Application of Swat Model to Estimate the Sediment Load From the Left Bank of Mosul Dam

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ABSTRACT

Mosul dam is the biggest dam in Iraq on Tigris River. It is a multipurpose dam with a designed storage capacity of $11.11*10^9$ m^3. The Soil and Water Assessment Tool (SWAT) working with Geographical Information System (GIS) was applied to simulate the daily runoff and sediment yield from the seven valleys entering the reservoir from the left side. The model was applied for the period 1988-2008 based on daily climatic data of Mosul city and Mosul Dam Stations. The results indicated that the average yearly water flow was $13.8 *10^6$ m^3. It varies with time and among the valleys depending on the soil type, land watershed topography, watershed area in addition the other effective factors, and rainfall depth of that year. The resultant average annual sediment yield was $702*10^6$ ton from these valleys. The sediment yield from each valley depends on runoff coefficient of the valley, soil type and plant cover. These factors affect soil detachment and rainfall properties (depth and intensity) that in turn affect rainfall detachment force. The total sediment yield for the considered period was $14753*10^3$ ton. This represent about 0.42% of the dead storage of the reservoir ($2.9*10^9 m^3$) which is about 0.11% of the total reservoir storage capacity.

Keywords: **Mosul Dam, Runoff, Sediment, SWAT model.**

1. Introduction

One of the major problems of dam operation is sediment deposition in its reservoir causing reduction in its storage capacity. It also affects different structural parts of the dam (e.g. gates, pumping stations, power house and turbines). During the design stage of the dam, sediment transport rates are calculated from the main rivers and valleys. Several methods and models were proposed to estimates sediment expected to accumulate within the reservoir. The storage capacity of dams is of extreme importance in areas experiencing water shortages like the Middle East (Al-Ansari, 1998). Iraq is facing water crises now (Al-Ansari and Knutsson, 2011) that necessities exact knowledge of the quantity of water impounded in the reservoirs. Despite the importance of this factor to insure prudent management of the water resources, such studies were not conducted in the Middle East in general and in Iraq in particular apart from the surveys carried out on Hemrin Reservoir in Iraq and two reservoirs in Jordan (Al-Ansari, 1987; Al-Ansari an Al-Alami, 2003 and Al-Ansari and Shatnawi, 2006). It is believed that such studies are of prime importance for Iraqi dams now due to the water shortages facing Iraq (Al-Ansari and Knutsson, 2011). Such studies will enable constructing new operation curves for the existing dams.

Mosul dam had constructed on the River Tigris with a designed water capacity of $11.11*10^9$ m^3 of which $2.9*10^9$ m^3 is considered as dead storage. The dam is located approximately 60 km northwest of Mosul city (Fig. 1). It is a multipurpose project for irrigation, flood control and hydropower generation. The majority of the water entering the reservoir flows from the River Tigris. The water surface area of the reservoir is 380 km^2. In addition to the sediment that enters the reservoir from the River Tigris, there are 10 main valleys feeding the reservoir, 7 from the left side and 3 from the right side (Mohammad, et al., 2012; Muhammad and Mohammed, 2005).

Al-Naqib and Al-Taiee (1990) selected two valleys (Fayda and Baqaq) on the left bank on Mosul Dam Reservoir to measure the sediment concentration for a number of storms for the period 1987-1988 at the beginning of dam operation. Their objective was to predict the sediment load draining into Mosul Dam Reservoir from the whole left bank valleys based on results of the selected two valleys due to similarities in climatological, geological, geomorphological and hydrological conditions. The amount of sediment load from the studied valleys from field evaluation for the rain season 1987-1988 was 19687 ton. Based on this result the total sediment load from all the valleys in the left bank was 378402 ton for the same period considered.

Muhammad and Mohamed (2005) estimated the surface runoff from all the valleys of the right bank of Mosul Dam Reservoir (seven valleys) based on computer simulation for morphological characteristics of the considered watersheds. Three models were linked to obtain the predicted surface runoff. The first was the GIS model to convert the physical characteristics of the basin to digital maps. The second was the Watershed modeling System (WMS) to delineate the basins boundaries and morphological characteristics, while the third was to estimate runoff depth, runoff coefficient and runoff volume based on Soil Conservation Services method (SCS) programmed by Visual Basic. The results indicated that the total runoff volume from all the considered valleys ranged between 34129 to 33075196 m^3 for the rainfall events ranging between 11 to 79.9 mm respectively.

Park, et. al. (2011) , developed the Soil and Water Assessment Tool (SWAT) by modifying land use and sediment routing ability for overland flow of sub watersheds by changing the model configuration and engine by applying a numerical model Vegetative Filter Strip VFS, which can simulate the trap efficiency for south Korea conditions. The model related the effect of upper watershed flow to the increase of the lower part flow if no diversion channel was installed. The model was applied for small watershed in South Korea for simulating a diversion channel and Vegetative Filter Strip VFS. The results indicated that the sediment can be reduced by 31, 65 and 68% with diversion channel, vegetative filter strip and vegetative filter strip with diversion channel respectively.

Mukundan et al. (2010) tested the variation of spatial resolution of soil data on SWAT model results for both flow and sediment for the considered watershed in North Fork Broad River in Georgia. The state soil geographic (STATSGO) database having a scale of 1:250000 was compared with soil survey geographic (SSURGO) database having a scale of 1:120000 in ArcSWAT model. The results of the model considered to evaluate the effect of soil data before calibration by using the default model parameters. The evaluation of the results indicated that there was no statistically significant difference ($\alpha = 0.05$) for both models of flow and sediment. Also the models indicated that most of the suspended sediment load in the considered watershed was from channel erosion.

Lelis and Calijuri (2010) applied the SWAT model on Sao Partolimeu watershed in southeastern Brazil to recognize the sites of more affected by erosion for that soil type and land use. The model was certified by measuring the runoff and sediment load from ten field plots under natural rainfall for the period 2006-2008. The results indicated that the model efficiency for estimating sediment load was sensitive to soil type and moisture, land use, plant cover and rainfall intensity.

Jeong, et al. (2010) advanced and evaluate the SWAT model for sub-hourly rainfall runoff flow. The procedure of SWAT model for infiltration, surface runoff flow, flow routing, impoundment and lagging was advanced to be suitable for simulating flow with sub-hourly time interval reach to one minute. The other variables such as evapotranspiration, base and lateral flow and soil moisture condition were simulated as daily values. The presented modification was evaluated by applying the model for 1.9 km^2 watershed; about 30% of the area was developed. The watershed located near Lost Creek in Austin Texas USA. The results of model calibration showed that it was more accurate for sub hourly simulation of 15 min. of stream flow having a determination coefficient (r^2) of 0.93, while this coefficient had a value of 0.73 for daily simulation. The presented modified SWAT model provides a tool for hydrology and non-point source pollution studies, and need more modification for water quality studies.

Jain, et al., (2010) simulated the runoff and sediment load yield for part of the Satluj River extended from Suni to Kasol in Western Himalaya based on SWAT model. The model was calibrated and validated based on observed runoff and sediment load yields. The results of daily runoff and sediment yield for validation periods were 0.33 and 0.26 respectively, while its values for runoff and sediment yield were 0.62 and 0.47 respectively for monthly period. They considered these values rationally satisfactory for estimating runoff and sediment yield based on remote watershed and limited data.

Lin, et al. (2010) studied the effect of Digital Elevation Model (DEMs) resolution which is generated from different sources on runoff and sediment yield in addition to total phosphor and total nitrogen. The considered DEMs were DLG5, local Digital Line Graph for 5m interval, ASTER30m, 1 arc-s ASTER Global DEM, 30m resolution, and SRTM90m 3 arc-s SRTM, 90m resolution. The results indicated that the runoff was not sensitive to resampling resolution, the sediment yield slightly sensitive (decreased) with coarser resolution while the total phosphor and nitrogen showed greater decrease for coarser resolution.

Chekol et al. (2007) studied the efficiency of SWAT model in Upper Awash River watershed for the evaluation of water resources. The results indicated that SWAT model is a suitable tool for water resource analysis and planning such as simulating runoff and sediment yield. The model evaluated was based on Nash Sutcliffe model efficiency; the values of efficiency were relatively high for both daily, weekly, and monthly discharges and monthly sediment yield. Also the results of simulation indicated that land management and conservation measures for the watershed can produce a reduction in sediment yield, while applying the parallel terrace can increase the reduction in sediment yield.

Mohammad et al. (2012) applied the SWAT model to estimate the surface runoff and sediment yield from the three main valleys on the right bank of Mosul Dam Reservoir for the period 1988-2008. The results indicated that the average yearly runoff volume from these valleys to the reservoir from right bank were $24.5*10^6$, while the average yearly sediment load was $42.7*10^3$ ton.

An extensive program to evaluate the actual capacity of Mosul Reservoir started in 2010 (Mohammad et.al. 2012 and Issa et.al. 2012). In this paper the sediment load carried by surface runoff from the main valleys of the left bank of Mosul reservoir had been estimated. The SWAT version 2009 model was applied for this purpose.

2. The Applied Model

The Soil and Water Assessment Tool SWAT version 2009 was applied to estimate the surface runoff and sediment load from the Left Bank Valleys of Mosul Dam Reservoir. This model was developed by Arnold, J. as quoted by Neitsch, et al. (2011). They considered the model was designed to predict the surface and ground water, sediment and agricultural chemical yields from watersheds. The model is suitable for wide range of watersheds areas and different soil types, land use, land cover for different management conditions. The SWAT is a physically based model, continuously simulating the flow, sediment and different chemical material of agricultural area such Nutrient, Phosphorus, and Bacteria. Since the model is a physically based, the surface properties are one of the major input data including topographic data, soil type, land use and monument, plant cover. Also the input data includes hydrologic and climate measurements, precipitation, temperature, wind, sunshine, and other data. This study specifically applied for runoff and sediment routing to estimate the total annual load that is entering Mosul Dam Reservoir from the left bank valleys for the period 1988when the dam started to operate.

The SWAT model presents two methods for estimating the excess rainfall (runoff). The first one is the SCS curve number method, and the second method is Green and Ampt infiltration equation (Green and Ampt, 1911) in Mays (2004). The curve number method was developed by U.S Department of Agricultural Soil Conservation Service SCS in 1972, now it is National Resource Conservation Service, NRCS, (Mays 2004). This method based on empirical measurements of rainfall-runoff data for different soil type, land use and land cover. The total daily runoff depth, or daily excess rainfall (R_{off}, mm) based on SCS method can be estimated from the following equation (Mays 2004):

$$R_{off} = \frac{(R_i - I_a)^2}{(R_i - I_a + S)} \tag{1}$$

In which:

R_i : Rainfall depth of day i, (mm);

I_a: Initial abstraction including before ponding including surface storage, (mm);

S: Potential maximum retention, (mm).

The potential parameter (S) is to be changed according to the soil type, land use, land cover, slope, and initial water content of the soil; this value can be determined by the following equation:

$$S = 25.4\left(\frac{1000}{CN} - 10\right)$$

(2)

In which:

CN : Curve number for that day.

The curve number is selected based on soil type and land use from tables for different soil classes and land uses (Mays, 2004). The Natural Resource Conservation Services (NRCS) classified the soil into four groups based on soil texture class and infiltration rate for different land use, management and land cover. The initial curve number determined from the table for each hydrologic response unit (HRU) which represents the curve number of normal antecedent moisture condition,CN_{II}. Then, the SWAT model recognizes the suitable curve number for each day, (CN_I) for dry moisture content and (CN_{III}) for wet moisture content of the soil for that day.

The sediment load carried with surface runoff is also estimated in this model. This includes the particle detachment by rainfall and flow, transport of particles by flow and deposition based on flow power and particle size that effect the ability of flow to continue to pick up particles or depositing them. The Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975 as quoted by Neitsch et al. 2011) is considered in SWAT to estimates the erosion produced by both rainfall and surface runoff flow for each single rain storm in the following form:

$$Q_{sed} = 11.8\ (Q_{Run}.q_{peak}.area_{hur})^{0.56}.K_{USLE}.C_{USLE}.P_{USLE}.LS_{USLE}.CRFG$$

(3)

In which:

Q_{sed}: Yields of Sediment in a considered interval (day), (tons),

Q_{Run}: Volume of surface runoff per unit area (mm/ha),

q_{peak}: Peak runoff rate (m^3/s),

$area_{hur}$: Hydrologic response unit area (ha),

K_{USLE}: Soil erodibility factor of the USLE,

C_{USLE}: Cover management factor of USLE,

P_{USLE}: Transport particle factor of USLE,

LS_{USLE}: Slope length factor of USLE,

$CRFG$: Factor of coarse fragment.

3. Study Area

The studied area covers the left bank of Mosul Dam reservoir (Fig. 1) which is part of Duhok Governorate. There is a wide variation in elevation of the area ranging between 1250 m.a.s.l. in the north east to 330 m.a.s.l. in the south west near Mosul Dam Reservoir. Geologically, the area is composed of two main parts (Awsi, 1990). The mountain area consists of Bekher Fold in the northern side and Duhok Fold in the southern east side. The second main part is a plain area with small local hills. The geological formation of the studied area in the mountain near Summel and Batel consist of Pilaspi Formation, which is dolostone, lime stone, marl and marly limestone area and both Lower Fars (Fatha) and Upper Fars (Injana) Formations in the plain area which are composed of sandstone, claystone, and siltstone in sequential layers (Al-Sinjari 2007). In the northern part of the studied area near the reservoir inlet, the main geologic formations are Pilaspi and Ana, while the Fatha and Injana Formations dominates the plain area.

To identify the soil classification, 15 sites were investigated as shown in Fig. 1. In addition, an explorer soil map of Iraqi (Buringh, 1960) and soil properties analysis for selected sites of the studied area (Al-Sinjari 2007) were also considered. The soil textures ranged between clayey, silty clay, and silty clay loam.

Based on NASA's Landsat GeoCover imagery and field research work by (Al-Sinjari 2007) and present research, the winter crops (wheat and barley) represent about 76.6% of the area, pasture and natural plants such as carthamus oxvanthus, alhagi maurom, raphanus rephanstem and others represent about 21% of the area, some types of vegetables and trees plating near the main valleys cover 0.4%, and 2% of urban and rural areas.

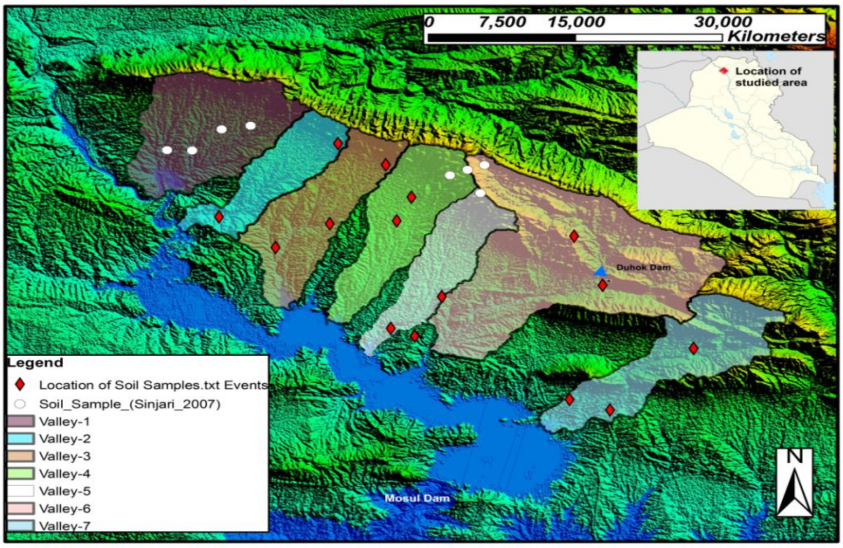

Fig. 1 Boundary of the seven valleys and its location from Iraq map

The study area (left side of Mosul Dam Reservoir) is composed of seven main valleys (Fig. 1). The available data of Digital Elevation Model, (DEM) 30*30m resolution was used to identify the watershed boundary, area, slope and other topographic properties. These valleys have a total area of 1241.5 km^2. The largest area is 100.8 km^2 for Kalac valley while the smallest is 388.8km^2 for Jardiam valley. The highest elevation is 1360 m.a.s.l. while the lowest near the outlet is 330 m.a.s.l., which is the highest operation level of the dam. The topographic properties of the seven valleys are shown in Table 1.

Table 1 Some properties of the considered seven valleys on the left bank of Mosul Reservoir.

Valley No.	1	2	3	4	5	6	7
Name of Valley	Althaher	Kalac	Nakab	Kurab Malik	Afkiri	Jardiam	Amlak
Watershed area (Km^2)	192.4	100.8	145.9	144.0	106.2	388.8	163.4
Watershed Slope %	0.086	0.069	0.060	0.082	0.074	0.148	0.126

4. Model Verification

The considered model was calibrated previously (Mohammad, et.al., 2012) based on the measured data of runoff and sediment load in Al_Khoser Seasonal River, the results showed a good agreements between the observed and simulated values for both runoff and sediment load . The watershed of this river is similar to the present research area in its geological formations, surface soil and climate (Jassim and Goff, 2006). The model was also verified again with the available data of estimated runoff and measured sediment load (Al-Naqib and Al-Taiee, 1990). The measured data for single storms for valleys Amlak and Jardiam were compared with the resulted simulated values to those evaluated by the model performance. Fig. 2 a and 2b shows the observed and simulated values of runoff and sediment load for the considered storms. The results indicates a good agreement between the observed and simulated values of runoff depth or volume, the Nash-model efficiency = 85.2% and determination coefficient (r^2)= 0.85, while for sediment load estimation, the Nash-model efficiency = 70.2 and determination coefficient = 0.70 . Table 2 shows the data and results of model evaluation values for considered storms.

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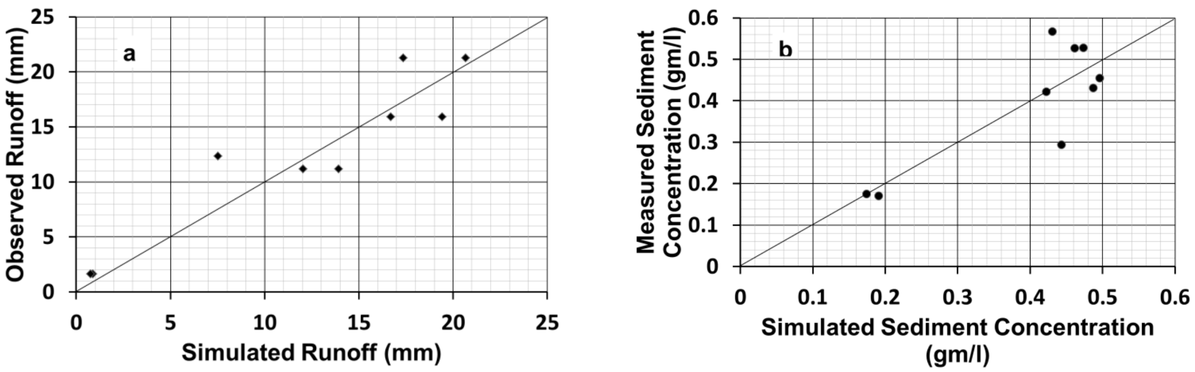

Fig. 2 Observed and simulated runoff depths (a), and sediment loads (b)

Table 2 Dates and rainfall depths of storms on Amlak and Jardiam valleys, for model verification for the period 1988-2008.

Storm No.	1	2	3	4	5
Date	11-15/1/88	15-17/1/88	5/2/1988	16-17/2/88	7-11/3/88
Rainfall (mm)	41	71	5	35	53

5. Results and Discussion

The Soil Water Assessment Tool (SWAT) model was applied to estimate the surface runoff and sediment load entering Mosul Dam Reservoir from the valleys of left bank side. The daily rainfall and other climatic data (temperature, wind speed, solar radiation and relative humidity) of Mosul Dam and Mosul Stations were considered for continuous simulation of runoff and sediment concentration at the outlets of the seven valleys considered for the left bank of the reservoir. The considered years of simulation are the first 21 years of Mosul Dam operation (1988-2008) to estimate the total load entering the reservoir and it is effect on the designed dead storage. The model was calibrated (Mohammad, et.al., 2012) and validated here to ensure it is ability for simulation. The results were good for both runoff and sediment load estimation.

The annual equivalent runoff depth varied between the considered valleys due to different factors affecting it such as soil classification, land use, plant cover, topography and other factors. Generally, the annual runoff coefficient for the considered watersheds for the studied period varied from 0.42 to 0.05 depending on the watershed and rainfall properties. Fig. 3 shows the runoff coefficient variation for the seven watersheds for considered period (1988-2008). The runoff coefficient is varying between the watersheds due to the effect of soil type and land use. Runoff coefficient for Jardiam watershed had the greatest value (average 0.28) in comparison with other watersheds for all the considered period due to the effect of land cover. About 60% of the area of this watershed is covered with natural plant and pasture which implies that no or little human activity such as tillage process took place within its catchment. In addition, soil with relatively high percent of clay covers this watershed. On the other hand, the lowest value (average 0.2) of runoff coefficient was for Nakab watershed. About 96.5% of the area of the watershed is covered with barley and wheat crops. This implies that this watershed is subject to human activities such as yearly tillage that decreases the runoff coefficient values. The runoff coefficients for each watershed were varying with time as shown in Fig. 3. This is due to the effect of rainfall distribution along the rainy season, as well as rainfall intensity and depth variations. All these factors have an influence on the runoff coefficient due to its effect on antecedent moisture content and infiltration rate. The maximum runoff coefficient for all watersheds was in 1991(Fig. 3) despite the fact that the total annual rain fall in that year was 281mm which is less that the average value (344mm for considered period). This is believed to be due to the effect of rainfall intensity in days 23 and 24 of March in that year where the rainfall depths were 25 and 96 mm respectively. This represents 43% of total rainfall depth of that year causing the increase in the runoff coefficients. The minimum runoff coefficient was in 2000 although the total annual rainfall depth was 275mm which is close to that in 1991. This is attributed to the fact that the rainfall distribution in 2000 had a maximum daily rainfall depth of 31mm, this represent 11% of total yearly depth, while other daily rainfall depths were quite less than this value. The decreasing of rainfall intensity decreases the runoff coefficients in comparison with other years.

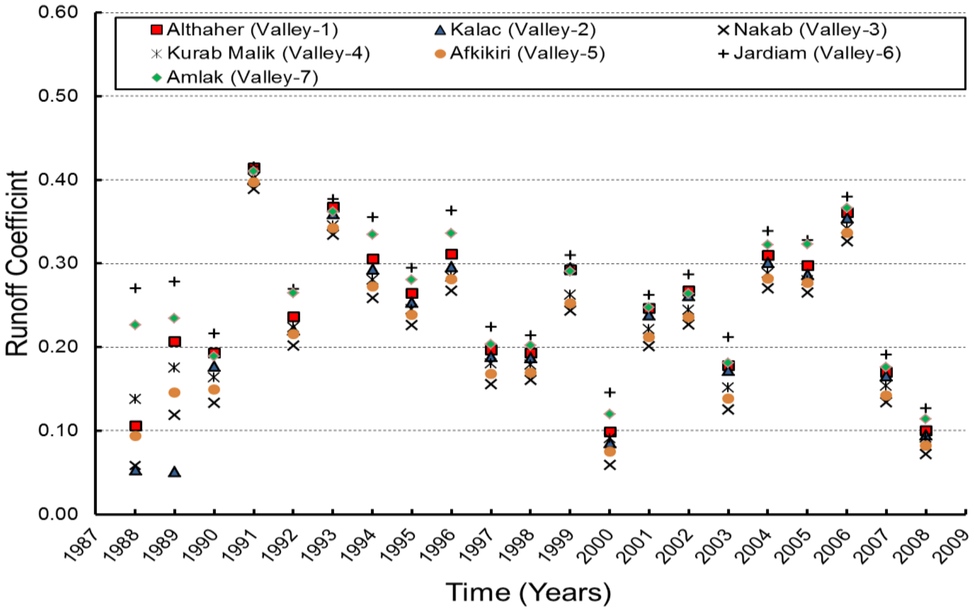

Fig. 3 Runoff coefficient for the seven watersheds of considered period (1988-2008)

The volume of surface annual flow entering the reservoir from each valley and the total accumulated volumes from all valleys are shown in Fig. 4. The volume of surface runoff varied between the valleys based on runoff coefficient and watershed area. For all the considered years, the highest runoff volume was in Jardiam Valley having the maximum runoff coefficient and maximum watershed area. The minimum runoff volume was in Kalak Valley having a minimum watershed area and low runoff coefficient in comparison with other valleys. The maximum annual surface runoff entering the reservoir from the seven valleys was $263.4*10^6$ m^3 for the year 1993 having maximum rainfall depth of 664mm. Although the maximum runoff coefficient was in 1991, the total rainfall depth was more effective. The minimum total surface runoff was $10.6*10^6$ m^3 in 2008 having a minimum rainfall depth of 95mm, and an average value of $13.8*10^6$ m^3.

The sediment yields per unit area for each watershed area are shown in Fig. 5 for the period1988-2008. The highest values of sediment yield were from Jardiam watershed having the greatest runoff coefficient which increases the surface runoff flow and energy of detachment and transport of sediment particles. The upper part (about 62%) of this area is composed of dolostone, limestone, marl and marly limestone that increase the runoff coefficient in comparison with the remaining part which is composed of clay, silty clay and silty clay loam soil having relatively low runoff coefficient. The surface flow from the upper part passing to the lower part can easily detach the soil due to the nature of the geological formations and to tillage activities which reduces the aggregation of particles and increases the rainfall and flow detachment rate.

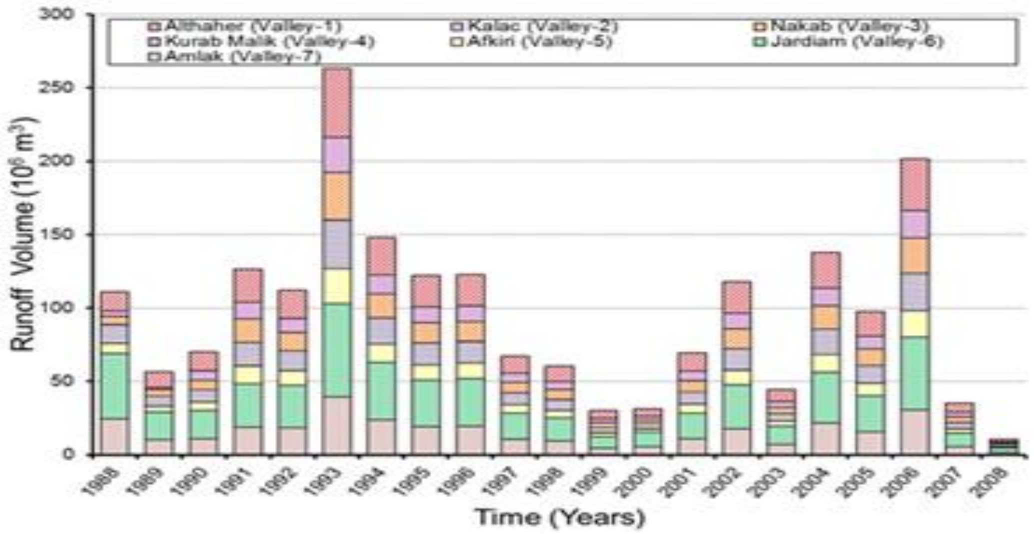

Fig. 4 Runoff volumes for the seven valleys for the period (1988-2008)

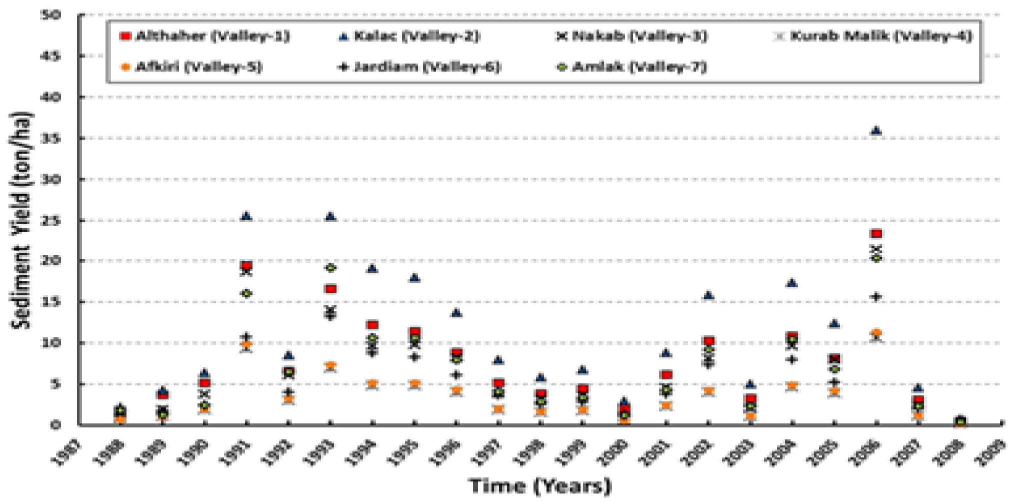

Fig. 5 Sediment yield per unit hectare for the seven Watersheds (1988-2008)

The maximum sediment yields for the all seven watersheds were in 2005. The highest values were for Kalac watershed which were 36 ton /hec. The total annual rainfall depth during 2006 was 512mm which is not the maximum depth of the considered period. During this year however, a number of storms of high rainfall intensity (67, 59, 42, 31 and 25 mm/day) took place which increased the rainfall energy for detachment of soil particle. In addition, the high rainfall intensity increased the runoff depth and surface runoff energy to detach and transport the soil particles.

The minimum sediment yields were during the year 2008 having minimum total rainfall depth of 95mm. The maximum and minimum sediment yields for this year were 0.78 and 0.17 ton/hec for Kalac and Kurab Malik watershed respectively. The runoff coefficient is low for this year due to the low water content of the soil that reduced the surface flow and sediment yield. The sediment yield entering the reservoir from individual watersheds and the total values from them all is shown in Fig. 6. The maximum total annual sediment load was $2128*10^3$ ton during 2006 and the minimum total load was $429*10^3$ ton during 2008 having the minimum rainfall and surface runoff. The average annual sediment yield from all the seven watersheds for the considered period was $702*10^3$ ton.

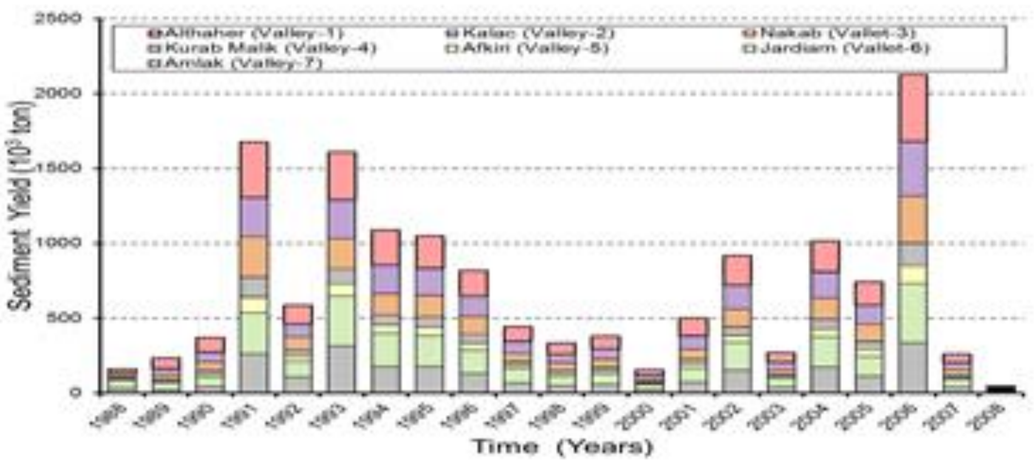

Fig. 6 Total annual sediment load from the seven watersheds (1988-2008).

The total sediment load from all the valleys for the period 1988-2008 was $14753*10^3$ ton. Fig. 7 shows the percent contribution of total sediment yield for the individual valleys. Althaher watershed has the maximum contribution percent, 22% of the total load of the considered period. This watershed is the second largest in its area after Jardiam watershed and the second watershed for the sediment yield per unit area after the Kalac watershed. Although the area of Jardiam watershed is 388.8 km^2, which is the largest, and sediment concentration within the average values (as shown in Fig. 6), but its contribution for sediment load is not more than 19%. This is due to the effect of Duhok Dam which is located at the upper part of this watershed (as shown in Fig. 1). The part of the watershed upstream the dam site covers an area of 135.4 km^2. This dam store water and trap the sediment load generated from that area, while the remaining free flow area is only 253.4 km^2 that contributes water and sediment directly to the reservoir. The percent of contribution of the other valleys are close together, 14, 16, and 17%, while valleys 4 and 5 having the minimum percent of 7 and 5% respectively. This is due to the effect of runoff coefficient which affects the total sediment load. The variation of runoff coefficient and its effect on sediment yield for the seven valleys are shown in Figs. 3 and 5.

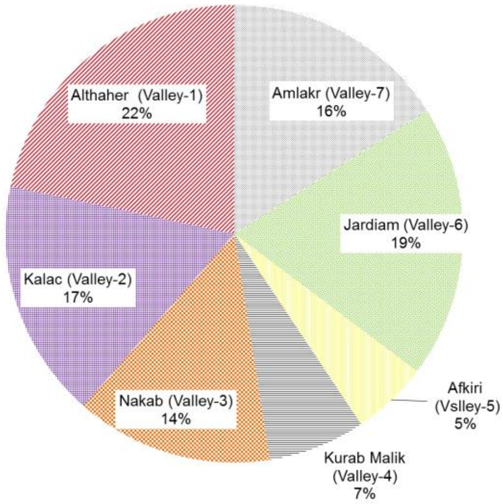

Fig. 7 Percent of contribution of each watershed in the total accumulated sediment for the considered period (1988-2008).

The results indicate that the average rate of erosion are 791, 1176, 672, 336, 356, 551, and 686 for valleys 1 to 7 respectively. The average values was about 653 ton/km^2, this average values is less than the global values of rate of erosion which is 1020 t/km^2 (10.2 t per hectare) (Yang et al. 2003). It implies that the studied valleys reduced the dead storage of Mosul Reservoir about 0.42%. In case we consider the total storage capacity of the reservoir, then these valleys had reduced it by 0.11% during the period 1988-2008. When annual sediment loads delivered from these valleys (Fig. 8) are compared with global estimates (Walling and Web, 1996; Walling, 2003, 2009 and Walling and Fang, 2003) it shows relatively high values. This is believed to be due to the seasonal nature of flow. During rain events the sediments are ready to be easily transported in relatively high concentrations to the reservoir. The nature of soil, geology and topography are additional factors to increase sediment concentrations.

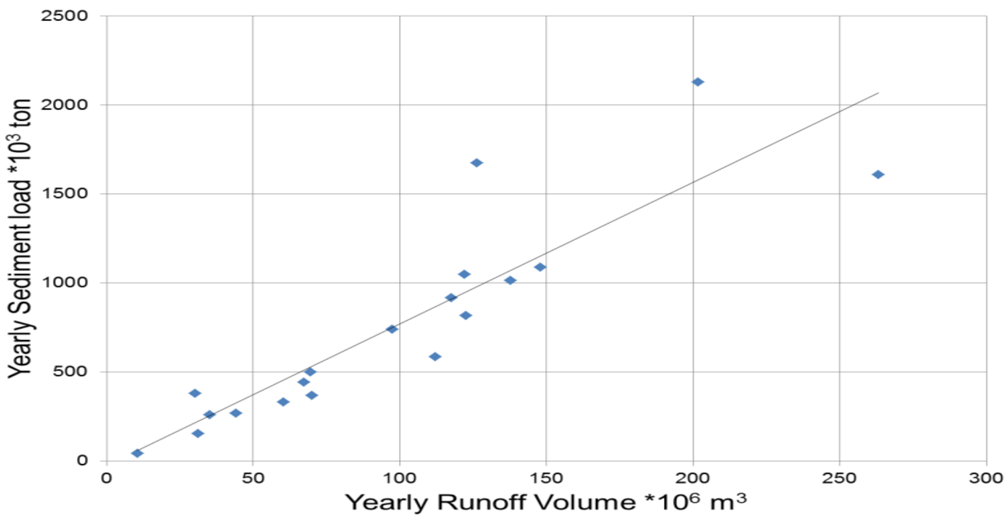

Fig. 8 Annual sediment loads from all seven catchments

Conclusion

Mosul Dam is the biggest dam in Iraq with a total designed storage capacity of $11.11*10^9 m^3$. Some of main structures of the dam had been affected by the sediment load accumulated through the years since its operation, specially the pumping station for Jazira Irrigation Project. The Soil and Water Assessment Tool (SWAT) model under Geographical Information System (GIS) was applied to simulate and route the surface runoff flow and sediment load that enters from the valleys on the left side of the reservoir. On this side there are seven main valleys (Althaher, Kalac, Nakab, Kurab Malik, Afkiri, Jardiam and Amlak). The SWAT model was applied for the period 1988 to 2008 to evaluate the total yearly runoff and sediment load from the left bank of the reservoir for this period. The results showed that the average yearly runoff volume from the seven valleys was $13.8 *10^6 m^3$ and the sediment load entering the reservoir was $702*10^3$ ton. This indicates that the total sediment load for the considered period was $14753*10^3$ ton. Althaher valley had the maximum percent of contribution of sediment load. The total sediment load for the 21 years of dam operation from these valleys does not exceed more than 0.42% of the of the dead storage ($2.9*10^9 m^3$) of the dam. These figures minimize the effect of these valleys on the storage capacity of the dam.

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References

Al-Ansari, N. A. (Ed.), (1987). Hemrin reservoir: geological and hydrological investigation. J. Water Res., Special Pub., No. 2.

Al-Ansari, N.A., (1998). Water resources in the Arab countries: Problems and possible solutions, UNESCO International conf. (Water: a looming crisis), Paris, 367-376.

Al-Ansari,N. A., Al-Alalami, H., (2003). Reduction of water storage capacity of the wadi arab dam (Jordan) due to reservoir sedimentation. Al Manara J. for Scientific Studies and Research. 9 (2), 155-168.

Al-Ansari, N.A., Knutsson, S., (2011). Toward prudent management of water resources in Iraq. J. Advance Science and Engineering Research. 1, 53-67.

Al-Ansari, N.A., Shatnawi, A., 2006. Actual storage capacity of Shar Habeel Ben Hasna Reservoir, Al Manara J. for Scientific Studies and Research. 12, 11-26.

Al-Naqib, S. Q., Al-Taiee, T. M., 1990. The effect of the suspended sediment load transported by Fayda and Baqaq Wadies on Mosul Lake as related to watershed characteristics, confidential, Dams and Water Resources Center, Mosul university, Iraq.

Al-Sinjari, M. A., 2007. Characterization and classification of some vertisols west of duhok governorate. Ph.D. thesis, University of Mosul, Iraq.

Awsi, R. U., 1990. Hydrologic of Duhok and Summel Region" , M.Sc. thesis, University of Mosul, Iraq.

Buringh, P., 1960. Soils and Soil Coditions of Iraq, Mininistry of Agriculture, Baghdad, Iraq, 322.

Chekol , D. A., Tischbein B., Eggers,H., Vlek, P., 2007. Application of SWAT for assessment of spatial distribution of water resources and analyzing impact of different land management practices on soil erosion in Upper Awash River Basin watershed. Lake Abaya Research Symposium (LARS) 2007, University of Siegen and Arba Minch University 7th to 11th May 2007 Ethiopia, 110-117.

Issa, E.I., Al-Ansari, N.A., Knutsson, S., 2012, Sedimentation and New Operational Curve for Mosul Dam, Iraq, Submitted to J. Hydrological Sciences.

Jain, S. K., Tyagi, J., Singh V., 2010. Simulation of runoff and sediment yield for a Himalayan Watershed using SWAT model. J. Water Resource and Protection, 2, 267-281.

Jassim, S.Z., Goff J.C., 2006. Geology of Iraq, Dolin, Pra-gue and Moravian Museum, Brno, 341.

Jeong, J., Kannan, N., Arnold, J., Glick, R., Gosselink , L., Srinivasan, R., 2010. Development and integration of sub-hourly rainfall–runoff modeling capability within awatershed model. J. Water Resources Management, V. 24, 15, 4505-4527.

Lelis, T. A., Calijuri, M. L., 2010. Hydrosedimentological modeling of watershed in southeast Brazil, using SWAT", An Interdisciplinary J. of Appl. Science, 2(5), 158-174.

Lin, S., Jing,C., Chaplot, V., Yu, X., Zhang, Z., Moore, N., Wu, J., 2010. Effect of DEM resolution on SWAT outputs of runoff, sediment and nutrients. Hydrology and Earth System Science Discussions. 7, 4411–4435.

Mays, L. W. ,2004, Water Resources Engineering", Exclusive right by John Wiley and Sons (Adia) Pte. Ltd.

Mohammad, E. M., Al-Ansari, N., knutsson, V., 2012. Sediment delivery from right bank valleys to Mosul Reservoir, Iraq. J. of Ecology and Environmental Sciences. 3(1), 50-53.

Muhammad, A. M., Hbdul-Baki, Y. T., 2005. Estimating water yield from all wadies that flows to eastern bank of mosul dam reservoir. J. of Al-Rafidain Engineering, 13(3), 40-53.

Mukundan, R., Radcliffe, D. E., Risse, L. M., 2010. Spatial resolution of soil data and channel erosion effects on SWAT model predictions of flow and sediment. J. of Soil and Water Conservation. 65(2), 92-104.

Neitsch, S. L., Arnold, J. g., Kiniry, J. R. and Williams, J. R. (2011), " Soil and Water Assessment Tools Theoretical Documentation", Texas Water Resources Institute Technical Report No. 406, Texas A and M University System.

Park, Y. S., Park, J. H., Jang W. S., Ryu, J. C., Kang, H., Choi J., Lim, K. J., 2011. Hydrologic response unit routing in swat to simulate effects of vegetated filter strip for South-Korean conditions based on VFSMOD . J. Water. 3, 819-842.

Walling, D.E., 2003. The changing sediment loads of the world's rivers. In Proceedings of the International Symposium on Sediment Dynamics in Changing Environments, Christchurch, New Zealand. Wallingford UK, IAHS Press IAHS Publication 325, 325–38.

Walling, D.E., 2009. The Impact of Global Change on Erosion and Sediment Transport by Rivers: Current Progress and Future Challenges,The UN World Water Assessment Programme, 26.

Walling, D.E. and Webb, B.W., 1996. Erosion and sediment yield: a global overview, Erosion and Sediment Yield: Global and Regional Perspectives. In Proceedings of the Exeter Symposium, IAHS, 1996.

Walling, D.E. and Fang, D. 2003. Recent trends in the suspended sediment loads of the world's rivers. Global and Planetary Change. Amsterdam, Elsevier. 39, 111–26.

Yang, D., Kanae, S., Oki, T., Koike, T. and Musiake, K. 2003. Global potential soil erosion with reference to land use and climate change. Hydrological Processes, Chichester,UK, Wiley. 17, 2913–28.