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Estimate the Sediment Load Entering the Left Side of Mosul Dam Lake Using Four Methods

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Abstract

Mosul Dam is one of the important dams in Iraq, it suffers like other dams from the problem of sediment accumulation in the lake. The daily surface runoff was estimated from seven main valleys in the left bank of the lake during the period (1/1/1988-31/8/2016) by applying SWAT model. The model performance was assessed using the statistical criteria R^2, IOA, NSE and T-Test, the results were good. The averages annual surface runoff from the main valleys to the lake ranged between $3.3*10^6$ m^3 to $42.1*10^6$ m^3. The daily sediment load was estimated by four methods, Bagnold method was used in SWAT sediments transport simulation, while Yang, Toffaletti methods and Excess Shear Theory were programed by MATLAB, The performance of sediments transport simulation using Bagnlod, Yang and Excess Shear Theory methods was assessed using the same four statistical criteria and the results were good, The averages annual sediment load from the main valleys to the lake were ($5.78*10^3$ - $68.62*10^3$), ($1.49*10^4$ - $42.13*10^4$), ($8.46*10^3$ - $160.77*10^3$) and ($4.26*10^4$ - $78.6*10^4$) tons for Bagnold, Yang, Excess Shear Theory and Toffaletti methods, respectively. The valley Jardiam is the main supplier of sediments to the left side of the dam lake with 56%.

Keywords: Mosul Dam Lake, SWAT Model, Sediment Load, Left Side Valleys.

1. Introduction

Water is the greatest gift of mankind. Water resources are very vital renewable resources that are the basis for the survival and development of any society. Human health and welfare, food security and industrial developments are dependent on adequate supplies of suitable quality of water. Conversely, too much water results in socioeconomic damages and loss of life due to flooding. The liveliness of natural ecological systems is dependent on mankind's stewardship of water resources. Proper utilization of these resources necessitates assessment and management of the quality and quantity of water resources both spatially and temporally [1].

Dams are usually constructed for water resources management purposes. They might be of multipurpose functions like flood prevention, irrigation and/or power generation, etc. [2]. Sediments are one of the major problems of dam operation. They reduce the storage capacity of the reservoir and they can cause serious problems concerning the operation and stability of the dam [3]. 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 is the main river entering the reservoir and the second is the side valleys on both sides of the reservoir [4].

Mosul Dam is one of the most important dams in Iraq, it suffers from the problem of the deposition of sediments in the lake of dam. The dam is located on the Tigris river in northern Iraq about 50 km north of Mosul and 80 km from Turkey and Syria [5].

Several studies have been conducted to estimate surface runoff and sediments resulting from rain using hydrological models such as WEPP, SWAT and HEC-HMS. [6] studied the sediments production of Sweedy Valley in the right Bank of Mosul dam lake by linking the Geographic Information System (GIS) with a computer model built using Visual Basic 6 and Universal Soil Loss Equation (USLE). [7] presented a study to examine the applicability of Soil and Water Assessment Tool (SWAT) in estimating daily discharge and sediments from mountainous forested watersheds namely Arnigad and Bansigad are located in lower Himalaya, India. [8] estimated the sediment yield from Ayvalı Dam watershed in Kahramanmaraş region, Turkey by using Water Erosion Prediction Project (WEPP) model. [9] conducted a study for the purpose of estimation the surface runoff and sediment yield using WEPP model in Southern Ontario, Canada. [10] used SWAT model for the simulation of the runoff and sediment yield from Kulekhani watershed, in Bagmati river basin, Nepal. [11] estimated the surface runoff and sediments in the Beheshtabad and Vanak watersheds in the northern Karun catchment in central Iran using SWAT model. [12] applied SWAT to a portion of the Ankara River catchment in the central Anatolia region of Turkey. [13] conducted a study to present continuous hydrologic simulation, as well as continuous simulation of soil and streambed erosion process in mountainous part of Nestos River basin (Macedonia-Thrace border, northeastern Greece) by using Hydrologic Engineering Center's Hydrologic Modeling System HEC-HMS model. [14] applied SWAT model to the South Tobacco Creek watershed in Canada to identify sediment sources and estimate the spatial distribution of sediment yield from both upland and channel erosion processes. [15] used SWAT model, while [16] used WEPP to estimate the surface runoff and sediments of three valleys (Sweedy, Crnold, Alsalam) located on the right bank of Mosul Dam lake. [17] estimated soil erosion and sediment transport on Rambla del Poyo, Valencia, Spain using the conceptual model TETIS. [18] tested the abilities of HEC-HMS to estimate surface erosion and sediment routing on House Creek watershed in Fort Hood, Texas. USA.

Further studies were conducted to estimate soil erosion by applying the Universal Soil Loss Equation model. [19] presented a study to estimate the annual soil loss using USLE model for Kulhan watershed of Shivnath basin, Chhattisgarh using Remote Sensing (RS) and GIS techniques. [20] estimated both magnitude and spatial distribution of potential soil erosion in Indravati catchment in India by using USLE model. [21] studied soil erosion in northern Kirkuk along the left side of Altin Kobry watershed using the Revised Universal Soil Loss Equation (RULSE) based on GIS.

The objective of this study is to estimate the surface runoff and sediments entering Mosul Dam lake from the main valleys in the left side during the study period (1/1/1988 - 31/8/2016). SWAT model was applied to estimate the surface runoff and sediments after the calibration and validation prosses, Bagnold Method was used in SWAT model to estimate sediment load. Yang, Excess Shear Theory and Toffaletti methods was programed by MATLAB to simulate sediments transportation. The other objective is to determine the delivery percent of the valleys, and which valleys are the main supplier of sediments to the lake.

2. Study Area

The studied area is located north of Iraq on the left bank of Mosul Dam lake located in 50 km north of Mosul, there are several main valleys from the left and right sides deliver sediments directly into the lake. The study area also included Alkhooser seasonal river watershed located in 45 km northwest of Mosul, it was used to calibrate and validate SWAT model. The seven main valleys Althaher, Kalac, Nakab, Kurab Mailk, Afkiri, Jardiam and Amlak pour directly in the left bank of Mosul Dam lake, as show in Fig. 1.

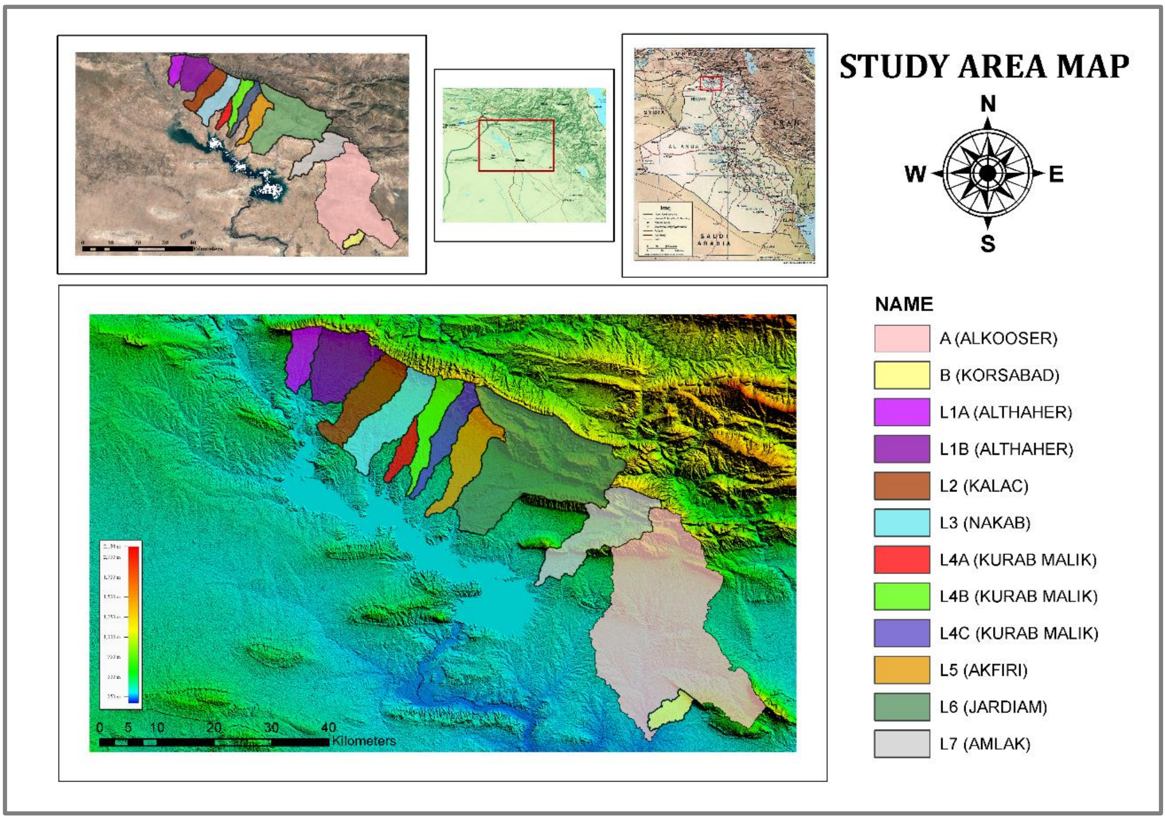

Fig. 1. Study area map.

There is a large difference in the elevation of this area above the sea level (AMSL), ranging from 1250 m in the north to 330 m in the northeast near the reservoir of Mosul Dam, while the areas of the valleys watersheds ranged from 89.45 to 387.7 km^2. This area consists of two main parts, the first part is the mountainous region of Baikher Fold on the north and Duhok Fold in the northwest, while the second part of the area is flatland with some hills [22]. These valleys were encoded by the symbols L1 to L7, respectively, in the case of secondary valleys in the main valley, the symbols (A), (B) and (C) were added to the original symbol, as in Althaher and Kurab Malik valleys, while the calibration and validation watersheds were encoded by the symbols (A) and (B), respectively.

The calibration and validation watersheds are part of Alkhooser seasonal river basin, located northwest of Mosul. The watershed (A) located at the top of the waterfalls site, it is area 696 km^2, it was used to calibrate the model which has field measurements of the surface runoff and sediment load. The watershed (B) located northeast of the waterfalls, it is area 38.3 Km^2, which is part of watershed (A) was used to validate the model [23]. Table 1 shows the morphological characteristics of the main seven valleys in the left side of the lake and the calibration and validation watersheds. The Digital Elevation Model (DEM) with resolution of (30*30) m produced by ASTER was adopted as an input in SWAT simulation to determine the study area terrain.

Table 1. Data of the seven valleys and the calibration and validation watersheds.

Valley Name		Valley Code	No. of Sub Basins	Morphological Characteristics			
				Area (km^2)	AMSL (m)	Avg. Slope (m/m)	Max Flow Distance (Km)
Left Side Valleys	Althaher A	L1A	9	48.72	553	0.0293	13.0
	Althaher B	L1B	24	115.3	568	0.023	17.6
	Kalac	L2	23	97.1	528	0.0166	22.9
	Nakab	L3	21	118.6	522.5	0.0149	24.7
	Kurab Mailk A	L4A	7	27.77	444	0.0129	13.3
	Kurab Mailk B	L4B	23	60.36	602	0.0236	27.1
	Kurab Mailk C	L4C	27	66.08	621	0.0275	26.6
	Afkiri	L5	19	89.45	572	0.02	26.5
	Jardiam	L6	27	387.7	707.5	0.0129	50.5
	Amlak	L7	27	148.2	676	0.0165	36.3
Calibration	Alkooser	A	25	696	457	0.0109	52.7
Validation	Korsabad	B	1	38.3	314	0.0074	10.2

The Iraq Exploration Map [24] and Soil Analysis for multiple sites were analyzed to determine the soil types of the valleys in the left bank of the dam lake, the soils of the area are clay, silt clay and silt clay loam [25]. The Harmonized World Soil Database (HWSD) was used to explain the types and data of the study area soils. This map contains a rich database of all necessary information that required in SWAT model simulation.

The area of the valleys that pour to the left side of the dam covers by winter crops (wheat and barley) with 76.6%, while grass and natural plants cover 21%. Some kinds of trees and vegetables as well as urban areas and villages cover the remaining part [25]. The Global Land Use Map (Globcover2009_L4_V2.3) was adopted for the purpose of determining the land use for the study area.

The daily climate data for two weather stations near the study area (Mosul and Dohuk Stations) were used to generate the SWAT weather database for the daily continuous simulation. The daily database included rainfall, wind speed, relative humidity, maximum and minimum temperatures, and solar radiation. The average annual precipitation of the study area was 369 mm along the study period.

3.1. SWAT Calibration

The Watershed (A) was used to calibrate the model which has field measurements of surface runoff and sediment load by [26]. [26] set up a surface runoff and sediment load measurement station at the outlet of the watershed (A). The watershed was used to calibrate the model because located near the area around the dam lake [15] and [16].

SWAT calibration for the surface runoff was carried out by changing curve number values (CN) within acceptable limits until the best results were obtained when comparing the observed and simulated surface runoff values, the best results were obtained by reducing the CN value

4%. The performance of the model was assessed using four statistical criteria, they were Regression Coefficient (R^2), Nash and Sutcliffe Model Efficiency (NSE), the Index of Agreement (IOA) and T-Test (T_{Test}). The values of R^2, NSE and IOA were 0.99, 0.64 and 0.89 respectively, while the value of T_{test} is 0.28, which is accepted for being less than the T_{test} tabular value which is 2.92 at the confidence level 5%, as shown in table 2.

Table 2. The observed and simulated values of the surface runoff and the statistical criteria values for the calibration.

No.	**Date of Storm**	**Rainfall (mm)**	**Observed Runoff (mm)**	**Simulated Runoff (mm)**	**R^2**	**NSE**	**IOA**	**T_{test}**
I	19/02/2003	19	1.26	1.76	0.99	0.64	0.89	0.28
II	21/02/2003	18	1.83	2.32				
III	15/01/2004	9	0.18	0.07				

The model was calibrated for sediment load then was assessment with the same statistical criteria, where R^2, NSE, IOA and T_{Test} were 0.99, 0.99, 0.99 and 0.75 respectively, T_{test} is acceptable as being less than the tabular value, as shown in table 3.

Table 3. The observed and simulated values of sediment load and the statistical criteria values for the calibration.

No.	**Date of Storm**	**Rainfall (mm)**	**Observed Sediment (kg/m^3)**	**Simulated Sediment (kg/m^3)**	**R^2**	**NSE**	**IOA**	**T_{test}**
I	19/02/2003	19	1.85	1.91	0.99	0.99	0.99	0.75
II	21/02/2003	18	2.1	2.14				
III	15/01/2004	9	0.6	0.54				

3.2. Yang Method Calibration

The method presented by [27] to estimate the sediments was calibrated by changing the coefficient (Ƞvs) in the sediment load estimation equation within acceptable limits [28]. The best results were obtained when the coefficient (Ƞvs) is 1.52. The performance of this method was assessed by the same four statistical criteria R^2, NSE, IOA and T-Test which was 0.99, 0.81, 0.92 and 0.73, respectively, T_{test} is acceptable as being less than the tabular value which is 2.92 at a confidence level 5%, as shown in table 4.

Table 4. The observed and simulated values of sediment load by Yang Method and the statistical criteria values for the calibration.

No.	**Date of Storm**	**Rainfall (mm)**	**Observed Sediment (kg/m^3)**	**Simulated Sediment (kg/m^3)**	**R^2**	**NSE**	**IOA**	**T_{test}**
I	19/02/2003	19	1.85	2.06	0.99	0.81	0.92	0.73
II	21/02/2003	18	2.1	2.43				
III	15/01/2004	9	0.6	0.29				

3.3. Excess Shear Theory Calibration

The method presented by [29] and [30] to estimate the sediment load was calibrated by changing the coefficient (Ƞsh) in the sediment load estimation equation within acceptable limits [31]. The best results obtained when the coefficient (Ƞvs) is 1. The performance of this method was assessed by the same four statistical criteria R^2, NSE, IOA and T-Test which is 0.99, 0.7, 0.89 and 0.68, respectively, T_{test} is acceptable as being less than the tabular value which is 2.92 at a confidence level 5%, as shown in table 5.

Table 5. The observed and simulated values of sediment load by Excess Shear Theory and the statistical criteria values for the calibration.

No.	Date of Storm	Rainfall (mm)	Observed Sediment (kg/m³)	Simulated Sediment (kg/m³)	R^2	NSE	IOA	T_{test}
I	19/02/2003	19	1.85	2.13	0.99	0.7	0.89	0.68
II	21/02/2003	18	2.1	2.52				
III	15/01/2004	9	0.6	0.24				

4. SWAT Validation

Field measurements of watershed (B) which conducted by [32] were used to validate the model for surface runoff estimation. The performance of the model was assessed using four statistical criteria. R^2, NSE, IOA, and T_{Test} were 0.98, 0.86, 0.96 and 0.33, respectively, T_{test} is accepted for being less than the T_{test} tabular value which is 2.92 at the confidence level 5%, as shown in table 6.

Table 6. The observed and simulated values of the surface runoff and the statistical criteria values for the validation.

No.	Date of Storm	Rainfall (mm)	Observed Runoff (mm)	Simulated Runoff (mm)	R^2	NSE	IOA	T_{test}
I	04/01/2003	14	0.312	0.12	0.98	0.86	0.96	0.33
II	19/02/2003	19	3.75	2.85				
III	17/01/2004	16	1.66	1.69				

5. Surface Runoff Estimation

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. When water is initially applied to a dry soil, the infiltration rate is usually very high. However, it will decrease as the soil becomes wetter. When the rate of application is higher than the infiltration rate, surface depressions begin to fill. If the application rate continues to be higher than the infiltration rate once the all surface depressions have filled, surface runoff will commence [33].

SWAT model estimate surface runoff by one of two methods, the first method is Green and Ampt method which requires a lot of information about the soil and measurements of rainfall depths with time in high resolution, for example every hour, these values are not available in the measurement stations of the study area. The second method is Curve Number Method, which is the most widely used in surface runoff estimation and has been adopted in this study for its compatibility with available rainfall and soil data. This method is based on soil characteristics, land use and hydrological conditions [34].

6. Sediment Load Estimation

Soil erosion is the detachment and transportation of soil particles from their original place to further downstream by erosion agents such as water and wind. It is one of the normal aspects of landscape development. The severity of erosion increases with the decrease in cover material most likely vegetation. The vegetation cover decreases the soil erosion by decreasing the impact of raindrops that cause the detachment of the soil particles. Therefore, bare soil is more likely to be eroded by different soil erosion agents than soil with vegetation cover [10].

6.1. Watershed Sediments Estimation

SWAT model estimates the process of soil erosion caused by rain using Modified Universal Soil Loss Equation (MUSLE). This method represents the use of MUSLE produced by [35] which is development of USLE which found by [36] as mentioned [37]. The USLE equation depends on the intensity of rainfall without taking into account the amount of infiltration if it is high or low. In the high infiltration, there is little runoff and therefore less erosion, while in the low infiltration there is a high runoff and therefore a larger erosion. The modification of the USLE equation convert the calculation of the erosion by the rain intensity to the surface runoff, while the other elements of the equation remained same. This development of the equation improved the sediment estimation process [38].

6.2. Channel Sediment Load Estimations

The sediment load delivered from the channels of the seven valleys (Althaher, Kalac, Nakab, Kurab Mailk, Afkiri, Jardiam, Amlak) were estimated using four methods Bagnold, Yang, Toffaletti and Excess Shear theory.

6.2.1 Bagnold method

[39] Used [40] formula which adopts Stream Power theory to find the sediment load transferred in terms of slope and flow velocity of the channel, SWAT model use this method for estimating the amount of sediments transferred in the channel. The sediment estimation equation is based on the maximum flow velocity [23].

6.2.2 Toffaletti method

Toffaletti presented a procedure for the determination of sediment transport based on the concept of Einstein theory. In his method, he first replaced the actual channel for which the sediment discharge is to be calculated by an equivalent two-dimensional channel of width equal to that of real stream and depth equal to the hydraulic radius of the real stream. Then he divided the flow depth into four zones to calculate the sediment load in it.

The main differences between Toffaletti and Einstein methods are that utilized: (1) the velocity distribution in the vertical, (2) a combination of several of Einstein correction factors into one, and (3) a relation of stream parameters (Sediment Transport for an Individual Grain and Intensity of shear on Individual Grain Size) to sediment transport at other than the two grain diameters above the bed [41]. The resulting SWAT simulation discharges were used as an input in the estimation of the sediment load using Toffaletti Method. The velocity and flow rate is then found using the Manning equation. A code was created in MATLAB to simulate the steps of the sediment load estimation using this method.

6.2.3 Yang method

Yang defined unit stream power as the time rate of potential energy dissipation per unit weight of water (flow velocity times energy gradient, which is approximated by the slope of the soil surface or channel bed) [28]. The resulting discharges from SWAT simulation was used as an input in sediment load estimation using Yang Method. A code was created in MATLAB to simulate the steps of this method to estimate the sediments.

6.2.4 Excess shear theory

The fundamental assumption in modeling sediment transport is involved in the mechanism of incipient motion of sediment transport on the bed surface. On the one hand, the stability of granular material in the river bed depends on the angle of repose at which the motion of particles occurs. The angle of repose equals the sweeping angle of the connected line between a particle center of mass and the contact point around which the particle rotates on the bed surface when the particle center of mass is vertically above the contact point, and thus, the angle of repose depends on the shape of the particle, the size of the particle, and the particle orientation on the bed surface. On the other hand, the flowing fluid exerts forces, initiating the motion of particles, on the particles. The threshold conditions are satisfied when the hydrodynamic moments of forces acting on the single particle balance the resisting moments of force. The hydrodynamic forces consist of the weight of the particle, buoyancy force, lift force, drag force, and resisting force. When the ratio of the active horizontal force to the vertically submerged force, called the Shields parameter, exceeds the critical value corresponding to the initial motion of the particle the particle will be in the submerged incipient motion [42]. [29] and [43] presented an equation for the purpose of estimating the sediment load using Excess Shear Theory. This method was also programmed using MATLAB.

7. SWAT and the Codes Simulation

The SWAT program was used in this study to estimate the surface runoff and also sediment loads resulting from the impact of rain storms on the seven valleys that pour into the left bank of the dam lake after calibrating and validating the model using the watershed (A) and (B), respectively, and obtaining good results. The topographic map (DEM) with resolution (30*30) m, the soil type map (HWSD) and the land use map (Globcover2009_L4_V2.3) insert in the model to determine the topography, soil type and land use of the valleys. A continuous daily simulation was conducted throughout the study period (1/1/1988 - 31/8/2016).

SWAT model divides each main basin into many subbasins and then calculates the surface runoff and the sediment load, as well as other data such as the discharge and sediments that flow in its channels until reaching the outlet of the basin. SWAT provides us with a data file generated from the daily simulation that includes many information as well as many other files that contain the data of the channels, including the slop, width and length of these channels.

A continuous daily simulation was carried out throughout the study period to estimate the sediment load using Yang, Toffaletti methods and Excess Shear Theory using the codes designed in MATLAB to simulate these methods. The resulting discharge from the simulation of SWAT model was used as an input in the codes because they were designed to estimate the sediment load only, as well as data for the dimensions of the channel and its other characteristics and other required data for each method.

8. Conclusions

The maximum surface runoff of Jardiam valley were 75.8*10^6 m^3 and 68.8*10^6 m^3 for the years 1988 and 1993, respectively, while the minimum amounts were 0.85*10^6 m^3 and 0.68*10^6 m^3 for the years 1999 and 2008, respectively. The average annual surface runoff along the study period is 42.1*10^6 m^3. The total surface runoff along the study period is 775.56*10^6 m^3. Fig. 2 shows the annual surface runoff of Jardiam. Table 7 shows the annual values of the maximum, minimum, average and total surface runoff for the study period of the seven valleys.

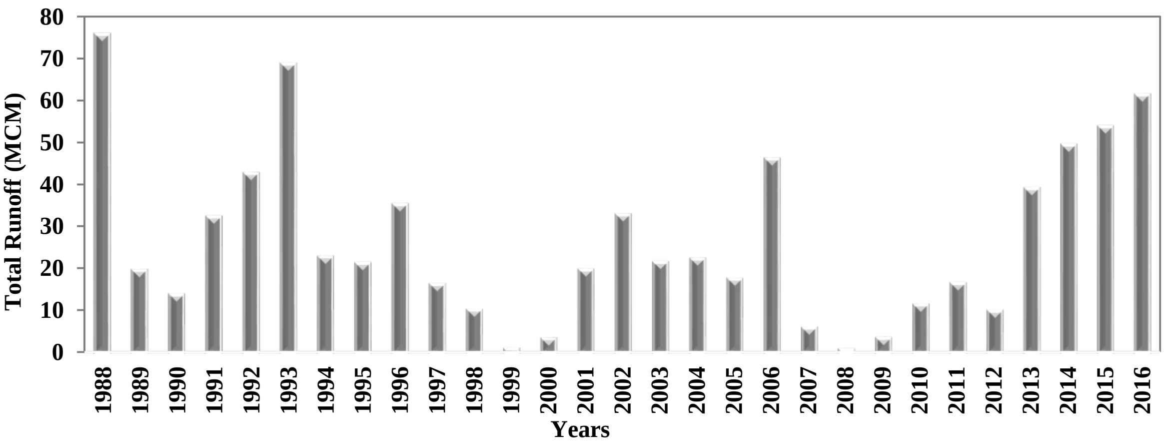

Fig. 2. Annual surface runoff of Jardiam valley.

Table 7. The annual values of the maximum, minimum, average and total surface runoff for the study period of the seven valleys.

Valley Code	Max Runoff (mcm)	Years of Max Runoff	Min Runoff (mcm)	Years of Min Runoff	Average Runoff (mcm)	Total Runoff (mcm)
L1A L1B	24.3 - 26.6	1988, 1993, 2016	0.04 - 0.5	1999, 2000, 2008, 2009	8.2	237.85
L2	12.4 - 13.4	1988, 1993, 2016	0.004 - 0.2	1999, 2000, 2007 - 2009, 2012	3.6	103.16
L3	15 - 15.9	1988, 1993, 2016	0.006 - 0.25	1999, 2000, 2007 - 2009, 2012	4.2	121.56
L4A L4B L4C	19.7 - 21.2	1988, 1993, 2016	0.006 - 0.46	1999, 2000, 2007 - 2009, 2012	5.7	165.93
L5	11.6 - 11.9	1988, 1993, 2017	0.006 - 0.3	1999, 2000, 2007 - 2009, 2012	3.3	95.64
L6	75.8, 68.8	1988, 1993	0.85, 0.68	1999, 2008	42.1	775.56
L7	29.3, 26.9	1988, 1993	0.29, 0.17	1999, 2008	9.9	288.06

The annual sediment load along the study period for Jardiam valley were 68.62*10^3, 42.13*10^4, 160.77*10^3 and 78.6*10^4 tons for Bagnold, Yang, Excess Shear Theory and Toffaletti methods, respectively. The total sediment load during the study period were 1989.88*10^3, 1221.78*10^4, 4662.19*10^3 and 2279.51*10^3 tons, respectively. Fig. 3 shows the annual sediment load along the study period for Jardiam. Table 8 shows the values of the averages annual sediment load and total sediment load over the study period of the four methods and the seven valleys.

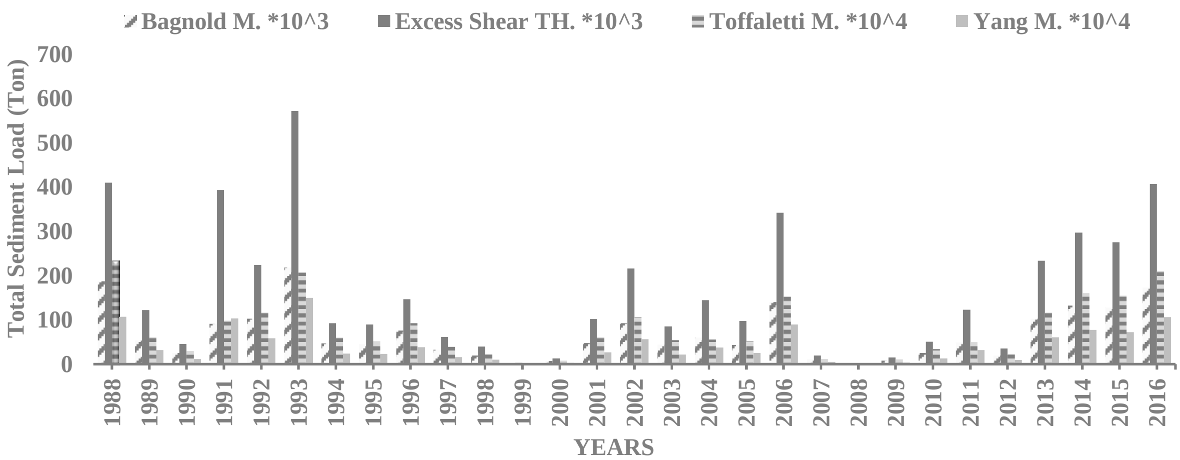

Fig. 3. Annual sediment load of Jardiam valley.

Table 8. The values of the averages annual sediment load and totals sediment load over the study period of the four methods and the seven valleys.

Valley Code	**Bagnold M. * 10^3**		**Yang M. * 10^4**		**Excess Shear TH. * 10^3**		**Toffaletti M. * 10^4**	
	Average Sed. Load (ton)	**Total Sed. Load (ton)**	**Average Sed. Load (ton)**	**Total Sed. Load (ton)**	**Average Sed. Load (ton)**	**Total Sed. Load (ton)**	**Average Sed. Load (ton)**	**Total Sed. Load (ton)**
L1A / L1B	18.35	532.17	14.05	407.35	35.83	1039.19	19.67	570.29
L2	7.0	203.01	1.67	48.36	11.24	326.09	5.3	153.73
L3	8.77	254.42	2.64	76.46	15.03	435.74	7.53	218.44
L4A / L4B / L4C	10.56	306.21	4.52	131.12	17.77	515.21	9.94	288.12
L5	5.78	167.53	1.49	43.18	8.46	245.26	4.26	123.67
L6	68.62	1989.8	42.13	1221.78	160.77	4662.19	78.6	2279.51
L7	22.84	662.42	6.5	188.5	37.09	1075.67	17.5	507.55

The results of this study showed that Jardiam valley is the main supplier of sediments to Mosul Dam lake from its left side with 56%. Its large area 387.7 km^2, land cover and high slopes plays a large role in increasing the amount of surface runoff and sediment load. Fig. 4 shows the percentages of sediment load delivered to the left side of the lake using the average of the four methods used in this study, Fig. 5, 6, 7 and 8 shows the percentages of sediment load delivered from the seven valleys using Bagnold, Yang, Excess Shear Theory and Toffaletti methods, respectively.

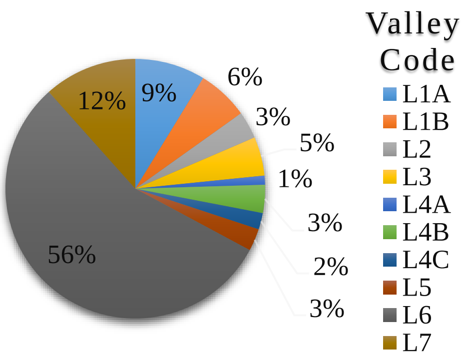

Fig. 4. The percentage of sediment load delivered to the left side of the lake using the average of the four methods used in this study.

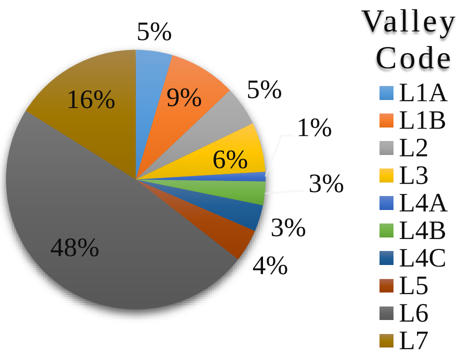

Fig. 5. The percentages of sediment load delivered from the seven valleys using Bagnold Method.

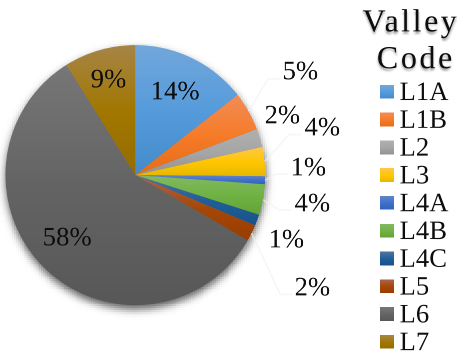

Fig. 6. The percentages of sediment load delivered from the seven valleys using Yang Method.

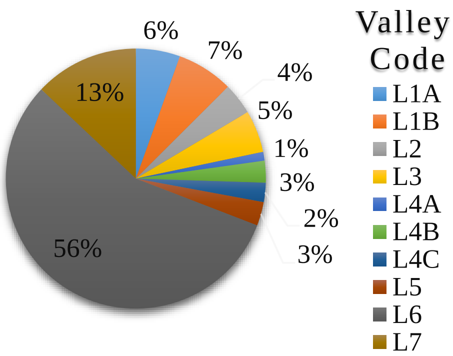

Fig. 7. The percentages of sediment load delivered from the seven valleys using Excess Shear Theory.

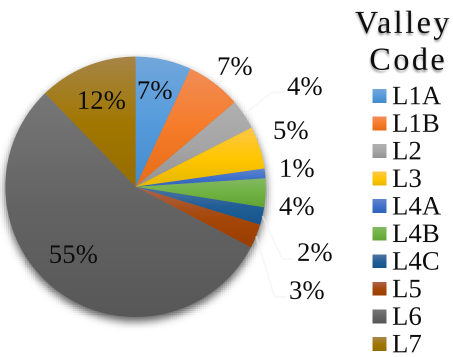

Fig. 8. The percentages of sediment load delivered from the seven valleys using Toffaletti Method.

The recommendations as following:

- SAWT model is recommended for estimating surface runoff and sediment load by the insertion of the needed data then the calibration and validation of the model. The output will be tables of results of water flow, sediments and water quality data with other details.

- Jardiam valley is the main supplier of sediments to Mosul dam lake from the left side with 56%. So, it is recommended to use all methods to reduce the soil erosion and sediment transport process in this valley.

- In general, there is large proportion of sediments entering the lake from the left bank valleys, so it is good to cultivate the land of these valleys and other possible methods to reduce soil erosion and thus reduce the amounts of sediments entering the lake.

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