JOURNAL OF
ENVIRONMENTAL HYDROLOGY

Open Access Online Journal of the International Association for Environmental Hydrology

VOLUME 24 2016

ESTIMATING LIFE SPAN OF RAINWATER HARVESTING RESERVOIRS IN SINJAR AREA, IRAQ

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Due to water shortage in different places in Iraq especially for areas far away from main river flows (Tigris and Euphrates Rivers), rainwater harvesting reservoirs were suggested previously to store runoff water for different water supply purposes. In this study, the Soil and Water Assessment Tool (SWAT) was applied to estimate the sediment load yields from each watershed of a selected reservoir to estimate probable life based on resultant sediment load and trap efficiency. The results indicates that the annual sediment load varied from $40*10^3$ to $4.4*10^3$ ton depending on watershed area and other effective properties, while the sediment yield per unit area were ranged between 9.5 to 20 ton/km^2. The estimated trap efficiency based on annual inflow and reservoir storage capacity were varied from a minimum of 96.5 to 100% due to high reservoir capacity in comparison to annual inflow. The resultant probable life of the reservoirs was greater than 100 years, indicating that the reservoir can economically accepted.

INTRODUCTION

One of the economic techniques that can be considered for rainwater harvesting is the installation of small reservoirs. Rainwater can be stored for supplemental irrigation, livestock and other purposes especially for arid and semi-arid regions. As all stored water in those reservoir is runoff flow, the sediment concentration load within this flow is relatively high, this load will be deposited in rainwater reservoirs and causes decrease of the span life of the reservoir. The sediment load depends on the properties of the watershed such as soil type, land use, land cover and topography in addition to rainfall properties. The detachment, transport and deposition of sediment are a complex phenomenon that depends on all previous factors. A probable life span of rain water harvesting dams proposed in previous study (Al-Ansari et al., 2013) for selected locations in Sinjar area North West of Iraq were estimated in this study. The reservoirs having specific storage capacity, based on probable sediment load deposited in the reservoirs and reservoir storage capacity, the dam life were estimated.

Jain et al., (2010) estimate the runoff and sediment load from Satluj river watershed in Western Himalayan based on Soil and Water Assessment Tool (SWAT). The model was calibrated and validate for both runoff and sediment load. Based on statistical criteria, the model results can considered reasonably satisfactory for both runoff and sediment load estimation.

Iskender and Sajikumar (2016) compared the performance of both GIUH and SWAT for estimating runoff hydrograph based sub daily rainfall data of in Manali watersheds. The results indicates that GIUH model gives a better result than SWAT model for hourly runoff hydrograph.

Dehvari (2014) applied Water Erosion Prediction Project (WEPP) to estimate surface runoff and sediment load for three watersheds within Lucknow River basin. The selected watersheds were different in slope and management in order to evaluate the effect of DEM resolution. Based on daily flow rate of Lucknow River, the t-test criteria showed a significant difference between observed and measured values, while Nash-Sutcliffe model coefficient showed a low deviation. The results showed that the runoff and sediment load of the considered model was not affected by Appling the DEM grid size of 1, 5 and 10m.

Al-Taiee and Rasheed (2011) applied Watershed Modelling System (WMS) to study the hydrological feasibility of constructing rain water harvesting dam on Al-Ajeej basin located south of Sinjar Mountain in North West of Iraq. The results indicated that the annual runoff volume ranged between 137 to 8.5MCM for considered period of study (1994-2006).

Adwubi, et al., (2009) estimated the annual rate of sediment load deposited in small reservoir Upper East Region of Ghana. The bathymetric survey and reservoir soil sampling were considered to achieve the study objective. The results indicated that the average annual sediment deposited for Doba, Dua, Zebilla and Kumpalgogo reservoirs were 1272, 3518, 2764 and 6135 t/year respectively. Also the results indicated that the sediment load decreased with increasing watershed area.

Chitata et al. (2014) investigated the capacity reduction of Mutangi Reservoir located in Southern of Zimbabwe from 2000 to 2012. The assessment of reservoir capacity of 2012 was based on hydrographic survey, grabs sampling and water depth-capacity method and was compared with capacity for the years 2000. The results of some empirical models showed that the average reservoir trap efficiency was 96.4% and that the rate of sedimentation for the three considered methods of estimation (hydrographic survey, grab sampling and water depth-capacity method) were 8539 t/y, 9110 t/y and 8265 t/y for the three methods respectively.

The most important factor that affects the span life of the reservoir is the continuing decrease of its capacity due to the deposition of sediment in the reservoirs causing continuous reduction in its storage capacity with time.

Garg and Jothiprakash (2008) modified the empirical relationship presented by Brune in 1953 and approach of Gill in 1979 to estimate probable life of Gobindsagar Reservoir or Bhakra Dam on Satluj based on capacity inflow ratio as most important factor that effect the trap efficiency (Garg and Jothiprakash. 2008). Revel et a. (2013) carried out several experimental work to investigate the most important factors that affect the sedimentation process in reservoirs. All previous work was related to the efficiency with capacity inflow ratio. The results indicated that the additional important factors are sediment inflow rate, spillway capacity or length and sediment properties.

Iraq is recently experiencing water shortage problems (Al-Ansari and Knutsson, 2011, Al-Ansari, 2013; Al-Ansari et al., 2014& 2015; Issa et al., 2014). The objective of this study is to estimate the probable life of the proposed rain water harvesting reservoirs (Al Ansari et al., 2013) south of Sinjar Mountain, North West of Iraq, due to deposition of sediments load transported by surface runoff pour in proposed reservoirs.

STUDY AREA

The study area is the watersheds of seven proposed rainwater harvesting reservoirs located in two main basins south of Sinjar Mountain as shown in Figure 1. The watersheds areas of the proposed reservoirs ranged between 378 to 4108 km^2 as shown in Table 1, which shows their properties as well. The area is located in semi-arid zone having average annual rainfall of 305mm for the period (1990-2011). As its semi-arid area, there is a high difference in the temperature between day and night in both summer and winter seasons with low humidity (Al-Qassab , et al. 1987).

The most important factors that affects therunoff and sediment detachment and transport are: soil type and land cover. Based on previous studies (Rasheed et al. 1994 and Al-Taiee and Rasheed 2011), the soil is within the formation of Injana and Fatha. It consists of calcareous, gypsum in addition to a percent of organic material. The soil classification of the area (based on grain size distribution) is mostly sandy loam; silty loam and silty clay loam (Figure 2). For both main valleys, a high percent of the area is covered by winter crop, mixed crop and pasture and seasonal vegetables and grass, while the remaindering area consists of bedrock exposure and dry area due to unsuitability for the plants to grow.

APPLIED MODEL

The Soil and Water Assessment Tool (SWAT) was applied to estimate the sediment load detached and transport to selected location of rain water harvesting reservoirs. It is a physically based model developed by the USDA-Agricultural Research Service (Arnold et al. 1998) for continuous simulation of flow and sediment routing, in addition to simulate transport and concentrate of different chemical materials from agricultural lands. The Soil Conservation Service method (USDA-SCS), Curve Number (CN) was applied in previous work (Al Ansari et al., 2013) based on Watershed Modell System (WMS) to estimate the surface runoff, then the results of the model were considered to optimize rainwater harvesting reservoirs size at selected sites of the study area.

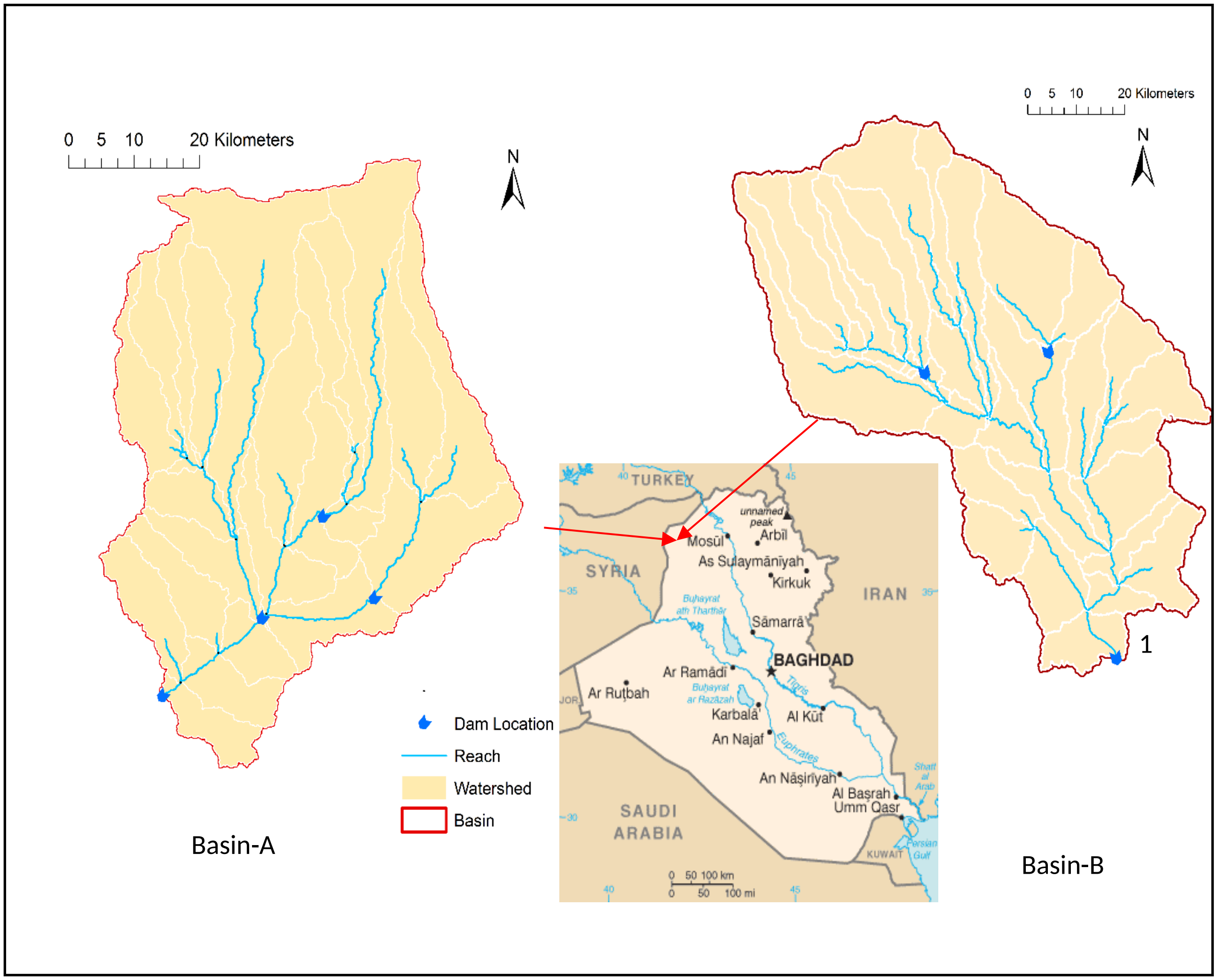

Figure 1. Watershed areas of selected reservoir and its location from Iraq Map.

Table 1: Details of the Watersheds Upstream the Selected Reservoirs.

	Basin A				Basin B		
Watershed properties	Watershed 1	Watershed 2	Watershed 3	Watershed 4	Watershed 1	Watershed 2	Watershed 3
Area (km2)	378	1,141	1,133	824	4,108	854	523
Average Slope %	1.15	1.58	3.41	1.70	1.25	2.38	1.84
Mean Elevation (m)	283	374	417	359	270	382	311

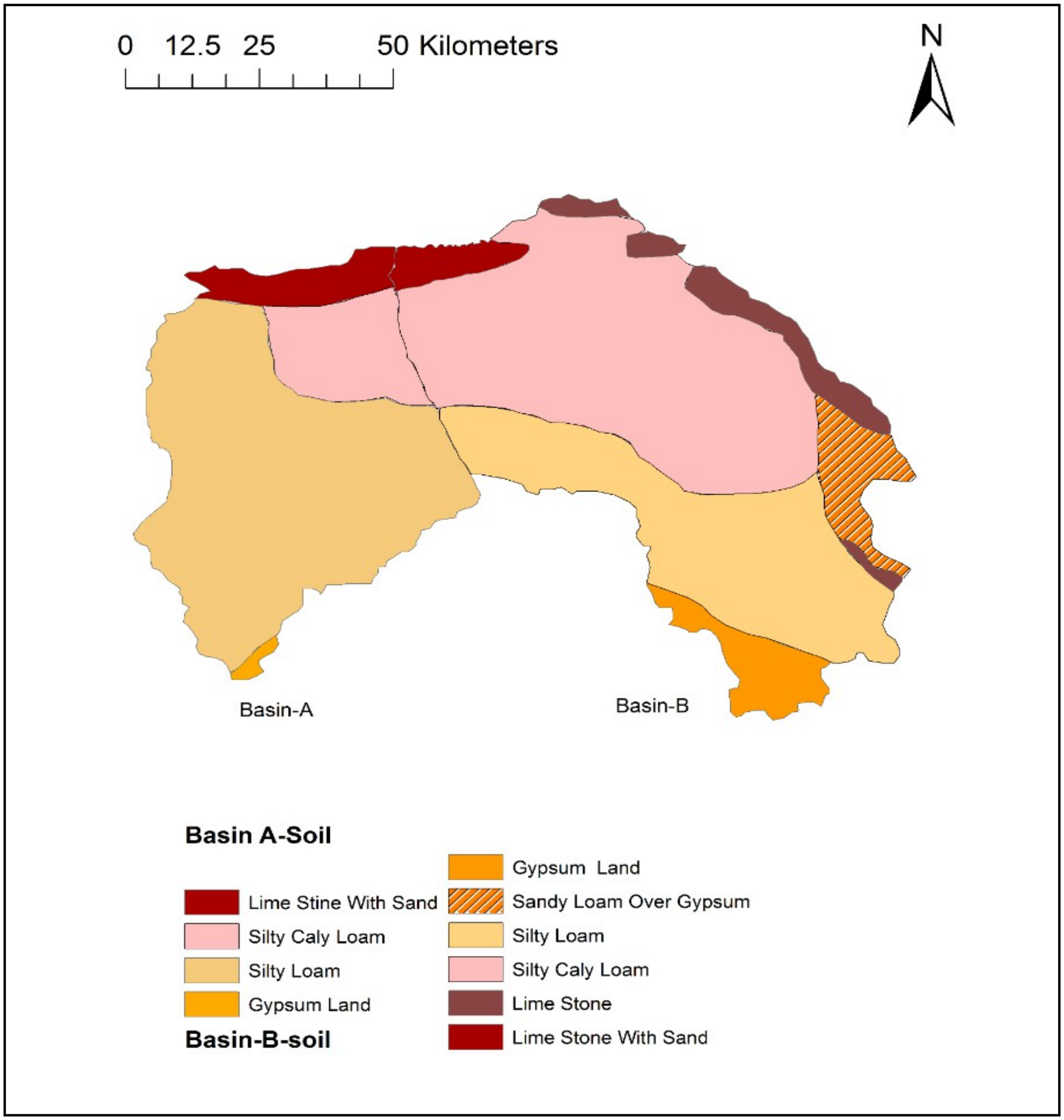

Figure 2. Soil type map of study area.

The sediment load estimation for the considered model (SWAT) was divided into two main parts, watershed and channel load for detachment and transport and deposition of sediment particles. Within the watershed flow, the Modified Universal Soil Loss Equation (MUSLE) which is a modified form of Soil Loss Equation (USLE) was considered in the following form, (Williams 1995 as quoted by Cao et al. 2006):

$$Sed = 11.8 \times (Qv_{surf} \times q_{peak} \times area_{hru})^{0.56} K_{USLE} \times C_{USLE} \times P_{USLE} \times LS_{USLE} \times CFRG$$

Sed : The sediment yield (ton),

Qv_{surf} : The surface runoff volume (mm/ha),

q_{peak} : The peak runoff rate (m3/s),

$area_{hru}$: The area of the HRU (ha),

K_{USLE} : The soil erodibility factor,

C_{USLE} : The cover and management factor,

P_{USLE} : The support practice factor,

LS_{USLE} : The topographic factor,

$CFRG$: The coarse fragment factor.

The factors soil: erodibility, cover and management, support practice, topographic factor and coarse fragment factor in above equation can be estimated by special formulas or tables for each one as presented by (Neitsch, et al. , 2011).

For channel sediment load estimation, the theory of Bagnold's (1977) based on stream power to estimate sediment load in terms of maximum flow velocity and channel slope(Neitsch, et al., 2011). The maximum flow velocity is calculated by the following equation:

$$v_{vh,pk}=\frac{q_{ch,pk}}{A_{ch}} \tag{2}$$

where:

$v_{vh,pk}$: The peak channel velocity (m/s),

$q_{ch,pk}$: The peak flow rate (m3/s),

A_{ch} : The cross section area of flow in the channel (m^2).

The maximum sediment concentration can be transport by channel flow can estimated based on the following equation:

$$Conc_{sed,ch,mx}=C_{sp}\times {v_{vh,pk}}^{spexp} \tag{3}$$

where:

$conc_{sed,ch,mx}$: The maximum concentration of sediment that can be transported by the water (ton/m3 or kg/L),

c_{sp} : a coefficient of sediment transport equation,

$spexp$: An exponent normally varies between 1.0 to 2.0.

The process of sedimentation or detachment within the watershed or channel depends on the sediment concentration and transport capacity. If the transport capacity is greater than sediment concentration, a particle detachment will take place; otherwise the suspended particles will be deposited.

Both runoff and sediment load models were calibrated and validated based on the measured values. The runoff hydrograph were calibrated (Al-Ansari et al., 2013) based on three observed hydrographs that were measured for the watershed in the study area. The results of the statistical criteria that were considered to evaluate the model were t-test and Nash and Sutcliffe Model efficiency. The results indicated that, based on t-test values, there is no significant difference between observed and measured value, while the model efficiency ranged between 95 to 72%. The results of sediment model were also calibrated based on field measurements for watershed area in North of Iraq similar in geological formations to the study area (Mohammad et al, 2016). The considered criteria to calibrate the model, model efficiency and index of agreements indicated a fair model performance; its values were 60% and 0.84 respectively. Based on Annual runoff and reservoir storage capacity, the reservoir trap efficiency was estimated.

RESULTS AND DISCUSSION

The storage capacity of selected reservoir sites and annual runoff volume was estimated previously (Al- Ansari et al., 2013) for the study area. The estimated annual runoff volume ranged between about 4 to 35 MCM based on watershed area and properties. It's important to estimate the reservoirs life span that can supply the required demand for supplemental irrigation of the estimated area supplied by the proposed reservoirs. Soil and Water Assessment tool (SWAT) was applied to estimate the sediment load carried with runoff flow pour in the harvesting reservoir. The considered model is a continuous simulation for the period 1990-2013. The total annual sediment load for the four watersheds in basin A and three watersheds in basin B are shown in Figure 3 and 4 respectively.

The total sediment load varied from watershed to the other based on based on: area, topographic properties and land cover. The average annual sediment load varied from about $40*10^3$ to $4.4*10^3$ ton

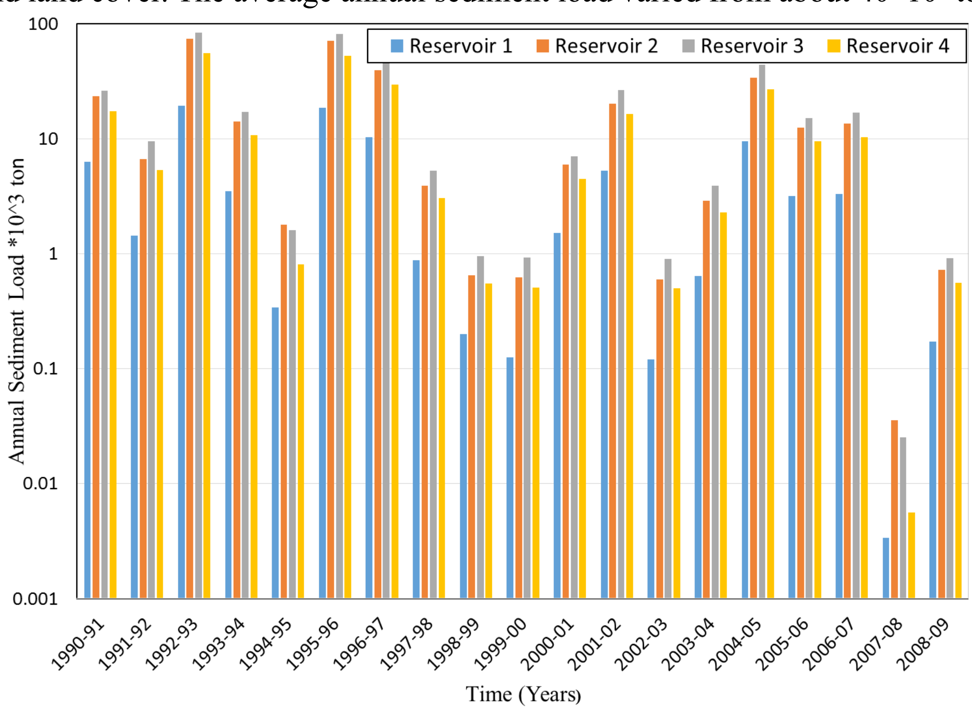

Figure 3. Estimated Annual sediment Load for of Selected Reservoirs in Basin A.

for the considered valleys. The sediment yield at the outlet of each watershed or at reservoir inlet were estimated per unit watershed area, the values ranged between about 9 ton/km^2 for valley 1 of 1.25%slope and located in relatively dry area to about 19 ton/km^2 for valley 3 of maximum slope (3.41%). The variation of watershed average slope is the most important factor that affects the values based on the results of the studied area.

Based on results of runoff hydrograph of each watershed and sediment load, a reservoir trap efficiency was estimated. The trap efficiency was considered to forecast the sediment load deposited in each reservoir. The values of capacity inflow ratio were relatively high for all studied reservoir due to high capacity in comparison to annual inflow. More than 66% of considered period, the capacity inflow ratio were greater than 1, while the minimum value was about 0.2. For these values, the trap efficiency values ranged between 100% and 96.5%, causing most of carried sediment with flow to be deposited in the reservoirs.

The probable of the life span of all reservoirs are greater than 100 years indicating that reservoir construction are economically feasible in comparison between initial cost and annual return from yield product and other purposes of water supply.

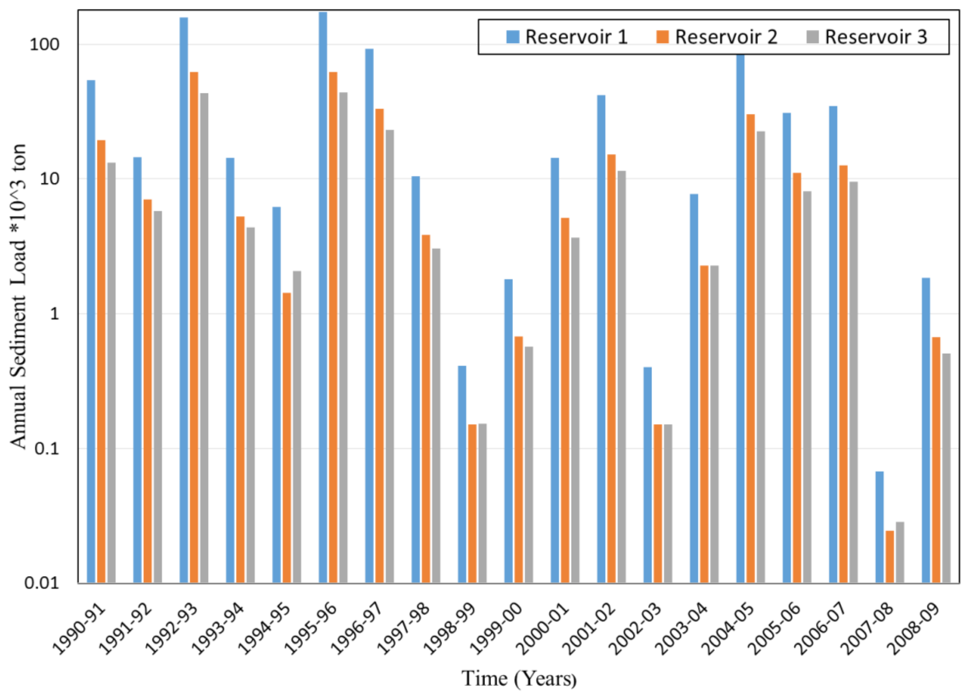

Figure 4. Estimated Annual sediment Load for Selected Reservoirs in Basin B.

CONCLUSION

Soil and Water Assessment Tool (SWAT) model was applied to estimate the annual sediment load of seven watersheds located in two main basins in Sinjar area North West of Iraq. Rainwater harvesting reservoirs at suitable site studied area were selected previously to supply water for supplementary irrigation. The results indicate that the range of annual load is between 9.5 to 20 ton/km^3 depending on watershed properties. Due to relatively high percent of reservoir capacity to annual inflow ratio, the trap efficiency was varying from 96.5 to 100%. The probable live of reservoirs are greater than 100 years indicating that the project considered economically accepted.

ACKNOWLEDGMENTS

The authors would like to express their thanks to Professors Rafid Alkhaddar of Liverpool JM University, UK, Professor Mustafa Alshawi of Salford University, UK, and Professor Kadhium Almuqdadi of the Arab Academy, Denmark for reviewing the manuscript and their fruitful discussions.

REFERENCES

Adwubi, A., B. Amegashie, W. Agyare, L. Tamene, S., Odai, C. Quansah, and Vlek, P. 2009. Assessing sediment inputs to small reservoirs in Upper East Region, Ghana. Journal of Lakes & Reservoirs: Research and Management, Vol. 14, pp. 279–287.

Al-Ansari, N. A. 2013. Management of Water Resources in Iraq: Perspectives and Prognoses, Journal of Engineering, Vol. 5, (8), pp. 667-684.

Al-Ansari, N. A., A. Ali and S. Knutsson. 2015. Iraq Water Resources Planning: Perspectives and Prognoses, ICCCE 2015 : XIII International Conference on Civil and Construction Engineering, Jeddah, Saudi Arabia, 26-27 January, 2015, pp. 2097-2108.

Al-Ansari, N., E. Mohammad, S. Knutsson, and S. Zakaria. 2013 Water Harvesting and Reservoir Optimization in Selected Areas of South Sinjar Mountain, Iraq. Journal of Hydrologic Engineering, ASCE, Vol 18, pp. 1607-1616.

Al-Ansari, N.A., A. Ali and S. Knutsson. 2014. Present conditions and Future Challenges of Water Resources Problems in Iraq, Journal of Water Resources and Protection, Vol.6, (12), pp.1066-1098.

Al-Qassab I., B. Al-Janabi, S. Al Timimi, A. Galib and A. Abdulmunim. 1987. The Iraqi map. Ministry of education and higher scientific research, Mosul University, Center of Maps Studies.

Al-Taiee, T. and A. Rasheed. 2011. Hydro engineering Feasibility Study of Surface Runoff Water Harvesting in Al-Ajeej Basin, North West Iraq. Tikrit Journal of Eng. Sciences, Vol. 18 (1), pp. 15-28.

Arnold, J. G., R. Srinivasan, R. Muttiah, and J. Williams. 1998. Large Area Hydrologic Modeling and Assessment Part I: Model Development. Journal of American Water Resources Association, Vol. 34, pp. 73-89.

Bagnold, R.A. (1977) Bedload Transport by Natural Rivers, J. Water Resources Research, 13,2, 303-312.

Brune G.M. (1953) Trap Efficiency of Reservoirs. Trans. Am. Geophysical Union 34(3), 407-418.

Cao, W., B. W. Bowden and T. 2006. Davie. Multi-variable and multi-site calibration and validation of SWAT in a large mountainous catchment with high spatial variability, Hydrology Process, Vol. 20, pp.1057–1073.

Chitata,T., T. Mugabe, and J. Kashaigili. 2014. Estimation of Small Reservoir Sedimentation in Semi-Arid Southern Zimbabwe. Journal of Water Resource and Protection, Vol. 6, pp. 1017-1028.

Dehvari, A.. 2014. Estimation of surface runoff and sediment yield using WEPP model in Southern Ontario, Canada. International Journal of Agriculture and Crop Sciences, Vol. 7 (11), pp. 876-889.

Garg, V. and V. Jothiprakash. 2008. Estimation of useful life of a reservoir using sediment trap efficiency. Journal of Spatial Hydrology, Vol. 8(2), pp. 1-14.

Gill M.A. (1979) Sedimentation and Useful Life of Reservoirs, Journal of Hydrology, 44, 89-95.

Iskender, I. and N. Sajikumar. .2016.. Evaluation of Surface Runoff Estimation in Ungauged Watersheds using SWAT and GIUH. ELSEVIER Procedia Technology, 24, pp. 09 –115.

Issa, I. E., N. Al-Ansari, G. Sherwany and S. Knutsson. 2014. Expected Future of Water resources within Tigris–Euphrates Rivers basin, Iraq. Journal of Water Resource and Protection, Vol. 6(5), pp. 421-432.

Jain, S., J. Tyagi, and V. Singh. 2010. Simulation of Runoff and Sediment Yield for a Himalayan Watershed Using SWAT Model. Journal of Water Resource and Protection, Vol. 2, pp. 267-281.

Mohammad E., N. Al-Ansari and , S. Knutsson. 2016. Annual Runoff and Sediment in Duhok Reservoir Watershed Using SWAT and WEPP Models. Journal of Engineering, Vol. 8, pp. 410-422.

Neitsch, S., J. Arnold, J. Kiniry and J. Williams. 2011. Soil and Water Assessment Tool Theoretical Documentation Version. Blackland Research Center-Texas SA TR, p. 406.

Rasheed, H., E. Mohammad and T. Awchi. 1994. A field study on influence of initial moisture content on infiltration function. Journal of Al-Rafidain Engineering, Vol. 2(3), pp. 1–10.

Revel, N., L. Ranasiri, R. Rathnayake and K. Pathirana. 2013. Estimation of Sediment Trap Efficiency in Reservoirs - An Experimental Study -, European International Journal of Science and Technology, Vol. 2 (10), pp. 134-146.

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