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Hydrological Modeling of Semi-Arid Region in Ungauged Watershed using AGWA Model

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Abstract

Number of methods have been developed to produce the hydrological behavior and information from hydro meteorological and geospatial data. The majority of these models have been developed to simulate the water discharge resulting from various meteorological conditions according to precipitation or single storm event. Automated Geospatial Watershed Assessment Tool (AGWA) a Geographic Information System (GIS) based watershed modeling tool is designed to simulate ungauged watersheds in arid & semiarid regions uses widely available standardized spatial datasets that can be obtained by design required data base.

In this study AGWA model has been applied in Khassa watershed which is located in north east of Iraq to obtain the general hydrological characteristics according to AGWA outputs that shows the response of Khassa watershed to the climate impacts in collaboration with topographic, soil type, land cover and other parameters to the amount of water income to achieve the watershed efficient management through sustainable development and planning for water resources.

Keywords: AGWA model, Semi-arid region, ungagged watershed, ArcGIS 10, SWAT, Global mapper, Hydrological modelling.

INTRODUCTION

Iraq is one of the countries that located in the region classified as an arid and semi-arid areas and will face significant shortage in water income as a result of both the increment in water demand and the reduction of water shares from the source countries, besides most of watersheds are not included the required or available observed data. Thus, the demands for the hydrological models that can predict and describe the hydrological behavior is increasing.

The U.S Department of Agriculture-Agricultural Research Services / Southwest Watershed Research Center (USDA-ARS), in cooperation with the U.S Environmental Protection Agency Landscape Ecology Branch (U.S. EPA), has developed the Automated Geospatial Watershed Assessment Tool (AGWA) a Geographic Information System (GIS) based watershed modeling tool to simulate ungauged watersheds in arid & semi-arid regions uses widely available standardized spatial datasets that can be obtained by design required data base. According to Köppen climate classification semi-arid region characterized with low annual rainfall rate varying from 25 to 50 centimeters and having scrubby vegetation with short, coarse grasses. The key components of AGWA model are the Kinematic Runoff and erosion model (KINEROS) and Soil and Water Assessment Tool (SWAT).SWAT model is watershed scale model developed to predict the impact of land management practices on water and sediment on large complex watersheds with varying soils, land use, land cover, and management conditions over extended time scale (Miller et al., 2004).There are a number of studies and researches have applied this model to predict and estimate the different hydrological responses especially water income and sediment yield.

Abdulla et al, (2007) applied the AGWA model to calculate the amount of sediment yield in three proposed basin sites in Kufranja watershed in Jordan using modeling environment AGWA - SWAT. The calibration process for sediment yield depends on the change in most sensitive parameters in SWAT model that can be considered as different scenarios in Kufranja basin.

Mohammad et al, (2012) studied the yearly surface runoff and sediment load for the main three valleys on the right bank of Mosul Dam Reservoir in Iraq using (SWAT) model to obtain the most erosive valleys and reduce the amount of sediment yield entering to the reservoir which is defiantly decreasing the life water storage.

Hamid et al, (2012)simulated the expected effect of Land use change on water income of the Gaza strip in Palestinian territory using the (AGWA) model. Three different scenarios simulated independently for land cover changes; 1. The land cover of 2007. 2. Land cover of 2020, 3. Full urbanized land cover. The analysis of the three different scenarios can give decision makers better understand for the future situation and assist them to advance towards achieving sustainable development planning for water resources system in the Gaza strip.

Mahmoud, (2014) applied the (AGWA) model to obtain the hydro geomorphological modeling for the Salt basin located in Tikrit north of Iraq which is considered as ungauged semi-arid region watershed and studying the impact of land cover changes and their responses in the level of sub-basins and entirely basin. The obtained modeling processes will help the stockholders in administrations to build the future studies for development plans for selected watershed.

The present study applied AGWA-SWAT model to predict and obtain the general hydrological behavior for Semi-Arid Region in ungauged watershed to achieve the watershed efficient management through sustainable development and planning for water resources.

Description of the Study Area

Khassa 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.

The Global Mapper version13 utility application is used to obtain the general topographic description and analysis for Khassa watershed and the majority of the catchment area as shown in Fig.1.

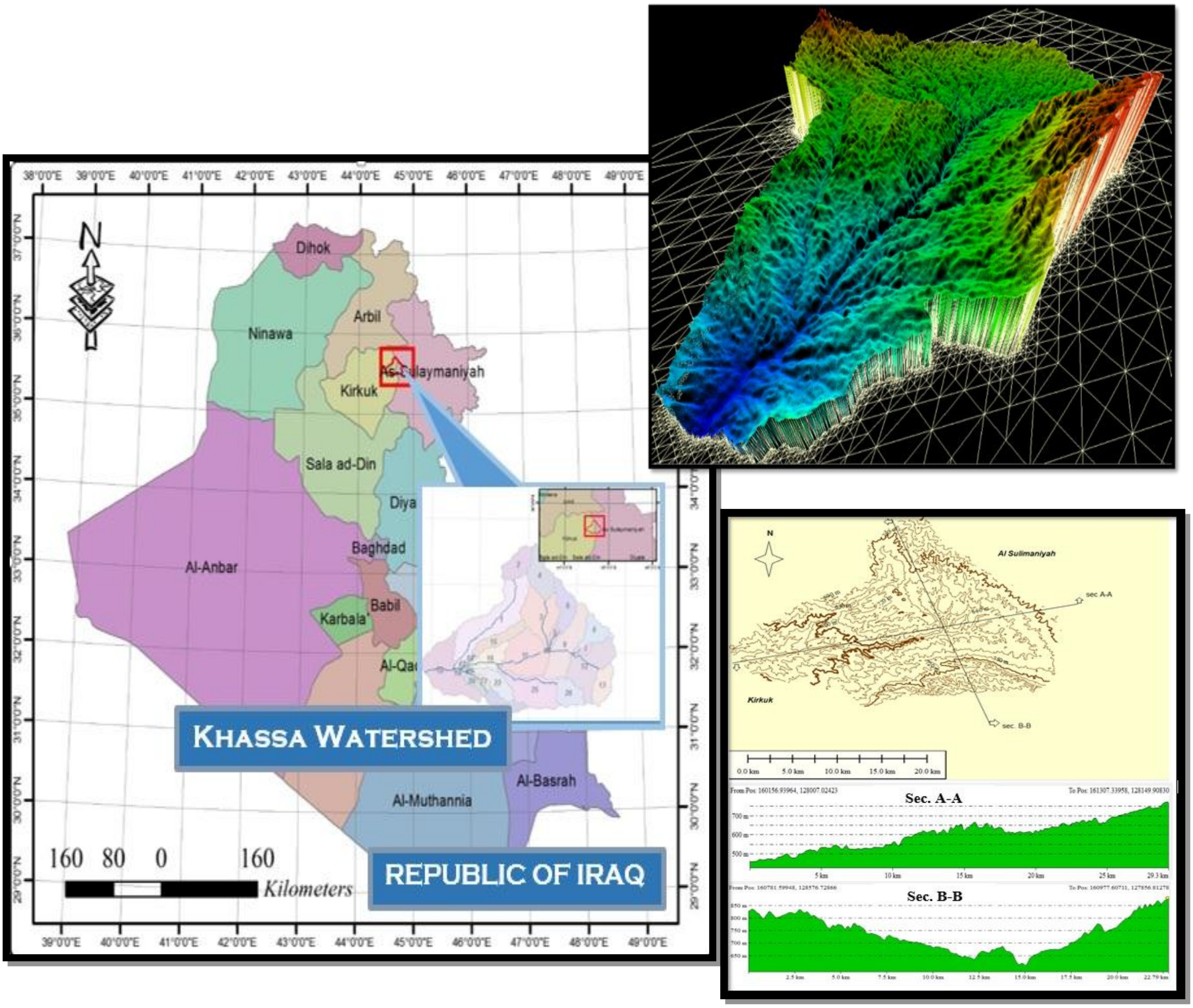

Figure 1. Khassa Watershed Location and 3D analysis topographic description

AGWA Model

The AGWA model is designed to lead the user in a gradual manner through the transformation of GIS data into simulation results. The model tools menu is aimed to show the orders of necessary tasks to conduct a watershed assessment, which is broken out into six major steps: 1. Watershed delineation 2.Parameterestimation 3. Generation of rainfall input 4.Model execution5.Changeanalysis 6.Model execution and visualization and comparison of results. The sequence of steps in the use of AGWA is presented in Fig. 2.

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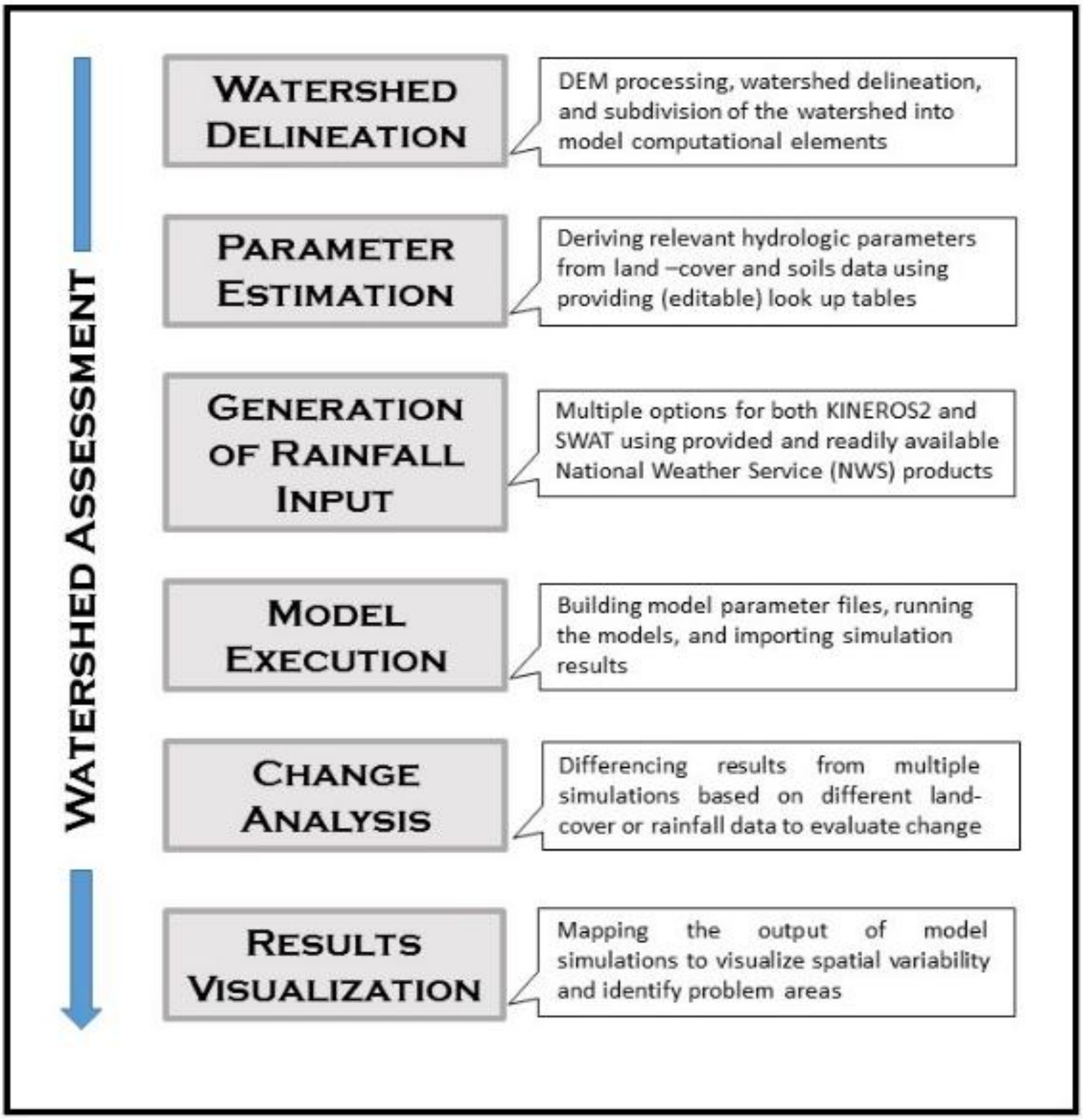

Figure 2. Sequence of Steps in the use of AGWA for hydrological modelling

Modeling Khassa watershed using AGWA: -

Preparing the raw data

A. Climate.

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. According to this Kirkuk, climatological station was selected to collect the daily climate data records for the period (1970-2000).

B. Satellite Data.

These data include data of Landsat satellite for land cover classification elements and digital elevation model DEM to extract the variables data of sub basins as shown in Fig. 3.

C. Soil Data. The soil map prepared by the Food and Agriculture Organization (FAO), one of the United Nations organizations is the latest classification system and compatible with ArcGIS as shown in Fig. 4.

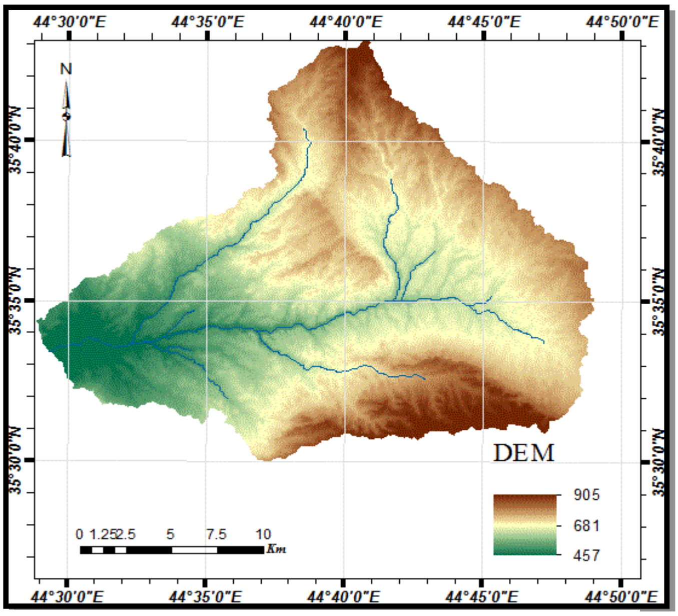

Figure 3. Digital Elevation Model (DEM) for study area

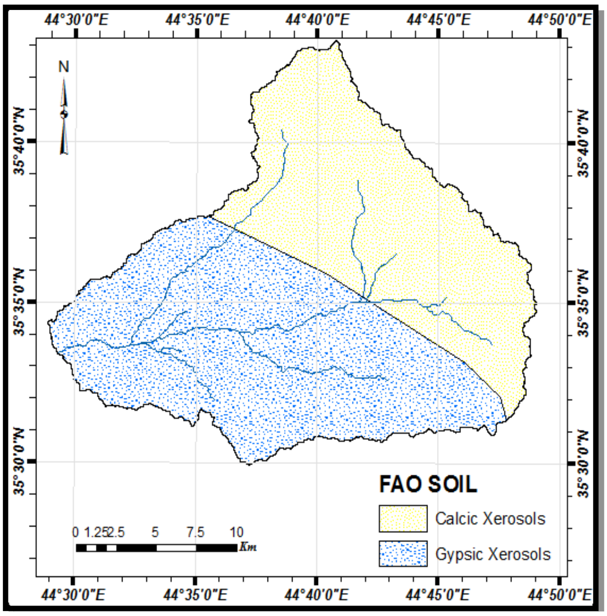

Figure4. Soil classification of the study area using the Harmonized World Soil Database, FAO

Creating the database

Databases are the bank of information in the form of digital schedules and are designed through a series of distribution maps for AGWA extensions outputs.

•Geometric correction of spatial data and soils map

This type includes geometric correction process for spatial data and soil map, it is converted to Universal Transverse Mercator (UTM) projection coordinates of geographical extension in order to accept them by AGWA model.

•Derivation of the hydrologic networks and watershed basins

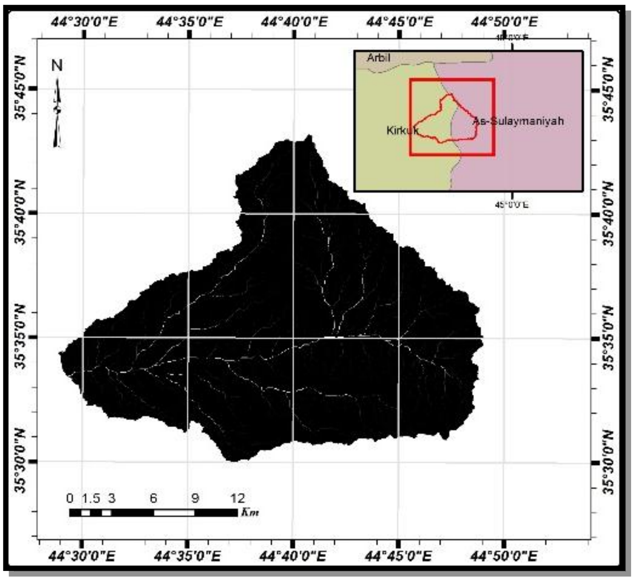

Figure 5. Water network derivation by the ArcGIS program

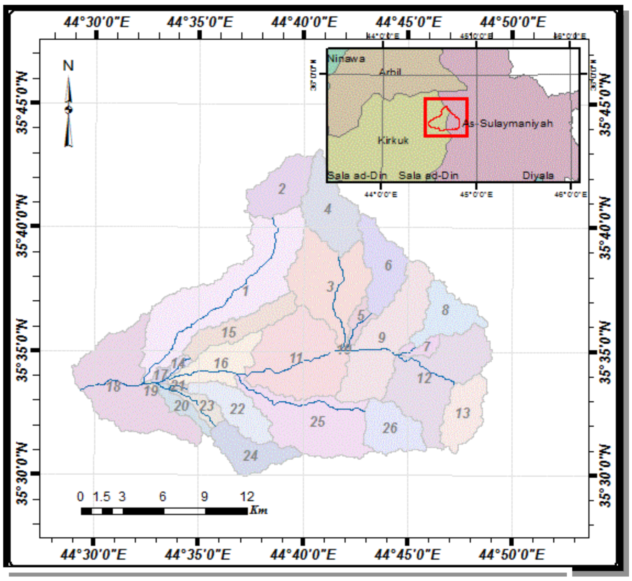

Figure 6. Distribution of sub basins in the main watershed

This process is accomplished using a digital elevation model (DEM) and derivation for water network is obtained by the ArcGIS program as shown in Fig.5 and developing the sub basins through the discretization option in AGWA as shown in Fig.6 the watershed area divided into (26) sub basins, according to the homogeneity of the hydrological properties, morphometric, hydrological transactions, and properties of the soil.

•Create the land cover map and re-classify according to (AGWA) model to estimate curve number (CN) Parameters

Land cover classification was based on the satellite Image (Landsat TM) and taken on 06.03.2009 through the Erdas-V8.4 program by using the oriented-classification, and has been building color land cover layer of the beam (7,4,2 RGB) and adopted as the basis for isolating land cover types dominant in the region as shown in Fig.7.

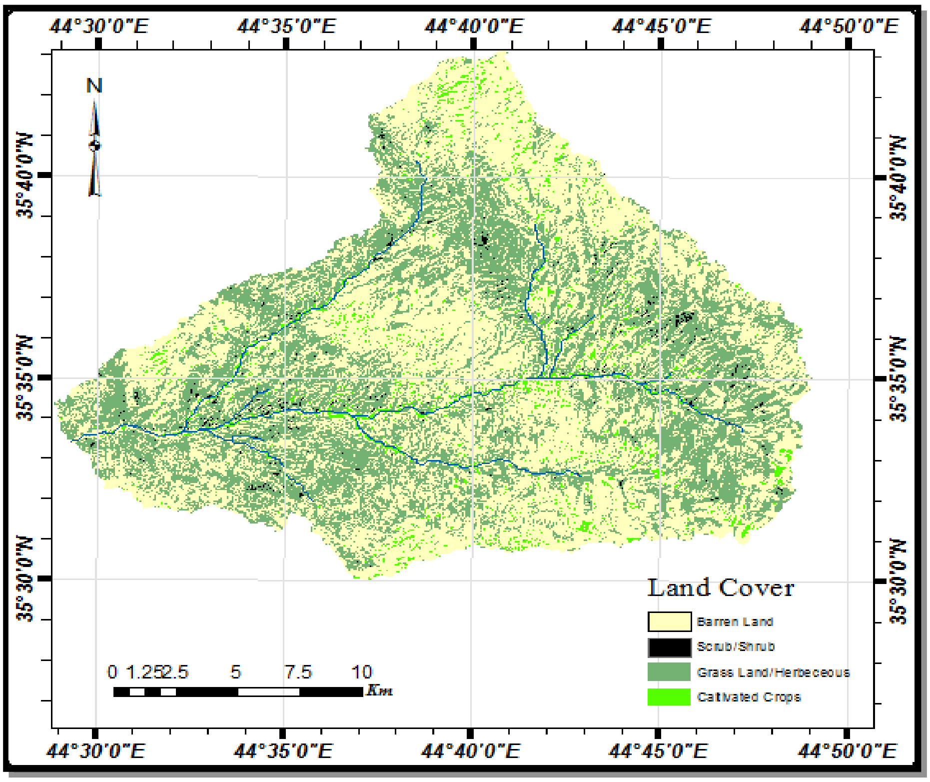

Figure 7. Distribution of the types of land cover for Khassa Chai watershed

Model Results: -

SWAT model is watershed scale model developed to predict the impact of land management practices on water and sediment on large complex watersheds with varying soils, land use, land cover, and management conditions over extended time scale (Miller et al., 2004). The advantage of this tool which uses all the data that have been incorporated except rain storm data is wide range of hydrologic results at the level of basins and channels.

• Precipitation

The inputs of precipitation data depend on the existence of several observation stations, since the study area devoid of climatic stations and the basic dependence is on 30 years' data of daily precipitation data from Kirkuk climate station as mentioned earlier, so the precipitation is distributed uniformly on the Khassa Chai catchment area.

• Evapotranspiration

SWAT model depends on three methods (Penman-Monteith, Priestley-Taylor and Hargreaves) to calculate the evapotranspiration (ET). The first one was based on solar radiation and air temperature, relative humidity and wind speed, while the second method adopted the same variables except wind speed, and the third adopts the air temperature only (Neitsch et al.,2005).The model results show that the annual evapotranspiration amount increases in the northeast part of the watershed i.e. sub basins (No. 2 and 4) as shown in Fig.8.

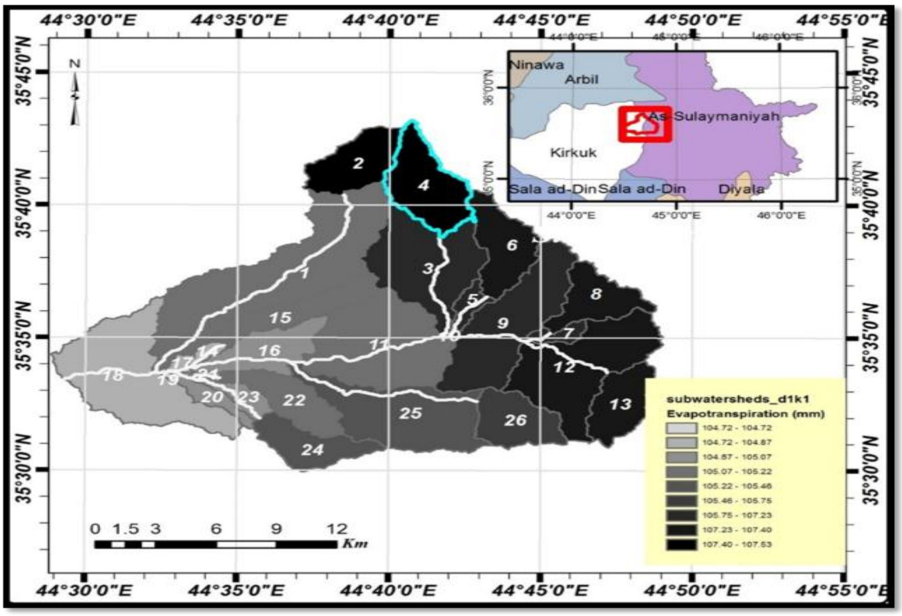

Figure 8. Annual Evapotranspiration rate distribution in the sub watersheds

• Surface runoff

Surface runoff occurs when the rate of precipitation exceeds the rate of infiltration and it is influenced by a set of factors, which are rainfall intensity, soil moisture and permeability. SWAT model depend on two methods to calculate runoff, the SCS (Soil Conservation Services) method and Green-Ampt Infiltration method (Neitsch et al., 2005). The model results show that the signified amount of annual surface runoff is in both sub watersheds (No. 2 and 4) as shown in Fig.9.

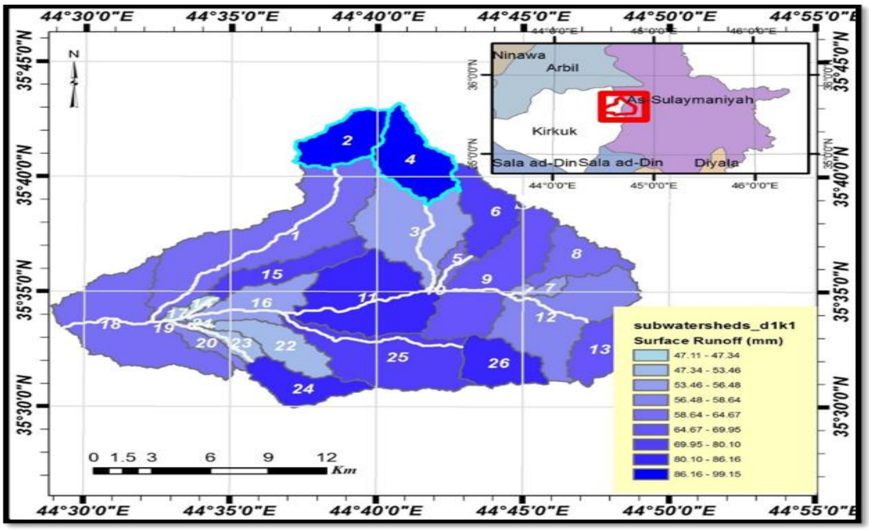

Figure 9. Annual Surface Runoff distribution in sub watersheds

• Water Yield

Water yield means the runoff from the drainage basin, including ground-water outflow to the stream plus ground water outflow that bypasses the gaging station and leaves the basin underground. Water yield is the precipitation minus the evapotranspiration (Langbein et al., 1995). SWAT model depends on SCS method in calculation of annual water yield rate.

SWAT model outputs annual water yield rate that consists of two levels, which are the sub watersheds and streams. For sub watersheds it is clear that the sub watersheds No. (3and 12) are most productive as shown in Fig.10, and for the streams level the results is shown in Fig.11.

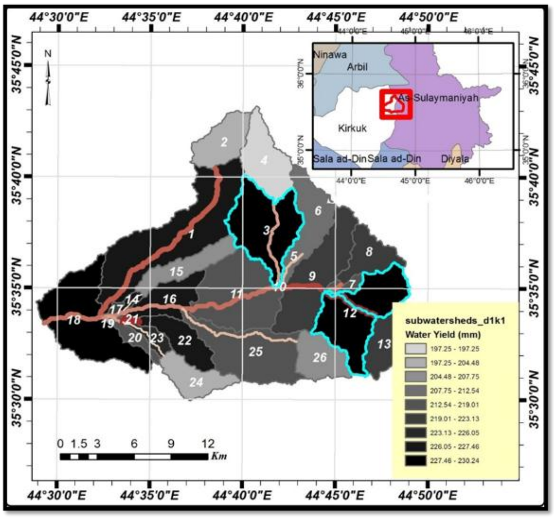

Figure 10 Annual water yield distribution in sub watersheds

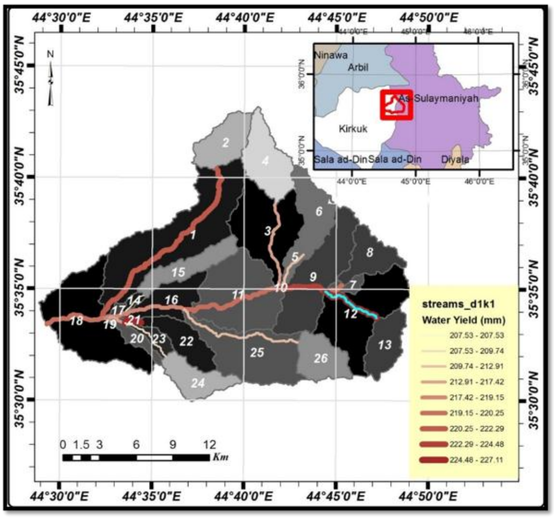

Figure 11 Annual water yield distribution in Streams

• Percolation

It is the process of water entering and percolating to the subsurface down to the water table. SWAT calculates the percolation for each layer of soil, according to a series of equations (Neitsch et al., 2005). As shown in the Fig.12 high value of percolation has been revealed in the sub basins (No. 3, 7, 12, 14, 22 and23), as a result of the terrain severity and the role of fissures and cracks in the rock formations, as well as the distribution of the formed depression phenomenon due to the high energy of water.

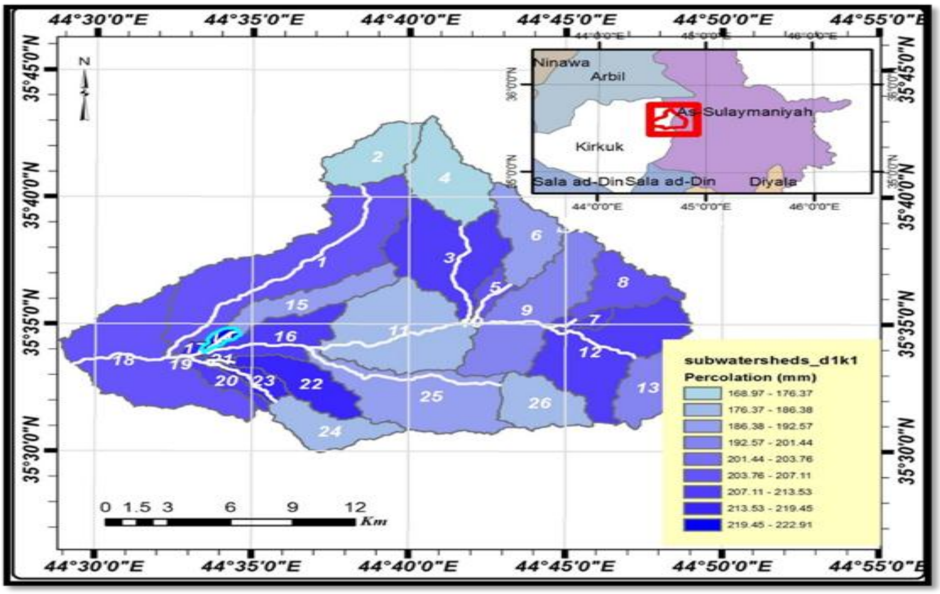

Figure 12. Annual Percolation depth distribution in Sub Watersheds

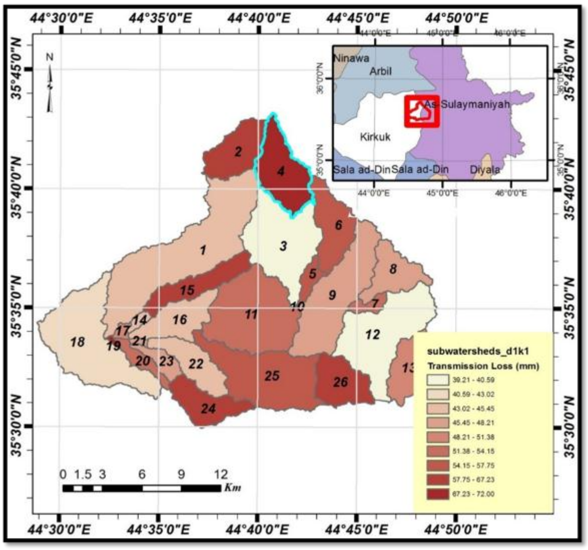

Figure 13. Annual Transmission Losses distribution in Sub watersheds

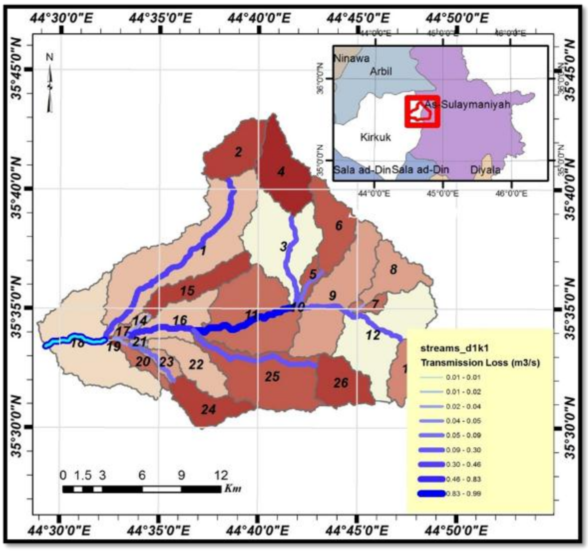

Figure14. Annual Transmission Losses distribution in streams

• Transmission Losses

Many arid and semiarid watersheds have ephemeral channels that obstruct large quantities of stream flow. The obstructions or transmission losses reduce runoff volume as the flood wave travels downstream (Neitsch et al., 2005). The model results show that the annual transmission loss distribution increases in the north east part of the watershed i.e. sub basin No. (4) As shown in Fig.13 and for the streams level the results is shown in Fig.14.

• Water Discharge

SWAT model calculates the annual rate of water discharge in m3/day according to the topographic, soil type, land cover, evapotranspiration, water yield, transmission losses and 30 years of daily climate as shown in Fig.15. The annual rate of water discharge for Khassa watershed was (249782.40) m^3/day.

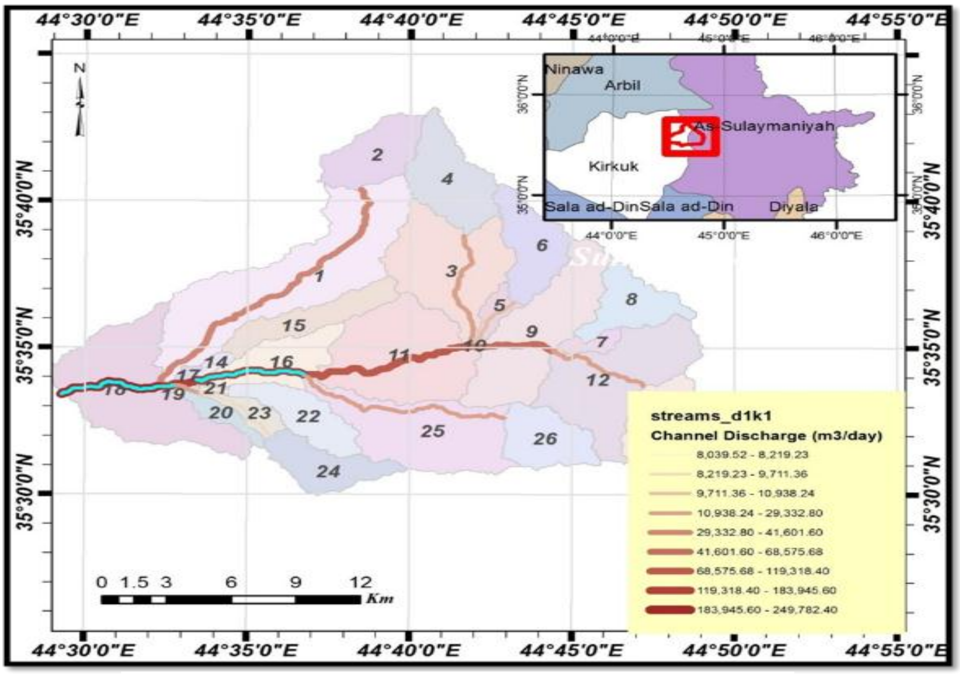

Figure 15. Annual water discharge distribution in sub watershed Streams

• Sediment Yield

There are two types of sediment yield results (degradation and deposition), the first one is for sub watershed and represented by units of (ton/ha) and the second is for channel and represented by units of (tons). SWAT model apply Modified Universal Soil Loss Equation (MUSLE) to calculate the sediment yield. The modified universal soil loss equation 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 $m^2hr/(m^3$-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).

As shown in Fig.16 for sub watersheds and Fig.17 for channels, the sub watershed(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 (2.24×10^3) ton.

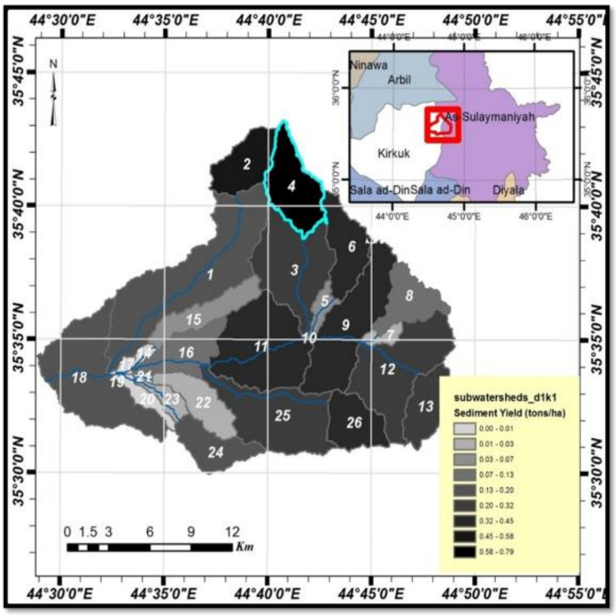

Figure 16. Annual Sediment Yield in Sub Watersheds

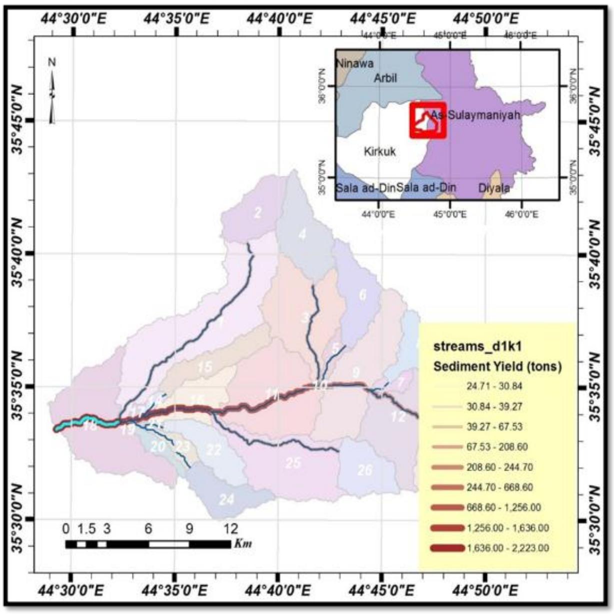

Figure 17. Annual Sediment Yield in Streams

Model Verification

According to available data and researches for Khassa watershed there are no records for hydrological observed data which classified the study area as ungauged watershed, we will focus in the conclusions of study on the values of annual rates of water discharge and sediment yield as per in the available predicted values for Khassa Chai dam planning report (MOWR, 2007) which is located in the bottom outlet south of the study area.

The ability of the model to predict the of water discharge for Khassa watershed is (249782.40) m^3/day is close to predicted value compared from the Khassa Chai dam planning report (MOWR, 2007) as shown in Table (1), and the annual amount of sediment yield is (2.24×10^3) ton is considered weak compared to the same planning report.

Table 1. Mean Annual inflow and Sediment Inflow (after MOWR, 2007)

Mean annual rate of water discharge	311040 m^3/day	
Mean Annual Sediment Inflow	Suspended Sediment	0.369 million tons
	Bed Load	0.074 million tons
	Total	0.443 million tons

CONCLUSIONS

AGWA model simulation for the general hydrological behavior of Khassa ungauged watershed depends on 30 years of daily climate data which vary in its values from wet years to dry years, accordingly in this study the ability of the model to predict the annual rates for hydrological characteristics depends on the ranges of climatological data and the accuracy of available geospatial datasets

This outputs and results helps the researchers and stockholders in administrations to achieve the efficient management and to build the future studies for sustainable development and planning for water resources.

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