Oct. 2012, Volume 6, No. 10 (Serial No. 59), pp. 1414–1419
Journal of Civil Engineering and Architecture, ISSN 1934-7359, USA

Runoff and Sediment Load from the Right Bank Valleys of Mosul Dam Reservoir

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Abstract: Mosul Dam is a Multipurpose Project on the River Tigris in Iraq with 11.11 billion m^3 storage capacity. It is used to store the water for irrigation, hydropower generation, and flood control. As in other dams in the world, this dam also have sedimentation problem. Sediment accumulation in its reservoir can effect the dam operation (pumping station, hydropower plants, and bottom outlets) and it will definitely shorten the life span of the dam. In this study, the SWAT (soil and water assessment tool) under GIS (Geographical Information System) was applied to simulate the yearly surface runoff and sediment load for the main three valleys on the right bank of Mosul Dam Reservoir. The simulation considered for the twenty one years begin from the dam operation in 1988 to 2008. The resultant values of the average annual sediment load are 35.6×10^3, 4.9×10^3, and 2.2×10^3 ton, while the average values of sediment concentration are 1.73, 1.65, and 2.73 kg/m^3 for the considered valleys one, two and three respectively. This implies that significant sediment load enters the reservoir from these valleys. To minimize the sediment load entering the reservoir, a check dam is to be constructed in suitable sites especially for valley one. The check dam can store the runoff water and trap the sediment load, and then the flow can be released to the reservoir.

Key words: Mosul dam, runoff, sediment load, SWAT model, GIS.

1. Introduction

Deposition of sediment in reservoirs can cause serious problems. They reduce the storage capacity of the reservoir and they can cause serious problems concerning the operation and stability of the dam [1]

One of the important factors in reservoirs design and operation is the sedimentation problem. Sediment delivered to the reservoir comes from two main sources. The first source is the main river entering the reservoir and the second source is the side valleys on both sides of the reservoir.

Due to the importance of the problem several empirical methods were developed and later modeling techniques was adopted [2].

Several types of models are used to predict sediment load among these Refs. [3–11]. In 2008, Ref. [12] developed the SWAT ArcView GIS Patch II for steep slope watersheds. Ref. [13] applied these models and got good results on Apucaraninha River watershed in southern of Brazil. Ref. [14] reviewed and introduced a number of selected papers which present and applied the SWAT (soil and water assessment tool).

Mosul dam is one of the biggest dams in Iraq, the dam is a multipurpose project, for flood control, irrigation, power generation, and water supply. In the last few years, sediment accumulation near the pump station that supply the irrigation water for Al-Jazera irrigation project appeared, which is one of the important projects in North of Iraq. This problem is becoming more severe with time and it is affecting the pumping rate and irrigation schedule of the project. The source sediment is from the main river and others runoff flow of valleys around the reservoir.

The objective of this study is to estimate the runoff volume and sediment loads entering Mosul Dam Reservoir from the main valleys on the right bank side. The accumulated yearly runoff and sediment loads

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were estimated for the period from 1988-2008. This period represent the first 21 years of the life operation of the dam.

2. Study Area

The studied area is located north of Iraq on the right bank of Mosul Dam reservoir (Fig. 1). The dam is about 60 km north of Mosul City. There are three main valleys that pour the runoff and the sediment load in the reservoir directly. High percent of studied area is a planted with seasonal crops (wheat and barley), vegetables and pastures, while the soil classification is mostly of silty loam, silty clay loam, and clay [15, 16]. Table 1 shows the topographic properties of the three studied valleys 1, 2, and 3 (Fig. 1).

For valley one shown in Fig. 2a, the maximum elevation is 770.2 meters above sea level, and the minimum elevation near the outlets is 313.5 meters. About 96% of the valley area is covered with a winter wheat crop, while the remaining 4% is a pasture land. The soil classification distribution is 63% of silty loam, 27% is silty clay loam, and the remaining 10% is clay soil. For valley two shown in Fig. 2b, the maximum elevation is 449.3 meters, and the minimum elevation is 306.5 meters. The crop cover area is 67.3% with winter wheat and vegetables, and 32.7% is pasture lands. The soil classification is 64% is silty loam, 25.6% clay, and the remaining 10.4% is silty clay loam. For valley three shown in Fig. 2c, the maximum elevation is 543.5 meters, and the minimum elevation near the outlet is 313.9 meters, about 46.2% of the total area in valley three is covered with wheat crop, 45.2% agricultural lands, and remaining 8.6% is pasture lands. The soil classification is 68.4% silty loam, 20.9% silty clay loam, and 10.7% is clay soil.

3. Application of the Model

SWAT (soil and water assessment tool) is a physically based model was developed to simulate and predict the runoff, sediment load, and agricultural chemical yields for large and complex watersheds having different soil type [17].

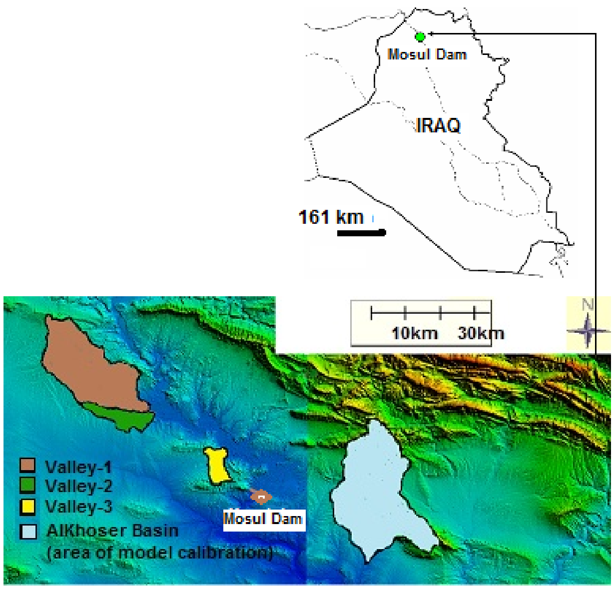

Fig. 1 Location of Mosul dam with the main valleys in the right bank.

Table 1 The topographic properties of the main valleys in the right bank of Mosul dam.

Valley No.	Area (km^2)	Slope %	Length (km)	Shape factor	Average level (meters)
1	450.76	3.59	38.80	3.5	446.62
2	78.52	2.17	21.82	6.09	388.38
3	50.06	5.25	10.86	2.36	404.89

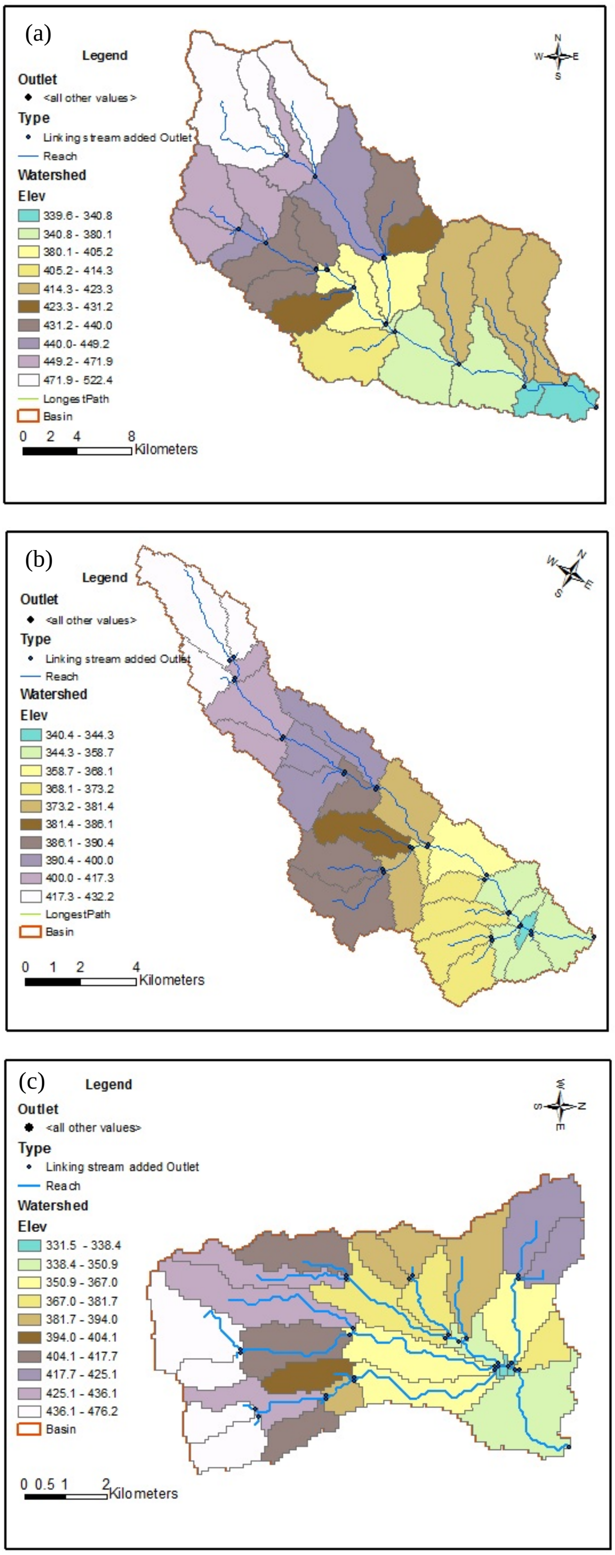

Fig. 2 Watershed boundary, sub-basins elevation, and flow net: (a) for valley-1; (b) for valley-2; (c) for valley-3.

In SWAT model, the surface runoff is estimated by two methods [18]: curve number procedure, and Green-Ampt infiltration method. In curve number method the values of the curve number (CN_2) which is the tabulated curve number considered for average conditions. These values corrected for dry condition (CN_1) and for moisture conditions (CN_3). The Green-Ampt infiltration method [19], on which the effective hydraulic conductivity is estimated based on saturated hydraulic conductivity and curve number as given by [20].

In SWAT model the estimation of erosion and sediment load yields based on MUSLE (modified universal soil loss equation) (Williams 1995 as quoted by Ref. [21]).

In order to verify and evaluate the model's results in the studied area, similar watershed was used. This watershed referred to as al-Khoser Seasonal River near the study area (Fig. 1).

The selected watershed is similar to the studied area in geology, surface soil and climate [22].

The studied area covers about 695 $km^{2.}$ The main part of the area is a silty clay loam, silty clay, silty loam, which covers 72%, 6%, and 4% respectively. The remaining 18.0% is composed of dolomite, limestone, marl and marly limestone, which is very tough and highly jointed and fractured, and cannot be used for agricultural practices [23, 24]. Three single storms were measured in this area [24], including the rainfall depth, runoff and sediment hydrographs. These storms were simulated in SWAT Model to evaluate and calibrate the model to be verification for the studied area. The observed and simulated runoff depth and sediment load for the three considered storm are shown in Table 2.

The results showed a good agreement between the observed and simulated values for both runoff volume and sediment load, for the runoff volume, the determination coefficient between observed and simulated values is 0.94 and the Nash-Sutcliffe, model efficiency value (E) is 0.81. Also for the sediment load, the determination coefficient and Nash-Sutcliffe model Efficiency values were 0.92 and 0.77 for the

Table 2 Observed and simulated runoff volume and sediment load for the considered storm of model verification.

Storm No.	Date	Rain (mm)	Observed Runoff Volume (MCM)	Simulated Runoff Volume (MCM)	Observed Average Sediment Load (*10^3 ton)	Simulated Average Sediment Load (*10^3 ton)
I	19/2/03	19	0.912	0.806	1.68	1.325
II	15/1/04	9	0.130	0.139	0.078	0.158
III	22/1/04	17	1.390	1.772	2.933	3.830

considered storms. This implies that the correlation is good and there is no significant difference between observed and simulated values.

4. Results and Discussion

The daily rainfall data, maximum and minimum temperature, sunshine, humidity, and wind speed of Mosul Dam and Mosul stations for the period 1988 to 2008 were considered in this study. The data were used to estimate the annual runoff volume and sediment load that delivered from the main valleys of right bank on Mosul Dam Reservoir. The SWAT (soil and water assessment tool) was considered for yearly simulation for both runoff and sediment of the three considered valleys.

The results of total annual runoff volume indicate that the average values are 20.6×10^6, 3.1×10^6, and 0.8×10^6 m^3 for valleys one, two, and three respectively (Fig. 3a–3c).

Table 2 Observed and simulated runoff volume and sediment load for the considered storm of model verification.

The contribution of these valleys for the reservoir inflow rate is limited. The maximum annual runoff volume for the considered valleys was in 1993 (62.0×10^6, 9.7×10^6 and 2.8×10^6 m^3 for the three valleys respectively) which are due the maximum annual rainfall depth in that year (656 mm). The minimum runoff volume were 0.28×10^6, 0.021×10^6, and 0.02×10^6 m^3 for the three valleys respectively for the year 2008 which had a minimum average annual rainfall depth of 78 mm.

The results of sediment load indicate that the average annual load carried by the runoff flow is 35.6×10^3, 4.9×10^3, and 2.2×10^3 ton for the three valleys respectively (Fig. 4a–4c). From these figures, we can see that the sediment concentration is highly fluctuating with time. This is due to the effect of rainfall intensity variation and other factors

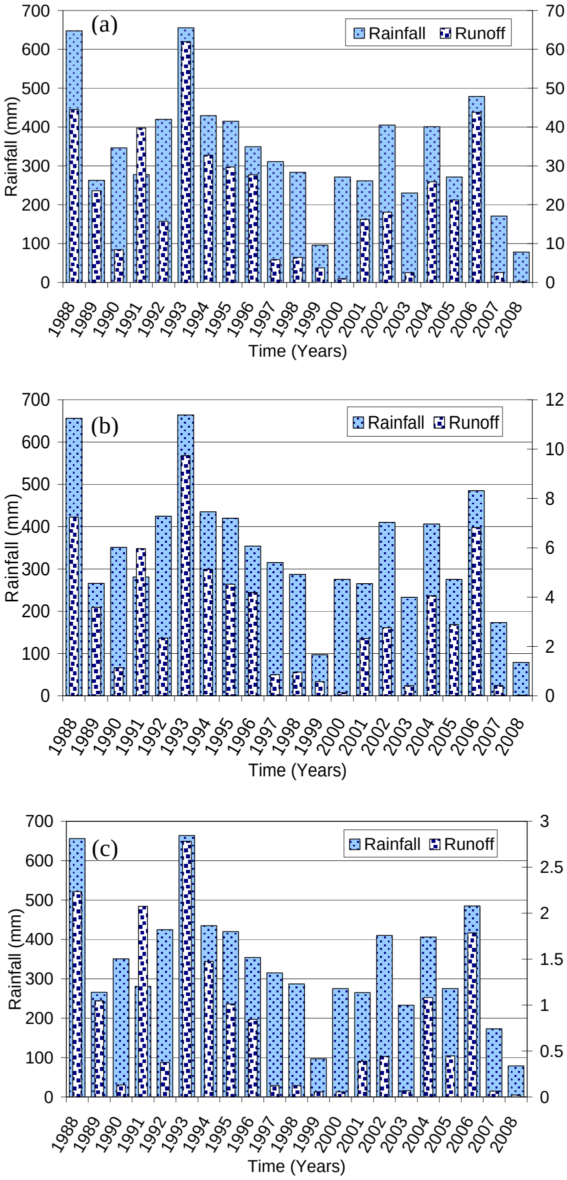

Fig. 3 Yearly rainfall depth and runoff volume: (a) for valley-1; (b) for valley-2; (c) for valley-3 for the considered period.

effecting sediment load concentration. The maximum sediment concentrations are 3.2, 2.7, and 4.5 kg/m^3 for the selected valleys respectively for the year 1988. The maximum rainfall intensity in that year was 63mm/day. The number of rainy days in that year was little while the intensity was high (35, 30 and 20 mm/day) and this was reflected on sediment concentration. During the year (1993) also relatively high sediment concentration can be recognized. In this year the rainfall depth and runoff volume was the maximum, while the sediment load was not at its maximum value. This is due to the fact that the rainy days having effective rainfall depth are distributed along the rainy season with maximum intensity of 55 mm.

The maximum annual sediment loads took place in 1988 (142.56 × 10^3, 19.38 × 10^3, and 10.15 × 10^3 ton) for the selected valleys respectively (Figs. 4a–4c). This year had the maximum annual rainfall depth of 656 mm and maximum runoff volume for all the valleys.

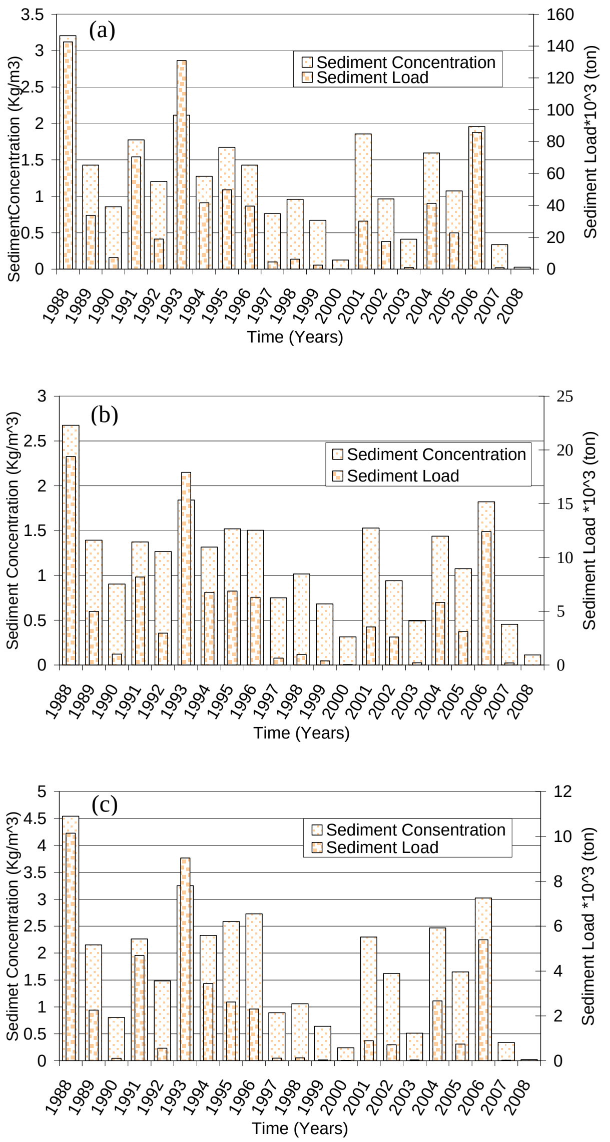

Fig. 4 Yearly sediment load and sediment concentration: (a) for valley-1; (b) for valley-2; (c) for valley-3 for the considered period.

5. Conclusions

The SWAT-2009 (soil and water assessment tool) working under GIS (Geographical Information System) was applied to estimate the yearly runoff and sediment load carrying from the main valleys at the right bank of Mosul Dam Reservoir. The simulation of the runoff and sediment load extended for twenty one years starting 1988. The objective is to estimate the total load that was carried with the runoff flow and delivered directly in to the reservoir. The results indicates that total annual sediment load entering the reservoir from the right bank valleys have a significant amount. This has negative effect on reservoir storage capacity and different hydraulic structures. The total sediment load of the considered period reaches to 747.5×10^3 ton for valley one, 104.3×10^3 ton for valley two, and 45.9×10^3 ton for valley three. This makes the total volume of sediment entered within the reservoir 716.2×10^3 m$^{3.}$ From these values, the average annual rate of erosion in the studied valleys is 78.9, 62.4, and 43.9 ton/km^2 respectively. These values of sediment load must be considered especially for valley one, a check dam in a suitable site may be constructed to store the temporary runoff water for a short period to settle the sediment load and then release the runoff to the main reservoir with minimum load.

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