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Hotspot Delineation in the Eastern Nile, Abbay/Blue Nile Basin, As a Criterion for the Optimal Risk Assessment and Watershed Management of the Basin

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Abstract: *Erosion hotspots within a drainage basin refer to an area that erodes more rapidly than anticipated or more rapidly than adjacent portions. Or, areas having high erosion rate as compared to the adjacent places. Since erosion can adversely affect ecosystems on-site as well as off-site, the estimation of runoff and soil loss in catchments is becoming more important. The main objective of this work is to: (1) delineate the hotspot areas (areas of erosion/sediment source) within the Abbay/Blue Nile Basin, (2) generate vulnerability maps to assess the risk possibilities at these areas as well as to support the watershed management approaches for the whole basin, (3) determine the environmental impact, and (4) evaluate sediment and water resources. The area under consideration is located to the northwestern of Ethiopia and to the East of Sudan, directly on the political boundary separating the two countries. The basin area is about 314458 km² and is fully dissected by streams that form the Blue Nile River. The majority of mentioned area is considered one of the most important highlands feeding the River Nile with both water and sediment. Therefore, Assessment of the erosion hotspots within this basin is essential for the management of the whole system. The Splash and sheet erosion are most widely observed within the highlands of the Blue Nile basin in Ethiopia, which generate noticeable amounts of sediments that induce and increase the erosion rate when the rills and gullies start to form. The slope, runoff intensity, and soil types are the most factors that play an essential rule in the erosion hotspots. The Digital Elevation Model (DEM) was used to derive the slope angels, shapes (concavity and convexity), profile curvature, as well as the flow direction vector. Approximately 65% of the area has a slope gradient less than 15%. However, very steep slopes (up to 65%) are also present, increasing the risk of erosion in these mountainous areas. Climate maps, runoff maps, soil maps, land use maps as well as satellite images were also used in the spatial calculations and modeling. For the modeling phase, the Water Erosion Prediction Project (WEPP) Model along with the Geo-Spatial Interface for WEPP (GeoWEPP), integrated with the GIS, were used. The potential reading of the resulted maps showed that the most affected areas with erosion lie within the highlands of Ethiopia where there are very steep slopes, soft soil cover, and intensive runoff. Also, down from the highlands in Sudan, there are several hotspots formed due to the erosion by mass movement which due to the existence of specific soil types.*

Keywords: *hotspot delineation, watershed management, Blue Nile Basin*

Introduction

Soil and water resources are clearly crucial for productive and sustainable economies and environments. Both soil and water resources are threatened by soil erosion and sediment redistribution. This problem is critical especially in the highlands such as the highlands within the Blue Nile River Basin (Fig. 1) in Ethiopia and Sudan (El-Swaify and Hurni, 1996). The Blue Nile river Basin (or the Abbay River Basin as called with the Amharic language in Ethiopia) is located to the northwestern of Ethiopia and to the East of Sudan, directly on the political boundary separating the two countries (35 and 65 percent of which is in Sudan and Ethiopia, respectively). It is a very important watershed basin forming the river Nile Basin. Erosion hotspots are places that are susceptible to be eroded through the processes of sediment detachments and transportation by raindrop impact and flowing water (Foster and Meyer, 1977; Wischmeier and Smith, 1978; Julien, 1998). Soil erosion is affected by the spatial topography, vegetation, soil properties, climate, and land use. Channel erosion features and their offspring, sediment deposits, are a natural part of all rivers.

They conform to recurring processes and patterns throughout both small and large systems (Herweg, 1996). Once erosion and sedimentation are understood as essential parts of the watershed system, sensibly techniques for managing them can be applied (Parker and Andrews, 1985; Morgan, 1995; Toy et al., 2002). During high flows and floods, channel erosion continues, with the bed and banks under considerably greater stress. Erosion is accelerated and the confined power of the currents may rapidly reshape the bed and banks (Morgan, 1995). When water spills onto the adjacent floodplain it interacts with features of the landscape that may not have experienced the influence of flowing water for a year, decades, or even centuries (Stocking and Murnaghan, 2001). During extreme floods, major new stream features can be formed, even to the extent that new channels can be created where previously there were none (WRC, 2000). In fact, if a channel has robust, self-supporting banks, the carving action of the water is often expressed as an aggressive downward excavation. In an incising channel, knick points often form. A knick point is a place at which the longitudinal (lengthways) slope of the bed suddenly steepens. In severe cases a headcut or waterfall can form, these are spots of high erosion effect (Morgan, 1995; Stocking and Murnaghan, 2001).

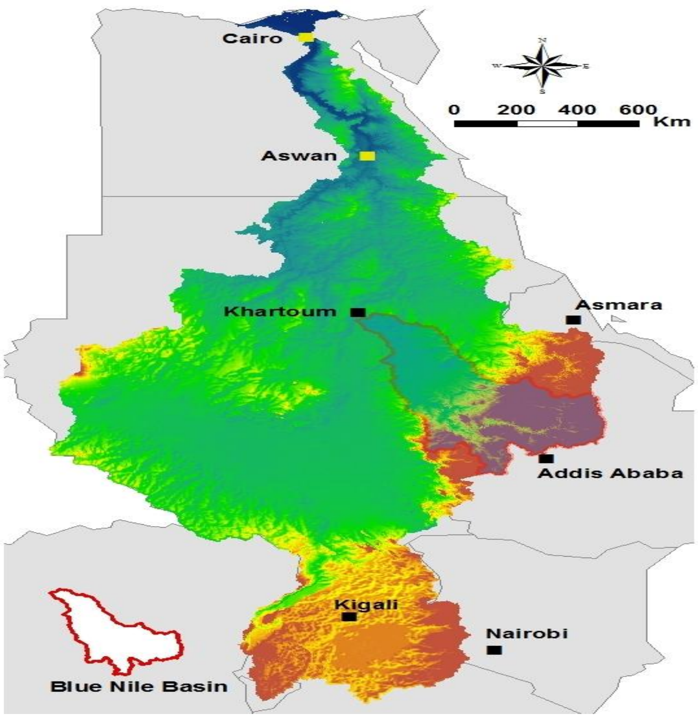

Fig. 1. A map showing the River Nile Basin and the location of the Blue Nile Basin. The map is based on the Digital Elevation Model (SRTM-30).

Erosion in the fields manifests itself in three main types: sheet erosion, rill erosion and gully erosion. Water from sheet flow areas merges together under certain conditions and forms small rills, the rills make small channels so that rill erosion represents an intermediate stage between sheet erosion and gulling. When the flow is concentrated (Stocking and Murnaghan, 2001), it can cause some erosion and much material can be transported within these small channels. A few soils are very susceptible to rill erosion. Rills gradually join together to form progressively larger channels, with the flow eventually proceeding to some established streambed. Some of this flow becomes great enough to create gullies (Herweg, 1996). These gullies may be of enormous size and shape, presenting a serious problem for their control. Soil erosion may be unnoticed on exposed soil surfaces even though raindrops are eroding large quantities of sediment, but erosion can be dramatic where concentrated flow creates extensive rill and gully systems. Soil erosion by water during the rainy season is a serious problem in the region, leading to declining agricultural production, decreased food security, and a sedimentation risk for water bodies (Brooks and McDonnell, 2000). River banks without deep root penetration are more susceptible to mass wasting than densely and deeply rooted banks. Erosion measurements are used to: (1) determine environmental impact, (2) design policies and programs, (3) plan conservation, (4) optimally allocate resources. A handicap for the control of the insidious is the difficulty of determining its magnitude. Four causes are often mentioned the literature: the large temporal and spatial variation of erosion, the paucity of accurate erosion measurements (Toy et al., 2002), the problem of extrapolating data from small plots to higher scales and the conversion of erosion into production and monetary units (Stocking and Murnaghan, 2001). Simulation models have become important tools for the analysis of hillslope and watershed processes and their interactions, and for the development and assessment of watershed management scenarios (Parcks, 1993). Since erosion can adversely affect ecosystems on-site as well as off-site, the estimation of runoff and soil loss in catchments is becoming more important as concerns about surface water quality increase (Metternicht and Gonzales, 2005; Santhi et al., 2006). For this the ‘‘hotspots’’, source areas of sediments, within a watershed need to be identified. However, many of the predictive models do not examine the problem in a geographic context (Cochrane and Flanagan, 1999; Pullar and Springer, 2000; He, 2003; Lu et al., 2005; Miller et al., 2007). Under these circumstances, a Geographical Information System (GIS) becomes a valuable tool. A GIS is a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world (Burrough, 1986; Bonham-Carter, 1996; Sharma et al., 1996; Pullar and Springer, 2000). One of the most promising of the physically based models currently used to model erosion is the Water Erosion Prediction Project (WEPP) model (Flanagan and Nearing, 1995; Baigorria and Romero 2007). Soil erosion by water during the rainy season is a serious problem in the region, leading to declining agricultural production, decreased food security, and a sedimentation risk for water bodies. Therefore, the ultimate goals were to determine the geomorphic state of the Blue Nile Basin, determine sources of sediment to the lake, and create a stream channel erosion hot-spot map. This work needs to be supported by field visits. Furthermore, although a straightforward process, the photogrammetric derivation of the topographic contours and Digital Elevation Models (DEMs) relies on the tonal quality of the original aerial photographs, easily identifiable ground control points, and the ease with which such points can be found in rural areas; areas where stable features such as roads, field boundaries, and buildings are often scarce. Figure 2 represents the workflow of data manipulation to investigate the soil susceptibility to erosion.

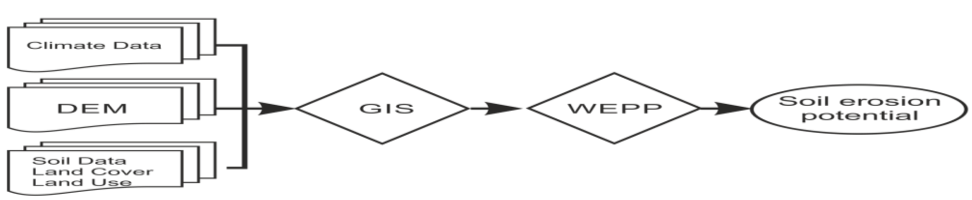

Fig. 2. Flowchart represents the workflow for generating a soil erosion potential map.

A repeatable methodology has to be demonstrated which facilitates the identification of areas that are particularly susceptible to the effects of erosion, to determine whether there is erosion or accretion of the streams banks or bed, and to quantify how much gain or loss (+ve or –ve change) has been occurring. The work based mainly on using the most sophisticated database and modeling tools to provide a basis for demonstrating the practical role of remote sensing, Geographical Information Systems (GIS), and digital photogrammetry. In addition, the work formed the basis for future monitoring studies using LIDAR data and imagery. The main objective of this work is to delineate the hotspot areas (areas of sediment source) within the Abbay/Blue Nile Basin. The majority of this area is considered one of the most important highlands feeding the Nile River with both water and sediment. Delineation and assessment of the erosion hotspots within this basin is essential for the management of the whole system. Analyze the spatial distribution of soil erosion in the area of interest.

Materials and Methods

The first step in the project was to create an organized plan based on available watershed data. Road maps and stream maps were used to measure the total length of streams to be assessed and to find access points to the streams. Most of the maps were provided by the ENTRO office in Addis Ababa in the form of geographic information system (GIS) datasets, which also were useful in creating maps for presenting the results. The total length of the stream channels was calculated and manipulated.

Included with the GIS datasets were aerial photographs of the watershed shot in 2002. These images proved immensely useful because they provided the necessary information to resolve discrepancies between field observations and the GIS streams and lakes data layer. Additionally, the aerial photos indicated areas that have undergone land-use change since 2000. The area under consideration is located to the northwestern of Ethiopia and to the East of Sudan, directly on the political boundary separating the two countries.

The basin area is 314458.37 km² fully dissected by streams that form the Blue Nile River (Fig. 3). Mean annual discharge of Abbay River (1920-2000) at the Sudanese border is approximately 50 km^3. Rainfall in Abbay-Blue Nile Basin ranges from nearly 2200 mm/yr in the Ethiopian Highlands to less than 200 mm/yr at the junction with the White Nile at Khartoum city in Sudan (Gebremichael et al., 2005). The Blue Nile Basin contributes about 60% of the Nile's flow at Aswan, Egypt, even though the Blue Nile comprises only about 8% of the total Nile catchment area.

The watersheds of the Basin have a range of sizes, slopes, climatic patterns, topography, drainage patterns, geological formations, soils, vegetation cover and anthropogenic activities. There are three broad topographical divisions: the highland plateau, steep slopes adjoining the plateau that tilt to the west and the western low lands with gentler topography comprising the remainder of the Basin. The general topography ranges from ca 360 m to ca 4200 m asl (Fig. 4). The steep slopes and the plateaus extend from 1500m to ca 4200m above sea level and combined cover about 65% of the Basin area.

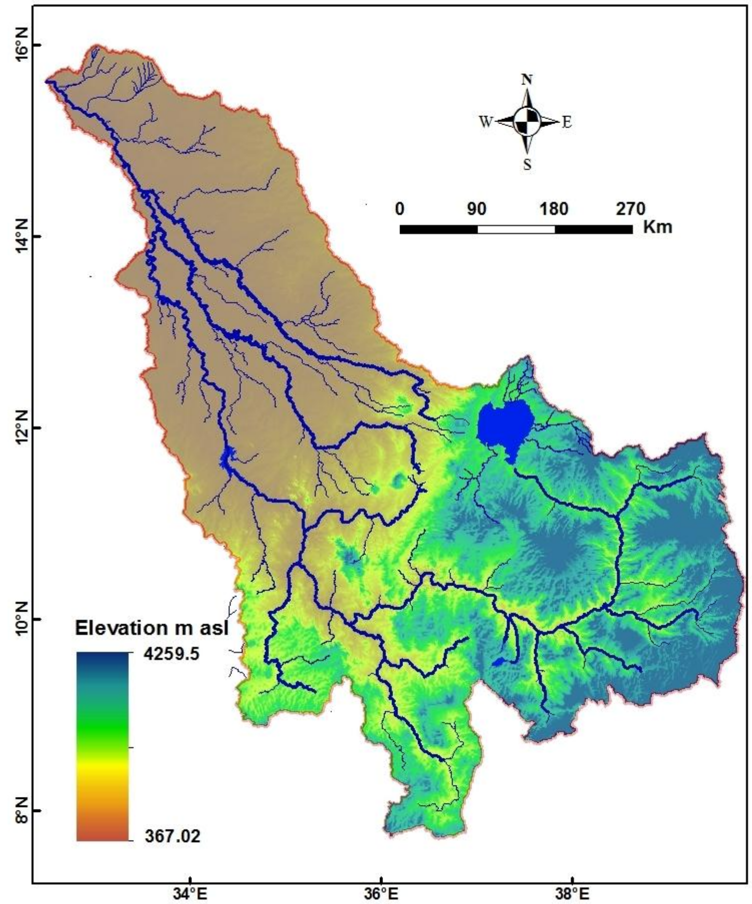

Fig 3. Blue Nile River (Abbay River) Basin.

Field data for running the model were obtained for the area. Two main climate regimes can be identified during the year in this area: the rainy season and the dry season. According to the land use classification, the main types in the watershed are croplands, cultivated pasture, natural pasture and shrubland. Approximately 65% of the area has a slope gradient less than 15% (Fig. 5). Very steep slopes (up to 65%) are also present, increasing the risk of erosion in this mountainous area. As steep slopes often occur adjacent to the river, water erosion will contribute directly to the river sediment load. The Water Erosion Prediction Project (WEPP) model is based on modern hydrological and erosion science and calculates runoff and erosion on a daily basis (Flanagan and Nearing, 1995; Savabi et al., 1995; Renschler, 2003). WEPP uses mainly physically based equations to describe hydrologic and sediment generation and transport processes at the hillslope and in-stream scales. The model operates on a continuous daily time step (Renschler et al., 2002; Flanagan et al., 2004; Baigorria and Romero 2007).

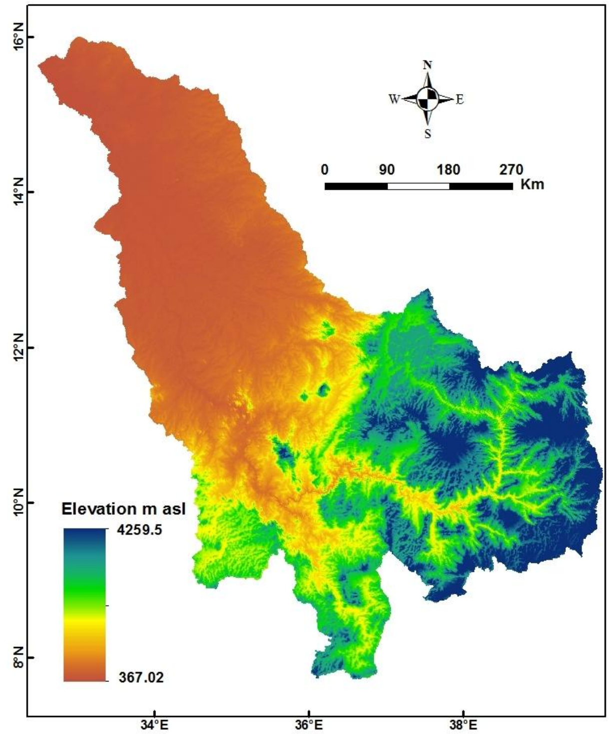

Fig. 5. Digital Elevation Model of the Blue Nile River Basin derived from SRTM 3 Arc Second.

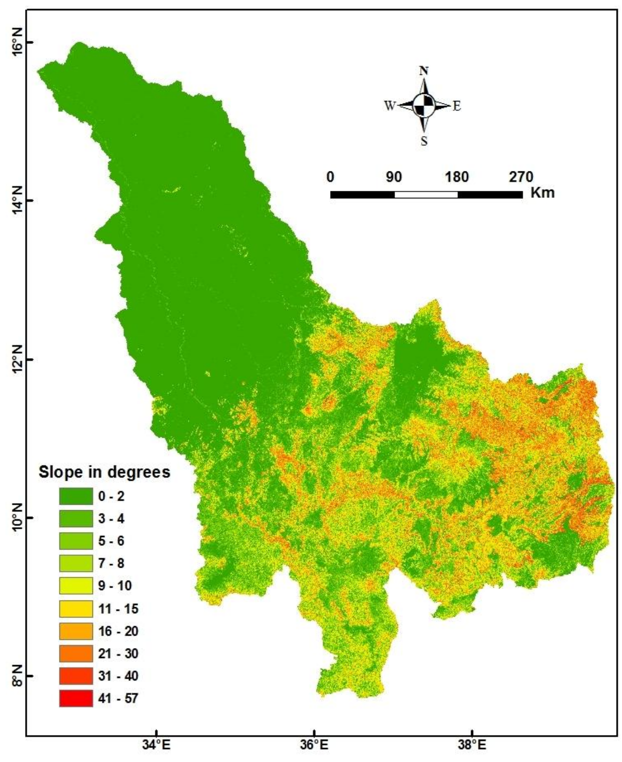

Fig. 5. The slope of the Blue Nile River Basin in degrees

Figure 6 illustrates the soil classification map and the landuse map of the Blue Nile River Basin. The Basin is characterized by three different geological formations: the crystalline basement exposed over 32% of the area, sedimentary formations covering about 11% in the deep valleys of major southern tributaries, and volcanic formations covering about 52% of the area in the North, Central and Eastern part of the Basin (Ministry of Water Resources, 1998). The dominant soil texture of the Basin is clay with the special type of shrinking and expanding clay, covering about 15% of the Basin (Gebrehiwot et al., 2011).

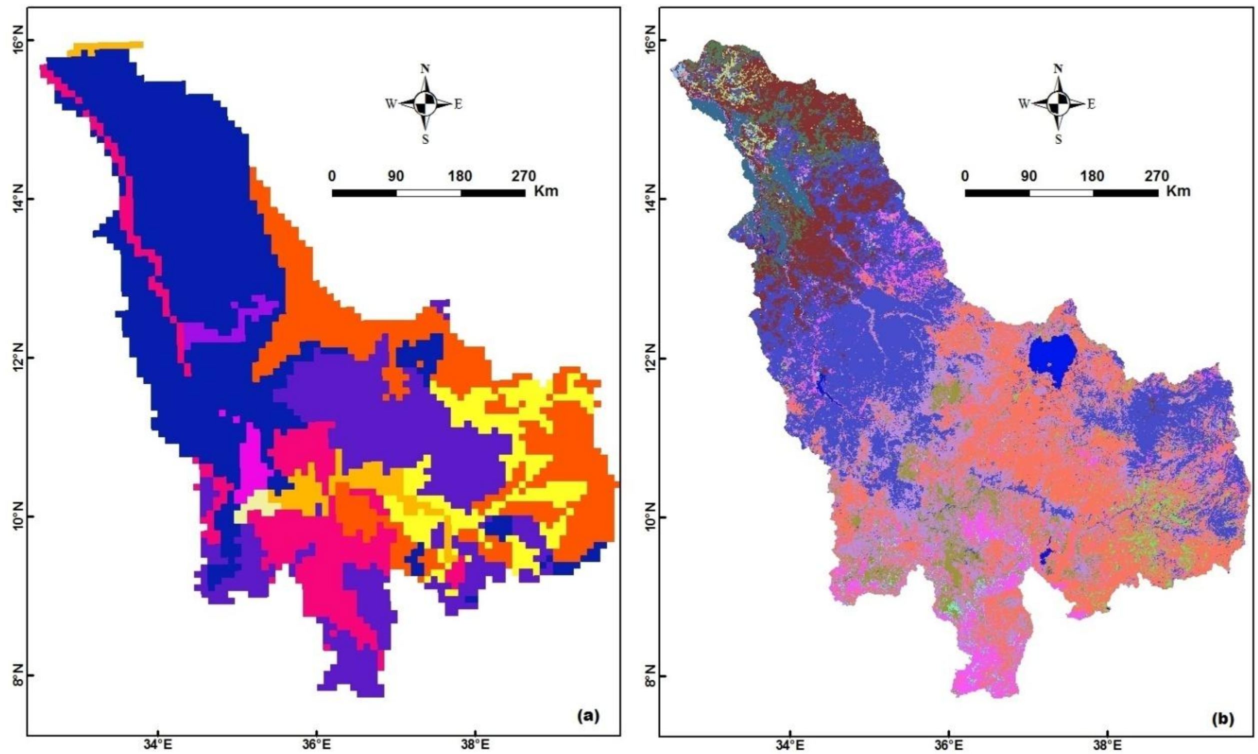

Fig. 6. A map showing: (a) the soil classification, and (b) the landuse of the Blue Nile River Basin (FAO, 2007).

Erosion potential mapping

Based on the fundamentals of infiltration, surface runoff, plant growth, residue decomposition, hydraulics, tillage, management, soil consolidation and erosion mechanics, it provides several major advantages over empirically based erosion prediction models (Singh, 1995), including the estimation of spatial and temporal distributions of net soil loss. WEPP uses mainly physically based equations to describe hydrologic and sediment generation and transport processes at the hillslope and in-stream scales. The model operates on a continuous daily time step (Cochrane and Flanagan, 1999; Baigorria and Romero 2007). The model's main disadvantage is the data requirement that may limit its applicability in areas with limited data. In addition, the watershed version of WEPP may be of limited applicability to large-scale catchments, as simulation involves individual hillslope scale models being "summed-up" to the catchment scale, increasing data requirements and error (Ranieri et al., 2002;

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Merrit et al., 2003). The basic databases required for the modeling include climate, soil, topography and land use information, while the basic maps required are climatic zones, soil units and digital elevation model (DEM). The DEM is used to derive the slope angle and slope shape (convexity or concavity) used by WEPP. The slope angle was calculated by using the algorithm developed by Monmonier (1982).

Precipitation and runoff data are used to estimate the rainfall runoff erosivity factor. DEM, with 30m grid cell size, is used to analyze the slope length and slope steepness. A soil map based on vectorized feature data is used to estimate the soil erodibility and transformed into the raster data file with 30m grid cell size. The slope shape is ascertained pixel by pixel, analyzing the altitude from the 3x3 pixel neighborhood to determine the flow direction vector. This determines two pixels on opposite sides of the central-evaluated pixel applying the definition of profile curvature (Fig. 7) the magnitude of the rate of change of the slope is described as a quadratic equation (Pellegrini, 1995; De Roo, 1996; Burrough and McDonnell, 1998).

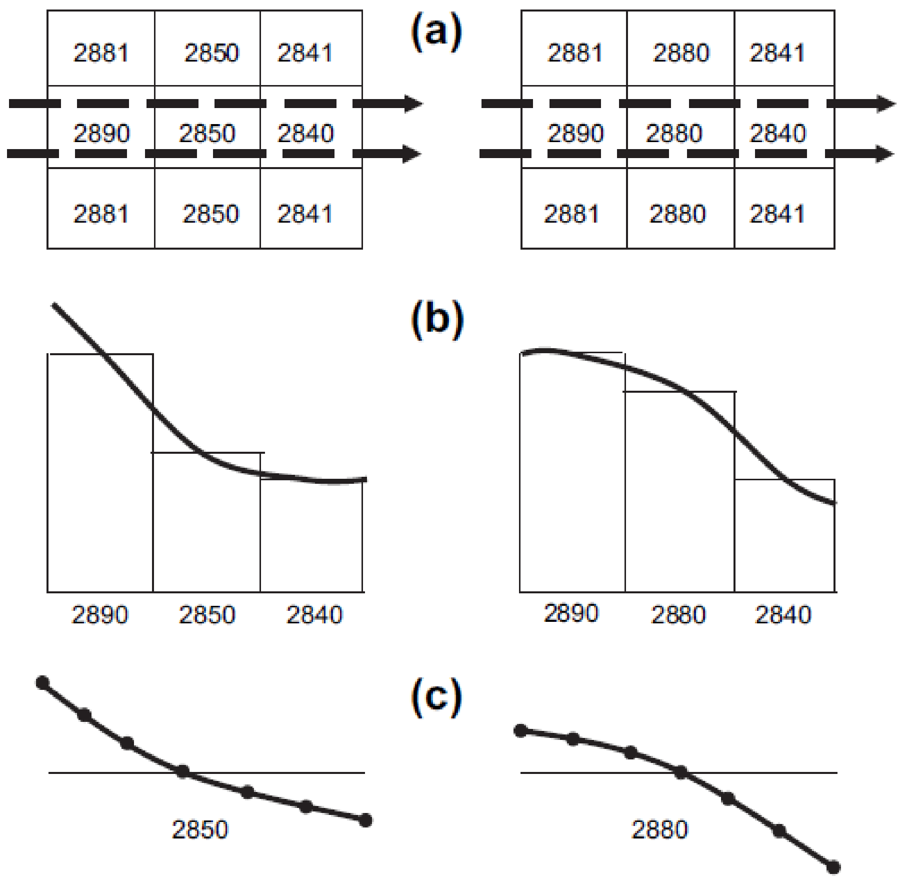

Fig. 7. Determination of the slope shape (profile curvature). (a) Flow direction by using DEM. (b) Profile view of the three pixels forming the flow direction and graphical fitting of the quadratic function using slopes. (c) Slope shape of the central-evaluated pixel. Concave and convex slope shapes at left and right, respectively.

Using the slope of the three pixels determining the flow direction through the central-evaluated pixel in the 3x3 pixel neighborhood, the quadratic equation is fitted. The points extracted at different distances from the center of the central-evaluated pixel are used to define the concavity or convexity of the slope in WEPP. The distances between each consecutive pair of extracted points are assigned as a unique overland flow element. The topography variables used are altitude and slope. In the present application, the digital elevation model (DEM) was provided the SRTM 0.3 arc second data and the slope map was generated from this DEM.

From the DEM the curvature conditions were modeled in the direction of the streams and parallel to the streams as shown in Figs. 8, 9, and 10. Soil erodibility (K) represents the susceptibility of soil or surface material to erosion, transportability of the sediment. The calculations and modeling procedure showed that the areas that are much susceptible to soil erosion are found in high lands and at the relatively high slopes. Some soil erosion occur at relatively flat areas such those in the Sudanese territories by mass erosion or mass fall. This may be mainly due to the soil type.

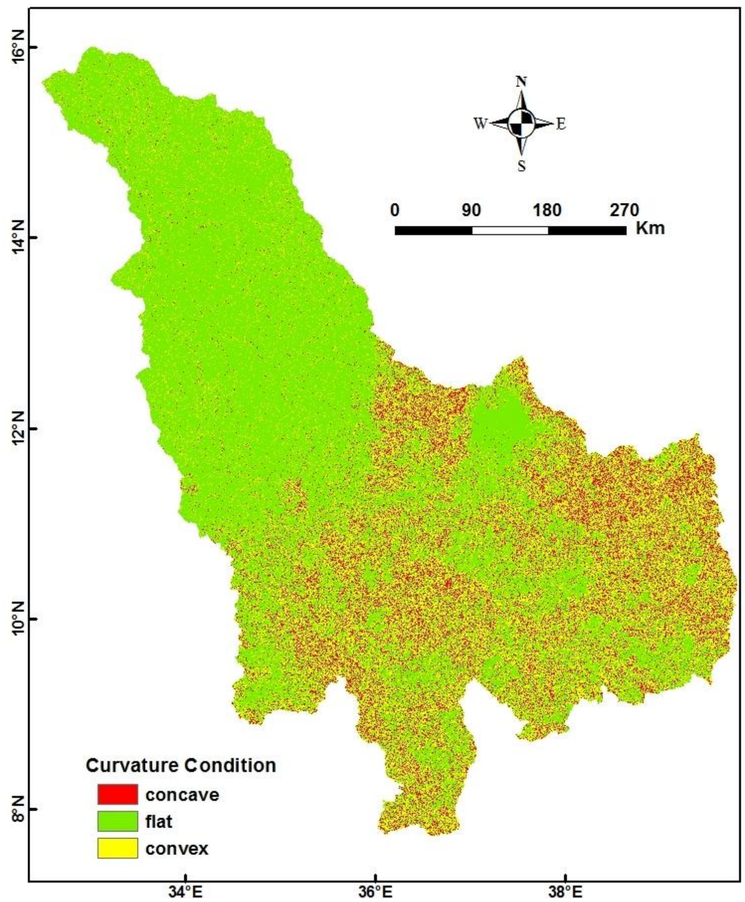

Fig. 8. A map showing the curvature condition of the study area.

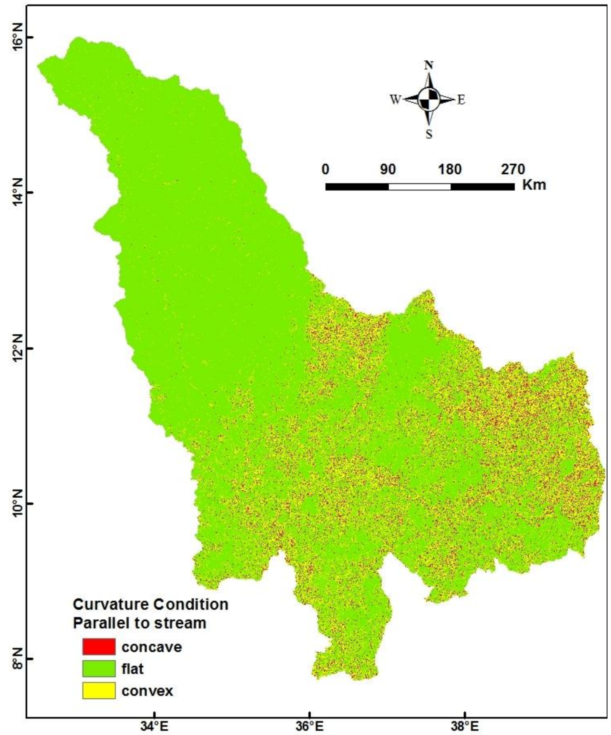

Fig. 9. A map showing the curvature condition, parallel to the streams of the study area.

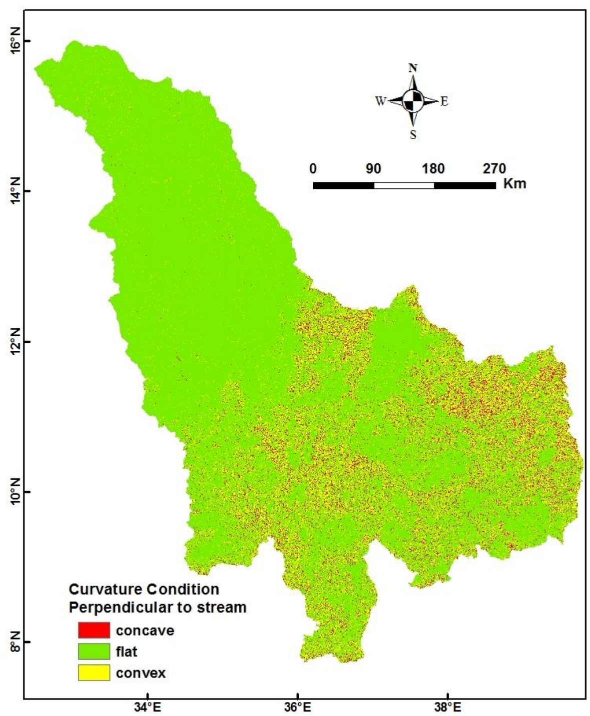

Fig. 10. A map showing the curvature condition, normal to the streams of the study area.

Conclusion

Both soil and water resources are threatened by soil erosion and sediment redistribution. This problem is critical especially in the highlands such as the highlands within the Blue Nile River Basin in Ethiopia and Sudan. The ‘‘hotspots’’, source areas of sediments, within a watershed need to be identified. However, many of the predictive models do not examine the problem in a geographic context. A Geographical Information System (GIS) becomes a valuable tool that is able to model the hotspots. A GIS is a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world. One of the physically based models currently used to model erosion is the Water Erosion Prediction Project (WEPP) model. The main objective of this work is to delineate the hotspot areas (areas of sediment source) within the Abbay/Blue Nile Basin. The majority of this area is considered one of the most important highlands feeding the Nile River with both water and sediment. The general topography ranges from ca 360 m to ca 4200 m asl. Approximately 65% of the area has a slope gradient less than 15% (Fig. 5). Very steep slopes (up to 65%) are also present. Areas that are much susceptible to soil erosion are found in high lands and at the relatively high slopes. Some soil erosion occur at relatively flat areas such those in the Sudanese territories by mass erosion or mass fall. This may be mainly due to the soil type.

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References

1. Baigorria, G.A., Romero, C.C., 2007. Assessment of erosion hotspots in a watershed: Integrating the WEPP model and GIS in a case study in the Peruvian Andes. Environmental Modelling & Software 22, 1175-1183.
2. Brooks, S.M., McDonnell, R.A., 2000. Research advances in geocomputation for hydrological and geomorphological modeling towards the twenty-first century.. Hydrological processes 14(11-12), 1899-1907.
3. Burrough, P.A., 1986. Principles of Geographical Information Systems for Land Resources Assessment. Oxford University Press.
4. Cochrane, T.A., Flanagan, D.C., 1999. Assessing water erosion in small watersheds using WEPP with GIS and digital elevation models. Journal of Soil and Water Conservation 54, 678-685.
5. De Roo, A.P.J., 1996. Soil erosion assessment using GIS. Geographical information systems in hydrology, Kluwer Academic Publishers, Dordrecht; Boston, pp 339-356.
6. El-Swaify, S., Hurni, H., 1996. Transboundary effects of soil erosion and conservation in the Nile basin. Land Husbandry 1, 6–21.FAO 2007. Digital Soil Map of the World. http://www.fao.org/geonetwork/srv/en/metadata.show?id=14116. Accessed, April, 2013.
7. Flanagan, D.C., Frankenberger, J.R., Engel, B.A., 2004. Web-based GIS application of the WEPP model. Paper No. 04e2024. American Society of Agricultural Engineers, St. Joseph, MI, 12 pp.
8. Flanagan, D.C., Nearing, M.A., 1995. USDA-Water Erosion Prediction Project (WEPP). WEPP user summary. NSERL Report No. 10. USDA-ARS National Soil Erosion Research Laboratory. West Lafayette, IN.

Foster, G.R., Meyer, L.D., 1977. Soil erosion and sedimentation by water – an overview. Procs. National Symposium on Soil Erosion and Sedimentation by Water, Am. Soc. Of Agric. Eng., St. Joseph, Michigan pp 1-13.

9. Gebrehiwot, S.G., Ilstedt, U., Gaerdenas, A.I., Bishop, K., 2011. Hydrological characterization of watersheds in the Blue Nile Basin, Ethiopia. Hydrology and Earth System Sciences 15, 11-20. DOI: 10.5194/hess-15-11-2011.
10. Gebremichael, D., Nyssen, J., Poesen, J., Deckers, J., Haile, M., Govers, G., Moeyer- sons, J., 2005. Effectiveness of stone bunds in controlling soil erosion on cropland in the Tigray highlands, Northern Ethiopia. Soil Use Management 21, 287–297.
11. He, C., 2003. Integration of geographic information systems and simulation model for watershed management. Environmental Modelling & Software 18, 809-813.
12. Herweg, K., 1996. Field manual of the assessment of current erosion damage (ACED). SCRP, Ethiopia.
13. Julien, P.Y., 1998. Erosion and sedimentation. Cambridge University Press, Cambridge, New York.
14. Lu, H., Moran, C.J., Prosser, I.P., 2005. Modelling sediment delivery ratio over the Murray Darling Basin. Environmental Modelling & Software 21, 1297-1308.
15. Merrit, W.S., Letcher, R.A., Jakeman, A.J., 2003. A review of erosion and sediment transport models. Environmental Modelling & Software 18, 761-799.
16. Metternicht, G., Gonzales, S., 2005. FUERO: foundations of a fuzzy exploratory model for soil erosion hazard prediction. Environmental Modelling & Software 20, 715-728.
17. Miller, S.N., Semmens, D.J., Goodrich, D.C., Hernandez, M., Miller, R.C., Kepner, W.G., Guertin, D.P., 2007. The automated geospatial watershed assessment tool. Environmental Modelling and Software 22 (3), 365-377.
18. Ministry of Water Resources 1998. Abbay River Basin Integrated Development Master Plan Project: Data Collection – Site Investigation Survey and Analysis, Phase 2. BECOM in collaboration with BRGM and ISL Consulting Engineers, Ministry of Water Resources, Ethiopia, Addis Ababa, Ethiopia.
19. Morgan, R.P.C., 1995. Soil erosion and conservation. Second Edition. Longman.
20. Parker, G., Andrews, E.D, 1985. On the time development of meander bends. Journal of Fluid Mechanics 162, 139-156.
21. Parks, B.O., 1993. The need for integration. In: Goodchild, M.F., Parks, B.O., Steyaert, L.T. (Eds.), Environmental Modelling with GIS. Oxford University Press, pp. 31-34.
22. Pullar, D., Springer, D., 2000. Towards integrating GIS and catchment models. Environmental Modelling & Software 15, 451-459.
23. Ranieri, S.B.L., de Jong van Lier, Q., Sparovek, G., Flanagan, D.C., 2002. Erosion database interface (EDI): a computer program for georeferenced application of erosion prediction models. Computers and Geosciences 28, 661-668.
24. Renschler, C., 2003. Designing geo-spatial interfaces to scale process models: the GeoWEPP approach. Hydrological Processes 17, 1005-1017.
25. Renschler, C., Flanagan, D.C., Engel, B.A., Frankenberger, J.R., 2002. Geo-WEPP e The Geo-spatial interface for the Water Erosion Prediction Project. ASAE meeting paper No. 022171, St. Joseph, Michigan.

26. Santhi, C., Srinivasan, R., Arnold, J.G., Williams, J.R., 2006. A modeling approach to evaluate the impacts of water quality management plans implemented in a watershed in Texas. Environmental Modelling & Software 21, 1141-1157.
27. Savabi, M.R., Flanagan, D.C., Hebel, B., Engel, B.A., 1995. Application of WEPP and GIS-GRASS to a small watershed in Indiana. Journal of Soil and Water Conservation 50, 477-483.
28. Sharma, K.D., Menenti, M., Huygen, A.V., 1996. Modeling spatial sediment delivery in an arid region using thematic mapper data and GIS. Transactions of the ASAE 39(2),, 551-557.
29. Singh, V.P., 1995. Computer Models of Watershed Hydrology. Water Resources Publications, Highlands Ranch, CO.
30. Stocking, M.A., Murnaghan, N., 2001. Field assessment of land degradation. Earthscan.
31. Toy, T.G., Foster, G.R., Renard, K.G., 2002. Soil Erosion. Wiley.
32. USACE., 1985. Remedial investigation and risk assessment, Jefferson Proving Ground, Madison, Indiana. Draft, Volume I, Chapter 11.0. U.S. Army Environmental Center, Aberdeen Proving Ground, MD.
33. Wischmeier, W.H., Smith, D.D., 1978. Predicting rainfall erosion losses –A guide to conservation planning. U.S. Department of Agriculture handbook No. 537.
34. WRC., 1999. Planning and management: foreshore condition assessment in farming areas of south-west Western Australia. Water and Rivers Commission, River Restoration Report No. RR3, Perth, Australia.
35. WRC., 2000. Fluvial geomorphology. Water and Rivers Commission, River Restoration Report No. RR6, Perth, Australia.
36. WRC., 2002. Stream channel and floodplain erosion. Water and Rivers Commission, River Restoration Report No. RR18, Perth, Australia.

Session VI

Environmental Science and Technology