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Original Research Article

Identification and prioritization of subwatersheds for land and water management in Tekeze dam watershed, Northern Ethiopia

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ABSTRACT

Sedimentation and/or soil erosion are huge problems that have threatened many reservoirs in the Northern Ethiopian highlands, particularly in the Tekeze dam watershed. This study has been conducted to identify and prioritize the most sensitive subwatersheds with the help of a semi-distributed watershed model (SWAT 2009) for improved management of reservoir sedimentation mitigating strategies at the watershed level. SWAT 2009 was chosen for this study due to its ability to produce routed sediment yield and identify principal sediment source areas at the selected point of interest. Based on a digital elevation model (DEM) the catchment was divided in to 47 subwatersheds using the dam axis as the main outlet. By overlaying land use, soil and slope of the study area, the subwatersheds were further divided in to 690 hydrological response units (HRUs). Model calibration (for the period of January 1996 to December 2002) and validation (for the period of January 2003 to December 2006) were carried out for stream flow rate and sediment yield data observed at Emba madre gage station. The results of model performance evaluation statistics for both stream flow and sediment yield shows that the model has a high potential in estimation of stream flow and sediment yield. Tekeze dam watershed has mean annual stream flow of 137.74 m^3/s and annual sediment yield of 15.17 t/ha/year. Out of the 47 subwatersheds, 13 subwatersheds (mostly located in the north eastern and north western part of the catchment) were prioritized. The maximum sediment outflow of these 13 subwatersheds, ranges from 18.49 to 32.57 t/ha/year and are characterized dominantly by cultivated land, shrub land & bare land with average land slope ranging from 7.9 to15.2% and with the dominant soil type of Eutric cambisols. These results can help to formulate and implement effective, appropriate and sustainable watershed management which in turn can help in sustaining the reservoir storage capacity of the dam.

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1. Introduction

Among serious offsite consequences of watershed responses that threaten the sustainability of dams built for various purposes throughout the world is sediment deposition in reservoirs (WCD, 2000). The amount of hydrological response of a catchment (stream flow and sediment yield) and how well the problem is addressed both during the planning stage and while the reservoir is in operation determines the length of time before the reservoir is filled with sediment. To adapt the dimensions of planned water resource developments so as to achieve the actual lifetimes of a reservoir requires the accurate estimation of sediment yield and stream flow and the location the sediment source (Nigussie et al., 2006).

In river basin management, watershed hydrological models have a vital role in simulating possible feature changes and their impact. This helps to determine improved measures of river basin management (Valentina et al., 2014). The main point of watershed development is conserving land and water. But other economic and social development of the watershed follows consequently. Any natural resource (land and water) development program must be started at the micro watershed level the primary starting point of all processes of hydrology (Dhruvanarayana, 1993). However, watershed management actions cannot be carried out at the same time over the entire area of a large watershed. Management activities useful for development have to be started with the most sensitive subwatersheds. Hence, it is mandatory to prioritize the subwatersheds lying in the main watershed (Karale, Bali, & Narula, 1977). Watershed prioritization is the process of ranking different sensitive subbasins of a larger basin, accordingly to be taken up for various interventions. The ranking of micro watersheds could be done depending on stream flow and sediment yield of subwatersheds at a specified time scale.

The Northern Ethiopian Highlands have characteristics dominated by steep slopes; intense rainfall and sparse vegetation cover. The high poverty, lack of technology and high population and livestock densities induce intense soil erosion and degradation problems in these Highlands. This not only reduces crop yields but also has various negative off-site consequences. The life expectations of many reservoirs in the area built for irrigation or water supply in the dry season are threatened by massive sedimentation (Vanmaercke et al., 2010). But still little is known about the amount and dynamics of sediment transport in the Northern Ethiopian Highlands.

The Tekeze Hydropower dam is the tallest arch dam in Africa, generating 300 MW power from a 180 m dam height. The total storage capacity of Tekeze dam is 9.2 billion m^3. According to Aforki (2006) 40% of the reservoir storage capacity (3.7 billion m^3) is provided as a volume (dead storage) for the sediment inflow through the 50 years design life time of the dam. The rate of sedimentation expected annually is about 75 million m^3 i.e. less than 1% of the total storage capacity. The sediment data in the feasibility study report of the dam is limited; hence the rate of sedimentation of the Tekeze reservoir still remains unpredicted. According to several studies carried out in the Tigray area the rate of sediment yield is almost double the above reported value.

Good watershed management is, therefore, needed to reduce the sedimentation of Tekeze dam reservoir to sustain its storage capacity at least up to its design period. Hence, in this study an attempt was made to identify and prioritize sub-watersheds according to their annual sediment yield to determine its impact on watershed management plan of Tekeze dam watershed in particular and Tekeze watershed in general. Applying a watershed hydrological model to estimate stream flow and sediment yield of each sub-watershed and the whole watershed under different land use land cover (LULC), is important in evaluating potential managements (Merritt, Letcher, & Jakeman, 2003). Even though a number of watershed models (empirical and physically based) are available (Arnold, 1998) SWAT 2009 model was used for this study.

2. Materials and methods

2.1. Location description

Tekeze River is the main tributary of the Atbara River, which is, in turn, one of the main tributaries of the Nile. Tekeze river basin is situated in the north-western part of Ethiopia and forms the most northern part of the Nile Basin within Ethiopia. Specifically the pilot study area, the Tekeze dam watershed is located south east of the basin in the range of geographical location 11° 39′ 32.17" and 13° 27′ 15.96″ East longitude, and 37° 33′ 27.63″ and 39° 40′ 7.24″ North latitude (Fig. 1). The major part of the Tekeze dam watershed is in the Amhara regional state and a small part is in Tigray regional state. The watershed covers a total surface area of 29,404 km^2.

2.2. Model input data source and preparation

The main core materials used in this study were GIS software, distributed watershed model SWAT2009 and thematic layers of the study area (digital elevation model, digital soil map, digital drainage map, digital land use and land cover).

2.2.1. Meteorological and hydrological data

The climatic data required by SWAT provides moisture and energy inputs to the watershed that control the water balance and determine the relative importance of the different components of the hydrologic cycle. The climatic variables required by SWAT consist of daily minimum / maximum air temperature, solar radiation, precipitation, wind speed and relative humidity. The model allows values of these variables to be input from records of observed data. The above meteorological data was obtained from the national metrological agency of Ethiopia. The long-term records (1996-2013) meteorological data was collected from six stations (Gonder, Lalibela, Maichew, Mekele, Samre and May-Tsebri) which lie inside and on the boarder of the study watershed. Since relative humidity, wind speed and solar radiation data records were limited for all the stations except for the Lalibela station, weather generator was used to generate those data by using Lalibela station records.

Stream flow records in a daily time step for the Tekeze dam watershed at Emba Madre gauging station was obtained from the hydrology department of Ministry of Water Resource, Irrigation and Energy of Ethiopia for the period 1996–2006. The sediment concentration record is a challenge to obtain since measurements on sediment concentration taken by the Ministry of water