cohen B (2006) Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. Technol. Soc 28:63–80

National Planning Commission (2012) Namibia 2011 Population and Housing Census Preliminary Results. Windhoek, Namibia

Cordano M, Frieze IH, Ellis KM (2004) Entangled affiliations and attitudes: An analysis of the influences on environmental policy stakeholders' behavioral intentions. J. Bus. Ethics 49:27–40

Cornelis WM (2006) Hydroclimatology of wind erosion in arid and semiarid environments. In dryland ecohydrology, Springer, Netherlands, pp 141-159

Duranton G (2015) Growing through cities in developing countries. World Bank Res. Obs 30:39–73

Evans R (2002) An alternative way to assess water erosion of cultivated land - Field-based measurements: And analysis of some results. Appl. Geogr 22:187–208

Frayne B (2007) Migration and the changing social economy of Windhoek, Namibia. Dev. South. Afr 24:91–108

Gaffield SJ, Goo RL, Richards LA, Jackson RJ (2003) Public Health Effects of Inadequately Managed Stormwater Runoff. Am. J. Public Health 93:1527–1533

Galletta A (2013) Mastering the semi-structured interview and beyond: From research design to analysis and publication. NYU Press

García-Ruiz JM, Lana-Renault N, Beguería S, Lasanta T, Regüés D, Nadal-Romero E, Serrano-Muela P, López-Moreno JI, Alvera B, Martí-Bono C, Alatorre LC (2010) From plot to regional scales: Interactions of slope and catchment hydrological and geomorphic processes in the Spanish Pyrenees. Geomorphology 120:248–257

Gray M, Keating J, Moody J, Swan D, Keating J (2008) Erosion Control in Otjomuise, Namibia

Greunen S (2013) Assessing the Resilience of Windhoek on the road to re-defining sustainability. 20th Gen. Assem. Conf. Commonw. Assoc. Archit, pp 1–12

Gutierrez J, Hernandez II (1996) Runoff and interrill erosion as affected by grass cover in a semi-arid rangeland of northern Mexico. J. Arid Environ 34:287–295

Haas J, Ban Y (2014) Urban growth and environmental impacts in Jing-Jin-Ji, the Yangtze, River Delta and the Pearl River Delta. Int. J. Appl. Earth Obs. Geoinf 30:42–55

Harris JA, Adams BJ (2006) Probabilistic assessment of urban runoff erosion potential. Can. J. Civ. Eng 33:307–318

Heckathorn D (2011) Snowball versus respondent driven sampling. Sociol. Methodol 4:355–366

Heitz C, Spaeter S, Auzet AV, Glatron S (2009) Local stakeholders' perception of muddy flood risk and implications for management approaches: A case study in Alsace (France). Land use policy 26:443-451

Huang SL, Yeh CT, Chang LF (2010) The transition to an urbanizing world and the demand for natural resources. Curr. Opin. Environ. Sustain 2:136–143

Izazola H, Martínez C, Marquette C (1998) Environmental perceptions, social class and demographic change in Mexico City: a comparative approach. Environ. Urban 10:107–118.

Labbe N, Mcbride N, Ray E (2006) Flooding and Erosion Control in the Informal Settlements of Windhoek, Namibia by Settlements of Windhoek, Namibia.

Lahnsteiner J, Lempert G (2007) Water management in Windhoek, Namibia. Water Sci. Technol 55:441-448

Lal R (1998) Soil erosion impact on agronomic productivity and environment quality. CRC. Crit. Rev. Plant Sci 17:319–464

Lal R (2001) Soil degradation by water erosion. L. Degrad. Dev 539:519–539

Lange A, Siebert R, Barkmann T (2015) Sustainability in Land Management: An Analysis of Stakeholder Perceptions in Rural Northern Germany. Sustainability 7:683–704

Ligonja PJ, Shrestha RP (2013) Soil Erosion Assessment in Kondoa Eroded Area in Tanzania Using Universal Soil Loss Equation, Geographic Information Systems and Socioeconomic Approach. L. Degrad. Dev 26:367 – 379

Lizárraga-Arciniega R, Appendini-Albretchsen C, Fitcher D (2001) Planning for beach ersoion: A case study, Playas de Rosarito, B.C. Mexico. J. Coast. Res 17:636–644

Magnusson E, Marecek J (2015) Doing Interview-based Qualitative Research: A Learner's Guide. Cambridge University Press

Mapani BS, Schreiber U (2008) Management of city aquifers from anthropogenic activities: Example of the Windhoek aquifer, Namibia. Phys. Chem. Earth 33:674–686

Merz B, Kreibich H, Schwarze R, Thieken A (2010) Assessment of economic flood damage. Nat. Hazards Earth Syst. Sci 10:1697–1724

Mitter H, Kirchner M, Schmid E, Schoenhart M (2014) The participation of agricultural stakeholders in assessing regional vulnerability of cropland to soil water erosion in Austria. Reg. Environ. Chang 14:385–400.

Mutekanga F, Kessler A, Leber K, Visser S (2013) The Use of Stakeholder Analysis in Integrated Watershed Management : Experiences From the Ngenge Watershed, Uganda. Mt. Res. Dev 33:122–131

Nearing MA, Pruski FF, O'Neal MR (2004) Expected cllimate change impacts on soil erosion rates - A review.pdf. Jounrnal Soil Water Conserv 59:43 – 50

Okoba BO, de Graaff J (2005) Farmers' knowledge and perceptions of soil erosion and conservation measures in the Central Highlands, Kenya. L. Degrad.Dev 16:475–487

Paterson RG, Luger MI, Burby RJ, Kaiser EJ, Malcom HR, Beard AC (1993) Costs and benefits of urban erosion and sediment control: The North Carolina experience. Environ. Manage 17:167–178

Pendleton W, Crush J, Nickanor N (2014) Migrant Windhoek: Rural-Urban Migration and Food Security in Namibia. Urban Forum, pp 1–15

Pickett STA, Cadenasso ML, Grove JM, Nilon CH, Pouyat R V., Zipperer WC, Costanza R (2008) Urban ecological systems: Linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Urban Ecol. An Int. Perspect. Interact. Between Humans Na, pp 99–122

Pimentel D (2006) Soil erosion: A food and environmental threat. Environ. Dev. Sustain 8:119–137

Pimentel D, Kounang N (1998) Ecology of Soil Erosion in Ecosystems. Ecosystems 1:416–426

Podwojewski P, Janeau JL, Grellier S, Valentin C, Lorentz S, Chaplot V (2011) Influence of grass soil cover on water runoff and soil detachment under rainfall simulation in a sub-humid South African degraded rangeland. Earth Surf. Process. Landforms 36:911–922

Prasannakumar V, Vijith H, Abinod S, Geetha N (2012) Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. Geosci. Front 3:209–215

Prell C, Hubacek K, Reed M (2009) Stakeholder Analysis and Social Network Analysis in Natural Resource Management. Soc. Nat. Resour 22:501–518

Reed MS (2008) Stakeholder participation for environmental management: A literature review. Biol. Conserv 141:2417–2431

Reidsma P, Ewert F, Lansink AO, Leemans R (2010) Adaptation to climate change and climate variability in European agriculture: The importance of farm level responses. Eur. J. Agron 32:91–102

Sennes V, Gombert-Courvoisier S, Ribeyre F, Felonneau ML (2012) Citizens' environmental awareness and responsibility at local level. Int. J. Urban Sustain. Dev 4:186–197

Shikangalah RN, Jeltsch F, Blaum N, Mueller EN (2016) A Review on Urban Water Erosion. J. Stud. Humanit. Soc. Sci. 5: 163 - 178.

Shuster WD, Bonta J, Thurston H, Warnemuende E, Smith DR (2005) Impacts of impervious surface on watershed hydrology: A review. Urban Water J 2:263–275

Stanghellini PS, Collentine D (2008) Stakeholder discourse and water management - implementation of the participatory model CATCH in a Northern Italian alpine sub-catchment. Hydrol. Earth Syst. Sci 12:317–331

Strahler AH (2010) Introducing physical geography. 5rd. John Wiley & Sons, Chichester,

Sutherland RA, Tolosa CA (2000) Multi-element analysis of road-deposited sediment in an urban drainage basin, Honolulu, Hawaii. Environ. Pollut 110:483–495

Tas M, Tas N, Durak S, Atanur G (2013) Flood disaster vulnerability in informal settlements in Bursa, Turkey. Environ. Urban 25:443–463

Tooth S (2000) Process, form and change in Dryland Rivers: A review of recent research. Earth Sci. Rev 51:67–107

Uitto JI (1998) The geography of disaster vulnerability in megacities: a theoretical framework. Appl. Geogr 18:7–16

UN - Habitat (2015) Habitat III Issue Papers 22 – Informal Settlements. New York

United Nations (2011) Paving the way for sustainable consumption and production: The Marrakech Process progress report. UNEP

Varvasovszky Z, Brugha R (2000) How to do (or not to do). A stakeholder analysis. Health Policy Plan 15:338–345

Vásquez-Méndez R, Ventura-Ramos E, Domínguez-Cortázar MA (2011) Soil Erosion Processes in Soil Erosion Processes in Semi Arid Areas : The Importance of Native Vegetation. INTECH Open Access Publ 1:25 – 41

Vrieling A, de Jong SM, Sterk G, Rodrigues SC (2008) Timing of erosion and satellite data: A multi-resolution approach to soil erosion risk mapping. Int. J. Appl. Earth Obs. Geoinf 10:267–281.

Wakhungu J, Huggins C, Nyukuri E, Lumumba J (2010) Approaches to Informal Settlements in Africa: Experiences from Kigali and Nairobi, pp 1-8

Wang G, Innes J, Yusheng Y, Shanmu C, Krzyzanowski J, Jingsheng X, Wenlian L (2012) Extent of soil erosion and surface runoff associated with large-scale infrastructure development in Fujian Province, China. Catena 89:22–30

Zegeye AD, Steenhuis TS, Blake RW, Kidnau S, Collick AS, Dadgari F (2010) Assessment of soil erosion processes and farmer perception of land conservation in Debre Mewi watershed near Lake Tana, Ethiopia. Ecohydrol. Hydrobiol 10:297–306

Zhongming W, Lees BG, Feng J, Wanning L, Haijing S (2010) Stratified vegetation cover index: A new way to assess vegetation impact on soil erosion. Catena 83:87–93

Zhou P, Luukkanen O, Tokola T, Nieminen J (2008) Effect of vegetation cover on soil erosion in a mountainous watershed. Catena 75:319–325

Chapter Five

General Discussion

5. General discussion

To date, many research initiatives are aimed at improving our understanding and management of water erosion. However, specific knowledge on urban water erosion is still limited. This holds true despite urban centres being currently home to the majority of the global population. This study aimed at assessing urban water erosion and the associated socio-environmental determinants. Improved knowledge was gained by responding to three specific objectives of the thesis. Accordingly, chapter one provided an overall introduction to the thesis, chapter two provided a literature review on urban water erosion, chapter three quantified a real extent of water erosion in a dryland urban area whereas chapter four analysed the stakeholders' perception on urban erosion. The current chapter (chapter five) provides a discussion of the key findings and the overall conclusion. The chapter further outlines prospective for future researches and proposes perspectives for Windhoek.

5.1 Key findings

Chapter two addressed the first objective of the thesis, to provide an in-depth literature review. The chapter demonstrated that scholars have indeed conducted some research on the subject of urban erosion. While the studies have identified specific causal factors of this phenomenon, much of the research has suffered from limitations of the methodologies applied. The review identified the lack of modelling approaches especially for urban areas. The models that are currently being used to assess urban erosion are mainly borrowed from agriculture, and therefore they are not well equipped to address some unique aspects of urban environments. This situation is exacerbated by the lack of data on the wide array of urban related aspects necessary to develop such models, including aspects of rates of urbanisation and urban growth, different development levels within a city and the diversity of urban land covers. Therefore, the need for developing models which cater for urban typical assemblies. Regions with extreme climatic conditions (subarctic and drylands) were found to be less studied, the least of which is Africa. These findings illustrated the pressing and urgent need for more studies on water erosion in Africa. This urgency is based on the rapid urban population growth in the continent (United Nations 2012), the high erosion indices due to land cover change in Africa (Yang et al. 2003) and predicted increase in intense rainfall events in drylands (Reich et al. 2001). The reviewed literature also lacked aspects addressing the issues of climate change, the extent of eroded areas in urban settings and they did not consider the features of socio-economic factors in their approaches. In the end, this chapter defined crucial areas that still need to be tackled.

Chapter three addressed the second objective of the thesis, to quantify a real extent of soil erosion in Windhoek, Namibia. Using the data from the field survey approach, the study showed that approximately 56% of the city is affected by water erosion. The study showed that the extent of urban erosion is not merely linked to topography, vegetation cover and the different choices of land management as it is generally the case with agricultural fields (McHugh et al. 2002; Vreiling et al. 2008; Zhongming et al. 2010; Wang et al. 2012), but the latter is strongly associated with the areas of different income classes in urban areas. Areas inhabited by lower income classes were found to be more affected than those of middle and higher income classes, thereby depicting the socio-economic features characterising the areas. This finding emphasises the importance for land management strategies to consider the various levels of the society when developing prevention and control measures. Furthermore, it backs the importance of using approaches that include socio-spatial factors in assessing urban water erosion. The importance of socio-economic factors (though not associated with the different income classes in other studies) in urban erosion has also been acknowledged by other scholars (Rowntree et al. 1991; Sathler et al. 2005). In terms of the vegetation cover, the study illustrates that city managers in drylands need to consider management schemes that preserve and maximise vegetation productivity to minimise erosion, aiming at grass cover of more than 40%.

The results of affected areas from the field survey were compared to the results derived from the most commonly used USLE approach. The USLE approach disregarded urban land management, leaving out pockets of vegetation covers and other typical urban features, hard surface cover such as footpaths. Furthermore, the USLE approach failed to detect differences occasioned by socio-spatial factors across the city. The study concluded that due to the variability of urban environments, the field survey approach was more applicable than the USLE approach for occupied areas while the USLE approach could be appropriate for areas prior to development. As with this study, other research (though based on agricultural fields) have praised the field survey for being realistic, addressing the problem at scale and for its possible use as a basis for standard method of erosion (Herweg 1996; Lal 1997, 1998) and also commended it in comparison to the USLE approach (Evans 2002). Based on this study, the finding lay emphasis for the need of tailored urban soil erosion models. It also stresses the importance of not disregarding typical urban socio-spatial features in assessing erosion so as to ensure appropriate research outcomes.

Chapter four addressed the third objective of the thesis, to analyse the stakeholders' perception on urban water erosion. The chapter focused on understanding the views and perceptions of the local community as a basis for developing prevention measures and a comprehensive water erosion policy. Differences in views among the different stakeholders' sectors were noted. The stakeholders' awareness of erosion damages appeared to have greatly influenced their perceptions, and these were perceived very seriously mostly by private householders (home owners), which means that home owners consider the city to be very susceptible to water erosion occurrences. According to Sennes et al. (2012), perceptions for environmental risks are strongly felt when stakeholders associate them with the negative effects on the quality of their life. It is therefore not surprising that the local authority sector perceived the situation to be moderate (less ranked than the home owners), and that the developers considered the damages not to be that serious. These three different levels of perceptions however imply that the city managers have to deal with the three groups differently. In other studies, perceptions of stakeholders from different groups, sectors or regions have also diverged with regards to other environmental aspects (for example Das 2011; Sennes et al. 2012; Lange et al. 2015).

Another diverging point was with the attitudes towards responsibilities for water erosion. The private householders and local authority sectors pointed fingers at each other for the responsibilities of erosion damage payments and of putting up prevention measures. Similar results and reasoning behind the pointing of fingers for environmental management responsibilities are also reported in agricultural-peri-urban areas, in Bordeaux Métropole, South West France (Sennes et al. 2012). This reluctance to take responsibility might undermine any measures and strategies to minimise erosion in urban areas. It also creates a predicament for those areas which are already affected, including the informal settlements where the land is not owned by the residents. Considering that some of their houses are made from cheap and or recycled materials, the damages could be devastating to their livelihoods and might possibly lead to injuries. This should even be more worrisome for Windhoek, seeing that nearly 60% of the city's population reside in the low income areas (Frayne 2007; Pendleton et al. 2014) and informal settlements are particularly home to up to 30% of the city's population (Labbe et al. 2006; Gray et al. 2008). This chapter showed that even though the communities seemingly understood the problem of erosion damages, it did not largely influence their attitudes towards their responsibilities, including that of the local authorities. Hence, approaches that sensitise stakeholders on the importance of managing erosion are essential and urgently needed for urban areas, especially for the city managers.

An understanding of the aspects exacerbating urban water erosion from broader perspectives may lead to stakeholders taking up erosion responsibilities appreciatively. In this study, the understanding of the stakeholders of factors influencing erosion appeared to be limited to the immediate features contributing to urban water erosion. Contributing factors added by the respondents themselves have simply supported the aspects that were already provided to them (Chapter four, Fig. 5, p. 78). Added factors by the respondents included roads being mainly gravel, dense squatter camps and the construction of houses on hilly spaces and on the water course; underdevelopment, and lack of boundary walls to redirect the water flow. Evidently, they failed to associate urban water erosion with the high urban population and the associated dynamics that leads to it. Approaches aimed at sensitising stakeholders need to demonstrate that dynamics contributing to erosion go beyond the immediate features of the area.

Most prevalent dynamics to explain this tendency are those leading to migration and refugee situation in cities, including natural disasters, economic pressure and civil conflicts. For example climate change affects agricultural systems. The inconsistency of rainfall seasons, less amount and distribution of rainfall combined with long dry spells affect the rearing of livestock through the loss of grazing space (Newsham and Thomas 2009; Padgham et al. 2015; Spear et al. 2015), and reduce the outputs of rain fed crop production on which many communities largely depend on (Morton 2007; Cooper et al. 2008; Bannayan et al. 2010; Mongi et al. 2010). For instance, as a result of drought, many people fled from Mexico and Haiti and became refugees in the cities of United States of America such as Florida (Schwartz and Notini 1994; Myers 2002). In terms of political instability, the city of Kampala is home to economic refugees from countries such as South Sudan, Somalia and Ethiopia, who fled war situations (Lyytinen 2015), while Bangkok housed war refugees from Laos and the borders of Malay (Beemer 2016). Other movement trends leading to population increases in urban areas include the search for cultural interactions (Bhugra and Becker 2005), the spread of religions (Hanciles 2003) and the attainment of higher levels of education (Dustmann and Glitz 2011).

The above movements aggravate the process of urbanisation, leading to the fast urban environmental changes, acceleration of water erosion and other environmental problems (Setchell 1995; Esteves and Finkl 1998; Matagi 2002). The movements also deepen the inability of urban centres to provide the necessary developments and services, including the provision of adequate structures for erosion control measures (Bronen 2008; Adamo 2010; Warner 2010). It is therefore considerably noteworthy for urban water erosion approaches to consider raising awareness about the influence of such migration trends on urban environmental systems, as part of long term management solutions for urban erosion.

5. 2 Future research prospective

This study improves the understanding of water erosion in urban areas. However, there is still a need for further studies to seek ways aimed at improving the approaches, validating the findings of this study in other urban areas, or simply using this study as a basis for further improvements on managing urban erosion.

Firstly, the review showed that there is a need for the integration of socio-economic aspects in urban planning when designing water erosion prevention measures and developing water erosion policies. These aspects may include income, education and types of structures. As chapter three demonstrated, these aspects are linked to the impacts in different land management zones occupied by people with different income. These aspects play a major role in the prevention of water erosion effects. The same aspects are largely associated with flood vulnerabilities and they are usually used to help offer advice for urban planning and the management of flooding (Adelekan 2010; Merz et al. 2010; Tas et al. 2013). Therefore examples for including them in erosion management can be tapped from cases of flooding. Furthermore, the review further outlined the need for studies oriented towards the detection of early erosion risk signals. Many water erosion studies have concentrated on rills and gullies, which means that erosion is only addressed when the problem has already become big and visible, and possibly caused damages. To minimise the problem, studies are needed to determine how city managers can identify the signs at much earlier stages and accordingly manage them to avoid environmental and economic losses. The review also stressed the need for studies that explore the reinforcement of the environmental policies, specifically with regards to urban water erosion.

Respectively, the use of a field survey approach proved to be very useful in providing detailed information. For this reason, a study using this approach is needed to quantify the secondary erosion damages to infrastructures. This would possibly help the city managers to realise and understand the economic losses for the city and the individuals. Furthermore, the sampling protocols applied in data collection of the real extent of erosion are unprecedented in terms of its application to a completely urbanised environment. Consequently, its robustness to include urban aspects (for example in even more densely populated areas than Windhoek or in different climate regions) is yet to be demonstrated. The potential to improve the robustness of the analysis component includes having more replica plots (for example minimum of three), in which statistical correlations can be drawn from, and consequently compare the variabilities of the various parameters assessed as in methods used for runoff measurements (for examples De Vente et al. 2008; Vrieling et al. 2008; Meusburger et al. 2010).

In addition, the commonly used USLE equation can be adjusted to be more applicable for urban environments. Adjustments may include changing from applying one value for an entire urban settlement to breaking it down into smaller scales that can be incorporated into the equation as different urban land use / cover, from the detailed urban areas. These include features such as concrete surfaces, footpaths, the gravel or just bare soil areas, areas cleared of vegetation, the various small pockets of vegetation cover and other urban land management practices such as terraces or retaining walls, sand bags, or trenches to divert water as a function of erosion control. These can be made possible by classifying high resolution satellite images such as Quick Bird and ASTER, combined with a thorough ground truthing validation. Such images provide high accuracy of at least 80% (Zuzel and Pikul 1993; Martinez-Mena et al. 1999; Boix-Fayos et al. 2007). Clearly, to improve the equation will require time and finances, especially for the case of doing a thorough ground truthing in bigger metropolitan areas.

Equally, potential studies are defined with regards to the analysis of the stakeholders' perceptions. Studies are needed that can help to break down the communities into even small categories. For instance, a study oriented towards analysing whether or not the age difference might influence perceptions and attitudes is needed. Similarly, people who have owned properties for longer periods might think differently about water erosion than new property owners. In addition, their values with regards to their properties and to the environment might differ, hence there is a need to assess how that would influence their perceptions and attitudes towards the responsibilities for water erosion. Furthermore, the level of education might play a role in the understanding and the perceptions of stakeholders in urban areas. While these information can be used to devise ways for selecting appropriate prevention measures of specific sites, understanding of the communities can also be used for other aspects of the society that might need to be addressed. It is very worthy noting that the mappings corresponded with the stakeholders' knowledge and perceptions in this study, demonstrating that the inputs from the stakeholders are equally sensible and useful. Furthermore, community consultations are likely to reduce conflicts between the communities and the local governments. Conflicts could possibly be brought by the mere fear of how communities' livelihoods might be affected by the local governments' plan when they are not consulted from the beginning.

Evidently, in order to minimise urban water erosion, it is essential for potential solutions to reflect on local, national and international issues leading to urbanisation. This is critical for urban ecosystems, considering that the effects of climate change, the increasingly urbanisation rate and the consequent fast growing of cities are unlikely to decline anytime soon. If actions are not urgently taken to address these diverse dynamics and trends leading to urbanisation, the consequential loss of vast vegetation cover, the subsequent water erosion problems and environmental degradation are likely to continue affecting urban ecosystems in many cities. Possible actions could include decentralising of economic functions to rural areas and provision of more drought resistance agricultural products. Such arrangements would significantly reduce the need to move to urban centres, thereby relieving cities from economic and environmental pressure, which consequently reduce the fast expansion of urban areas. In terms of natural disasters, ecological systems would require in-depth understanding and long-term collective efforts to reverse the negative impacts. To provide slightly quicker remedies for the concurrent water erosion problems, investigations aimed at understanding and improving processes affecting critical cycles and the amount of ecological fluids in urban ecosystems are currently required.

5.3 The proposed next step for Windhoek

The study proposes that the city prioritise the development of a water erosion control plan. This plan could be developed in four main steps. The first step would be to develop water erosion municipal bylaws or policies in which the control plan will be based and also to show how the control plan can be linked to other activities of land management in the city. Currently, the issue of water erosion is completely missing in the existing Town Planning Scheme and in the other legal documents such as environmental and development related policies that regulate the township layouts (outcome of interviews, November 2015). The second step would be to do site inventories and detailed mapping in order to identify the existing aspects of the sites. These include mapping aspects such as land uses, geology, soil type, land contours, hydrology, vegetation drainage patterns, streams, endangered species, water bodies and other environmental aspects. Some of these maps might be already available, hence reducing the amount of work that needs to be carried out. The third step would be to do the data analysis and interpretation of the maps to identify detailed critical areas for water erosion, indicating the strengths and limitations of the sites in relation to water erosion, and what needs to be added or minimised in specific sites. The last step would be to develop the control plan document. This involves determining suitable land uses, stating the limits for clearing and grading, outlining the type and ranges of buildings that could be possibly allowed, indicating the possible courses for the runoff / storm water systems that should be installed, stating the natural spaces to be preserved, determining water erosion control measures and possible soil conservation measures needed.

The control plan should not be for construction activities only, instead it should be applied to all activities which may result in the destabilisation of soil conditions such as those involving filling, grading and excavation activities. The plan would need to be communicated to the public and possibly be translated into main local languages so that the public can easily understand it. Engaging the public from the beginning when developing a water erosion control plan is one way of educating the public and raising awareness. Other possible ways include producing pamphlets and flyers / brochures or attaching information to their water bills and communicating through the meetings in the communities' own structures or through radio programmes once the erosion control plan is formulated. Importantly, the awareness should be centred on sensitising, informing and directing the attention of the public to the importance of the plan and the associated benefits.

5.4 Overall conclusion

The main challenge of understanding and managing urban water erosion is heavily linked to the failure of the practised approaches to go beyond the typical assessment of seemingly environmental aspects involved. The consequential risks of water erosion are far deeper than the apparent interactions of environmental processes. The risks of water erosion result from a combination of complex social, economic and environmental aspects. Therefore, in order to comprehensively understand how urban erosion can be managed, these dynamics have to be well and equally understood.

Realising the diversity of the problems leading to urban water erosion compels urban centres to recognise the magnitude of aspects that need to be reflected on at different scales. It is therefore important to commence approaches for managing urban water erosion by carrying out urban-specific investigations aimed at: (i) scientifically improving natural cycles that influence water storages and nutrients for plants in urbanised dryland ecosystems for managing and improving the vegetation cover, (ii) reducing the problem of water erosion resulting from the interactions of socio-economic-environmental elements despite the seemingly inevitable rapid urban changes, (iii) making use of high resolution satellite images to improve the adopted methods for assessing urban erosion, with the timing of the satellite images being a very crucial point in terms of vegetation cover, (v) developing erosion specific policies and management strategies that incorporate socio-spatial human elements in assessing erosion, and (iv) monitoring various processes leading to water erosion at local, national and international levels.

To conclude, this study has shown that accelerated water erosion is a problem in dryland urban areas. The use of in-depth literature reviews established a fundamental foundation for the research and proved to be immensely useful in establishing the way forward. The use of a combined field survey with the interview approach have allowed the possibility of understanding both environmental and social aspects of water erosion. The study offered a foundation for future research and set the basis for strategies of managing urban water erosion. Therefore, it has successfully laid the important grounds for improving the various approaches needed to observe, monitor and reduce the problem of water erosion in urban areas.

5.5 References

Adamo SB. 2010. Environmental migration and cities in the context of global environmental change. Environ. Sustain. 2:161–165.

Adelekan IO. 2010. Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria. Environ. Urban. 22:433–450.

Aksoy H, Kavvas ML. 2005. A review of hillslope and watershed scale erosion and sediment transport models. Catena 64:247–271.

Amsalu A, de Graaff J. 2006. Farmers' views of soil erosion problems and their conservation knowledge at Beressa watershed, central highlands of Ethiopia. Agric. Human Values 23:99–108.

Ananda J, Herath G. 2003. Soil erosion in developing countries: A socio-economic appraisal. J. Environ. Manage. 68:343–353.

Anigbogu NA. 2001. The Reciprocal Relationship Between Construction and Soil Erosion. J. Environ. Sci. 4:55–59.

Bannayan M, Sanjani S, Alizadeh A, Lotfabadi SS, Mohamadian A. 2010. Association between climate indices, aridity index, and rainfed crop yield in northeast of Iran. F. Crop. Res. 118:105–114.

Beemer B. 2016. Bangkok, Creole City: War Slaves, Refugees, and the Transformation of Culture in Urban Southeast Asia. Lit. Compass 13:266–276.

Bertram S, Broman CM. 1999. Assessment of Soils and Geomorphology in central Namibia. Swedish University of Agricultural Sciences: Minor Field Studies No. 71.

Bhugra D, Becker A. 2005. Migration, cultural bereavement and cultural identity. World Psychiatry 4:18–24.

Boix Fayos C, Martinez-Mena M, Calvo-Cases A, Arnau-Rosalen E, Albaladejo J, Castilo V. 2007. High spatial resolution data acquisition for the geosciences: kite aerial photography. Earth Surf. Process. Landforms 32:85–101.

Bong C, Lau T, Ghani A. 2011. Sediment deposition characteristics of urban concrete drains in Kuching. In: Managing Rivers in the 21st Century: Sustainable Solutions for Global Crisis of Flooding, Pollution and Water Scarcity. p. 712 –720.

Bronen R. 2008. Alaskan communities' rights and resilience. Forced Migr. Rev. 31:30–32.

Bryan RB. 2000. Soil erodibility and processes of water erosion on hillslope. Geomorphology 32:385–415.

Cantón Y, Solé-Benet A, De Vente J, Boix-Fayos C, Calvo-Cases A, Asensio C, Puigdefábregas J. 2011. A review of runoff generation and soil erosion across scales in semiarid south-eastern Spain. J. Arid Environ. 75:1254–1261.

City of Windhoek. 2010. Municipality of Windhoek, Namibia.

Climate-data.org. 2012. http://en.climate-data.org/location/834/. Retrieved 24 August 2016.

Cohen B. 2006. Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. Technol. Soc. 28:63–80.

Colosimo MF, Wilcock PR. 2007. Alluvial Sedimentation and Erosion in an urbanizing wtershed, Gwynns Falls, Maryland. J. Am. Water Resour. Assoc. 43.

Cooper PJM, Dimes J, Rao KPC, Shapiro B, Shiferaw B, Twomlow S. 2008. Coping better with current climatic variability in the rain-fed farming systems of sub-Saharan Africa: An essential first step in adapting to future climate change? Agric. Ecosyst. Environ. 126:24–35.

Cordano M, Frieze IH, Ellis KM. 2004. Entangled affiliations and attitudes: An analysis of the influences on environmental policy stakeholders' behavioural intentions. J. Bus. Ethics 49:27–40.

Cornelis, W. M. (2006). Hydroclimatology of wind erosion in arid and semiarid environments. in Dryland ecohydrology, Chapter 9. Dryland Ecohydrology, DOdorico and A. Porporato (eds.), 141-159. Springer, Netherlands.

Das B. 2011. Stakeholders' perception in identification of river bank erosion hazard: A case study. Nat. Hazards 58:905–928.

De Baets S, Poesen J, Reubens B, Muys B, De Baerdemaeker J, Meersmans J. 2009. High spatial resolution data acquisition for the geosciences: kite aerial photography. Earth Surf. Process. Landforms 34:155–161.

De Vente J, Poesen J, Verstraeten G, Van Rompaey A, Govers G. 2008. Spatially distributed modelling of soil erosion and sediment yield at regional scales in Spain. Glob. Planet. Change 60:393–415.

Duranton G. 2015. Growing through cities in developing countries. World Bank Res. Obs. 30:39–73.

Dustmann C, Glitz A. 2011. Migration and education. Norface Migration, Discussion paper No. 2011-11.

Erdogan EH, Erpul G, Bayramin I. 2007. Use of USLE/GIS methodology for predicting soil loss in a semiarid agricultural watershed. Environ. Monit. Assess. 131:153–161.

Esteves J, Finkl, C W. 1998. Coastal Education & Research Foundation, Inc. J. Coast. Res. 26:39–52.

Evans R. 2002. An alternative way to assess water erosion of cultivated land - Field-based measurements: And analysis of some results. Appl. Geogr. 22:187–208.

Fan C, Li J. 2004. A modelling analysis of urban stormwater flow regimes and their implication for stream erosion. Water Qual. Res. J. Canada 39:356–361.

Feng S, Fu Q. 2013. Expansion of global drylands under a warming climate. Atmos. Chem. Phys. 13:10081–10094.

Fu B-J, Wang Y-F, Lu Y-H, He C-S, Chen L-D, Song C-J. 2009. The effects of land-use combinations on soil erosion: a case study in the Loess Plateau of China. Prog. Phys. Geogr. 33:793–804.

Gaffield SJ, Goo RL, Richards LA, Jackson RJ. 2003. Public Health Effects of Inadequately Managed Stormwater Runoff. Am. J. Public Health 93:1527–1533.

Gaiser T, Stahr K, Billen N, Mohammad M. 2008. Modeling carbon sequestration under zero tillage at the regional scale. I. The effect of soil erosion. Ecol. Modell. 218:110–120.

Gold J, Muller A, Mitlin D. 2001. The principles of local agenda 21 in Windhoek: Collective Action and the Urban Poor. London.

Gray M, Keating J, Moody J, Swan D, Keating J. 2008. Erosion Control in Otjomuise, Namibia.

Greunen S. 2013. Assessing the Resilience of Windhoek on the road to re-defining sustainability. 20th Gen. Assem. Conf. Commonw. Assoc. Archit.:1–12.

Haas J, Ban Y. 2014. Urban growth and environmental impacts in Jing-Jin-Ji, the Yangtze, River Delta and the Pearl River Delta. Int. J. Appl. Earth Obs. Geoinf. 30:42–55.

Hanciles JJ. 2003. Migration and Mission: Some Implications for the Twenty-first-Century Church. Int. Buttletin Mission. Res. 27:146 –153.

Harper S, Maritz N. 1998. The Avis Dam Environment: Greenspace's draft management plan. Windhoek, Namibia.

Heitz C, Spaeter S, Auzet AV, Glatron S. 2009. Local stakeholders' perception of muddy flood risk and implications for management approaches: A case study in Alsace (France). Land use policy 26:443–451.

Herweg K. 1996. Field manual for assessment of current erosion damage. University of Berne.

Huang SL, Yeh CT, Chang LF. 2010. The transition to an urbanizing world and the demand for natural resources. Curr. Opin. Environ. Sustain. 2:136–143.

IPCC. 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

Jimoh HI. 2001. Erosion studies in a Nigerian city: A methodological approach. Environmentalist 21:97–101.

Joubert DF, Rothauge A, Smit GN. 2008. A conceptual model of vegetation dynamics in the semiarid Highland savanna of Namibia, with particular reference to bush thickening by Acacia mellifera. J. Arid Environ. 72:2201–2210.

Khosrokhani M, Pradhan B. 2013. Spatio-temporal assessment of soil erosion at Kuala Lumpur metropolitan city using remote sensing data and GIS. Geomatics, Nat. Hazards Risk 5:252–270.

Kinnell PIA. 2010. Event soil loss, runoff and the Universal Soil Loss Equation family of models: A review. J. Hydrol. 385:384–397.

Knapp AK, Beier C, Briske DD, Classen AT, Luo Y, Reichstein M, Smith MD, Smith SD, Bell JE, Fay PA, et al. 2008. Consequences of More Extreme Precipitation Regimes for Terrestrial Ecosystems. Bioscience 58:811.

Kötter T, Friesecke F. 2007. Developing urban Indicators for Managing Mega Cities.

Labbe N, Mcbride N, Ray E. 2006. Flooding and Erosion Control in the Informal Settlements of Windhoek, Namibia.

Lahnsteiner J, Lempert G. 2007. Water management in Windhoek, Namibia. Water Sci. Technol. 55:441–448.

Lal R. 1997. Degradation and resilience of soils. Philos. Trans. R. Soc. B Biol. Sci. 352:997–1010.

Lal R. 1998. Soil erosion impact on agronomic productivity and environment quality. CRC. Crit. Rev. Plant Sci. 17:319–464.

Lal R. 2001. Soil degradation by water erosion. L. Degrad. Dev. 539:519–539.

Lange A, Siebert R, Barkmann T. 2015. Sustainability in Land Management: An Analysis of Stakeholder Perceptions in Rural Northern Germany. Sustainability 7:683–704.

Le Roux JJ, Morgenthal T, Malherbe J. 2008. Water erosion prediction at a national scale for South Africa. Water SA 34:305–314.

Leh M, Bajwa S, Chaubey I. 2013. Impact of Land Use Change on Erosion Risk: An Integrated Remote Sensing, Geographic Information System and Modeling Methodology. L. Degrad. Dev. 424:409–421.

Ligonja PJ, Shrestha RP. 2013. Soil Erosion Assessment in Kondoa Eroded Area in Tanzania Using Universal Soil Loss Equation, Geographic Information Systems and Socioeconomic Approach. L. Degrad. Dev. 26:367 – 379.

Lyytinen E. 2015. Congolese refugees' "right to the city" and urban (in) security in Kampala, Uganda. J. East. African Stud. 9:593–611.

Mapani BS, Schreiber U. 2008. Management of city aquifers from anthropogenic activities: Example of the Windhoek aquifer, Namibia. Phys. Chem. Earth 33:674–686.

Martinez-Mena M, Alvarez Rogel J, Albaladejo J, Castillo VM. 2000. Influence of vegetal cover on sediment particle size distribution in natural rainfall conditions in a semiarid environment. Catena 38:175–190.

Matagi SV. 2002. Some issues of environmental concern in Kampala, the capital city of Uganda. Environ. Monit. Assess. 77:121–138.

McHugh M, Harrod TR, Morgan RPC. 2002. The extent of soil erosion in upland England and Wales. Earth Surf. Process. Landforms 28:99–107.

McLeman R, Smit B. 2006. Migration as an adaptation to climate change. Clim. Change 76:31–53.

Mendelsohn J, Jarvis A, Roberts C, Robertson T. 2002. Atlas of Namibia: A Portrait of Land and its People. SA: David Philip Publ.

Merz B, Kreibich H, Schwarze R, Thieken A. 2010. Assessment of economic flood damage. Nat. Hazards Earth Syst. Sci. 10:1697–1724.

Meusburger K, Bänninger D, Alewell C. 2010. Estimating vegetation parameter for soil erosion assessment in an alpine catchment by means of QuickBird imagery. Int. J. Appl. Earth Obs. Geoinf. 12:201–207.

Mitter H, Kirchner M, Schmid E, Schoenhart M. 2014. The participation of agricultural stakeholders in assessing regional vulnerability of cropland to soil water erosion in Austria. Reg. Environ. Chang. 14:385–400.

Miyata S, Kosugi K, Nishi Y, Gomi T, Sidle RC, Mizuyama T. 2010. Spatial pattern of infiltration rate and its effect on hydrological processes in a small headwater catchment. Hydrol. Process. 24:535 – 549.

Mongi H, Majule AE, Lyimo JG. 2010. Vulnerability and Adaptation of Rain Fed Agriculture to Climate Change and Variability in semi-arid Tanzania. African J. Environ. Sci. Technol. 4:371–381.

Morgan RPC. 1995. Soil Erosion and Conservation. Essex, England: Longman, 3.

Morton JF. 2007. The impact of climate change on smallholder and subsistence agriculture. Proc. Natl. Acad. Sci. U. S. A. 104:19680–5.

Mukundan R, Pradhanang SM, Schneiderman EM, Pierson DC, Anandhi A, Zion MS, Matonse AH, Lounsbury DG, Steenhuis TS. 2013. Suspended sediment source areas and future climate impact on soil erosion and sediment yield in a New York City water supply watershed, USA. Geomorphology 183:110–119.

Mutekanga F, Kessler A, Leber K, Visser S. 2013. The Use of Stakeholder Analysis in Integrated Watershed Management : Experiences From the Ngenge Watershed, Uganda. Mt. Res. Dev. 33:122–131.

Myers N. 2002. Environmental refugees: a growing phenomenon of the 21st century. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 357:609–13.

National Planning Commission. 2012. Namibia 2011 Population and Housing Census Preliminary Results. Windhoek, Namibia.

Nearing MA, Pruski FF, O'Neal MR. 2004. Expected climate change impacts on soil erosion rates: A review. Journal Soil Water Conserv. 59:43 – 50.

Newsham A, Thomas D. 2009. Agricultural adaptation, local knowledge and livelihoods diversification in North-Central Namibia. Tyndall Cent. Clim. Chang. Res.:1–48.

Omon EJ, Ogheneruemusua GJ. 2014. Evaluating soil erosion in the Benin metropolis, Edo. Int. J. Phys. Sci. 2:38–45.

Ozcan AU, Erpul G, Basaran M, Erdogan HE. 2008. Use of USLE/GIS technology integrated with geostatistics to assess soil erosion risk in different land uses of Indagi Mountain Pass - Cankiri, Turkey. Environ. Geol. 53:1731–1741.

Padgham J, Abubakari A, Ayivor J, Dietrich K, Fosu-Mensah B, Gordon C, Habtezion S, Lawson E, Mensah A, Nukpezah D, et al. 2015. Vulnerability and Adaptation to Climate Change in the Semi-Arid Regions of West Africa. The Global Dryland Initiative, UNDP.

Paterson RG, Luger MI, Burby RJ, Kaiser EJ, Malcom HR, Beard AC. 1993. Costs and benefits of urban erosion and sediment control: The North Carolina experience. Environ. Manage. 17:167–178.

Pickett STA, Cadenasso ML, Grove J, Nilon CH, Pouyat R V, Zipperer WC, Costanza R. 2008. Urban ecological systems: Linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. Urban Ecol. An Int. Perspect. Interact. Between Humans Nat.:99–122.

Pimentel D, Kounang N. 1998. Ecology of Soil Erosion in Ecosystems. Ecosystems 1:416–426.

Pimentel D. 2006. Soil erosion: A food and environmental threat. Environ. Dev. Sustain. 8:119–137.

Poesen J, Nachtergaele J, Verstraeten G, Valentin C. 2003. Gully erosion and environmental change : importance and research needs. Catena 50:91–133.

Portnov BA, Paz SA. 2008. Climate Change and Urbanization in Arid Regions. Ann. Arid Zone 47:1–15.

Pradhan B, Chaudhari A, Adinarayana J, Buchroithner MF. 2012. Soil erosion assessment and its correlation with landslide events using remote sensing data and GIS: A case study at Penang Island, Malaysia. Environ. Monit. Assess. 184:715–727.

Prasannakumar V, Vijith H, Abinod S, Geetha N. 2012. Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. Geosci. Front. 3:209–215.

Reich P, Eswaran H, Beinroth F. 2001. Global Dimensions of Vulnerability to Wind and Water Erosion. Sustain. Glob. farm.: 838–846.

Reidsma P, Ewert F, Lansink AO, Leemans R. 2010. Adaptation to climate change and climate variability in European agriculture: The importance of farm level responses. Eur. J. Agron. 32:91–102.

Rejman J, Turski R, Paluszek J. 1998. Spatial and temporal variations in erodibility of loess soil. Soil Tillage Res. 46:61–68.

Reynolds JF, Smith DMS, Lambin EF, Turner BL, Mortimore M, Batterbury SPJ, Downing TE, Dowlatabadi H, Fernandez RJ, Herrick JE, et al. 2007. Global Desertification: Building a Science for Dryland Development. Science. 316:847–851.

Rowntree KM, Natsaba MM, Weaver AVB. 1991. Changing Patterns of Erosion in a Peri-Urban Catchment, Maseru, Lesotho. In: Sediment and Stream Water Quality in a Changing Environment: Treds and Explaination. p. 93 –102.

Sathler R, Guerra AJT, Polivanov H, Marçal MDS. 2005. Erosive Processes in Urban Areas in the Island of Maranhão - Brazil. Soc. Nat. 1:161–173.

Schwartz ML, Notini J. 1994. Desertification and migration: Mexico and the United States. US. Commission on Immigration Reform.

Sennes V, Gombert-Courvoisier S, Ribeyre F, Felonneau M-L. 2012. Citizens' environmental awareness and responsibility at local level. Int. J. Urban Sustain. Dev. 4:186–197.

Setchell C. 1995. The growing environmental crisis in the world's mega cities: the case of Bangkok. A third World Plan. Rev. 17:1689–1699.

Shikangalah RN, Jeltsch F, Blaum N, Mueller EN. 2016. A Review on Urban Water Erosion. J. Stud. Humanit. Soc. Sci. 5: 163 - 178.

Shuster WD, Bonta J, Thurston H, Warnemuende E, Smith DR. 2005. Impacts of impervious surface on watershed hydrology: A review. Urban Water J. 2:263–275.

Sietchiping R. 2000. Understanding Informal Urban Patterns By Integrating Geographical Information Systems (GIS) And Cellular Automata (CA) Modelling. Icstm.

Spear D, Baudoin M, Hegga S, Zaroug M, Okeyo A, Haimbili E. 2015. Vulnerability and Adaptation to Climate Change in the Semi-Arid Regions of Southern Africa. The Global Dryland Initiative, UNDP.

Spencer KL, Droppo IG, He C, Grapentine L, Exall K. 2011. A novel tracer technique for the assessment of fine sediment dynamics in urban water management systems. Water Res. 45:2595–2606.

Strahle AH. 2010. Introducing Physical Geography. (5th ed). Chichester: John Wiley & Sons

Tamim A, Pallu S, Wunas S, Baja dan S. 2012. Soil Erosion in the Urban Catchment Area of Baubau City, Indonesia. Int. J. Eng. Innov. Techology 2:421–425.

Tas M, Tas N, Durak S, Atanur G. 2013. Flood disaster vulnerability in informal settlements in Bursa, Turkey. Environ. Urban. 25:443–463.

Tooth S. 2000. Process, form and change in dryland rivers: A review of recent research. Earth Sci. Rev. 51:67–107.

Tredoux G, Van Der Merwe B, Peters I. 2009. Artificial recharge of the Windhoek aquifer, Namibia: water quality considerations. Bol. Geol. y Min. 120:269–278.

Uni-Koeln 2003. http://www.uni-koeln.de/sfb389/e/e1/download/atlas_namibia/e1_download_physical_geography_e.htm. Retrieved 25 August 2016.

United Nations. 2012. World Urbanization Prospects: The 2011 Revision. New York.

Valentin C, Poesen J, Li Y. 2005. Gully erosion: Impacts, factors and control. Catena 63:132–153.

Vásquez-Méndez R, Ventura-Ramos E, Domínguez-Cortázar MA. 2011. Soil Erosion Processes in Semi-Arid Areas: The Importance of Native Vegetation. INTECH Open Access Publ. 1:25 – 41.

Verón S., Paruelo JM, Oesterheld M. 2006. Assessing desertification. J. Arid Environ. 66:751–763.

Vrieling A, de Jong SM, Sterk G, Rodrigues SC. 2008. Timing of erosion and satellite data: A multi-resolution approach to soil erosion risk mapping. Int. J. Appl. Earth Obs. Geoinf. 10:267–281.

Vrieling A. 2006. Satellite remote sensing for water erosion assessment: A review. Catena 65:2–18.

Wang G, Innes J, Yusheng Y, Shanmu C, Krzyzanowski J, Jingsheng X, Wenlian L. 2012. Extent of soil erosion and surface runoff associated with large-scale infrastructure development in Fujian Province, China. Catena 89:22–30.

Warner K. 2010. Global environmental change and migration: Governance challenges. Glob. Environ. Chang. 20:402–413.

Wei W, Chen L, Yang L, Fu B, Sun R. 2012. Spatial scale effects of water erosion dynamics: Complexities, variabilities, and uncertainties. Chinese Geogr. Sci. 22:127–143.

Wischmeier W, Smith D. 1978. Predicting Rainfall erosion losses - a guide to conservation planning. U.S. Department of Agriculture, Agriculture Handbook No. 537. Beltville, Maryland, USA.

Yair A, Raz-Yassif N. 2004. Hydrological processes in a small arid catchment: Scale effects of rainfall and slope length. Geomorphology 61:155–169.

Yang D, Kanae S, Oki T, Koike T, Musiake K. 2003. Global potential soil erosion with reference to land use and climate changes. Hydrol. Process. 17:2913–2928.

Zhang J, Murray R, Tredoux G. 2004. Regional Fractured Aquifer Modelling using Telescopic Mesh Refinement (TMR) Method. Proc. 2004 Water Inst. South. Africa Bienn. Conf.:351–359.

Zhongming W, Lees BG, Feng J, Wanning L, Haijing S. 2010. Stratified vegetation cover index: A new way to assess vegetation impact on soil erosion. Catena 83:87–93.

Zuzel JF, Pikul Jr JL. 1993. Effects of straw mulch on runoff and erosion from small agricultural plots in northeastern Oregon. Soil Sci. 156:111–117.

Acknowledgement

Foremost, I would like to thank my Almighty God for seeing me through. Furthermore, I want to thank my supervisors for their amazing and endless support that enabled me to do this thesis. Prof. Jeltsch for your encouragement even when the situation seemed impossible; for your advice, for always being there, and for all your time to read and comment on the manuscripts. Prof. Paton, for your amazing support and critiques, for making time for me throughout the stay, for putting up with my downs and for being patient. PD Dr. Blaum, for this opportunity and for your positive communication with DAAD throughout. Furthermore, I am very grateful for the funding by DAAD and the German Federal Ministry of Education and Research (BMBF) in the framework of the OPTIMASS project (01LL1302A). In addition, I want to thank Theo Alugodhi, for your help with the maps and Jennifer Keyserli for all your immediate help and time. I also want to express my profound appreciation to Mr. Joseph Ihula, for all your encouragement and for being there. To my sister Ingemary Shikangalah, cousins and friends, thanks for being there throughout. Lastly, to the University of Namibia for giving me time off to study, thank you.

Declaration of authorship

This thesis is prepared without any illegal use and it is original except for the shares of co-authors in papers submitted to the journals (chapter 2, 3 & 4) and, where references are indicated. The thesis has not been submitted for any other degree and to any other University or other higher learning institutions.

____

Rosemary Ndawapeka Shikangalah

Potsdam, Germany, September 2016