# Climate Change Effect on Sediment Yield at King Talal Dam (Jordan)

Fayez Abdulla and Tamer Eshtawi
Water Resources and Environmental Engineering Division, Civil Engineering Department, Jordan University of Science & Technology, P.O Box 3030, Irbid 22110, Jordan

## Abstract

With a yearly precipitation of 200 mm in most of the country, Jordan is considered one of the least water-endowed regions in the world. Water scarcity in Jordan is exacerbated by growing demands driven by population and industrial growth and rising living standards. Major urban and industrial centers in Jordan including the Capital Amman are concentrated in the northern highlands, mostly contained within the boundaries of the Zarqa River Watershed (ZRW). The ZRW is the third most productive basin in the greater Jordan River System. King Talal Dam was built few kilometers upstream of the Zarqa-Jordan confluence to regulate its input mostly for the benefit of agricultural activities in the Jordan Valley. King Talal Dam (KTD) is the most important one in Jordan. It lies at the outlet of Zarqa River watershed (ZRW). This dam has a capacity of $86\times10^6$ $m^3$, which serves irrigation purposes in the Jordan Valley. However, the dam suffers from accelerated annual sedimentation.

Concerns regarding the sensitivity of the ZRW to potential climate change have prompted the authors to carry out the current study. The methodology adopted is based on simulating the hydrological response of the basin under alternative climate change scenarios. The Soil and Water Assessment Tool (SWAT) is a powerful time-variable hydrologic model that has rarely been applied in arid environments. In this paper, the performance of SWAT in the semi-arid Zarqa River watershed (ZRW) was assessed. The SWAT model was calibrated for Zarqa basin using records spanning from 1980 through 1994. The model was validated against an independent data record extending from 1995 through 2002. Calibration and verification results were assessed based on linear regression fitting of monthly and daily flows. Monthly calibration and verifications produced good fit with regression coefficient r values equal to 0.928 and 0.923, respectively. Annual volume predictions correlated well with measured flow in both the calibration ($r = 0.94$) and validation ($r = 0.93$) periods. For model validation the simulation results were compared to the measured values over 12 years period. Good agreement was obtained in some of the years.

Utilizing the SWAT modeling environment, scenarios representing climate conditions with ±20% change in rainfall, and $1^oC$ , $2^oC$ and $3.5^oC$ increases in average temperature were simulated and assessed. Unique relationship between the percent change in precipitation scenarios and the parallel change in sediment yield has been studied at different change in temperature to evaluate the degree of sediment sensitivity with temperature and precipitation.

The study shows that climate warming can dramatically impact runoffs, groundwater recharge and sediment yield in the basin. However the impact of warming can be greatly influenced by significant changes in rainfall volume.

**Keywords**: Zarqa River, Climate change, Sediment, SWAT

## Introduction

Watershed models are widely applied to investigate runoff dynamics and associated pollutants loadings such as sediment yield. Prediction of sediment yield from catchments is essential in the study of reservoir sedimentation, morphologic modeling, and soil-conservation planning. Numerous approaches used to estimate soil loss and sedimentation may be classified as (1) empirical models; (2) physically-based models; or (3) combination of empirical and physical models (Sun et al., 2002). Empirical models are based on analyses of experimental data. Examples of empirical models include the rating curve method and the universal soil loss equation (USLE) (Wischmeier et al., 1958). Because transport of sediment is mainly controlled by floods; especially large floods, the rating curve may result in a large margin of error. The USLE model provides an estimate of soil loss based on six variables. Although it is easy to use, USLE only describes the erosion processes for overland flow. Physically-based models are considered to be pure mathematical models for simulating the soil erosion processes based on the conservations of energy and mass principles. Examples include ANSWERS (Beasley et al., 1980), WEPP (Nearing et al., 1989), EUROSEM (Morgan et al., 1998), and GUEST (Misra and Rose, 1990).

In recent years many numerical models for simulating either the soil erosion or sediment yield have been developed. Murakami et al. (2001) coupled the SWM model with sediment discharge from overland flow to predict the outflow of soil from agricultural-oriented watershed. Ichikawa et al. (2000) developed a model for simulating surface runoff by using general kinematic wave techniques. Spatial distribution of the discharge and the flow area were calculated in Ichikawa's model assuming that the rainfall runoff system was in a steady state. Parlange et al. (1999) and Hairsine et al. (1999) developed a soil erosion model that described the sediment transport of the multiple-size particles

There are some methods have been used in the prediction of sediment yield. These methods based on two criteria of prediction. The first criterion considers hydrological data to predict sediment but the second criterion based on the channel flow only with a unique relationship for each catchments area.

## The study area

A great part of Jordan (about 90%) is located in arid and semi arid climate which has led to the limitation of water resources. The average precipitation is ranging between 50 and 600 mm/year. Rainfall is concentrated in the highlands bordering the Jordan Valley, 90% of Jordan is receiving less than 200 mm/year. The demand for water in the country is high and steadily growing with all sectors (Domestic, industrial and agricultural) competing for limited supplies of costly water (Jridi, 2005). The Zarqa river watershed (ZRW) is located in the north part of Jordan as shown in Figure 1. It is the most important one in Jordan where more than 40% of the total population of Jordan is living in ZRW. Four wastewater treatment plants (WWTPs) were constructed to handle to generated wastewater. These plants are As-Samra, Baq'a, Jarash and Abu Nuseir. As-Samra is the largest one and serves about one third of the inhabitants of Jordan (MWI, 2005).

King Talal Dam (32$^{o}$12'N, 35$^{o}$48'E; 300 m above sea level) is located at the outlet of ZRW, 40 km northwest of Amman and 15 km southwest of Ajlun. The dam capacity is 86 million cubic meters. KTD serves irrigation purposes in the Jordan Valley. However, the dam suffers from accelerated annual sedimentation. The average annual precipitation in the western part of the basin reaches about 400 mm, while in the eastern part it rarely exceeds 150 mm (Rahbeh, 1996). The bulk amount of precipitation falls in the winter season between October and May. The climate is Mediterranean with hot, dry summers and moderately cool, wet winters. Table 1 summarized the climatic parameters over the basin (Al-Akhras, 1996).

According to the Class-A pan evaporation measurements, the long-term average of annual evaporation varies from less than 2500 mm in the southwestern parts to more than 3200 in the northeastern and eastern parts of the study area (Rahbeh, 1996). $ET = EP * CP$, where: ET = evapotranspiration, EP = pan evaporation and CP = is the pan coefficient. Al Mahamid (2005) found that the correlation between the monthly ET to EP for the period of (1970/71-2001/02) ranges from 0.49 to 0.75 in winter and from 0.55 to 0.62 in summer (Al-Akhras, 1996). ZRW soil texture can be divided into five soil groups (clay soil, silty clay soil, silty clay loam soil, and silty loam soil) as shown in Figure 2. The thicknesses of these types vary in the basin from about 100 cm to 250 cm. In shallow soil texture, soil thickness can reach less than 50 cm (Al Mahamid, 2005). Table 2 shows the main soil properties for these groups.

The western and the northeastern parts of the study area contain more than 90 % of agricultural activities and vegetation. Agricultural land, forest land and pasture land are concentrating in the western part of ZRW. Urban land presents in the southwestern part of ZRW (the north part of Amman city and Zarqa city). Barren land presents in the eastern part of ZRW. Generally the landuse types of ZRW contain the following: 65% as bare rock, thin soils and urbanization and 35% as natural vegetation, forest, irrigated agriculture (cereals, vegetables, fruit trees, olives, bananas and citrus) and rained agriculture (cereals, vegetables, fruit trees, olives, bananas and citrus) as shown in figure 3.

## The SWAT Model

The Soil and Water Assessment Tool (SWAT) (Arnold et al., 1993), is a long-term, continuous simulation watershed model. AWAT is a modification of the SWRRB model (Simulation for Water Resources in Rural Basin) (Williams et al., 1985; Arnold et al., 1990). There are three major components of AWAT (1) Subbasin, (2) Reservoir Routing, and (3) Channel Routing. The sub-basin component consists of eight major divisions. These are surface hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, ground water and lateral flow. The compilation and input of hydrological data that are required by the SWAT model can be extracted with the use of a geographical information system (GIS), mainly from map layers including land use/land cover, digital elevation models (DEM), soil, slope, drainage and watershed boundary. Tripathi et al., (2004) applied (SWAT) model to the runoff and sediment yield of a small agricultural watershed in eastern India using generated rainfall. Jayakrishnan et al., (2005) described some recent advances made in the application of SWAT and the SWAT-GIS interface for water resources management. Also, many applications of SWAT were conducted by FitzHugh and Mackay (2000). Muttiah and Wurbs, (2002) studied the water balance of large watershed in Texas using the soil and water assessment tool (SWAT). Spruill et al., (2001) evaluated SWAT in the modeling of daily streamflows in a small central Kentucky watershed over a two-year period. Franeos et al., (2000) applied the SWAT model, coupled to a GIS, to the Kerava watershed (South of Finland), an agricultural subbasin of the Vantaa watershed draining into the Baltic Sea. Arnold and Fohrer (2005) implied that More than 50 participants from 14 countries discussed their modeling experiences with the SWAT model in the first International SWAT Conference held in August 2001. SWAT model has used Modified Universal Soil Loss Equation (MUSLE) in sediment calculation (SWAT2000 manual). MUSLE is a modified version of the

Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978). The modified universal soil loss equation (MUSEL) is:

$$Y = 11.8(Q_{surf} .q_{peak} .area)^{0.56} K.LS.C.P.(CFRG)$$

Where: $Y$ is the sediment yield on a given day (metric tons). $Q_{surf}$ is the surface runoff volume (mm $H_2O$/ha). $q_{peak}$ is the peak runoff rate ($m^3$/s). $K$ is the soil erodibility factor (0.013 metric ton $m^2$ hr/ ($m^3$-metric ton cm)). $C$ is the cover and management factor. $P$ is the support practice factor. $LS$ is the topographic factor $CFRG$ is the coarse fragment factor. The core runoff prediction mechanism within SWAT is a modified Curve Number approach, which is one of the most widely applied methods for predicting runoff.

## Data preparation

Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) is a multipurpose environmental analysis system (EPA, 2001). It was developed by the U.S. Environmental Protection Agency's (EPA's) Office of Water. The modeling environment BASINS is used in the modeling process. The contour map was used to prepare the Digital elevation map (DEM grid map). Then, the DEM was used to delineate ZRW and to divide it into small basins. The main streams and the outlets of these sub-basins were identified. Firstly, the automatic delineation tools was used with some iterations to get a suitable number of the watershed subbasins then the manual delineation tool was used to improve delineated subbasins based on the location of King Talal Dam (KTD) and the location of flow Jarash bridge gauge which needed for the calibration process. SWAT requires special reach theme in BASINS-GIS interface. This reach theme which is called RF1 theme contain special database for main streams. Based on RF1 theme and the delineated subbasins, the subbasins outlet can be improved as a final stage of watershed delineation as well as the watershed reservoirs. BASINS improve three GIS themes, subbasin theme, Stream theme, and outlet theme as shown in figure 6.

Eighteen rainfall stations have been used in the modeling process. Based on these stations Thiessen polygons was prepared to determine the weighted point rainfall for each subbasin. For evaporation data, UM EL-JUMAL evaporation station at the east of basin and KHIREBIT ES SAMRA evaporation station at the middle of basin are used to construct the potential evaporation time series for the watershed. Landuse map and soil map was overlapping in BASINS to estimate the subbasins properties from landuse and soil. For SWAT model, special database files must be prepared. Watershed configuration file, subbasin general file, HRU general file, and main channel file are produced from BASINS interface data. Management file was prepared Based on the land use classification. Management file contain a very sensitive parameter which is curve number (CN2). In the modeling process a daily rainfall with area depth reduction factor 0.9 was used. So, the climatic simulation was used for the hydrological process except rainfall process. An average pan coefficient 0.6 is used for pan evaporation data (Al-Akhras, 1996). Daily stream flow from As-Samra was obtained to be an input to SWAT model at subbasin 3.

## Model Calibration

The model was manually calibrated for fifteen years period from 1/1/1980 to 31/12/1994. In the calibration process, the main criterion was to minimize the error between the simulated and the measured mean annual flows for the total calibration period at Jarash Bridge gauging station (AL0060) and to minimize the error between the simulated and the measured mean annual sediment yield at King Talal Dam. The calibration period contains dry, wet, and normal flood flow years. SWAT model contain a huge number of parameters, most of them are measured or estimated from BASINS database. Before the calibration process, sensitivity analysis had performed to consider the most sensitive parameters. Table 3 shows the most sensitive parameters used in the calibration process.

For the stream flow, the simulated mean flow for the calibration period (1980-1994) was calibrated to be 2.39 $m^3$/s which is the same value for the observed mean stream flow in this period. The model predicted mean monthly streamflows satisfactorily as indicated by r = 0.93 and the slope of the relationship between measured and predicted flow was nearly unity (0.99).

The basic sediment yield calibration were obtained by adjusting crop practice factor (C) for land use (USLE_C in crop.dat) then Adjust USLE crop management factor (P) (USLE_P) and modify (USLE_K) in the soil file. The model predicted mean annual sediment yield as indicated by r = 0.87. The slope of the relationship between measured and predicted was nearly unity (0.93). Figure 7 shows a scatter plot of observed and simulated mean annual sediment yield using SWAT model. Figure 8 also shows the comparison between the observed and simulated mean annual sediment yield at King Talal Dam. The model reflected fair to good result as indicated in the comparison between the observed and predicted sediment yield in the calibration period.

Land use parameters have an indicated importance in the calibration of sediment yield hydrology. Curve number parameter (CN2) in the stream flow parameters and the land cover/plant factor (USEL_C) in the sediment parameters reflect the most sensitive parameters in each parameter groups table 3. Figure 9 studied the sensitivity of CN2 parameter and Figure 10 studied the sensitivity of USEL_C parameter. A relationship between the percentage of increase or decrease the parameter value and the percentage of increase or decrease the sediment yield has been improved in this sensitivity study. Also linear relationships have been investigated for the two parameters.

Figures 9 and 10 show unique relationships that $\pm 1\%$ in the CN2 value changes the annual sediment yield by $\pm 9.9\%$ and $\pm 1\%$ in the USEL_C value changes the annual sediment yield by $\pm 0.51\%$.

### Model validation

Model validation was done during seven years from 1/1/1995 to 31/12/2001. Figure 11 shows the comparison between the observed and simulated mean annual sediment yield at King Talal Dam. The model reflected fair result as indicated in the comparison between the observed and predicted sediment yield in the validation period. Figure 11 shows very good simulated years such as (year 1998) as well as poor simulated years such as (year 1999).

### Sediment yield distribution

Figure 12 show the distribution of sediment yield through the basin. Average annual sediment yield ranged from 0.05 t/ha in the east part to 15 t/ha in the west and southern west part in the basin. The west part contains agricultural land that has high USEL_C factor also this part has higher precipitation and surface runoff than others. In Figure 13, the maximum average sediment yield was in February (0.7 t/ha).

### Climate change scenarios

Commonly, hydrological modeling process aims to study and predict the effect of different changes on the water yield from the studied catchment's area. SWAT model is used in the evaluation of different management scenarios. One of the most important environmental problems at the global scale is the climate change due to the global warming. Climate change scenario can give a suitable indication for the future changes in the water yield.

Future human activities are nowadays believed to be increasing the atmospheric concentrations of greenhouse gases. This alters energy balances and tends to warm the atmosphere which will result in climate change. Some reports indicate that mean annual global surface temperature has increased by about 0.3–0.6 $^{o}$C since the late 19th century and it is anticipated to further increase by 1–3.5 $^{o}$C over the next 100 years (Dibike and Coulibaly, 2005). This will lead to an increase in precipitation in some regions while other regions will experience reduced precipitation ±20% (Matondo et.al, 2004). In this research different climate change scenarios were investigated to study the effect of climate change on the annual sediment yield. Change the temperature by 1$^{o}$C and 2$^{o}$C was tested. Also different precipitation scenarios (-20%, -10%, 10%, and 20% change in the annual precipitation) was investigated. Figure 12 study the effect of these different scenarios on the annual sediment yield. Figure 13, Figure 14, and Figure 15 study the relationship between different climate change scenarios and the change in the sediment yield for different changes in temperature. At no change in annual temperature the climate change relationship was: $y = 3.04x + 7.4$ where $y$ is % change in the sediment yield and $x$ is the precipitation scenarios. This relationship changes to be: $y = 3.12x + 10.71$ at increase the temperature by 1$^{o}$C as well as $y = 3.15x + 10.18$ at increase the temperature by 2$^{o}$C. In these relationships, the slope increases by increasing the annual temperature. This means that the sediment yield is sensitive with the annual temperature as well as more sensitive with the annual precipitation.

In SWAT model with increasing the rainfall by 10%, the mean annual sediment yield increases by 34% at no change of temperature and increases by 37.5% at increasing the temperature by 1$^{o}$C. Figure 15 shows that at $\pm 1\%$ change in the annual precipitation, the annual sediment yield changes by $\pm 3\%$. This value of change can be reach to $\pm 3.2\%$ at increasing the temperature by 2$^{o}$C

### Conclusions

- SWAT model proved to be suitable tools for use on large-scale watershed, especially those with urban and rural land use. SWAT worked in acceptable behavior in the monthly and yearly simulation stream flow of semi arid region. Also, it worked in acceptable behavior in yearly simulated sediment yield of semi arid region as indicated by r = 0.871.
- Testing climate change scenarios has been successfully studied. At 10% reduction of rainfall and increasing average annual temperature by 1$^{o}$C, the sediment yield decreases by 25.9%. Also, 10% increase in annual rainfall with increasing average annual temperature by 2$^{o}$C increases the sediment yield by 34.0%. Generally, at $\pm 1\%$ change in the annual precipitation, the annual sediment yield changes by $\pm 3\%$.
- Sediment yield is sensitive with the change of annual temperature. This sensitivity is indicated by the

increasing the slope value of the relationship between percent change in sediment and the percent change in the annual precipitation.

## References

1. Tripathi M, Panda R, Raghuwanshi N, Singh R. Hydrological Modeling of a small watershed using generated rainfall in the soil and water assessment tool model. Hydrological Processes 2004; 18:1811-1821.
2. Jayakrishnan R, Srinivasan R, Santhi C, Arnold J. Advances in the application of the SWAT model for water resources management. Hydrological Processes 2005; 19:749–762.
3. FitzHugha TW, Mackayb DS. Impacts of input parameter spatial aggregation on an agricultural nonpoint source pollution model. Journal of Hydrology 2000; 236:35–53.
4. Muttiah R, Wurbs R. Scale-dependent soil and climate variability effects on watershed water balance of the SWAT model. Journal of Hydrology 2002; 256:264-285.
5. Spruill C, workman S, taraba J. Simulation of Daily and Monthly Stream Recharge from Small watershed using the SWAT Model. American society of civil engineers ASCE 2001; 43(6):1431-1439.
6. Franeos A., Bidoglio G, Galbiati L, Bouraoui F, Elorza F, Rekolainen S, Manni K, Granlund K. Hydrological and Water Quality Modeling in a Medium-sized Coastal Basin. Physics and chemistry of the Earth 2001; 26:47-52.
7. Arnold J, Fohrer N. SWAT2000: current capabilities and research opportunities in applied watershed modeling. Hydrological. Processes 2005; 19:563–572.
8. Grassland, Soil & Water Research Laboratory, Agricultural Research Service, Black land Research and Extension Center, and Texas Agricultural Experiment station. The soil and water assessment tool (SWAT) user's manual version2000. 2002. [Online] [accessed 2006 March]. Available from URL http://www.epa.gov.
9. U.S. Environment Protection Agency EPA. Better Assessment Science Integrating Point and Nonpoint Sources BASINS: User manual Version 3. 2001. [Online] [accessed 2006 March]. Available from URL http://www.epa.gov.
10. Jridi A. The Development of Jordanian Jordan River Basin: The Main Historical Steps. French Institute for Forestry; 2005.
11. Rahbeh M. Rainfall-Runoff Relationships for Zarqa river basin [Master thesis]. University of Jordan; 1996.
12. Al-Akhras M. Rainfall-runoff relationship for representative watersheds in Al-Muwaqqar basin [Master thesis]. University of Jordan; 1996.
13. Al Mahamid J. Integration of Water Resources of the Upper Aquifer in Amman-Zarqa Basin Based on Mathematical Modeling and GIS, Jordan. Freiberg Online Geology FOG, vol. 12; 2005.
14. Ministry of Water and Irrigation - Jordan. WAJ, 2005. (Archived Data).
15. USDA – ARS Southwest Watershed Research Center and US – EPA Office of Research and Development Las Vegas, Nevada. Automated Geospatial Watershed Assessment (AGWA) - A GIS-Based Hydrologic Modeling Tool: Documentation and User Manual Version 1.4. 2004.
16. Dibike Y and Coulibaly P. Hydrologic impact of climate change in the Saguenay watershed: comparison of downscaling methods and hydrologic models. Journal of Hydrology 2005; 307:145–163.
17. Matondo J, Graciana P, and Kenneth M. Evaluation of the impact of climate change on hydrology and water resources in Swaziland: Part II. Physics and Chemistry of the Earth 2004; 29: 1193–1202.

**Figure 1** Zarqa River basin ((Jridi, 2005)

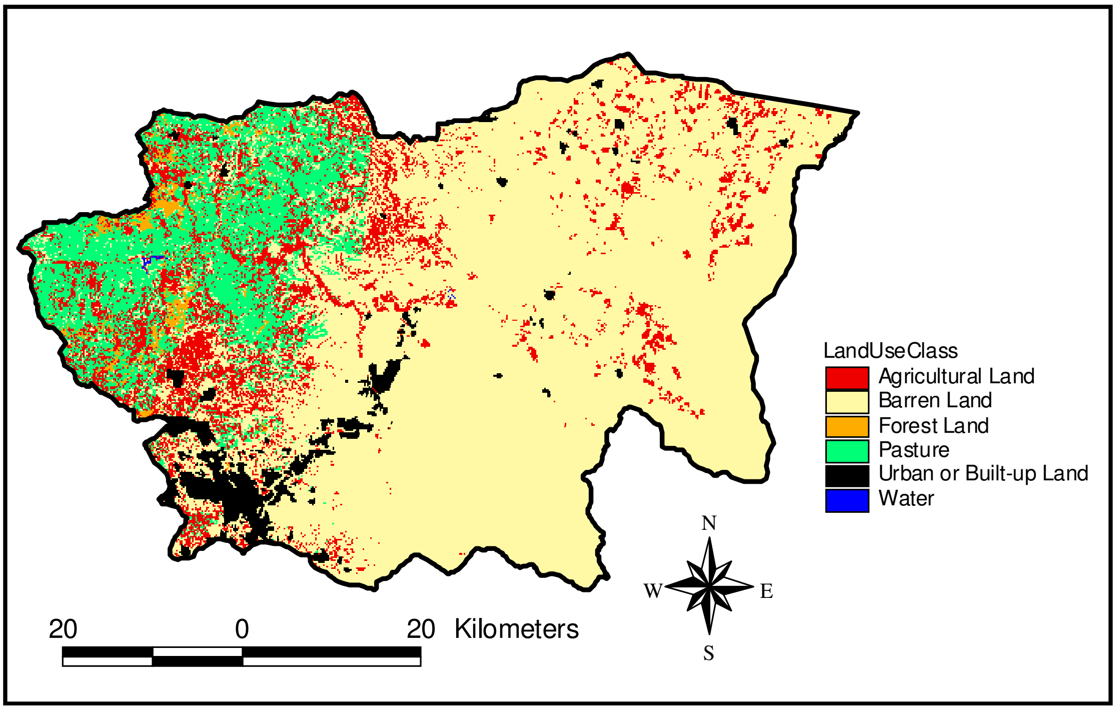

Figure 3 Zarqa basin land use (Al Mahamid, 2005)

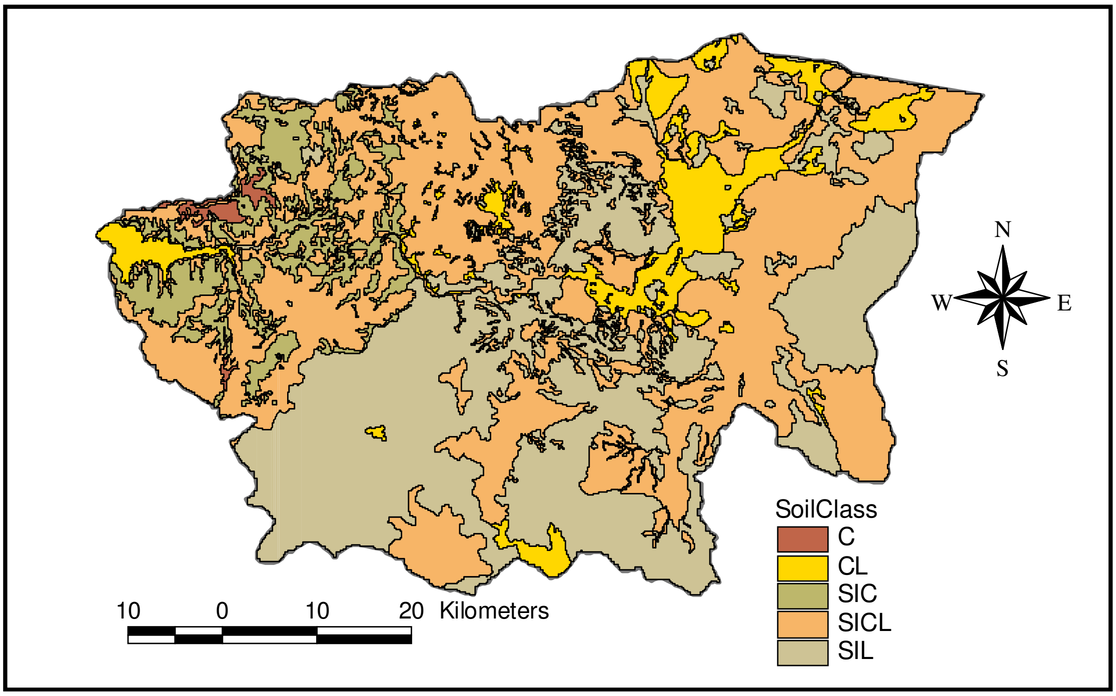

Figure 2 Soil texture in Zarqa basin (Al Mahamid, 2005)

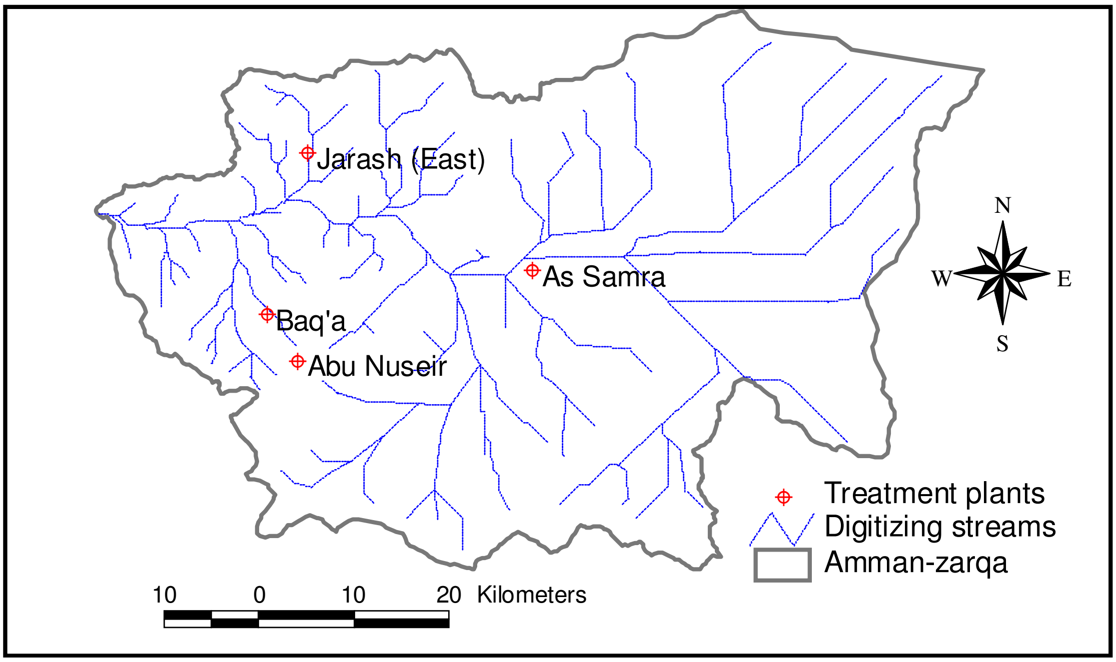

Figure 2 The main treatment plants in Zarqa basin

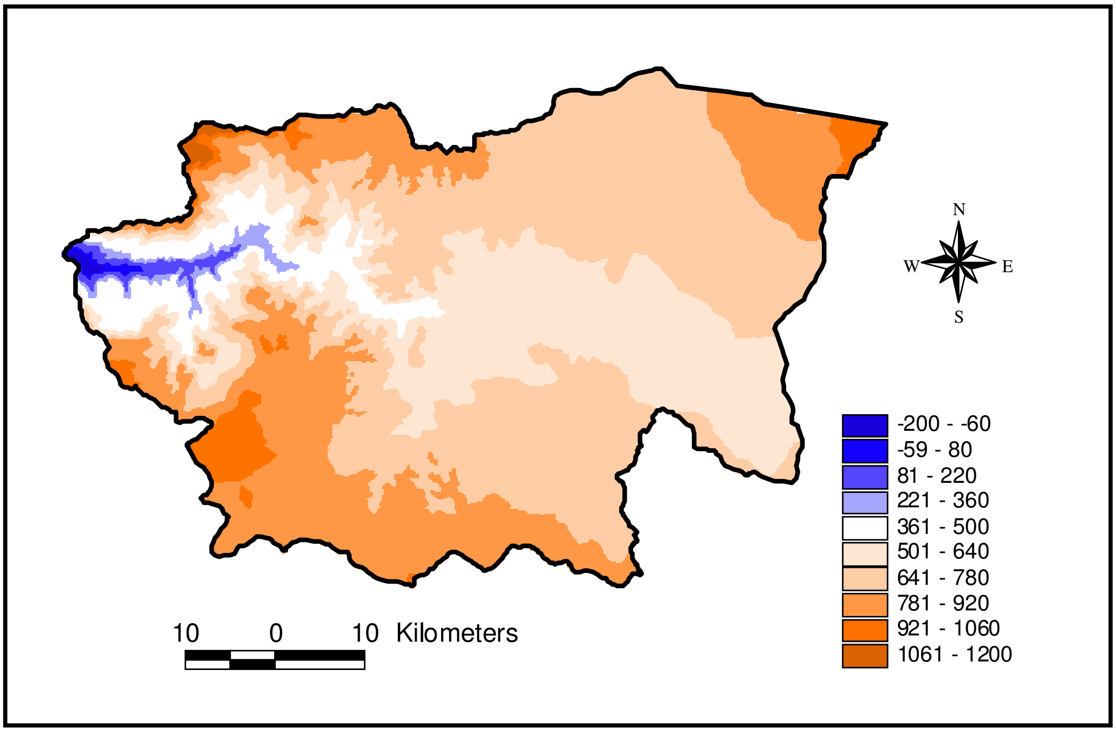

Figure 3 DEM map

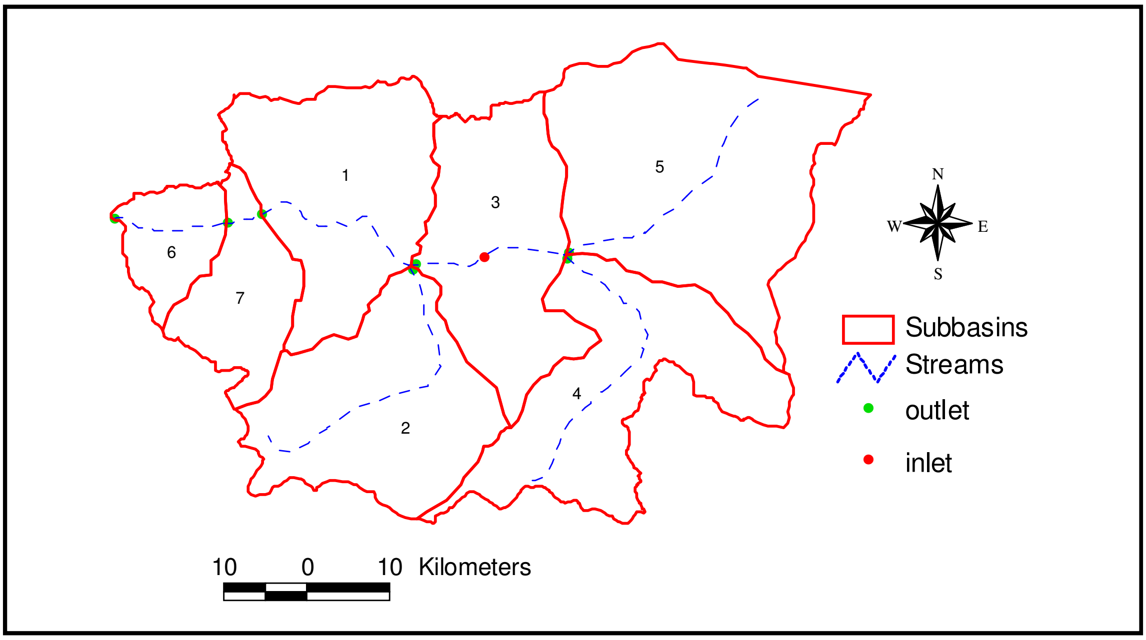

Figure 4 Delineation results of Zarqa basin

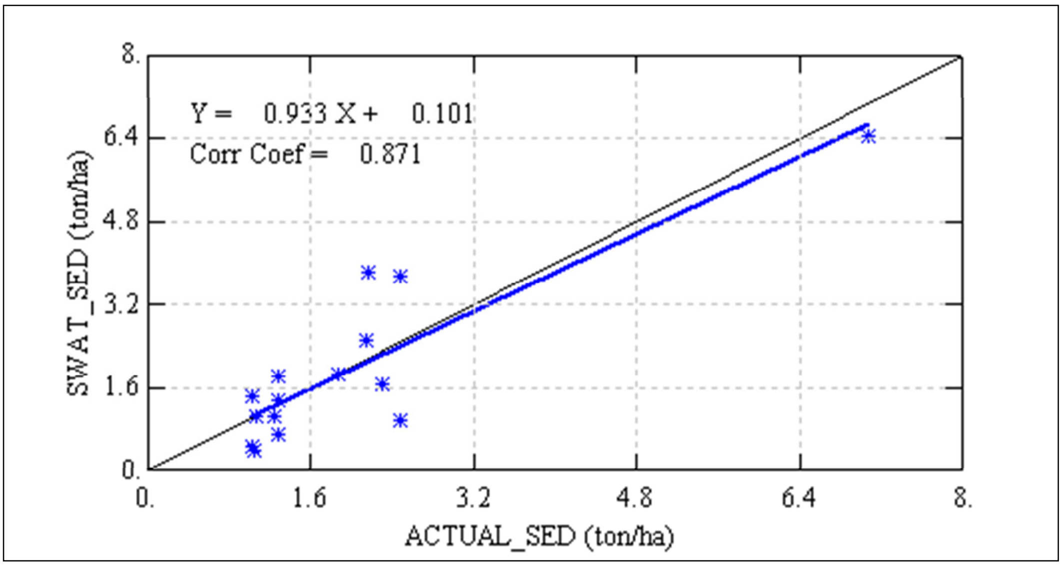

Figure 5 Scatter plot for the yearly relationship between observed & predicted sediment yield in (t/ha)

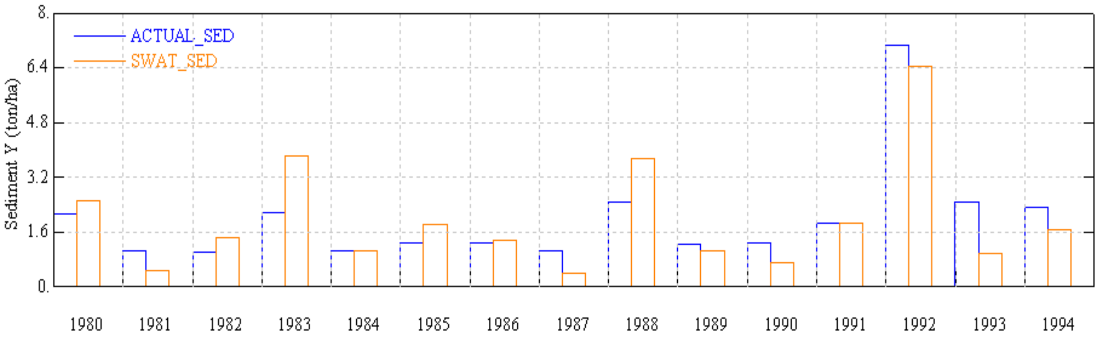

Figure 6 Analysis plot for yearly sediment yield (t/ha)

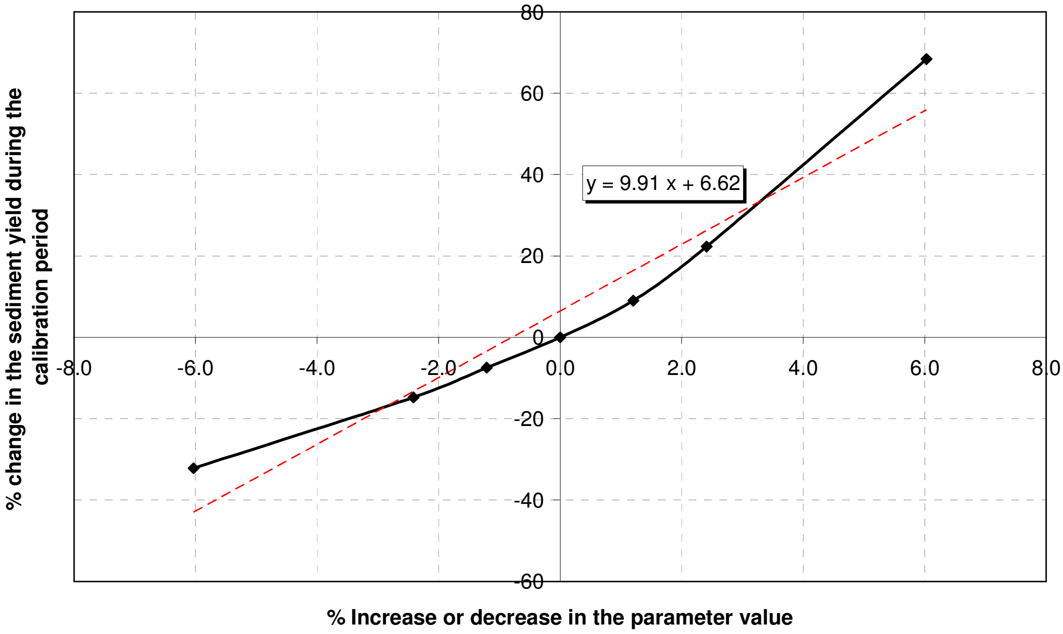

Figure 7 Sensitivity study for CN2 parameter

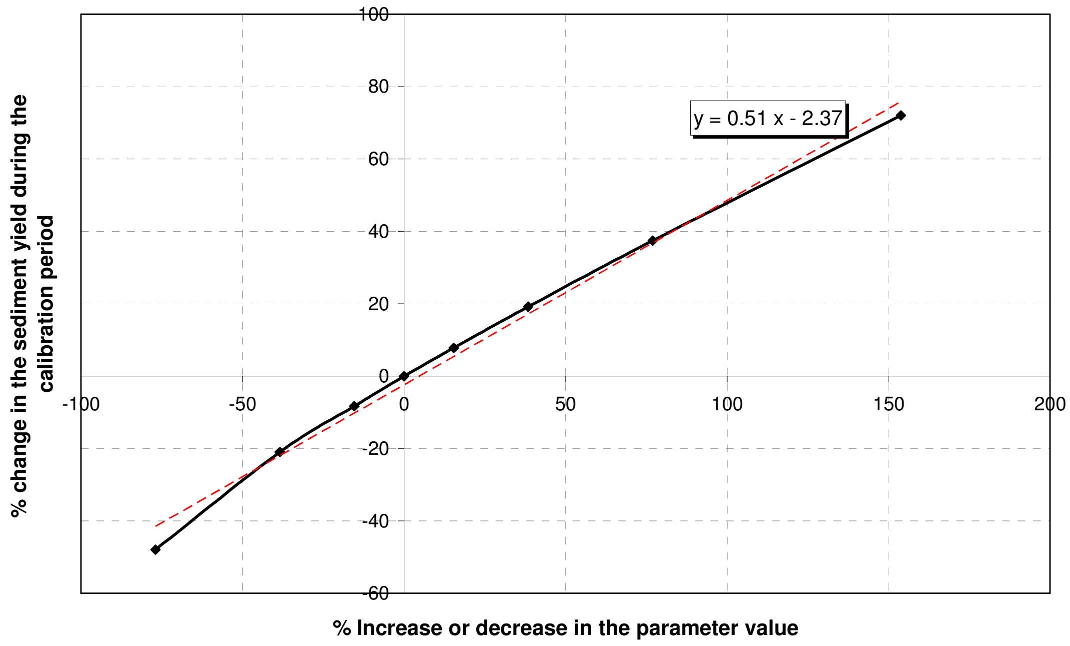

Figure 8 Sensitivity study for USEL_C parameter

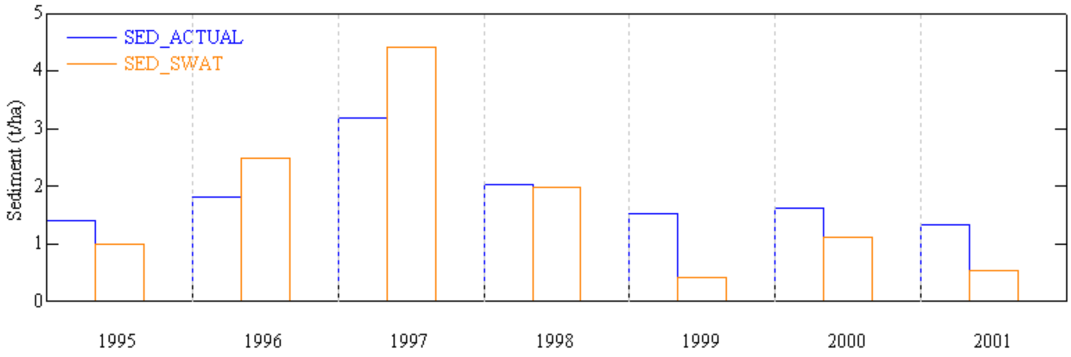

Figure 9 Analysis plot for yearly sediment yield (t/ha)

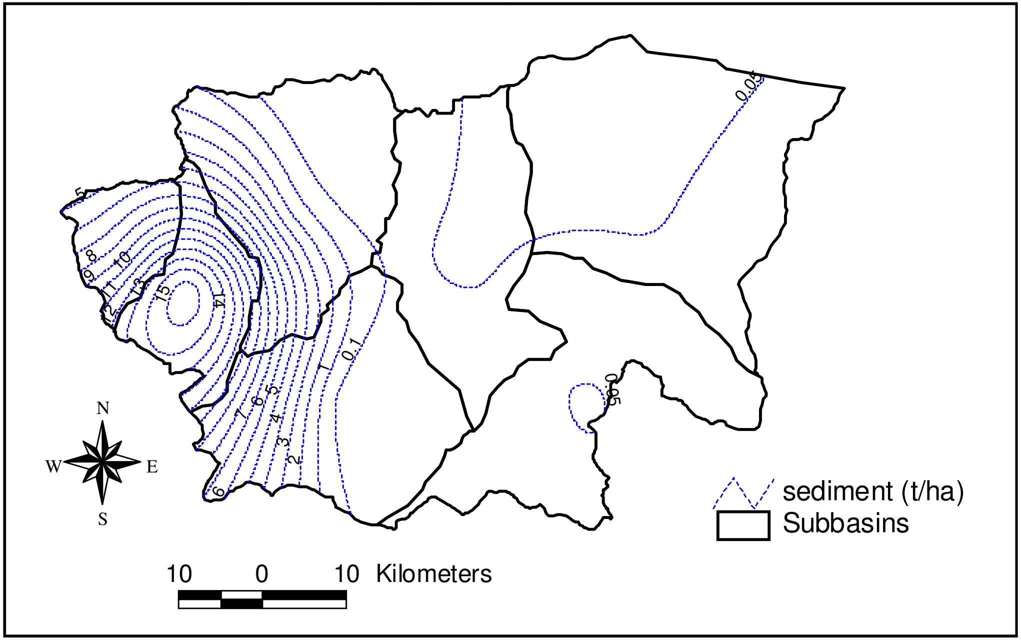

Figure 10 Average annual sediment yield distribution through the basin (SWAT model)

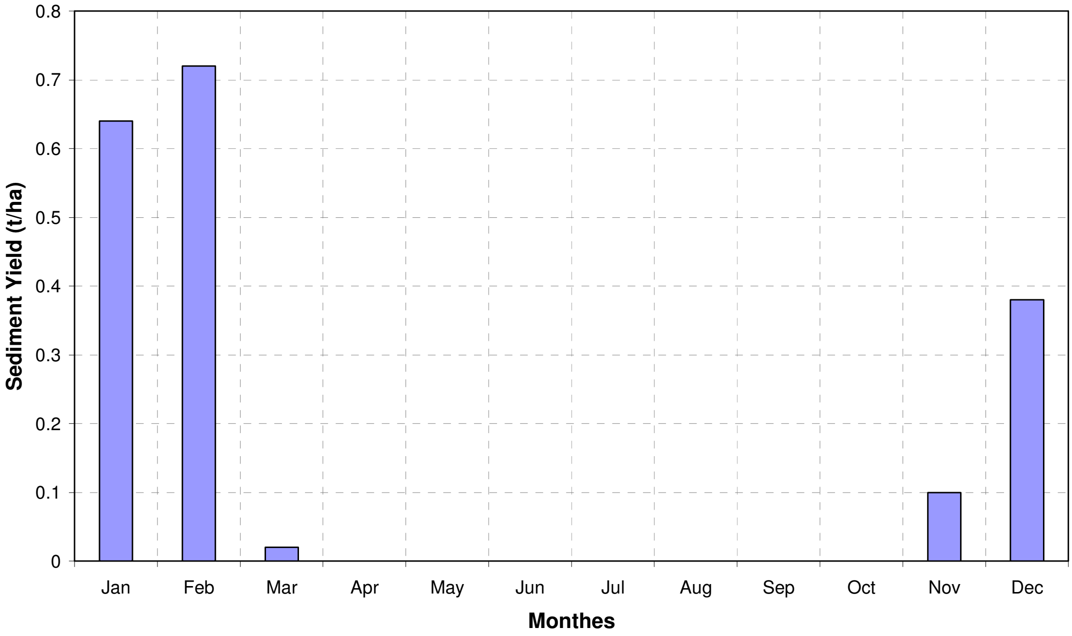

Figure 11 Average sediment yield during the year (SWAT model)

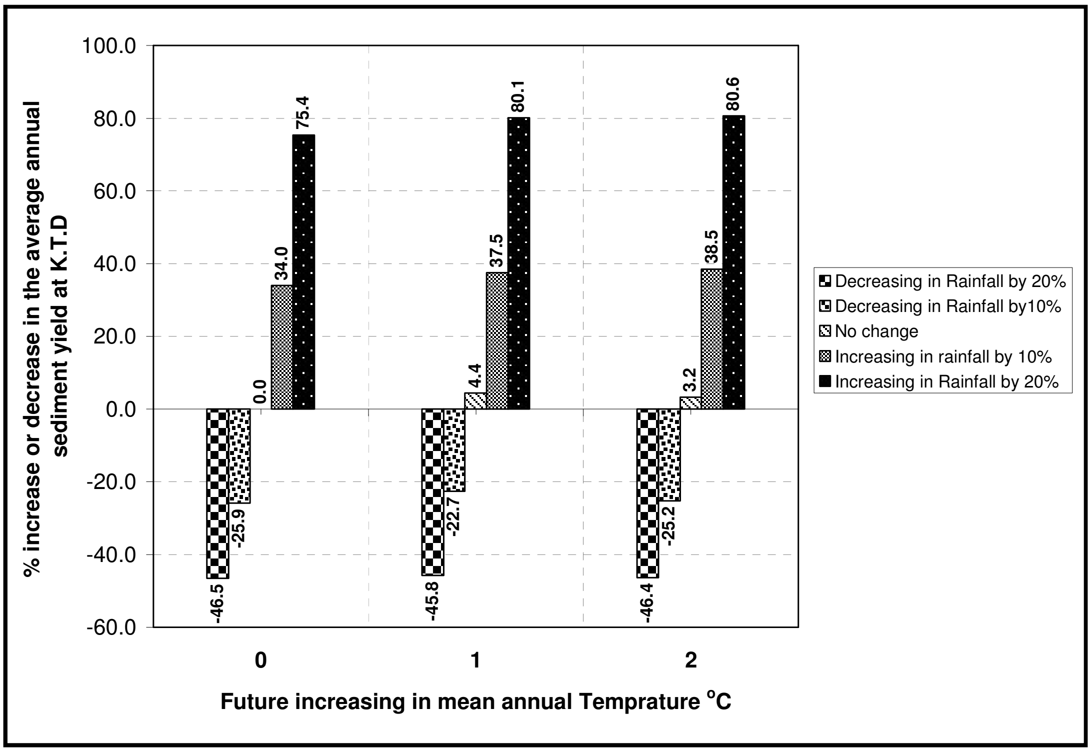

Figure 12 The effect of climate scenarios on the mean annual sediment yield using SWAT model

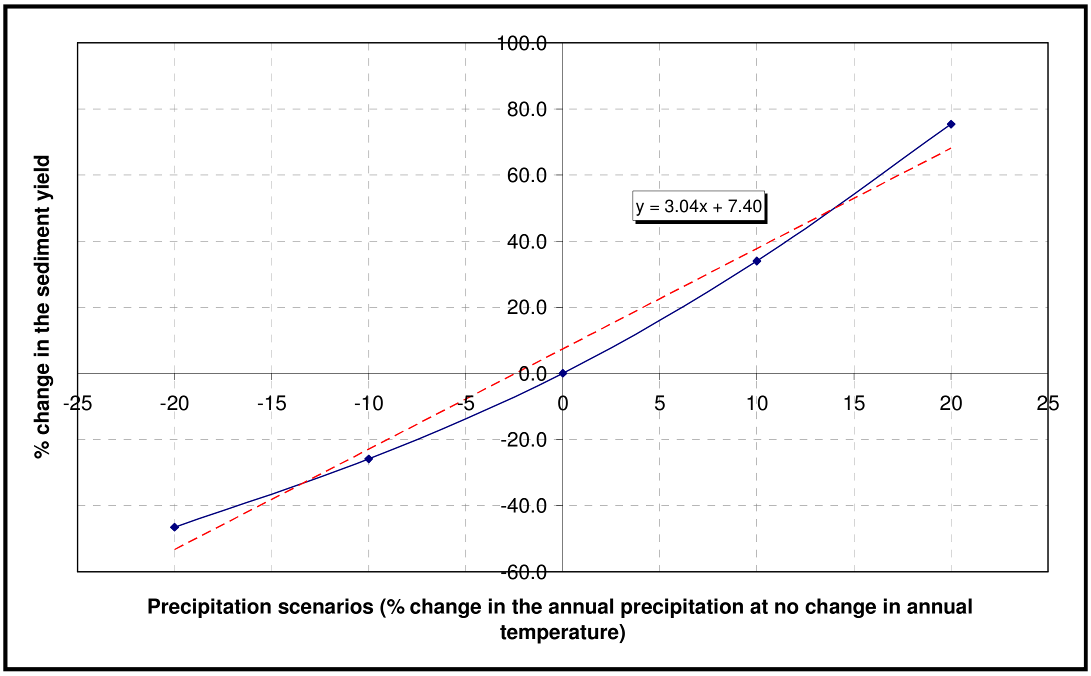

Figure 13 different precipitation scenarios with no change in temperature

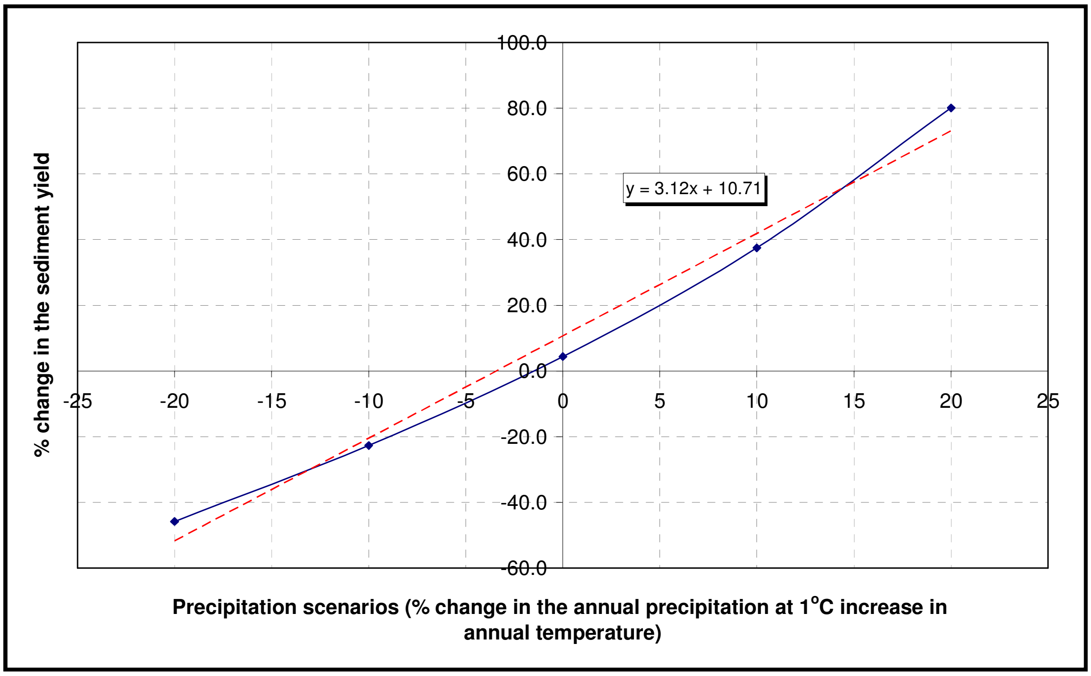

Figure 14 different precipitation scenarios with increase the temperature by 1$^{o}$C

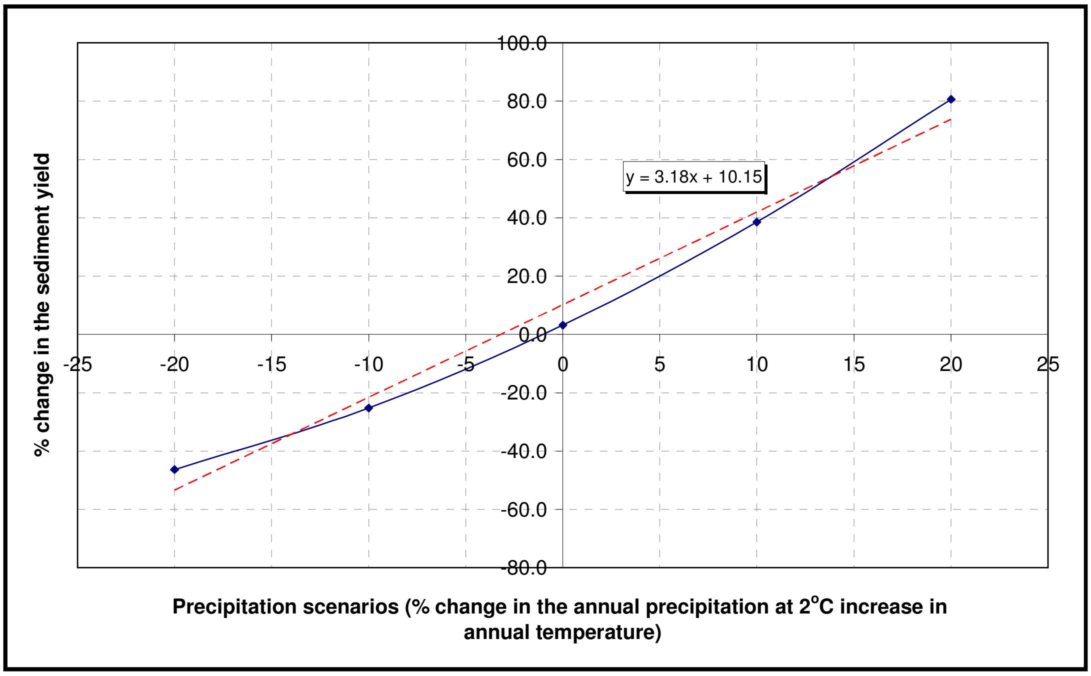

Figure 15 different precipitation scenarios with increase the temperature by 2$^{o}$C

Table 1 Averages of the climatic parameters in the study area (1970-2002) (Al-Akhras, 1996, Al Mahamid, 2005).

| **Parameters** | **Months** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Oct.** | **Nov** | **Dec** | **Jan** | **Feb** | **Mar** | **Apr** | **May** | **Jun** | **Jul** | **Aug** | **Sep** |
| Minimum daily temperature °C | 13.3 | 8.9 | 6.1 | 4.1 | 4.7 | 6.7 | 9.7 | 13.1 | 16 | 18 | 17.8 | 16.3 |
| Maximum daily temperature °C | 27.5 | 20.4 | 16.3 | 13.6 | 15.9 | 18.3 | 23.9 | 28.4 | 31.5 | 33.1 | 32.5 | 31.4 |
| Mean daily temperature °C | 20.4 | 14.7 | 11.2 | 8.8 | 10.3 | 12.5 | 16.8 | 20.7 | 23.7 | 25.6 | 25.2 | 23.9 |
| Sunshine duration (hrs/day) | 8.3 | 6.8 | 5.4 | 5.3 | 6.2 | 7.2 | 8.2 | 10.1 | 11.1 | 11.4 | 10.8 | 9.3 |
| Wind speed (m/s) | 1.6 | 1.9 | 1.9 | 1.9 | 2.2 | 2.2 | 2.3 | 2.3 | 2.4 | 2.4 | 2.1 | 1.7 |
| Relative humidity (%) | 71 | 73.4 | 81.1 | 82.6 | 81.1 | 73.5 | 65.2 | 59.2 | 59.8 | 63.7 | 68 | 69.3 |
| Solar radiation MJ/m$^2$ | 4.2 | 6.3 | 11.8 | 18.0 | 26.0 | 33.0 | 31.8 | 27.5 | 22.7 | 14.2 | 7.9 | 4.4 |
| Rainfall (mm) | 7.3 | 25.1 | 48.9 | 61.8 | 55.1 | 42.9 | 12.8 | 1.9 | 0 | 0 | 0 | 0 |
| Class-A pan (mm/d) | 7.6 | 5.2 | 3.2 | 2.8 | 3.8 | 5.2 | 8.1 | 11 | 12.5 | 13.4 | 11.8 | 10 |
| Potential evapo- transpiration (mm/d) | 4.2 | 2.5 | 2.3 | 2.1 | 2.6 | 3.9 | 5.7 | 6.8 | 7.6 | 8.1 | 7.2 | 5.6 |

Table 2 The main soil texture parameter in Zarqa basin (**Ministry of Water and Irrigation, 2005**)

| **TEXTURE** | **description** | **$K_S$ mm/hr** | **n** | **$S_{MAX}$** | **SAND %** | **SILT %** | **CLAY %** | **$K_{FF}$** |
|---|---|---|---|---|---|---|---|---|
| **C** | Clay | 0.600 | 0.475 | 0.810 | 27.000 | 23.000 | 50.000 | 0.340 |
| **CL** | Clay loam | 2.300 | 0.464 | 0.840 | 32.000 | 34.000 | 34.000 | 0.390 |
| **SIC** | Silty clay | 0.900 | 0.479 | 0.880 | 9.000 | 45.000 | 46.000 | 0.310 |
| **SICL** | Silt clay loam | 1.500 | 0.471 | 0.920 | 12.000 | 54.000 | 34.000 | 0.400 |
| **SIL** | Silty loam | 6.800 | 0.501 | 0.970 | 23.000 | 61.000 | 16.000 | 0.490 |

Where: $Ks$ is the saturated hydraulic conductivity, $n$ is soil porosity, $S_{max}$ is the maximum soil saturation and $K_{FF}$ is the soil erodibility factor

Table 3 Calibrated parameters (SWAT model)

| **Name** | **Definition** | Estimated value | Calibrat-ed value | Units | Possible range (16) | | SWAT data base file |
|---|---|---|---|---|---|---|---|
| | | | | | Min | Max | |
| **Stream flow parameter group** | | | | | | | |
| CN2 | Curve number | 80.700* | 82.700* | None | 0 | 100 | Manage-ment file |
| SOIL_AWC | Available water capacity of the soil layer | 0.1125* | 0.1085* | mm $H_2O$/mm soil | 0 | 1 | Soil file |
| SOIL_BD | Bulk density | 1.4000* | 1.2510* | g/cm$^3$ | 1 | 2.5 | Soil file |
| SOIL_Z | Depth from soil surface to the bottom | 1500.0 | 2200.0 | mm | 0 | 3500 | Soil file |
| **Sediment parameter group** | | | | | | | |
| USLE_C | Water erosion applicable to the land cover/plant factor | 0.03* | 0.13* | None | 0.001 | 0.5 | Crop data |
| USLE_P | Support practice factor | 1 | 0.95 | None | 0 | 1 | Manage-ment file |
| USLE_K | soil erodibility factor | 0.33* | 0.35* | None | 0 | 0.65 | Soil file |

* This value is the average from the different landuse and soil groups