ARTICLE IN PRESS
Journal of King Saud University – Engineering Sciences (2016) xxx, xxx–xxx

King Saud University
Journal of King Saud University – Engineering Sciences
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ORIGINAL ARTICLES

# Cost effectiveness of sediment management strategies for mitigation of sedimentation at Jebba Hydropower reservoir, Nigeria

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Received 21 September 2015; accepted 13 January 2016

**KEYWORDS**
Cost analysis;
Jebba Reservoir;
Sediment management;
SWAT;
Watershed

**Abstract** In this study, a calibrated hydrologic model, Soil and Water Assessment Tool (SWAT) interfaced with Geographical Information System (GIS) tool was used to study the effect of different sediment management methods in a watershed (12,992 $km^2$) upstream of Jebba Lake, Nigeria. Sediment management strategies considered are (i) reforestation of the watershed, (ii) application of vegetative filter strip (VFS) and (iii) construction of stone bunds. Cost analysis of implementing the selected erosion control measures within the watershed was also carried out to compare the cost effectiveness of each of the management strategies. The results showed that application of VFS, reforestation, and stone bunds to critical zones of the watershed reduced the sediment yield up to 65.6%, 63.4% and 12% respectively while the financial analysis of implementing reforestation, VFS and stone bunds revealed 84.9%, 73.3% and 70.5% reduction respectively in the costs to be incurred if sediments are allowed to accumulate in the dam. From this analysis, it can be concluded that the sediment management scenarios considered in this study are cost effective and sustainable when compared with the costs incurred in tackling the effect due to reservoir sedimentation. Overall, the study showed that hydrological models such as SWAT can be used to study strategies for water resource management. In addition, it can provide policy makers the decision support tools to evaluate the cost and benefits of adopting Best Management Practices (BMPs) particularly for sediment control in erosion prone watersheds.


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Peer review under responsibility of King Saud University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jksues.2016.01.003
1018-3639 

## 1. Introduction

Reservoir sedimentation has been a major problem confronting hydropower dams in many parts of the world. Not only that excessive sediment accumulation in the hydropower reservoirs may be responsible for loss in storage capacity of the dam, it may also lead to many negative effects both within and downstream of reservoirs which may include high turbidity, loss of flood-carrying capacity and reduction in water quality. In Nigeria, the current level of silt deposition in the three (3) hydropower reservoirs (i.e. Jebba, Kainji and Shiroro) might have reached a critical situation and has already taken toll on the generating capacities of the hydropower stations. An urgent rehabilitation of the dams is therefore, needed to enhance the economic and viable operating lives of the hydroelectric plants. Also, a proper sediment management and control strategies are required at the watersheds located upstream of the reservoirs to reduce the erosion processes and other activities that may lead to sediment production. In recent times, application of modelling tools interfaced with GIS has been frequently used in this area of research as it provides the platform to streamline GIS processes tailored towards hydrological modelling. The importance of modelling sediment management scenarios cannot be overemphasized as it provides better understanding of soil erosion processes and a guide towards identifying erosion prone areas for the purpose of proposing Best Management Practices (BMPs) to reduce sediment production in the areas of interest.

One of the most widely used models to simulate various hydrological and sediment parameters in a watershed is the Soil and Water Assessment Tool (Neitsch et al., 2011). SWAT was originally developed by the United States Department of Agriculture (USDA) to predict the impact of land management practices on water, sediment and agricultural chemical yields in large un-gauged basins (Arnold et al., 1995). The SWAT model is a catchment-scale continuous time model that operates on a daily time step with up to monthly/annual output frequency. SWAT has also been used to study various BMPs for the purpose of sediment reduction in a watershed and to curb soil erosion and sediment transport.

The application of modelling tools to study different scenarios of sediment management and land use change have been achieved by various researchers. However, the scenarios modelled and the modelling tools employed differ from one researcher to the other. One of the works in the literature is the sediment management of Upper Blue Nile basin which was modelled at a daily time step by Betrie et al. (2011). In their study, SWAT was used to assess the impact of different catchment management interventions on soil erosion and ultimately on sediment yield. It was discovered that the introduction of buffer strips, stone bund and reforestation reduced the sediment yield at the outlet of Upper Blue Nile by 44%, 41% and 11%, respectively. While the reduction of sediment yield at 15 subbasin outlets varied from 29% to 68% by the buffer strip, 9% to 69% by stone-bund and 46% to 77% by reforestation.

Also, Ogbu and Mbajiorgu (2013) applied Soil and Water Assessment Tool (SWAT) on a watershed (3765 km$^2$) in south-eastern Nigeria, to predict streamflow and sediment discharge from the Ebonyi River Watershed. Land use change was simulated using six land-use change scenarios, representing combinations of decreasing grassland (93.76–0.09%) and increasing agricultural land (0.09–93.76%). Results showed that expansion of agricultural land to about 19% of the watershed area increased average daily streamflow and sediment discharge to about 29% and 44%, respectively. Also, about 72% and 99% increase was obtained for streamflow and sediment discharge, respectively, when agricultural land was expanded to 94% of the watershed area.

In this work, an attempt is made to test the applicability and suitability of SWAT to study the effect of selected sediment management methods on the reduction of sediment into Jebba dam in Nigeria. Cost analysis of implementing each of the sediment management strategies was carried out.

## 2. Description of study area

The study area is the watershed at the upstream of Jebba Lake located in central area of Nigeria between Latitude 8.99° and 10.31° N and Longitude 4.79° and 5.01° E. It has a perimeter of about 567 km and an estimated area of 1,299,156 ha (12,992 km$^2$). The study area forms a subbasin in the existing lower Niger River basin situated in Hydrological Zone II of Nigeria which consists of 23 principal subbasins and with an estimated area of 15.6 million ha (NWP, 2004). Fig. 1 shows the location of the study area as well as the stream network within the map of Nigeria.

The major river that traverses through the watershed is River Niger. Some of the tributaries to this River within the watershed are Rivers Awun, Moshi, Eku, Kotangora and Wuruma. The watershed has a range of elevation between 114 m and 403 m above sea level. The average monthly discharge at Jebba station situated at the outlet of the watershed is 1053 m$^3$/s for the period of 1984–2008, with a minimum value of 378 m$^3$/s in February, 1984 and a maximum value of 3636 m$^3$/s in October, 1998. The soil in the study area is predominantly sandy loam soil. Vegetation within the area is guinea savannah which is mainly characterised with tall grasses and scattered trees. Main activities for sustainability in the area are farming, fishing, hunting, trading and weaving. The selection of the area to test the applicability of SWAT is based on the availability of input data at the hydrological stations established by Kainji and Jebba hydroelectric power stations and also at the Nigerian Meteorological Agency (NIMET) located at Ilorin, Kwara State.

## 3. Methodology

### 3.1. Modelling of sediment yield with SWAT

The Soil and Water Assessment Tool (SWAT) used in this study was interfaced with Mapwindow-GIS to simulate the hydrology, predict the sediment yield and identify erosion prone areas of a watershed (12,992 km$^2$) upstream of Jebba Reservoir in Nigeria. SWAT was calibrated and validated using measured flow data from 1990 to 1995. Sediment samples collected from three locations within the watershed from May to December, 2013 were also analysed and used to spatially calibrate and validate the model. The model was statistically evaluated using coefficient of determination, $R^2$ and Nasch-Sutcliffe Efficiency, NSE. The model showed a good agreement between the observed and simulated values for both calibration and validation period as indicated by acceptable