JOURNAL OF ENVIRONMENTAL GEOGRAPHY
Journal of Environmental Geography 7 (1–2), 23–28.
DOI: 10.2478/jengeo-2014-0003
ISSN: 2060-467X

SEDIMENT DYNAMICS IN A SMALL, 2ND ORDER URBAN RIVER AWBA CATCHMENT, IBADAN, NIGERIA

Aderemi Adediji[1*], Olutoyin A. Fashae[2]

[1]Department of Geography, Obafemi Awolowo University, Faculty of Social Sciences, 20005 Ile-Ife, Nigeria
[2]Department of Geography, University of Ibadan, Faculty of Social Sciences, 200284 Ibadan, Nigeria
*Corresponding author, e-mail: remiadediji2003@yahoo.co.uk

Research article, received 02 February 2014, accepted 06 March 2014

Abstract

The sediment dynamics in a small 2nd order catchment of River Awba in the territory of the University of Ibadan, Nigeria was investigated between January and December 2012. The river was gauged by daily measurements of water level as well as sampling of water for determination of suspended sediment load. In this regard, apart from weekly sample, twelve (12) storm flow events which occurred during the day were sampled for determination of suspended sediment concentration. The results showed that during the storms the suspended sediment concentration varied between 636 mg/l in May and 3641.5 mg/l in September, with a mean of 2136.8 mg/l. Also, the value of monthly suspended sediment yield ranged from 10.85 kg in January to 288.4 kg in October with a mean of 89.5 kg. The variability in monthly sediment load closely followed the trend of monthly rainfall in the study area. However, in order to minimize the storm runoff and sediment load generated from the rainstorms events, the paved surfaces within the study catchment should be grassed with the planting of some few tree species. This could further reduce the rate of floods occurrence.

Keywords: gauged, suspended sediment, rainfall, River Awba catchment

INTRODUCTION

Sediment yield is an indication of soil erosion in the river catchments. It comprises of both suspended and dissolved load discharge through the basin outlet. These materials (both suspended and solute load) are generated from both interfluvial areas and channel subsystems within the drainage basin. For instance, Mwamba and Torres (2009) in United States, stated that rivers are the major source of ocean sediment, and the coastal and marine environment is the ultimate sink for most fluvial systems. Thus, it might seem likely that significant changes in erosion or sediment transport within the drainage basin would be reflected in the changes in sediment delivery in coastal and marine environment. However, the link between sediment dynamics within a fluvial system and sediment load at the river outlet is not always strong or direct. This is because storage opportunities or time lags may make some drainage basins/catchments, slowly responsive or relatively unresponsive to environmental change. However, the amount of material or sediment generated and transported from the basin depends on both physiographic and catchment characteristics such as climate (rainfall), vegetation/land use condition, slope factor, basin area, relief ratio, drainage density and sinuosity index.

In this regard a lot of published studies exist on factors influencing catchment sediment yield in both tropical and extra tropical regions (e.g. Smets et al., 2008; Peng, 2008 in United States; Bracken and Kirkby, 2005; Nadal and Reques, 2008; Nadal et al., 2008; Noenu et al., 2010; Fang et al., 2012; Nu-Fang et al., 2012; Taguas et al., 2013 in Spain; Lopez et al., 2010 in Italy; Wei et al., 2007; Zeng et al., 2008 in China; Adriana et al., 2012 in France; Ogunkoya, 1980; Ogunkoya and Jeje, 1987; Oluwatimilehin, 1991; Jeje et al., 1999; Adediji and Jeje, 2004; Adediji et al., 2013 in Southwestern Nigeria). For example, Slattery and Phillips (2010) in central Spain observed that land use changes determine the spatial and temporal evolution of plant cover, which directly influences trends in water resources, soil erosion and conservation. According to them, changes in land use especially in terms of vegetation composition will bring about changes in sediment production in the watershed. Also, Nadal et al. (2008) observed that a small catchment in a badland area of relatively humid environments (Mediterranean areas) shows highly active processes of physical and chemical weathering related to seasonal variations in moisture (rainfall) and temperature. Bracken and Kirkby (2005) in two semi-arid catchments of southeast Spain showed that a storm event on 20th June 2002 of 83.0mm was responsible for a maximum runoff depth of 12cm and a maximum hillslope sediment transport of 1886 cm^3/m which suggested that measured sediment transport is related to runoff. In the hilly areas of Loess Plateau, North China, Zheng et al. (2008) observed that the mean sediment concentration tends to be stable for large flood events, suggesting a strong similarity between surface flow-sediment relationships at inter and intra-event temporal scales. However, Wei et al. (2007) also in the semi-arid loess hilly area in China observed that the processes of runoff and sediment/soil loss are complicated and uncertain with the interaction of rainfall and land use which is due mainly to different stages of vegetation succession. Adriana et al. (2012) in south western France observed that grass strips along rivers and ditches prevented soil sediments from entering the surface water but did not reduce soil losses and that crop redistribution within the catchment was as efficient as planting grass strips. Other studies especially in Nigeria, have also examined the effects of both rainfall characteristics and land use/vegetation on sediment dynamics of 3rd order catchments in southwestern Nigeria. In this regard, apart from Adediji and Jeje (2004)'s work, there is little or no known studies on sediment yield dynamics from either the 1st or 2nd order basin in southwestern Nigeria in particular and in Nigeria as a whole.

Hence, this study will attempt to relate rainfall to sediment yield dynamics in a 2nd order urbanized catchment in the University of Ibadan, Ibadan, Oyo-State, Southwestern Nigeria. The 1st and 2nd order basins are ideal for the study of hydrological response pattern because they are relatively small and have homogenous physiographic and land use/vegetation attributes (Adediji and Jeje, 2004). More importantly they can respond very quickly to rainfall events in the form of storm-flow as well as to drought in sparsely vegetated areas (e.g. urbanized catchments). Hence, the main objective of this study is to relate rainfall to sediment production from a 2nd order stream draining through the built up part of University of Ibadan Estate. This study will further advance the research frontier on aspect of sediment dynamics from a small urbanized river catchment in this part of the world.

STUDY AREA

River Awba, a 2nd order river catchment within the estate of the University of Ibadan, Ibadan, Nigeria constitutes the study area. The study river basin is between Latitudes 7°25'58" and 7°26'42" and Longitudes 3°53'21" and 3°54'26" East of Greenwich Meridian (*Fig. 1*). The drainage area is 2.08 km^2, its drainage density is 1.93 km/km^2. River Awba drains through a part of the academic area of the university especially the Faculties of Science and Social Sciences as well as Departments of Petroleum and Agricultural Engineering, and emptied its water into University dam/reservoir that is very close to the Zoological Garden of the university (*Fig. 1*) The dam on R. Oba at the university has been silted up and overgrown by hydrophytes such as ferns and water weeds among which are *Pistia stratiotes*, *Scirpus cubensis* and Rhnchospora corymbosa. Other common plants around the dam include *Lemna spp; Wolffia arrhiza, Nymphaea spp;* and *Ipomoea aquatica*. Specifically, these water weeds have virtually completely colonized the surface area of the reservoir. Because, the study stream basin is mostly built-up, it usually experiences annual flooding. In fact, in August/September 2011, many properties including animals at the University Zoological Garden were destroyed by floods. Specifically, the land use map *(Fig. 2)* of the study area shows that paved/built-up area and the grass vegetation constitutes the largest proportion of the study catchment. Other land uses such as swamp and gallery vegetation along the stream channels covered the smaller portion of the study area.

The stream basin is underlain by Precambrian Basement Complex Rocks. Specifically, the area is underlain by granites, gneisses and schists (Symth and

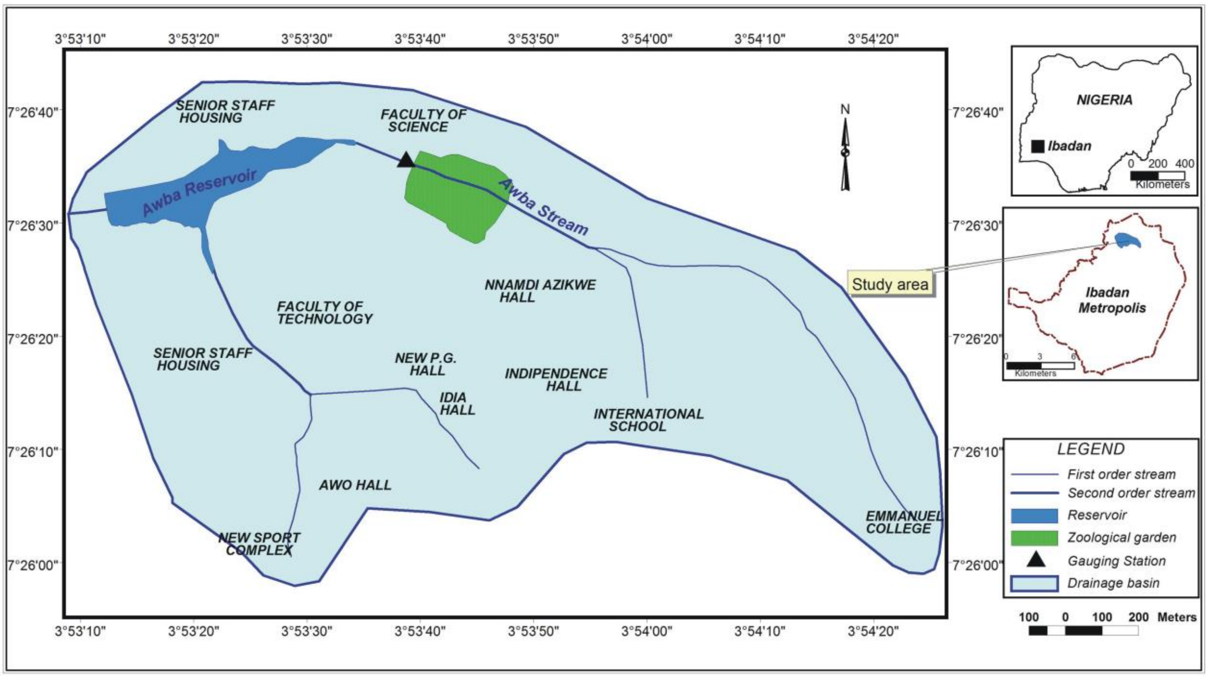

Fig. 1 Map of the Drainage Basin of River Awba within the University of Ibadan

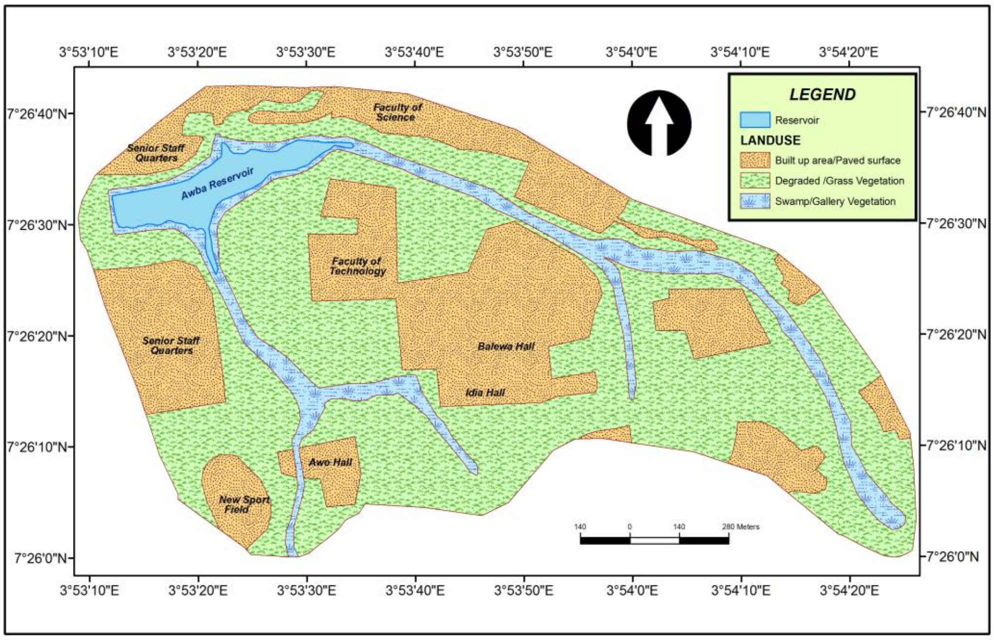

Fig. 2 Land use map of the River Awba catchment within the University of Ibadan

Montgomery, 1962). It is under Köppen's Af humid tropical rain forest climate. The mean annual rainfall is about 1400 mm and distributed between the months of March and October with peaks in July and September and a short dry spell in August although, thus varying from year to year in its occurrence (Iloeje, 1981). The rainfall effectiveness is between 6–9 months in the year. The onset and withdrawal of rains are marked by thunderstorms accompanied by high rainfall intensity. The temperature is high and almost uniform throughout the year because of the tropical climatic conditions with mean monthly value of about 27°C, while daily maximum temperatures ranges between 25°C and 30°C depending on the location and season (Iloeje, 1981).

MATERIALS AND METHODS

The study river catchment was delineated from the topographical sheet of Ibadan N.W. on a scale of 1:50,000. The topographic map used in this study was corrected following the methods suggested by Morisawa (1957) and Morgan (1971). Thereafter, the drainage network of the corrected maps was then ordered using strahler's method. Subsequently, the attributes of the study basin such as Basin area (A) and drainage density (Dd) were determined following the method by Gregory and Walling (1973).

Land use map of the study catchment was compiled from Google Image of the area at 2.5 m spatial resolution. The study stream was gauged at its exit point immediately after the Zoological Garden. The gauging station was installed at the exit point to monitor change in water level during the study period (from January 2012 until December 2012). The gauge reading was observed twice a day, in the morning (around 7.30 am) and in the evening (about 5.30 pm). The daily readings of the staff gauge were obtained for the study stream. Also, the stream flow discharge was determined using velocity-area technique. Details of the procedures involved are documented elsewhere (see Oluwatimilehin, 1991; Adediji, 2003). This was done at various stages/water levels and used to derive the discharge rating equation for the study stream. The discharge rating equation derived for the study catchment was expressed as:

$$\text{Log } Q = 0.138 + 1.062 \text{ Log } H$$

where:

Q = stream flow discharge (l/s)
H = stage/water level (cm)

The rating equation derived for the study stream was used to convert daily stage to discharge. Water sample was taken weekly during the study period. However, sampling was intensified during rainy season. In this regard, the storm runoff generated from rainfall events that occurred during the day were all sampled for the determination of suspended sediment concentration. The rating curve derived was used to obtain sediment concentration for discharges for which sampling was not done. Therefore, the rating curve technique was used to convert the stream flow discharge (m^3/s) or (l/s) to sediment concentration (mg/l) (see Miller, 1961; Walling, 1977).

Determination of suspended load involved the filtration of each 100 ml stream water sample suing Whatman Glass Fibre Circles (GFC) and a vacuum pump assembly, oven drying, cooling in a desiccator and weighing the sediment residue together with filter paper. The weight of the filter paper was subsequently subtracted to determine the weight of the residue expressed in mg/l (see Oluwatimilehin, 1991; Adediji, 2003).

Rainfall data especially daily and monthly rainfall amount between January and December 2012 was obtained from the automated weather station situated within the study catchment and under the supervision of the Department of Environmental and Agricultural Engineering, University of Ibadan, Ibadan, Nigeria.

RESULTS AND DISCUSSION

The result on the area extent covered by each of land uses identified and classified from the Google Image of the area is as shown in *Table 1*. According to *Table 1*, the largest proportion of the study basin is currently grass/degraded vegetation surface. This is distantly followed by built-up/paved surfaces and swamp/gallery vegetation at the exit point and along the stream channels, respectively. This further indicated that substantial portion of the study catchment is exposed to direct rain drop impact which might produce accelerated erosion as well as flooding. As evident from *Table 2*, the values of storm sediment concentration obtained for the study urbanized stream ranged from 636 mg/l on 21st May, 2012 to 3792 mg/l on 15th of October, 2012 with mean value yield of 2136.8 mg/l and standard deviation of 1290.9. Also, the value of storm suspended sediment yield recorded at the beginning of the rainy season especially on 4th of April 2012 (2375 mg/l) is far higher than value recorded at the middle of the wet season on the 7th of July 12 (648 mg/l) (see *Table 2*). This may not be unexpected as a lot of wastes dumped into the drainage channels and bare surfaces around the students' hostels and academic areas within the interfluvial areas of the study catchment are moved by storms runoff into the stream.

Table 1 Areal extent (m^2) of the land uses classified from the Google Earth Image of the study catchment

Land Use	Areal extent (m^2)	% of the study area
Built-up/Paved surface	702071	33.37
Swamp/Gallery Vegetation	243511	11.57
Degraded/Grass Vegetation	1158453	55.06
TOTAL	2104036	100

However, with the progressive development in the bush regrowth around the study stream channel during the peak of the rainy season coupled with high rainfall interception by bush/plant cover may possibly account for relatively low sediment concentration of 648 mg/l recorded on 7th of July, 2012. Generally, the high mean suspended sediment concentration (2136.8 mg/l) obtained for the study stream may not be unexpected because of the urbanized nature of the study catchment, where the predominant grassy vegetation is trampled as footpaths and connection route to most buildings within the studied catchment. As expected the higher mean suspended sediment concentration was high because low interception, high runoff velocity, and less time for water to infiltrate to the soil. As shown in *Table 2*, the values of storm sediment concentrations compared favourably with the results obtained from urbanized catchments in the same general area of South-western Nigeria and other parts of the humid tropical region (e.g. Oyegun, 1980 in Ibadan Northeast (Upper Ogunpa); Adediji and Jeje, 2004 in Ile-Ife; Jimoh, 2005 in Ilorin, Southwestern Nigeria; Pushparajah, 1985 in Thailand). For instance, the maximum sediment concentration (3792 mg/l) obtained for the study stream, though higher but compared favourably with the storm sediment concentration of 3475.55 mg/l recorded by Adediji and Jeje (2004) from an urbanized 2nd order stream (Odo-Ogbe) draining Oja-Titun area in Ile-Ife, Southwestern Nigeria. Also, the highest value obtained in this study is in accordance with the maximum value of 4780 mg/l obtained by Pushparajah (1985) from Huay Ma Feang Stream (urbanized streams) in Thailand during the rainy season of 1983. Also, the values of maximum suspended sediment concentration obtained is in accordance with the findings by Fang et al. (2011) in a small agricultural watershed of the three Gorges in China where maximum storm flow sediment concentration varied from 183 to 62, 138g/m^3 with a mean suspended sediment concentration of 7962g/m^3.

Further, as shown in *Table 2*, the monthly total sediment yield for the study streams ranged from 10.85kg in January to 288.40 kg in October with the mean soil loss of 123.59 kg and standard deviation of 89.50. The monthly suspended sediment yield rose from 10.85 kg in April to 262.70 kg in July and declined to 107.58 kg in September and rose again to 288.40 kg in October and eventually decreased to 18.75 kg in December, 2012 more or less synchronously with the monthly rainfall. It is quite evident from *Fig. 3* and *Table 2* that the monthly total sediment yield closely follows the pattern of monthly rainfall. This was also in accordance with the observation made by Adediji et al (1995) in Ile-Ife area of South-western Nigeria.

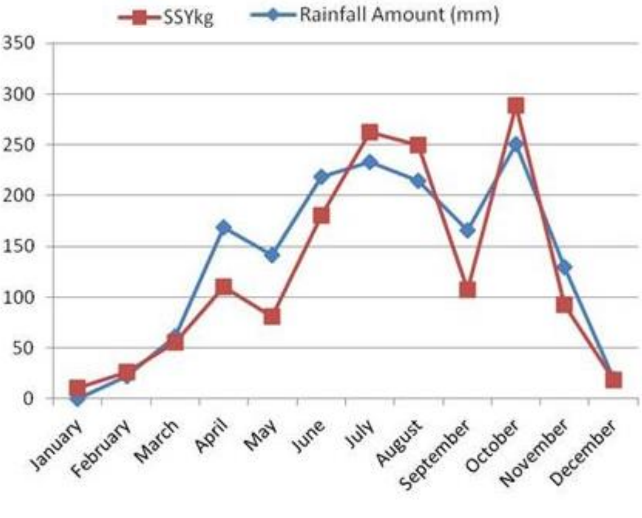

Fig. 3 Relationship between amount of rainfall (mm) and the sediment yield of the River Awba catchment

Table 2 Rainfall events and suspended sediment concentrations of the study catchment

Rainfall Event	Date	Rainfall Amount (mm)	Suspended Sediment Load (mg/l)[a,b]
1	4-4-12	32.7	2375
2	20-4-12	32.7	1053
3	4-5-12	32.7	643
4	21-5-12	32.7	636
5	7-7-12	44.1	648
6	15-7-12	111.9	3308
7	16-7-12	122.7	3721
8	20-8-12	30.3	979
9	20-9-12	78.3	3641
10	25-9-12	70.9	2350
11	10-10-12	101.7	2494
12	15-10-12	154	3792

[a]Mean suspended sediment load = 2136.8mg/l
[b]Standard deviation of suspended sediment load = 1290.9

As evident from Fig. 4, the storm suspended sediment concentrations significantly related to storm flow discharge of the study stream ($r = 0.71$ at $p = 0.01$). This further confirmed the findings by Nadal et al. (2008) in a small catchment with badlands in Spain where significant relationships was obtained among rainfall, runoff and suspended sediment. The result obtained in this study is also in accordance with the findings of Zokaib and Naser (2012) in Hilkot watershed of Pakistan where a good relation was observed between rainfall, runoff and soil/sediment loss under different land uses.

CONCLUSIONS

The dynamics of suspended sediment yield in a 2nd order River Awba stream within the estate of University of Ibadan, Ibadan, Nigeria was undertaken in this study. The study was carried out between January and December, 2012. The results showed that storm suspended sediment concentration was relatively higher at the beginning of the rainy season (2375 mg/l (4th of April, 2012) than at the middle of wet season (648 mg/l) (7th of July, 2012). However, the monthly suspended increases with the increase in monthly rainfall amount. For instance, the monthly sediment yield increase by 240.25 kg between January and October. The total sediment load discharged from the study river catchment was estimated at 1.48 tonnes/year which compared favourably with Adediji and Jeje's (2004) findings from the same general study area (i.e. Southwestern Nigeria).

In the light of the above, in order to minimize the rate of storm runoff and load/yield generated from rain storm events in the study area, the paved surfaces in the interfluvial areas of the study river catchment should be grassed and avoid trampling .The inclusion of rapid growing tree species will enhance the reduction in the sediment loss into the study stream. This will subsequently minimize the rate of flood generation around the Zoological garden of the university in the study catchment. This is in accordance with the observation made by Adriana et al. (2012) in southwestern France that in order to preserve the quality of surface water as well as reduction of sediment concentration, the farmers should keep a minimum acreage of grass land especially in areas bordering the river channel as also required by official French regulation.

Acknowledgements

We appreciate the sincere efforts of Mr. Adigun of the Remote sensing laboratory of the Department of Geography, University of Ibadan for his prompt and adequate

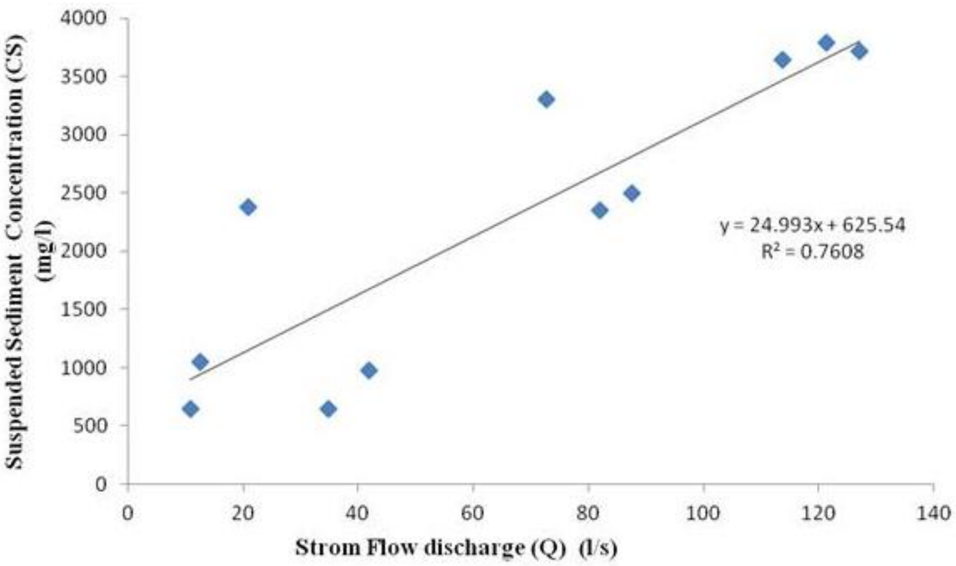

Fig. 4 Relationship between suspended sediment (CS) and stream flow discharge (I/s) (Q)

measurements of the stage during the study period and also Mr. Olofinyo of the Physical Geography Laboratory for analysing the sediments.

References

Adediji, A. 2003. Sediment delivery ratios in Opa Reservoir Catchment, Southwestern Nigeria, Unpublished Ph.D Thesis, Department of Geography, Obafemi Awolowo University, Ile-Ife, Nigeria.

Adediji, A., Jeje, L.K. 2004. Channel erosion in the Opa Basin, Southwestern Nigeria. *Journal of Environmental Hydrology* 12, 1–11.

Adediji, A, Jeje, L.K., Ibitoye, M.O. 2013 Urban development and informal drainage patterns: Gully dynamics in Southwestern Nigeria, *Applied Geography* 40, 90–102. DOI: 10.1016/j.apgeog.2013.01.012

Adriana, F, Jean-Christophe, P, Jean-Claude, M., Yveg, L.B. 2012. Designing management options to reduce surface runoff and sediment yield with Farmers: An experiment in south-western France. *Journal of Environmental Management* 96, 74–85. DOI: 10.1016/j.jenvman.2011.11.001

Bracken, L.J., Kirkby, M.J. (2005): Differences in hillslope runoff and sediment transport rates within two semi-arid catchments in Southeast Spain, *Geomorphology*, 68, 183–200. DOI: 10.1016/j.geomorph.2004.11.013

Fang, F.N., Zhi, H.S., Lu, L., Zhang, G., Gian-Jin, L., Lei, A. 2012. The effects of rainfall regimes and land use changes on run off and soil loss in a small mountainous watershed, *Catena* 99, 1–8. DOI: 10.1016/j.catena.2012.07.004

Fang, N., Shi, Z., Li, L., Jang, C. 2011. Rainfall, runoff, and suspended sediment delivery relationships in a small agricultural watershed of the Three Gorges area, China. *Geomorphology* 135, 558–568. DOI: 10.1016/j.geomorph.2011.08.013

Gao, P. 2008 Understanding watershed suspended sediment transport. *Progress in Physical Geography* 32, 243–248. DOI: doi: 10.1177/0309133308094849

Gregory, K.J. and Walling, D.E. (1973) Drainage Basin, Form and Process. A Geomorphological Approach. Edward Arnold, London, 58 pp.

Jeje, L.K, Ogunkoya, O.O., Oluwatimilehin, J.M. 1999. Solute load concentrations in some streams in the Upper Osun and Owena drainage basin, central western Nigeria. *Journal of African Earth Science* 29 (4), 799–808. DOI: 10.1016/s0899-5362(99)00130-x

Jimoh, H.I. (2005) Tropical rainfall events on erosion rates in a rapidly developing urban area in Nigeria. *Singapore Journal of Tropical Geography* 26, 74–81. DOI: 10.1111/j.0129-7619.2005.00205.x

Iloeje, N.P. 1981. A new geography of Nigeria, new revised edition. Longman Publishers, London.

Mwamba, M.J., Torres, R. 2009. Rainfall effects on marsh sediment redistribution, North Inlet, South Carolina, USA. *Marine Geology* 89, 267–287. DOI: 10.1016/s0025-3227(02)00482-6

Miller, J.P. 1961. Solutes in small streams draining single roc k types San gre de Cristo Range, New Mexico, U.S. Geol. Survey Water Supply Paper 1535F.

Morgan, J.P. 1971. Soil Erosion. Longman, London and New York.

Morisawa, M.E. 1957. Accuracy of determination of stream length from Topographic Maps Trans. Amer. *Geophysical Union* 38, 86–88. DOI: 10.1029/tr038i001p00086

Nadal-Romero, E., Regues, D. 2008. Sediment yield from badland areas in Mediterranean environments. *Progress in Physical Geography* 29, 182–190.

Nadal-Romero, E., Regnes, D., Latron, J. 2008. Relationships among rainfall, runoff and suspended sediment in a small catchment with badlands. *Catena*, 74, 127–136. DOI: 10.1016/j.catena.2008.03.014

Slattery, M.C., Phillips, J.D. 2010. Controls on sediment delivery in coastal plain rivers. *Journal of Environmental Management* 92, 284–289. DOI: 10.1016/j.jenvman.2009.08.022

Nu-Fang, F., zhi-Hua, S., Lu, L., Zhong, G., Lei, A. 2012. The influence of rainfall regime and land use on runoff and soil loss in a small mountainous watershed. *Catena* 99, 1–8. DOI: 10.1016/j.catena.2012.07.004

Pushparajah, E. 1985 Development of induced soil erosion and flash floods in Malaysia. *Ecologist* 15 (1-2), 19–25.

Smets, T., Poesen, J., Bochet, E. 2008. Impact of plot length on the effectiveness of different soil surface covers in reducing runoff and soil loss by water. *Progress in Physical Geography*, 32, 654–661. DOI: 10.1177/0309133308101473

Taguas, E.V., Ayuso, J.L., Perez, R., Giraldez, J.V., Gomez, J.A. 2013. Intra and inter-annual variability of runoff and sediment yield of an Ohre micro catchment with soil protection by natural ground cover in southern Spain. *Geoderma*, 206, 49–62. DOI: 10.1016/j.geoderma.2013.04.011

Thair, O., Anas, D. 2010. River-basin planning and management. *Geoforum* 40, 484–494.

Walling, D.E. 1977. Assessing the accuracy of suspended sediment rating curve for a small basin. *Water Resources Research* 13(3), 531–538. DOI: 10.1029/wr013i003p00531

Wei, W., Liding, C., Bojie, F., Zhilin, H., Dongping, W. 2007. The effect of land uses and rainfall regimes on runoff and soil erosion in the semi-arid loess hilly area, China. *Journal of Hydrology* 335, 247–258. DOI: 10.1016/j.jhydrol.2006.11.016

Zheng, M., Qiangguo, C., Qinjua, C. 2008. Modelling the runoff-sediment yield relationship using a proportional function in hilly areas of Loess Plateau, North China. *Geomorphology* 93, 288–301. DOI: 10.1016/j.geomorph.2007.03.001

Zokaib, S., Naser, G. 2012. A study on rainfall, runoff and soil loss relations at different land uses. A case in Hilkot watershed in Pakistan. *International Journal of Sediment Research* 27, 388–393. DOI: 10.1016/S1001-6279(12)60043-2