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RESEARCH ARTICLE

Sediment Yield Problems in Khassa Chai Watershed Using Hydrologic Models

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ABSTRACT

Upland erosion and sedimentation are one of the severe problems which faces dams as sediments occupy spaces within reservoirs storage, hence, decreasing live water storage which is the main purpose of dam's construction. Iraq is one of the countries that will face a significant shortage of water income as a result of both the increment in water demand and of the reduction of water shares from the source countries. Thus, the existing dams in Iraq represent a strategic resource to fulfill water demands, and the sedimentation at these dams is studied to assess the quantity of sediments that reach to these reservoirs and decrease available water volume and useful life of reservoir. In the current study, Khassa Chai Dam is located in the Northeast of Iraq and its main watershed basin covers an area of about 412 km^2 between Kirkuk and Al Sulaymaniyah Governorates has been selected to estimate and predict the amount of sediment yield based on 30 years of daily climate data and the events of different intensity rainstorms. Automated geospatial watershed assessment (AGWA) tool model has been used to simulate Khassa Chai Dam catchment area. This model utilizes the geographic information system (GIS) application to analyze the required data from GIS layer for digital elevation model, soil type, land use, and land cover by interference with the required climate data. The key components of AGWA model are the soil and water assessment tool model and kinematic runoff and erosion (KINEROS) model which are able to simulate complex watershed behavior to explicitly account for spatial variability of soils, rainfall distribution patterns, and vegetation. The hydrologic characteristics for Khassa Chai catchment area according to the SWAT outputs show that the most erosive sub-basins are not able to deliver the eroded material or sediments to the reservoir due to their transmission losses, percolation, and other minor obstacles. KINEROS model simulation for sediment yield is much closer to the behavior of Khassa Chai watershed in erosion and sediment transport according to the single storm events and for individually selected sub-watersheds which are closed in their location to reservoir inlet.

Keywords: Automated geospatial watershed assessment, geographic information system, methods of combat, reservoir, sedimentation

INTRODUCTION

There are many studies concerning with upland erosion and sediment yield. This chapter represents research works with a variety of objectives, methodologies, and related factors. Understanding of the quantity of sediment transported from the upstream due to upland erosion and its reach to the reservoir is necessary for effective reservoir and basin management. Sedimentation affects the useful life of a reservoir for which is important for flood control and water supply. Some of the following studies are dealing with a number of terms related to the reservoir sedimentation pattern.

As the flow velocity decreases. This reduces the sediment transport capacity of the stream and causes settling. The pattern of deposition generally begins with a delta formation in the reservoir headwater area. Density currents may transport finer sediment particles closer to the dam.[1] Trung (2005) applied soil and water assessment tool (SWAT) model to simulate water quality problems in upper CONG watershed located in Vietnam.[2]

In this study, SWAT model simulation results show that sediment is not a severe problem with the watershed, but the real threats are the nitrogen loads. Amare analyzed the sediment yield amount from the Angereb Watershed in Ethiopia to estimate the functional life of the reservoir using agricultural nonpoint source pollution model.[3]

To improve the functional life for the reservoir, this study recommended the reduction of sediment inflow and removing

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sediment out of the reservoir. The importance of this study is clear from the way of recommending and applying the calibration and verification process according to the local conditions, where most of hydrologic predicting models depend on general limitations and parameters Omran (2007) studied the sedimentation in AL-Adhaim dam's reservoir.[4]

The results indicated that the distribution of sedimentation on the reservoir is approximately uniform along the whole area. This is due to the continuous filling during the operation period and the ground topography. It was found that during a period of 60 years from the beginning of the operation, the thickness of sedimentation could reach 220 cm at the upstream part of the reservoir. Al-Mahamid (2007) applied arc-view soil and water assessment tool (AVSWAT) 2000 model to simulate Mujib Dam Catchment area. Mujib dam was constructed in 2003 and allocated at the Kings Highway between Karak and Madaba Governorates in Jordan. This dam has been selected to estimate the quantity of sediment reached to its reservoir during the period between November 2003 and December 2006.[5]

As a result, the study is predicting the quantity and the quality of water and sediment inflow to the reservoir according to the observed data, also using the AVSWAT model abilities to identify the regions with highly soil erosion and sediment yield to manage these regions to reduce these values in sequence to decrease the threats of sedimentations. Suresh 2000 shows that there are several factors which affect the sediment yield such as land use and soil type, catchment size, and rainfall.[6] Sediment yield is simply defined as the amount of eroded sediment discharged by a stream at any given point. It represents the total amount of fluvial sediment exported by the watershed tributary to a measurement point, and it is the parameter of primary concern in reservoir studies. Since much-eroded sediment is re-deposited before it leaves a watershed, the sediment yield is often much less than the erosion rate within that same watershed. The ratio between the erosion rate and sediment yield is known as the sediment delivery ratio.[7]

There is a big difference between the sediment yield and soil erosion from a watershed. The soil particles detached, transported, and deposited to other places are referred to as erosion. It is true that all eroded materials from watershed do not get into the stream system, but some of them remain on the watershed. The soil particles detached from comparatively level fields, with little or no surface runoff, move only for shorter distance and are not transported to a downstream point in the watershed.[5]

The analysis of sediment sources aims to estimate the total amount of sediment eroded on the watershed on an annual basis, called annual gross erosion. The annual gross erosion AT depends on the source of sediments in terms of upland erosion AU, gully erosion AG, and local bank erosion AB, thus

$$AT = AU+AG+AB$$

Upland erosion AU, generally, constitutes the primary source of sediment, other sources of gross erosion such as mass wasting or bank erosion AB and gully erosion AG must be estimated at each specific site. For instance, the annual volume of sediment scoured through lateral migration of the stream and the upstream migration of head cuts can be determined from past and recent aerial photographs and field surveys. In stable fluvial systems, the analysis of sediment sources focuses on upland erosion losses from rainfall and snowmelt.[1]

ESTIMATING OF SEDIMENT YIELD

Several methods have been developed to estimate the sediment yield from the watershed. Wischmeier and Smith (1965 and 1978) developed the universal soil loss equation (USLE) for predicting gross soil erosion from agricultural watersheds in the USA, USLE predicts average annual gross erosion as a function of rainfall energy and can be used for predicting the average annual sediment yield by applying a delivery ratio (the sediment yield at any point along the channel divided by the source erosion above that point) in large watershed. However, the accurate estimation of the delivery ratio is generally difficult at many places, due to non-availability of measured data. Furthermore, USLE is not considered an appropriate model for water quality modeling.

MUSLE is a modified version of the USLE developed by Williams, 1975. In MUSLE, the rainfall energy factor is replaced with a runoff factor. This modification, allows the equation to be used for predicting of sediment yield, eliminates the need for delivery ratios, and allows the equation to be applied to individual storm events (Neitsch *et al*., 2005). The modified USLE is:

$$Sed=11.8.\ (Q_{surf}.\ q_{Peak}.A)^{0.56}.K.C.P.LS.CFRG$$

Where Sed is the sediment yield on a given day (metric tons), Q_{surf} is the accumulated runoff or rainfall excess (mm), q_{peak} is the peak runoff rate (m^3/s), A is the area of the sub-region in (km^2), K is the soil erodibility factor (metric ton m^2 h/[m^3-metric ton cm]), C is the cover and management factor, P is the support practice factor, LS is the topographic factor, and CFRG is the coarse fragment factor (Williams, 1995).

The above equation represents two main factors; hydrological factors which are Q_{surf} and $q_{\ peak}$, and the other main factor is erodibility of land surface system which is divided into two sub-main factors; physical character of land surfaces such as soil erodibility properties and susceptibility to erosion, and watershed management methods to reduce soil erosion such as vegetation cover over land surface and soil conservation practices (Das, 2000).

METHDOLOGY

To obtain the results, the following methods are used:

Description of Study Area

Location

Khassa Chai Dam Watershed is located in the Northeast of Iraq on Khassa Chai River, 10 km Northeast of Kirkuk City. The Khassa Chai River is a tributary of Zaghitun River which is flowing into the existing Adhaim Dam reservoir.

Automated Geospatial Watershed Assessment (AGWA2) model (AGWA Tool) is used to describe and identify the location of Khassa Chai Dam watershed as shown in Figure 1 based on the digital elevation model (DEM) layer map and

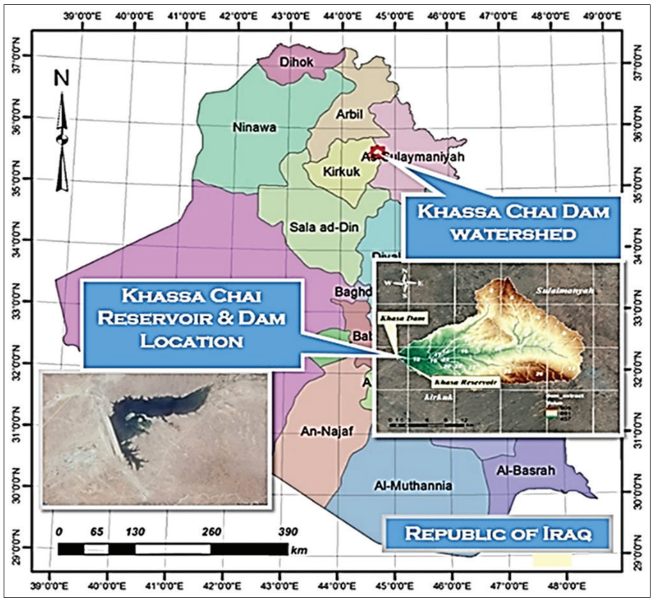

Figure 1: Description of Khassa Chai dam watershed location

satellite image (Landsat TM) that taken in according to the digital projected administrative Iraq map layer.

Topography

The Global Mapper version13 utility application is used to obtain the general topographic description and analysis for Khassa Chai watershed and the majority of the catchment area as shown in Figure 2 with three-dimensional analysis in Figure 3.

Weathered is silt and clay soils. While the area dominant with conglomerate (Upper Bakhtiari Formation), the top soils are characterized by weathered gravels in addition to the transported (alluvium) soils which are differ with their underlain rocks (MOWR, 2007).[8]

Geology

Physiographic geology shows that the area classified as a foothill zone within an unstable shelf of Iraq. This zone is the central part of Iraqi unstable platform which shows compressional folding of lower tertiary. The area of a site consists of Paleogene–Neogene thick Molass sediment of Fars group (Fatha and Injana) and Bakhtiari group (Muqdadia and Bai-Hassan), in addition to, recent river terraces and alluvial deposition. Topographically the area is hilly terrain and slopping toward the southwest.

Climate

The climatic data were taken from the available records of Kirkuk Meteorological Station covering the period (1941–2001) which is compiled by the Iraqi Meteorological Organization. Table 1 shows a summary of climatic factors (MOWR, 2007).[8]

Top soil

The study area is covered by various soil types, depending on their underlain parent rocks which are decomposed into covered soil by the action of weathering. The outcrops of silty claystone rock (Lower Bakhtiari Formation), are generally Formation weathered is silt and clay soils. While the area dominant with conglomerate (Upper Bakhtiari Formation), the top soils are characterized by weathered gravels in addition to the transported (alluvium) soils which are differ with their underlain rocks.[8]

Modeling of Sediment Yield

The principal sediment modeling problems analyzed in reservoirs can be divided into four major categories:[7]

1. Water and sediment yield from the watershed (as in the present study).
2. Rate and pattern of sediment transport, deposition, and scour along the reach above the dam under different operation rules.
3. Localized patterns of deposition and scour in the vicinity of hydraulic structures.
4. Scour, transport, and deposition of sediment in the river below the dam.

The model was linked to geographic information system (GIS) which is a relational database system that allows management of multiple layers of spatially distributed information by combining forming overlays to aid synthesis and interpretation by users. Hence, GIS does not generate new data but by manipulating the database to get the relationships to become clearer. Erosion or sediment yield models can be implemented in a GIS through user interfaces or shells written in a variety of computer languages. The interface allows the user to (1) define a study area;(2) select management practices; (3) select soil and water conservation practices such as contouring, terraces, and strip cropping; (4) access the GIS database to attach attributes to model parameters; (5) execute the model modify attribute tables; and (6) analyze and display the results.[7] An example of these models which linked to GIS is the AGWA model which is applied in the present study.

Modeling Khassa Chai Watershed using AGWA Model

Climate data

The required data must be provided on a daily basis for SWAT model, which give the possibility to predict results simulation on daily, monthly, and annual basis.

For more accurate and realistic results, the observed daily data should be represented by long-term database for climate, according to this Kirkuk climatological station was selected to collect the daily climate data records for the period (1970–2000).

Daily precipitation data

Daily precipitation data were collected from the records of Kirkuk climatological station for the period (1970–2000) with annual average precipitation equal to 380.9 mm.

Temperature data

In this study, the model daily temperature of 30 years' data shows a clear impact on the model operation. As it calculates a set of variables such as evaporation, melting snow and top soil temperature for deferent depth

Rainstorm event data

Rainstorm event data are used especially for (kinematic runoff and erosion [KINEROS2]) model extension in sub-basins modeling.

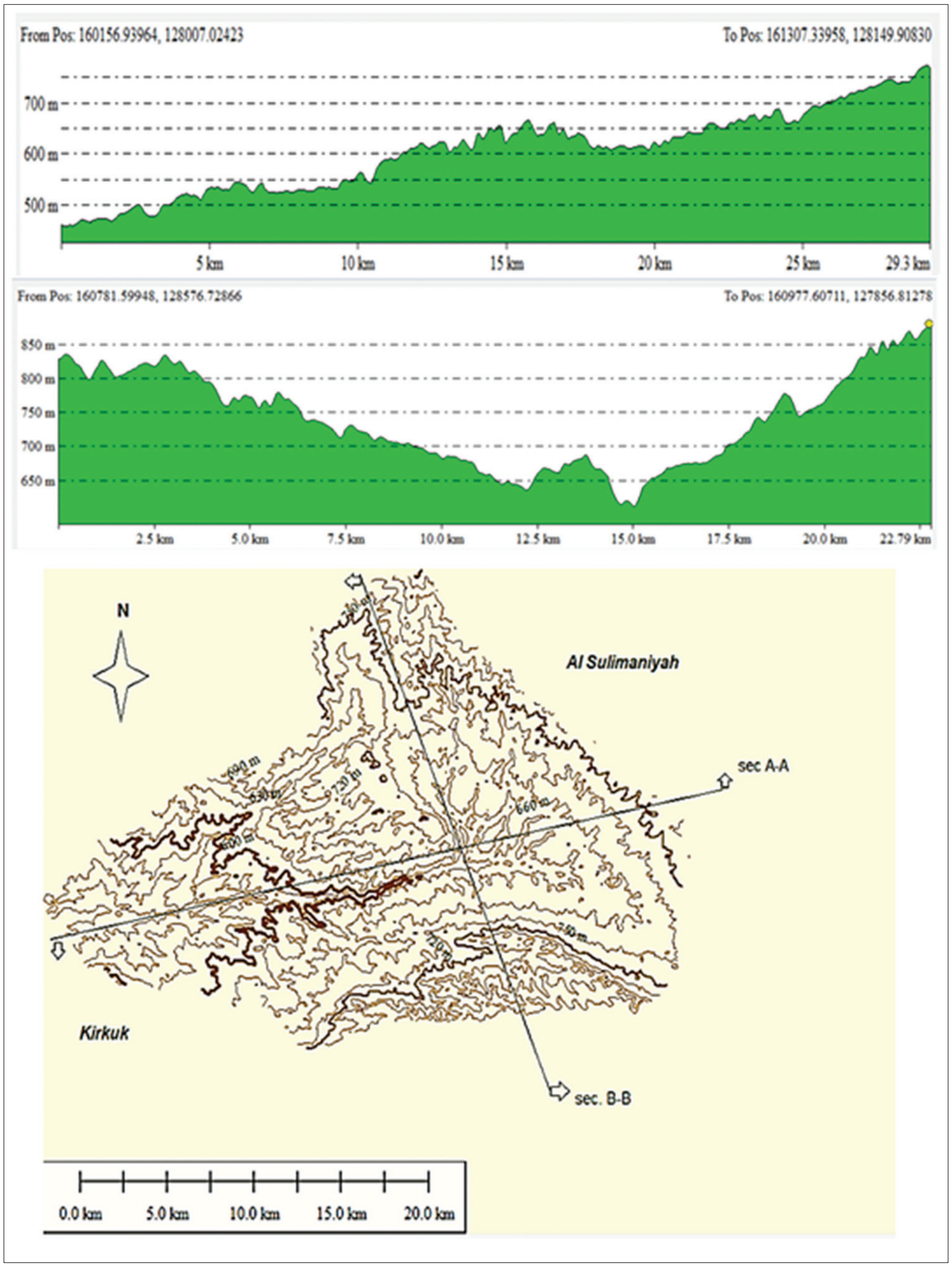

Figure 2: Topographic distribution of Khassa Chai dam catchment area

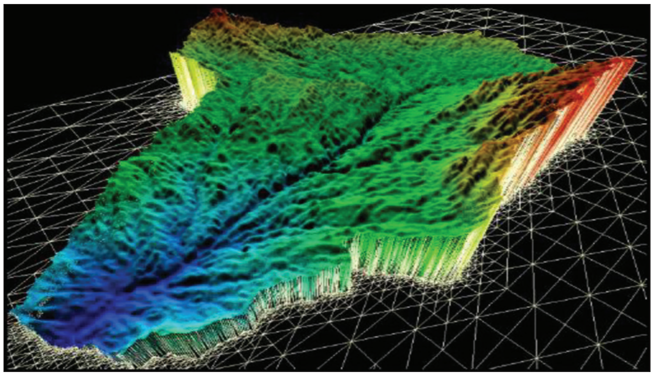

Figure 3: Three-dimensional analysis for the topography of Khassa Chai dam Catchment area

Satellite data

These data include data of landsat satellite for land cover classification elements and DEM to extract the variables data of sub-basins.

Digital terrain data (DEM)
For this study, basin digital release accurately (30) m was extracted as shown in Figure 4. DEM represents the foundation to run the model based on GIS application.

Satellite images data
In this study, landsat satellite images belong to the year (2009) were used and verified with site observation as shown in Figure 5.

Table 1: Summary of the climate data of Kirkuk station (after Mowr, 2007)

Climate factor	Maximum value	Minimum value	Average value
Temperature °C	49.52	−6.7	22.4
Relative humidity %	72	22	46
Wind speed (m/s)	30	-	2.8
Evaporation (mm)	398.8	46.3	-
Evaporation (free water surface/year) (mm)	-	-	1642.9
Precipitation (mm/month)	769.9	201.6	369.3

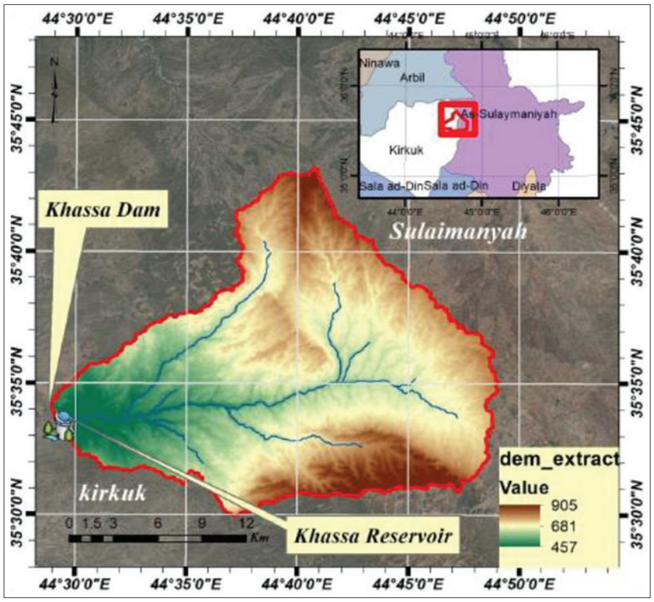

Figure 4: Digital elevation model for the study area

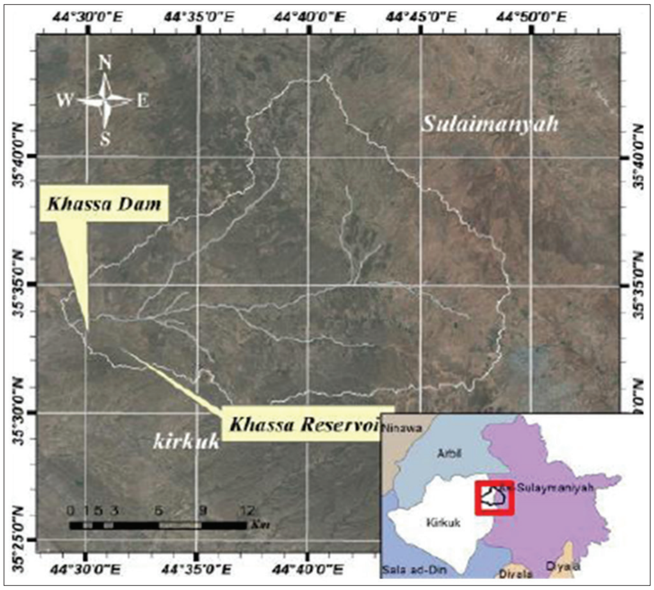

Figure 5: Landsat images for the study area

Soil data

The soil map prepared by the Food and Agriculture Organization (FAO), one of the United Nations organizations is the 58 latest classification system and compatible with GIS

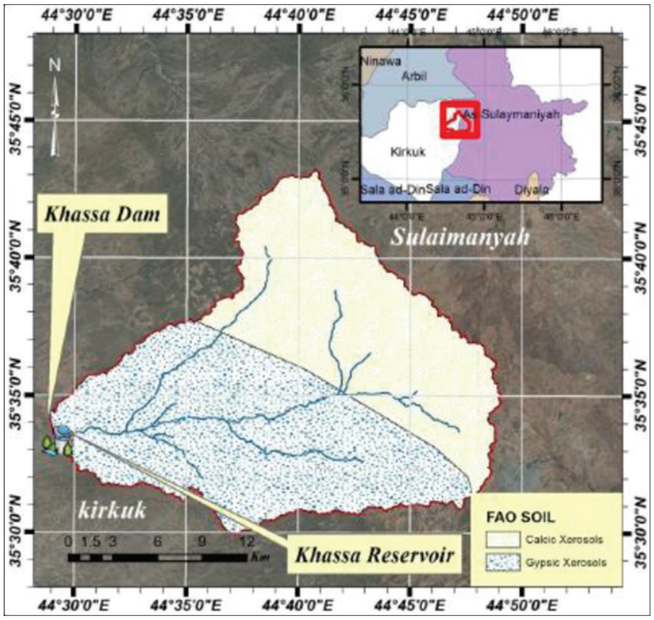

Figure 6: Soil classification of the study area the harmonized world soil database, Food and Agriculture Organization

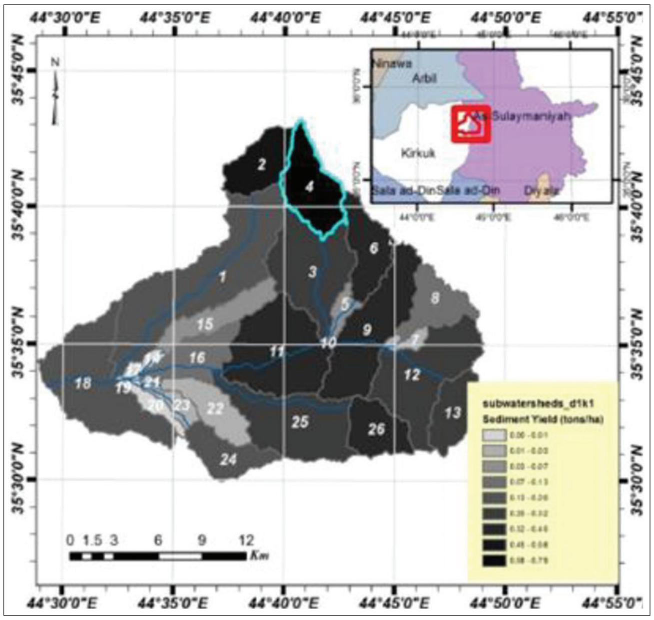

Figure 7: Annual sediment yield in sub-watersheds

have been issued this map by scale 1/5,000,000 in 2006. FAO soil map layer for the study area within the AGWA model shows two types of soils as shown in Figure 6 which identified by Calcic Xerosols and Gypsic Xerosols (FAO, 2012) with different characteristics.[9]

Selection of the Model

At this stage, hydrological modeling depends on the level of results required if it is in the level of the whole main basin or on a sub-watersheds level. The use of SWAT model suitable for the relative evaluating at the main basin level, while at the level of the sub-basins, the (KINEROS2) model is a specialist in hydrologic evaluation. Furthermore, both models have outputs at the level of the basin and channel.

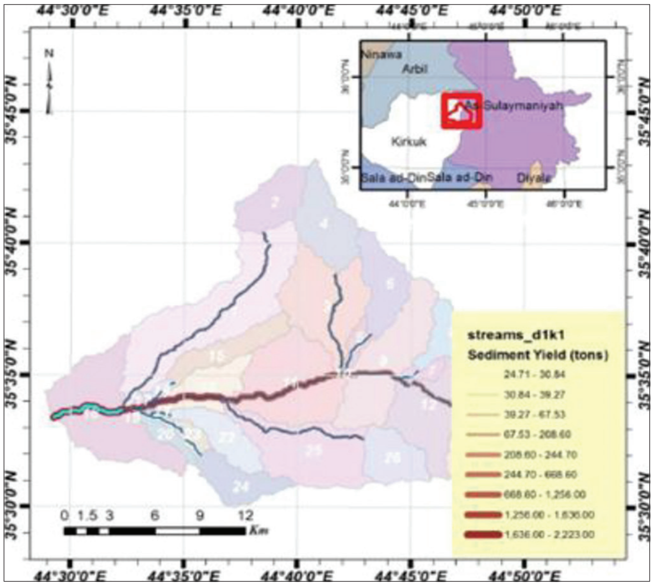

Figure 8: Annual sediment yield in streams

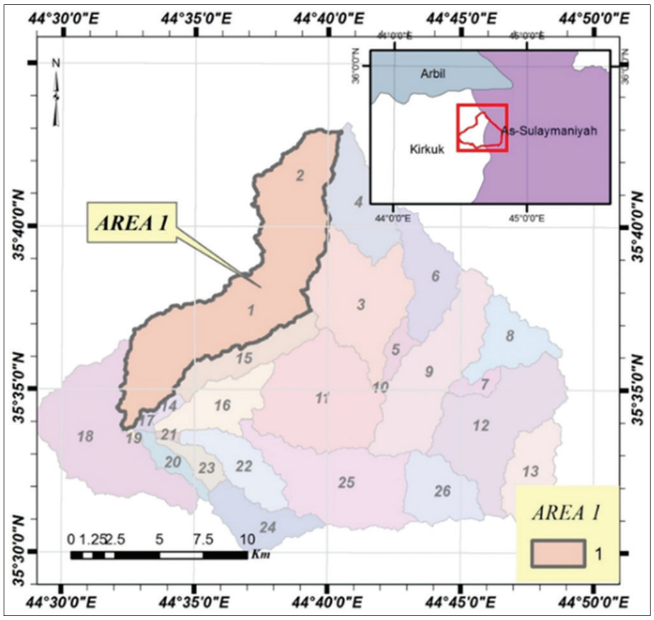

Figure 9: Area 1 watershed by kinematic runoff and erosion two model

RESULTS AND DISCUSSION

The results of AGWA model represent the evaluation of land use and land cover effects on the watershed response for water and sediment according to the available climatological data and assigned area of study. The key components of AGWA model are the SWAT and KINEROS2 models which are able to simulate complex watershed representations to explicitly account for spatial variability of soils, rainfall distribution patterns, and vegetation.

Table 2: Sediment particles distribution with sediment concentration for area 1

Total outflow (m^3)	Sedimentation particle size (mm)	Sediment yield (tons)	Concentration (ppm)
347,535.6	0.004 mm	4255.490	12.24×10^3
	0.033 mm	6676.998	19.21×10^3
	0.250 mm	13,707.908	39.44×10^3
	Total sediment	24,640.3996	70.89×10^3

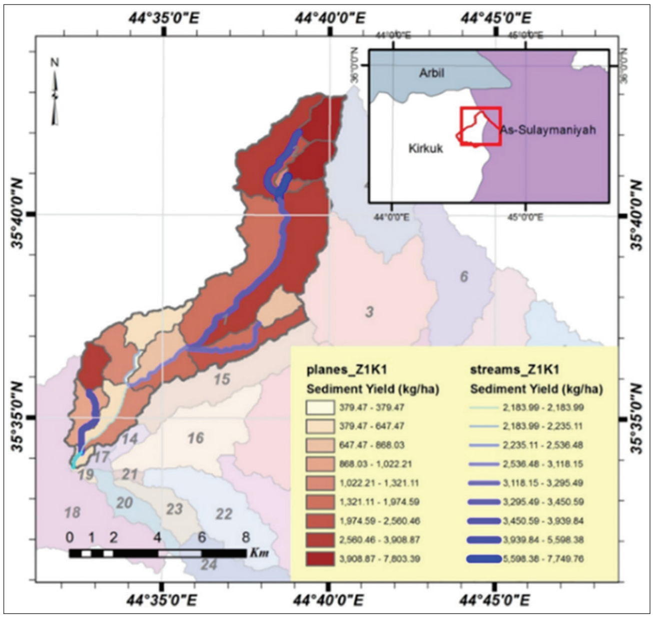

Figure 10: Laden runoff in the bottom outlet of the watershed

Figure 11: Sediment yield distribution for watershed and streams of area 1

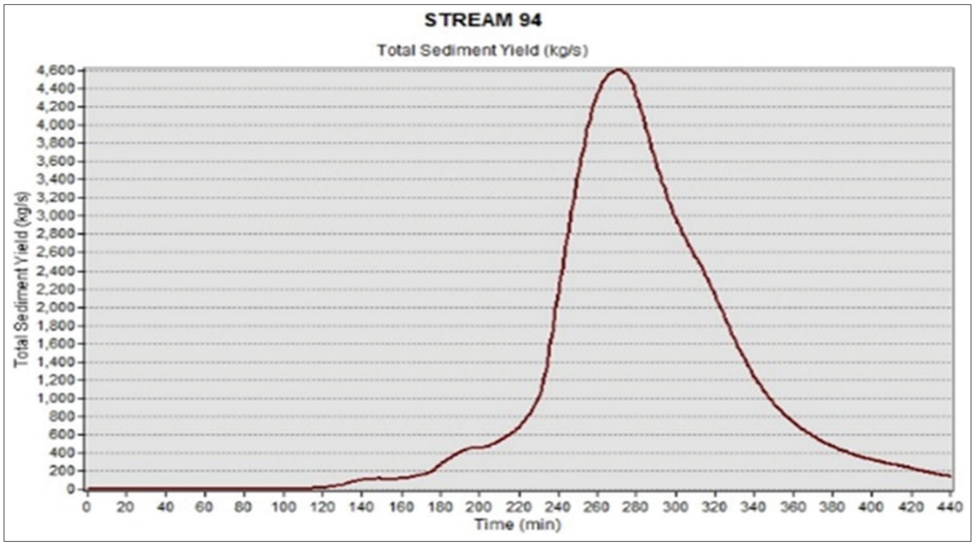

Figure 12: Total sediment yield hydrograph for area 1

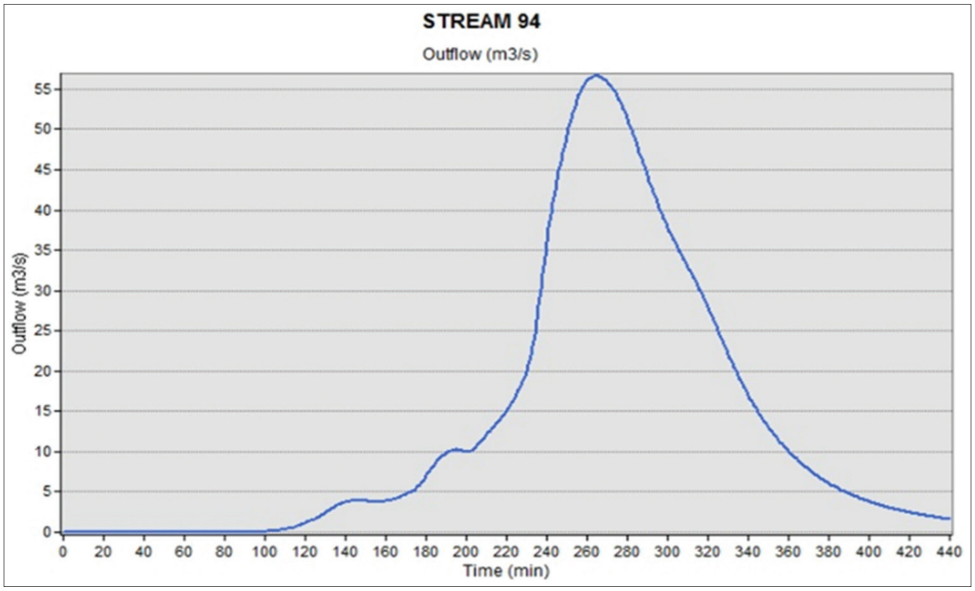

Figure 13: Peak outflow hydrograph for area 1

SWAT Model Results

I. As shown in Figure 7 for sub-watersheds and Figure 8 for channels, the subwatershed No. (4) is highly erosive and more productive for sedimentations. Channels in mainstream closer to the reservoir have a higher potential for sediment transport to the reservoir site with annual rates equal to 2.24×103 ton.

II. The hydrological characteristic of Khassa Chai catchment area according to the SWAT outputs shows that the most erosive sub-basins (No. 4 and 3) are not able to deliver the eroded material or sediments to the reservoir due to their transmission losses, percolation, and other minor obstacles.

KINEROS2 Model Results

In this study, Area 1 has been selected to simulate the sediment yield in Khassa Chai main watershed according to the location and ability to deliver the sediments to the reservoir with accordance with all required parameters. Area 1 consists of sub-watersheds No. (1) and (2) with a total area of 63 km^2 and location close to the reservoir as shown in Figure 9.

Area 1

KINEROS2 model applies a scenario of a single rainstorm event for the watershed (AREA 1) equal to 60 mm depth during 8 h (MOT-IMOS) which represents similar rainstorms events that take place at the Khassa Chai upstream and vary from 48 mm up to 80 mm during 6 h up to 24 h. The impact of this rainstorms can be observed by the amount of laden runoff in the bottom outlet of the watershed as shown in Figure 10.

The results obtained from KINEROS2 model for sediment yield in the subwatershed (Area 1) show the processes for the erosion, transportation, and deposition through digital geospatial distribution as shown in Figure 11 and supported by the hydrographs representing the total sediment yield and peak outflow hydrograph as shown in Figures 12 and 13.

The total amount of sediment yield accumulated in the watershed outlet calculated according to the obtained hydrographs for the total sediment yield(kg/s) and peak outflow(m^3/s) as shown in Figures 5-13 is equal to 24,640.39 tons with sediment concentration equal to 70.89×10^3 ppm as given in Table 2.

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