Chapter

Introductory Chapter: Soil Erosion at a Glance

Konstantinos Kaffas and Vlassios Hrissanthou

1. Introduction

Wind and precipitation are the two weather elements prevailing as the generating causes of soil erosion, inducing the so-called wind erosion and water erosion. While erosion by wind is internationally termed wind erosion, erosion caused by water can be found by a variety of definitions, such as water erosion, sheet erosion, surface erosion, rill erosion, interrill erosion, land erosion, and soil erosion. Most frequently, it is referred to as soil erosion and as such will be denoted in the present chapter. Despite the fact that there is ample literature on both erosion types and though wind erosion is a major environmental problem, especially in large open areas, with sparse vegetation and loose soils, modelers have put appreciably greater effort on studying soil erosion as a hydrologically-driven magnitude. This short review is dedicated to soil erosion, aiming to report some key information on its background and modeling.

1.1 Definition of the problem

Soil erosion, globally recognized as the main cause of land degradation, is the physical phenomenon, triggered by rainfall, during which soil particles are detached from the soil mass and washed downslope by surface runoff. Sediment is detached from soil surface both by the raindrop impact and shearing force of flowing water [1]. Thus, soil erosion is mainly due to rainfall and runoff. Erosion due to rainfall, also known as splash erosion, is the first stage in the water erosion process. At this stage, raindrops act like little bombs detaching soil particles and destroying soil structure [2]. Subsequently, the detached soil particles are carried away by the flowing water and the soil can be further eroded, depending on the runoff's transport capacity. At this point, reasonable questions are raised: What happens to the soil surface when soil is continuously removed, due to erosion by wind, rainfall and runoff? Would not that lead to constant drop of soil surface level? And what effect would that have to plants, ecosystems, and humans? The answer is that as soil gets eroded and removed, it is also formed by the physical, chemical and biological weathering of rocks. Ultimately, it could be stated that there is a permanent soil loss when soil is removed at rates greater than the ones it is formed.

Among the obvious consequences are soil loss and changes in the land surface morphology; yet, the implications go much deeper. It is well documented that soil erosion leads to decline of soil fertility and to considerable loss of productive cultivated and arable land or even to desertification, with serious socioeconomic effects [3–8]. A degradation of physical properties of soil involves a decline in soil structure resulting to an increase in bulk density, decrease in total macroporosity, reduction in infiltration, and increase in surface runoff and, finally, in aggravation of soil erosion by water [9]. Apart from the effects on soil fertility, soil development, soil degradation, and soil diversity [10], an eroded and fractured soil can ease the deep percolation of water and sediments to the aquifer. Moreover, surface runoff washes down toward the stream network, carrying sediments that have been previously abstracted from the soil. As stated by Unger and McCalla [11], water erosion is a major contributor to water pollution. Hence, groundwater and surface water contamination by influx of rain water and sediments, which can be carriers of polluting factors, is a further side effect, especially in agricultural basins where fertilizers and pesticides are in use. Generally, soil erosion is directly connected to a series of environmental issues, such as problems with the vegetation growth, increase of soil acidity levels, muddy floods, etc.

It would not be an exaggeration to say that the effects of soil erosion are more evident in the adjacent fluvial systems than in the soil surface itself. The greatest part (more than 90%, many times) of the instream sediment derives from sediment inflow as the product of rainfall and runoff erosion. Thus, a river, in effect, can be considered a body of flowing sediments as much as one of flowing water [12]. Depending on the hydraulic conditions and the sediment transport capacity of streamflow, this sediment gets deposited or/and transported downstream, unceasingly embroidering the morphological profile of rivers and streams. The influx of erosion yields to the streams has positive and negative impacts. Aside from what was discussed above regarding potential contaminations, sediments are also carriers of nutritional factors, necessary for the thriving of riparian and fluvial ecosystems. A balanced amount of deposition provides the appropriate grounds of spawning for fish and macroinvertebrates. Contrarily, excessive sedimentation can cause changes in faunal assemblages, the decline of macrophyte growth, and the clogging of spawning gravel [13] or even, effectively, ravage their natural habitats. Excessive deposition can cause increase of flood events, by diminishing the cross-sectional areas. High concentrations of sediment—as a product of soil erosion—in rivers can lead to degradation of water quality, which in turn would result in an increase of water treatment costs. Sediment transport, also, greatly affects the morphology of the shoreline and the coastal zones. According to Samaras and Koutitas [14], coastal areas are subject to "pressures" from upstream watersheds in terms of sediment transport.

Soil erosion, implicitly, takes a toll on hydraulic structures, such as reservoirs and hydroelectric schemes. Sediments constitute—even today—the worst implication associated with dams, due to excessive sedimentation which leads to a considerable storage loss. Even when sediment flushing is a viable solution for recovering and maintaining storage capacity of small- to medium-sized hydropower reservoirs, observations have documented significant environmental damage due to sediment release downstream [15, 16]. According to Cui et al. [17], the accumulation of fine sediment in reservoirs and the potential impact of sediment flushing constitute even a cause for dams to be removed in some cases. It is true that in several cases, dams are decommissioned or even abandoned due to sedimentation (Nizam Sagar dam, Katteri dam, Bhakra dam (India), Sanmenxia dam (China), Peligre dam (Haiti), Melton dam, Umberumberka dam (Australia), and others [18]). This is, obviously, not attributed to manufacturing defects but to failed prediction of the sediment discharge at the location of the dam, prior to its construction, in other words, to the underestimation of soil erosion and sediment discharge of basins drained by dams.

1.2 Factors influencing soil erosion

In order to assess if and under what conditions erosion will take place, a critical question has to be answered: are all soils equally prone to erosion?

As to their susceptibility to erosion, soils can be placed into a spectrum ranging from erodible to non-erodible. Erodible are usually characterized non-cohesive soils with little or no resistance to erosion, while non-erodible are soils notably less susceptible to erosion. This characterization is made on the basis of the physical properties of soil, alone, regardless any exogenous factors like land cover, land use, or support practices. Studies on the physical properties of soil have shown that soil texture (sand, silt, clay content) and organic matter play an important role to soil erodibility [19–23]. According to Wischmeier and Mannering [24], a soil's inherent erodibility is a complex property dependent both on its infiltration capacity and its capacity to resist detachment by rainfall and transport by runoff. Thus, the effect of soil characteristics can be observed in two consecutive stages, first being the endurance of soil to the raindrop impact and its resistance to detachment. The more concrete is the structure of the soil, the more armored it is against splash erosion. The second stage initiates with surface runoff, when the intensity of rainfall exceeds the infiltration capacity of the soil. Most relevant studies point out silt as the main culprit for soil susceptibility to erosion. In fact, the effect of the silt content in a soil is such that it can itself be a regulating factor of the soil's erodibility. Wischmeier and Mannering [24] report that a soil type becomes less erodible with decrease in silt fraction, regardless of whether the corresponding increase is in the sand fraction or the clay fraction. Generally, silty and sandy soils with low content in clay and organic matter are known to be more prone to erosion [23–25]. For a better comprehension of soils' texture, FAO's World Reference Base for Soil Resources [26] provides particle classes, according to their size (**Table 1**).

Despite being well-aggregated, silty soils suffer a collapse of their aggregations when wetted, allowing the non-aggregated fine particles to be easily transported by runoff [22]. Sandy soils are, also, susceptible to detachment due to their low cohesion, but their high permeability to water, resulting in low runoff rates, in combination with their large size and density, makes it difficult to transport by runoff. Clayey soils are characterized by high cohesion and low infiltration rates; they are very resisting to detachment but are easily transported, once detached from the soil body.

Despite what was discussed above, soil erosion processes are characterized by even greater complexity. An ensemble of additional parameters, such as land cover type, land use practices, weather conditions, etc., influences soil erosion at a large extent. As shown by Morin and Benyamini [27], the antecedent moisture conditions, as well as the duration and intensity of rainfall, play an important role and cannot be ignored. It is well-known that the denser the land cover and canopy, the more the raindrop impact, and thus the erosive force of rainfall is contained. Mohammad and Adam [28] support that the lowest runoff and soil erosion rates are associated with the forest and with natural vegetation. The effect of land cover

Soil texture	Diameter limits (mm)
Very coarse sand	1.25–2.00
Coarse sand	0.63–1.25
Medium sand	0.20–0.63
Fine sand	0.125–0.20
Very fine sand	0.063–0.125
Coarse silt	0.02–0.063
Fine silt	0.002–0.02
Clay	<0.002

Table 1.
Particle size classes (WRBSR-FAO).

and land use practices on soil erosion at the basin scale has been well documented—among others—in [28–31].

As stated—very early—by Middleton [19], all soils are somewhat susceptible to erosion by runoff water. Thus, reliable information on soil erosion rates is an essential prerequisite for the design of targeted erosion and sediment control strategies [32].

2. Review of literature

What is mentioned in the previous sections dictates the necessity for soil erosion quantification and highlights soil erosion modeling as the utmost vital action taken, in the context of an integrated management at the basin scale.

Soil degradation by accelerated erosion is a serious problem and will remain so during the twenty-first century. Soil erosion prediction and assessment have been a challenge to researchers since the 1930s, and several models have since been developed [33]. However, the treatment of soil erosion in the form of soil conservation plans has made its appearance long before that, in the early nineteenth century. As stated by Dotterweich [34], the first extensive essay on soil conservation known to the western world was published in Germany in 1815, while the rise of professional soil conservation occurred in the late nineteenth and early twentieth centuries. Substantially, the first decades of the nineteenth century can be considered as the outset of the profound understanding and studying of the phenomenon of soil erosion. It is remarkable that the third president of the United States, Thomas Jefferson, in one of his letters in 1813 [35], demonstrates his awareness of the on- and off-site effects of soil erosion, the role of runoff in soil erosion, and the interaction of soil conservation, hydrology, and crop production, important scientific topics today in understanding, predicting, and modeling soil erosion, 200 years later [36].

The most significant, and groundbreaking for that time, theory regarding soil erosion was introduced in 1899 by Davis. His theory, known as cycle of erosion [37], is an idealized model for stream erosion and landscape development in which stream erosion occurs in a gradual sequence of stages (young, mature, and old). During these stages, the soil surface erodes up to the point it becomes a peneplain. Davis' cycle of erosion dominated in geomorphology for more than half a century.

After 1950, the Davisian theory began to be questioned. Among those who challenged it was Chorley [38, 39] who rejected the Davisian cycle of erosion and suggested a quantitative method based on general system theory and numerical modeling. King has also tried to dispute the Davisian cycle of erosion [40, 41]; however, his theories did not manage to escape the Davisian cyclical nature. According to Bishop [42], the dissatisfaction was embodied in Strahler's [43] call for radical change and the embracing of a new approach and underpinning concepts, ultimately taking the discipline into spatial and temporal scales much reduced from the grand vision and sweeping canvas of Davis and his disciples. Strahler's call is now being heard in long-term landscape evolution as geomorphology embraces quantitative and geochemical analytical approaches to the sorts of questions that Davis sought to address [42].

Boardman [44] highlights some of the most notable and influential advances of the recent past, among which are the following: Trimble [45] with its emphasis on sediment storage and the relationship between erosion on the hillslopes and the role of the valley-bottom stream; Govers' and Poesen's [46] empirical study of rill and interrill areas; De Ploey's [47] attempt to categorize eroding western European landscapes; and Blaikie's [48] recognition that degradation occurs because of people-land relationships often involving social and economic opportunities and constraints [44].

The Universal Soil Loss Equation (USLE) [49] is one of the most significant advances in soil and water conservation in the twentieth century. It has been applied in almost all the kinds of climatic conditions and types of soils around the globe, as an individual model, while it also constitutes an important component of many models and hydromorphological softwares. Since then, there have been many parallaxes and modifications of USLE, the most known of which are the Modified Universal Soil Loss Equation (MUSLE) [50] and the Revised Universal Soil Loss Equation (RUSLE) [51].

The evolution of the soil erosion and the sediment transport modeling has consistently followed the evolution of technology. In the last few decades, there has been a hectic advancement in the domain of soil erosion modeling, as a result of the advancements in computer science. This resulted in the development of a plethora of integrated models that—in many cases—fully address the study of the hydromorphological processes. There is a wide range of integrated models that simulate the runoff, the soil erosion, and the stream sediment transport processes, on a continuous (long-term) or on an event-time basis. Some notorious examples, with a prominent position in literature, are the following: the Agricultural Nonpoint Source (AGNPS) model [52], the Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS) model [53], the Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS) [54], the Soil and Water Assessment Tool (SWAT) [55, 56], the European Soil Erosion Model (EUROSEM) [57], the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) [58], and the Watershed Erosion Prediction Project (WEPP) [59]. These models have been applied both stand-alone and as a part of integrated mathematical models, to model the sedimentary cycle [60–63].

Author details

Konstantinos Kaffas[1*] and Vlassios Hrissanthou[2]

1 Faculty of Science and Technology, Free University of Bozen-Bolzano, Bozen-Bolzano, Italy

2 Department of Civil Engineering, Democritus University of Thrace, Xanthi, Greece

*Address all correspondence to: konstantinos.kaffas@unibz.it

References

[1] Jain MK, Das D. Estimation of sediment yield and areas of soil erosion and deposition for watershed prioritization using GIS and remote sensing. Water Resources Management. 2010;**24**(10):2091-2112. DOI: 10.1007/s11269-009-9540-0

[2] Cotching WE. Soil Health for Farming in Tasmania. Devonport, Tasmania: Richmond Concepts and Print; 2009

[3] Lal R. Soil Erosion Research Methods. 3rd ed. Ankeny, IOWA: Soil and Water Conservation Society; 1994

[4] Koulouri M, Giourga C. Land abandonment and slope gradient as key factors of soil erosion in Mediterranean terraced lands. Catena. 2007;**69**(3):274-281. DOI: 10.1016/j.catena.2006.07.001

[5] Çetin SC, Karaca A, Haktanır K, Yildiz H. Global attention to Turkey due to desertification. Environmental Monitoring and Assessment. 2007;**128**(1-3):489-493. DOI: 10.1007/s10661-006-9342-2

[6] Panagos P, Standardi G, Borrelli P, Lugato E, Montanarella L, Bosello F. Cost of agricultural productivity loss due to soil erosion in the European Union: From direct cost evaluation approaches to the use of macroeconomic models. Land Degradation and Development. 2018;**29**(3):471-484. DOI: 10.1002/ldr.2879

[7] Novara A, Pisciotta A, Minacapilli M, Maltese A, Capodici F, Cerdà A, et al. The impact of soil erosion on soil fertility and vine vigor. A multidisciplinary approach based on field, laboratory and remote sensing approaches. Science of the Total Environment. 2018;**622**:474-480. DOI: 10.1016/j.scitotenv.2017.11.272

[8] Chalise D, Kumar L, Spalevic V, Skataric G. Estimation of sediment yield and maximum outflow using the IntErO model in the Sarada River Basin of Nepal. Water. 2019;**11**(5):952. DOI: 10.3390/w11050952

[9] Lal R, editor. Soil erosion by wind and water: Problems and prospects. In: Soil Erosion Research Methods. New York, USA: Routledge; 2017. pp. 1-10

[10] Dotterweich M. The history of soil erosion and fluvial deposits in small catchments of Central Europe: Deciphering the long-term interaction between humans and the environment—A review. Geomorphology. 2008;**101**(1-2): 192-208. DOI: 10.1016/j.geomorph.2008.05.023

[11] Unger PW, McCalla TM. Conservation tillage systems. Advances in Agronomy. 1980;**33**:1-58. DOI: 10.1016/S0065-2113(08)60163-7

[12] McCully P. Silenced River: The Ecology and Politics of Large Dams. London, United Kingdom: Zed Books; 2001

[13] Graf W, Leitner P, Hanetseder I, Ittner LD, Dossi F, Hauer C. Ecological degradation of a meandering river by local channelization effects: A case study in an Austrian lowland river. Hydrobiologia. 2016;**772**(1):145-160. DOI: 10.1007/s10750-016-2653-6

[14] Samaras AG, Koutitas CG. Modeling the impact of climate change on sediment transport and morphology in coupled watershed-coast systems: A case study using an integrated approach. International Journal of Sediment Research. 2014;**29**(3):304-315. DOI: 10.1016/S1001-6279(14)60046-9

[15] Crosa G, Castelli E, Gentili G, Espa P. Effects of suspended sediments

from reservoir flushing on fish and macroinvertebrates in an alpine stream. Aquatic Sciences. 2010;**72**(1):85. DOI: 10.1007/s00027-009-0117-z

[16] Brown CB. The Control of Reservoir Silting, Miscellaneous Publication (No. 521). Washington, DC: United States Department of Agriculture; 1943

[17] Cui Y, Booth DB, Monschke J, Gentzler S, Roadifer J, Greimann B, et al. Analyses of the erosion of fine sediment deposit for a large dam-removal project: An empirical approach. International Journal of River Basin Management. 2017;**15**(1):103-114. DOI: 10.1080/15715124.2016.1247362

[18] Kaffas K, Hrissanthou V, Sevastas S. Modeling hydromorphological processes in a mountainous basin using a composite mathematical model and ArcSWAT. Catena. 2018;**162**:108-129. DOI: 10.1016/j.catena.2017.11.017

[19] Middleton HE. Properties of Soils which Influence Soil Erosion (U.S. Department of Agriculture Technical Bulletin No. 178). Washington, DC: U.S. Department of Agriculture; 1930

[20] Wischmeier WH, Johnson CB, Cross BV. Soil erodibility nomograph for farmland and construction sites. Journal of Soil and Water Conservation. 1971;2:189-193

[21] Meyer LD, Harmon WC. Susceptibility of agricultural soils to interrill erosion 1. Soil Science Society of America Journal. 1984;**48**(5):1152-1157. DOI: 10.2136/sssaj1984.03615995004800050040x

[22] Gilley JE. Erosion water-induced. In: Hillel D, editor. Encyclopedia of Soils in the Environment. Elsevier; 2005

[23] Finch S, Samuel A, Lane GP. Fertilisers and manures. In: Lockhart and Wiseman's Crop Husbandry Including Grassland. 9th ed. Woodhead Publishing/Elsevier; 2014. DOI: 10.1533/9781782423928.1.37

[24] Wischmeier WH, Mannering JV. Relation of soil properties to its erodibility. Soil Science Society of America Journal. 1969;**33**(1):131-137. DOI: 10.2136/sssaj1969.03615995003300010035x

[25] Finch S, Samuel A, Lane GP. Lockhart and Wiseman's Crop Husbandry Including Grassland. 8th ed. Woodhead Publishing/Elsevier. DOI: 10.1533/9781855736504.1.25

[26] Iuss Working Group Wrb. World reference base for soil resources 2014, update 2015: International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports. 2015;**106**:192

[27] Morin J, Benyamini Y. Rainfall infiltration into bare soils. Water Resources Research. 1977;**13**(5):813-817. DOI: 10.1029/WR013i005p00813

[28] Mohammad AG, Adam MA. The impact of vegetative cover type on runoff and soil erosion under different land uses. Catena. 2010;**81**(2):97-103. DOI: 10.1016/j.catena.2010.01.008

[29] Martínez-Casasnovas JA, Sánchez-Bosch I. Impact assessment of changes in land use/conservation practices on soil erosion in the Penedès–Anoia vineyard region (NE Spain). Soil and Tillage Research. 2000;**57**(1-2):101-106. DOI: 10.1016/S0167-1987(00)00142-2

[30] Panagos P, Borrelli P, Meusburger K, van der Zanden EH, Poesen J, Alewell C. Modelling the effect of support practices (P-factor) on the reduction of soil erosion by water at European scale. Environmental Science & Policy. 2015;**51**:23-34. DOI: 10.1016/j.envsci.2015.03.012

[31] Turner BL, Fuhrer J, Wuellner M, Menendez HM, Dunn BH, Gates R. Scientific case studies in land-use driven soil erosion in the Central United States: Why soil potential and risk concepts should be included in the principles of soil health. International Soil and Water Conservation Research. 2018;**6**(1):63-78. DOI: 10.1016/j.iswcr.2017.12.004

[32] Collins AL, Walling DE, Sichingabula HM, Leeks GJL. Using 137 Cs measurements to quantify soil erosion and redistribution rates for areas under different land use in the Upper Kaleya River Basin, Southern Zambia. Geoderma. 2001;**104**(3):299-323. DOI: 10.1016/S0016-7061(01)00087-8

[33] Lal R. Soil degradation by erosion. Land Degradation and Development. 2001;**12**(6):519-539. DOI: 10.1002/ldr.472

[34] Dotterweich M. The history of human-induced soil erosion: Geomorphic legacies, early descriptions and research, and the development of soil conservation—A global synopsis. Geomorphology. 2013;**201**:1-34. DOI: 10.1016/j.geomorph.2013.07.021

[35] Jefferson T. In: Betts EM, editor. Letter to CW Peale, Apr. 17, 1813. Thomas Jefferson's Garden Book. Philadelphia, PA: American Philosophical Society; 1944. p. 509

[36] Laflen JM, Flanagan DC. The development of US soil erosion prediction and modeling. International Soil and Water Conservation Research. 2013;**1**(2):1-11. DOI: 10.1016/S2095-6339(15)30034-4

[37] Davis WM. The geographical cycle. The Geographical Journal. 1899;**14**(5):481-504. DOI: 10.2307/1774538

[38] Chorley RJ. A re-evaluation of the geomorphic system of WM Davis. Frontiers in Geographical Teaching. 1965:21-38

[39] Chorley RJ, Beckinsale RP, Dunn AJ. The History of the Study of Landforms or the Development of Geomorphology: The Life and Work of William Morris Davis. Vol. 2. Psychology Press; 1973

[40] King LC. The study of the world's plainlands: A new approach in geomorphology. Quarterly Journal of the Geological Society. 1950;**106**(1-4):101-131. DOI: 10.1144/GSL.JGS.1950.106.01-04.06

[41] King LC. Canons of landscape evolution. Geological Society of America Bulletin. 1953;**64**(7):721-752. DOI: 10.1130/0016-7606(1953)64[721:COLE]2.0.CO;2

[42] Bishop P. Long-term landscape evolution: Linking tectonics and surface processes. Earth Surface Processes and Landforms. 2007;**32**(3):329-365. DOI: 10.1002/esp.1493

[43] Strahler AN. Dynamic basis of geomorphology. Geological Society of America Bulletin. 1952;**63**(9):923-938. DOI: 10.1130/0016-7606(1952)63[923:DBOG]2.0.CO;2

[44] Boardman J. Soil erosion science: Reflections on the limitations of current approaches. Catena. 2006;**68**(2):73-86. DOI: 10.1016/j.catena.2006.03.007

[45] Trimble SW. A sediment budget for Coon Creek basin in the Driftless area, Wisconsin, 1853-1977. American Journal of Science. 1983;**283**(5):454-474. DOI: 10.2475/ajs.283.5.454

[46] Govers G, Poesen J. Assessment of the interrill and rill contributions to total soil loss from an upland field plot. Geomorphology. 1988;**1**(4):343-354. DOI: 10.1016/0169-555X(88)90006-2

[47] De Ploey J. Erosional systems and perspectives for erosion control in European loess areas. In: Schwertmann U, Rickson RJ, Auerswald K, editors. Soil Erosion Protection Measures in Europe. Germany: Catena Verlag; 1989. pp. 93-102

[48] Blaikie PM. The Political Economy of Soil Erosion in Developing Countries. Harlow, Essex, England: Longman Scientific & Technical/Wiley; 1985

[49] Wischmeier WH, Smith DD. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. In: Agriculture Handbook No. 282, U.S. Department of Agriculture, Washington, DC; 1965

[50] Williams JR. Sediment-yield prediction with universal soil loss equation using runoff energy factor. In: Present and Prospective Technology for Predicting Sediment Yields and Sources. Proceedings of the Sediment Yield Workshop; Oxford, MS; 1975. pp. 244-252

[51] Renard KG, Foster GR, Weesies GA, McCool DK, Yoder DC. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE) (Vol. 703). Washington DC: US Government Printing Office; 1996

[52] Young RA, Onstad CA, Bosch DD, Anderson WP. AGNPS, Agricultural Nonpoint Source Pollution. A Watershed Analysis Tool. Conservation Research Report 35. Washington, DC: US Department of Agriculture; 1987

[53] Knisel WG. CREAMS: A Field-Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management System. Conservation Research Report No. 26. Washington, DC: USDASEA; 1980

[54] Beasley DB, Huggins LF, Monke EJ. ANSWERS: A model for watershed planning. Transactions of ASAE. 1980;**23**(4):938-944. DOI: 10.13031/2013.34692

[55] Neitsch SL, Arnold JG, Kiniry JR, Williams JR. Soil and Water Assessment Tool Theoretical Documentation Version 2009. College Station, Texas, USA: Texas Water Resources Institute, Texas A&M University; 2011

[56] Arnold JG, Kiniry JR, Srinivasan R, Williams JR, Haney EB, Neitsch SL. Input/Output Documentation Version 2012. Texas, USA: Texas Water Resources Institute; 2012

[57] Morgan RPC, Quinton JN, Smith RE, Govers G, Poesen JWA, Auerswald K, et al. The European Soil Erosion Model EUROSEM: A dynamic approach for predicting sediment transport from fields and small catchments. Earth Surface Processes and Landforms. 1998;**23**(6):527-544. DOI: 10.1002/(SICI)1096-9837(199806)

[58] United States Army Corps of Engineers (USACE). Hydrologic Modeling System HEC-HMS, User's Manual, Version 3.5. Davis, California, USA: Hydrologic Engineering Center; 2010

[59] Laflen JM, Lane LJ, Foster GR. WEPP: A new generation of erosion prediction technology. Journal of Soil and Water Conservation. 1991;**46**(1):34-38

[60] Yesuf HM, Assen M, Alamirew T, Melesse AM. Modeling of sediment yield in Maybar gauged watershed using SWAT, Northeast Ethiopia. Catena. 2015;**127**:191-205. DOI: 10.1016/j.catena.2014.12.032

[61] Pak J, Fleming M, Scharffenberg W, Ely P. Soil erosion and sediment yield modeling with the hydrologic modeling system (HEC-HMS). In: World Environmental and Water Resources

Congress 2008. Honolulu, Hawaii: Ahupua'A; 2008. pp. 1-10

[62] Kaffas K, Hrissanthou V. Computation of hourly sediment discharges and annual sediment yields by means of two soil erosion models in a mountainous basin. International Journal of River Basin Management. 2019;**17**(1):63-77. DOI: 10.1080/15715124.2017.1402777

[63] Mati BM, Morgan RPC, Quinton JN. Soil erosion modelling with EUROSEM at Embori and Mukogodo catchments, Kenya. Earth Surface Processes and Landforms. 2006;**31**(5):579-588. DOI: 10.1002/esp.1347