A review on urban soil water Erosion

Rosimary N. Shikangalah, Florian Jeltsch,
Niels Blaum and Eve N. Mueller*
University of Potsdam, Germany.

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 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 identifies limitations in methods employed, and gaps in focal research topics and urban-specific management strategies. In particular, the paper argues that approaches oriented towards minimising 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.

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 has significantly escalated in the last couple of decades, consequential to the rapid population growth and diverse human activities (Cantón, et al., 2011). Currently, 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 worldwide has been affected by soil degradation as a result of human activities (Lal, 2001; Pimentel &

* **Rosemary N. Shikangalah** is a PhD student at Universität Potsdam, Institute for Biochemistry and Biology, Department of Plant Ecology and Nature Conservation, Am Mühlenberg 3, 14476 Potsdam - Golm, Germany.. Email: rosemaryihula@gmail.com

Prof. Dr Florian Jeltsch is the Head of Department of Plant Ecology and Nature Conservation, Institute for Biochemistry and Biology, Am Mühlenberg 3, 14476 Potsdam - Golm, Germany. Email: jeltsch@uni-potsdam.de
PD. Dr Niels Blaum is a lecturer at Universität Potsdam, Institute for Biochemistry and Biology, Department of Plant Ecology and Nature Conservation, Am Mühlenberg 3, 14476 Potsdam - Golm, Germany. Email: blaum@uni-potsdam.de

Dr. Eve Nora Paton is a professor at Technische Universität Berlin, Department of Ecohydrology and Landscape Evaluation, Ernst-Reuter-Platz 1, 10587 Berlin, Germany. Email: eva.paton@tu-berlin.de

Authors to whom correspondence should be addressed: Emails: rosemaryihula@gmail.com and rshikangalah@gmail.com Tel: +49 152 52 152 002.

Volume 5, Number 1, 2016 - ISSN 2026-7215

Kounang, 1998). These areas include 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 (United Nations, 2012). This urbanisation process is further accelerated by climatic changes. Particularly 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 (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. 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 analysed the specific types of erosion explored, the different methods engaged in the studies and lastly the consideration of specific environmental factors influencing erosion.

3. Results

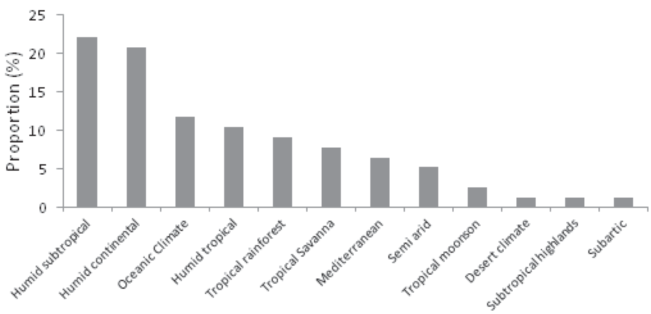

Figure 1: The proportion of publications in specific climate regions

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).

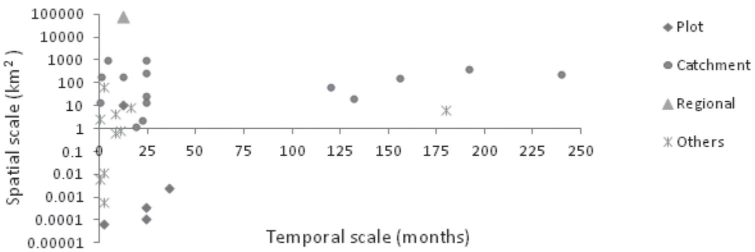

Figure 2: Distribution of scales employed. ***Although often scales overlap, a 'plot' scale ranges from areas of 0.01m² to 10 000m², a 'catchment' scale ranges from less than 1km² to several hundreds of km² while a 'regional' scale refers to areas larger than a catchment (Wei et al., 2012). 'Others' 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 scales. At micro scales, the damage extended to single unit properties within a settlement, especially during flooding (see 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 activity 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).

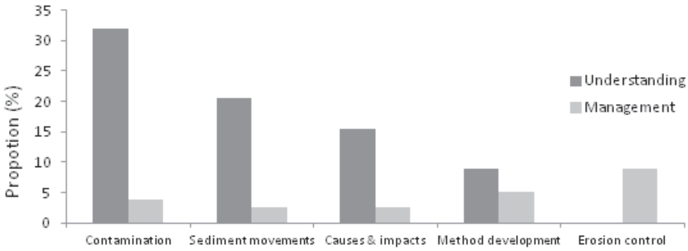

Figure 3: Focal research topics addressed in the publications

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 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 automobile 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%) (see 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 average 85% of sediments, whereas gulling walls contributed 10% and agricultural areas added 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).

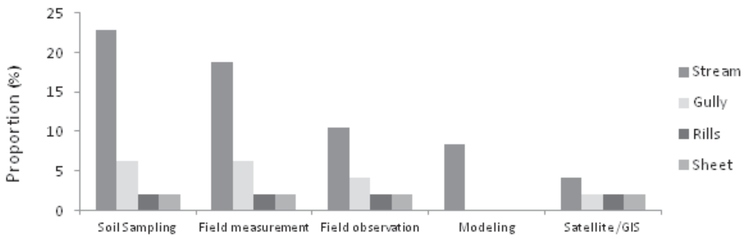

Figure 4: Methods and types of urban erosion researched

The type of erosion primarily studied, 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, aimed at understanding the processes of sediment transport in runoff over grass, was based on laboratory experiments (Deletic, 2005).

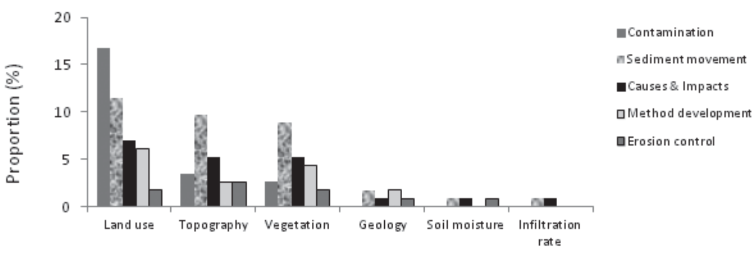

Figure 5: Key factors considered in erosion studies in relation to focal research areas

The most frequently considered influencing factors in the reviewed soil erosion studies, included land use (43%), topography (24%) and vegetation cover (23%) (Fig. 5). Surprisingly, independent from the focal research topic of the study, the important soil-related factors influencing erosion (i.e. geology, soil moisture and infiltration rate) were only rarely or not at all considered. Examples of studies that had not considered the related soil properties included investigations on urbanised 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 to 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).

4. Discussion

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 developping 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 majority of cities in Africa and Asia are experiencing rapid population growth, brought about by the dramatic increase of urbanization, due to global warming and decrease of annual precipitation (Portnov & Paz, 2008; United Nations, 2012). Despite this high relevance, the developing regions, and more especially Africa, have received very limited attention regarding urban water erosion studies to date. This holds true even 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.

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 (Figs 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 the 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 a regional scale have received ample attention since the 1990s (De Vente, Poesen, Verstraeten, Van Rompaey, & Govers, 2008).

4.3 Research approaches

Interestingly, modern methods in erosion research, such as satellite based studies, GIS and computer modeling, are 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, such as streams. Addressing this variability would require further refinement of the model or the integration of new approaches. Similar concerns in terms of applicability also apply to the CREAMS model (Aksy & Kavvas, 2005). Even though it has been adjusted for the 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 contexts. 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 analysing storm-based events even 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 analysing severe storm events (Borah & Bera, 2003). This is problematic since such events are critical in urban areas, and are often leading to flash flooding, which especially occurs in areas with inefficient drainage systems.

Even though current models disregard some of the important factors for the urban environment, the integration of various modeling approaches generally 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 parameterisation and testing (Merritt, et al., 2003).

4.4 Focal factors and processes

The specific approach applied clearly determines the influencing factors considered. Fig. 5 indicates 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 physically-based model approaches of erosion (Venkatesh, Lakshman, Purandara, & Reddy, 2011). The lack of such an in-depth understanding of underlying processes implies that the more complex dynamics of urban water erosion is insufficiently resolved. This clearly also hampers the management of erosion risks in urban areas.

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 urbanisation (Kates & Parris, 2003; Seto, Guneralp, & Hutyra, 2012). Consequent damages to society and to critical environmental systems could be close to 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 a 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 the 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 the development of strong and long lasting management measures.

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 minimisation. To start with, only a 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 socio-economic 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, and 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, the stakeholders' understanding and perception of water erosion are hardly considered, even though such information can be very instrumental in developing applicable solutions for the affected communities.

To conclude, urban-specific interdisciplinary studies that (i) systematically explore all underlying factors and drivers that influence erosional processes across scales, (ii) careful evaluate the applicability of different approaches adapted, and (iii) better integrate modern approaches such as remote sensing, GIS and urban-specific process-based computer modeling are urgently needed. Further, more research should be oriented towards (iv) the detection of early erosion risk signals, (v) the 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 on understanding the views and perceptions of the local communities with regard to water erosion.

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 Texas , Part 1. *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

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 watershed, 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. Vol. 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

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 erosion: 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., & 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.

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 cllimate 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 explanation*. (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. Presentation at the Center for Strategic and Urbanization.* 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