# Application of Automated Geospatial Watershed Assessment (AGWA) Tool to Evaluate the Sediment Yield in a Semi-arid Region: Case Study, Kufranja Basin-Jordan

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## ABSTRACT

Prediction of sediment yield from catchments is essential in the investigation of reservoir sedimentation and other hydrological and geological studies. Many methods have been used in the prediction of sediment yield. Soil and Water Assessment Tool (SWAT) is a newly developed model that can be applied to rural watershed. SWAT model has used Modified Universal Soil Loss Equation (MUSLE) in sediment calculation. The Automated Geospatial Watershed Assessment Tool (AGWA) is a GIS based watershed modeling tool. This paper improved a hydrological modeling using modeling environment AGWA and SWAT model to evaluate the sediment yield in Kufranja basin in Jordan. The sediment yield has been calculated at three proposed dam sites in the basin. The calibration process depended on the most sensitive parameters in SWAT model. Long term rainfall series were used in the modeling process. AGWA studies the change in the most sensitive parameter in the SWAT model. The change in this parameter can be considered as different scenarios in Kufranja basin.

**KEYWORDS:** Automated Geospatial Watershed Assessment (AGWA), Sediment yield, Semi-arid region, Kufranja Basin, Jordan.

## INTRODUCTION

Today's environmental managers, urban planners and decision-makers are increasingly expected to examine environmental and economic problems in a larger geographic context. One of these problems is sediment yield. Prediction of sediment yield from catchments is essential in the study of reservoir sedimentation, morphologic modeling and soil-conservation planning. Thorough records for sediment yield are generally not available. There are some methods that have been used in the prediction of sediment yield. These methods are based on two criteria of prediction. The first criterion considers other hydrological data to predict sediment but the second criterion is based on the channel flow only with a unique relationship for each catchment area. The Soil and Water Assessment Tool (SWAT) is a newly developed model that can be applied to ungauged rural watershed with small subwatersheds. It is developed by the U. S. Department of Agriculture, Agricultural Research Service (USDA-ARS). The SWAT model is process based and its major components include surface hydrology, weather, sedimentation, soil temperature, crop growth, nutrients, pesticides, ground water and lateral flow.

Chaplot et al. (2005) studied the effect of the accuracy of spatial rainfall information on the modeling of water, sediment, and $NO_3$–N loads at the watershed level using

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SWAT model. 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 resource management. Also, many applications of SWAT have been studied by Bouraoui et al. (2005). 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:

$$Y = 11.8(Q_{surf} . q_{peak} .area)^{0.56} K.LS.C.P.(CFRG) \tag{1}$$

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 and $CFRG$ 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 worldwide and is readily modeled using GIS (SWAT2000 Manual). The SCS Curve Number equation is written as:

$$Q_s = \frac{(R - I_a)^2}{R - I_a + S} \tag{2}$$

where: $Q_s$ is total surface runoff (mm), R is the daily rainfall (mm), $I_a$ is the initial abstraction such as infiltration and interception prior to runoff (mm), $S$ is a retention parameter based on the combination of soil, land use and land-cover. Initial estimates of $I_a$ and $S$ are commonly derived from look-up tables, which are a core component of AGWA. The Automated Geospatial Watershed Assessment Tool (AGWA) is a GIS based watershed modeling tool. AGWA was developed as a multipurpose hydrologic analysis system for use by watershed (semi-arid watershed), water resource, land use and natural resource managers and scientists for developing watershed and basin-scale studies. AGWA prepares input files for the models using standardized spatially-distributed datasets such as elevation, soils and land cover data. AGWA is an extension for the Environmental Systems Research Institute’s (ESRI) ArcView, version 3.X (ESRI, 2001), a widely used and relatively inexpensive Personal Computer (PC)-based GIS software package. AGWA was developed under the following guidelines: (1) that its parameterization routines are simple, direct, transparent and repeatable; (2) that it is compatible with commonly available GIS data layers and (3) that it is useful for assessment and scenario development (alternative futures) at multiple scales. There are six major steps involved in AGWA analysis: (1) watershed delineation; (2) parameter estimation; (3) rainfall generation; (4) model execution; (5) change analysis; and (6) visualization of results.

The primary distribution method for AGWA is via the Internet as a free, modular, open-source suite of programs (www.tucson.ars.ag.gov/ agwa or www.epa.gov/ nerlesd1/ land-sci/ agwa/). Under the modeling environment (AGWA), Kepner et al. (2004) studied the San Pedro River in Arizona and Sonora using SWAT model. Their study defined future scenarios, in the form of land-use/land-cover grids, were examined relative to their impact on surface-water conditions. Miller et al. (2006) studied in detail general applications of AGWA. AGWA provides the functionality to conduct all phases of a watershed assessment for SWAT and KINEROS2. SWAT2000 is the current version of SWAT and is a continuous-simulation model for use in large (river-basin scale) watersheds. KINEROS2 is an event-driven model designed for watersheds characterized by predominantly overland flow. The AGWA tool combines these models in an intuitive interface for performing multi-scale change assessment, and provides the user with consistent, reproducible results. Data requirements include elevation, land-cover, soils and precipitation data, all of which available at no cost over the Internet. Model input parameters are derived directly from these data using optimized look-up tables that are provided with the tool.

In this paper, a hydrological modeling has been performed using modeling environment AGWA and SWAT model to evaluate the sediment yield in Kufranja basin in Jordan at the proposed dam sites catchment area. These results of sediment have been compared with a study that used a special equation based on the channel flow in Jordan to calculate the sediment.

**Study Area and Data Collection**

Wadi Kufranja basin is located in Northwest Jordan, with a distance around 70 km to the northwest of Amman city. It lies between the Palestinian coordinates of E (207-227) and N (185-197) (Figure 1). It comprises an area of about 112 km$^2$. Its opal elongated shape has a longest axis of 42 km and a shortest axis of 13 km (Sa'ad, 1996). This basin is a typical rural and agricultural area. Wadi Kufranja is one of the small sub-basins of the Jordan River side wadis drainage system, draining westward. The topography and relief of this basin is rather complex. It changes rapidly from east to west towards the outlet of the basin and towards the wadi drains. Kufranja has poor measured data, so the use of AGWA is suitable for this case.

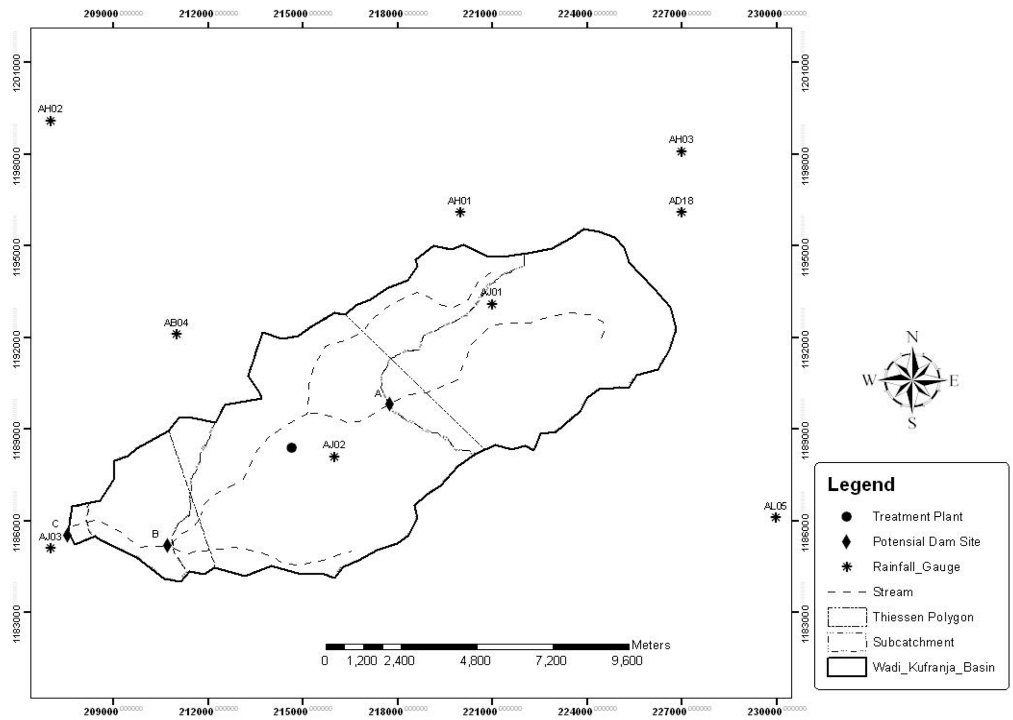


**Figure 1: Kufranja Basin.**

Since Wadi Kufranja drains westward at the west escarpment slopes, it belongs climatologically to the second region in Jordan (Western Escarpment Slopes) except the lower part of the basin which belongs to the first region (Low Land). The mean annual rainfall at Wadi Kufranja ranges from about 600 mm to about 300 mm. Ten rainfall-gauging stations are located within the vicinity of the watershed. Rainfall data for these stations were obtained from the Water Authority of Jordan. Stations located within the watershed boundary were used in the modeling process. The selection of these stations was based on their coverage of the watershed to give a representative estimation of the precipitation characteristics of the basin. The rainfall data represents the daily precipitation over the time interval that extends from 1952 till 2004. Climatic variables of Ras Muneif station was selected to represent the climatic conditions in Kufranja Watershed. Table (1) lists the mean monthly temperature, relative humidity, wind speed and class (A) pan evaporation of Ras Muneif station. Mean monthly temperature ranges from 5.4 °C in January to about 21.3 °C in July and August. The mean annual relative humidity is about 51% and it varies from 43% in May to about 61% in January. Class A pan evaporation varies from 93 mm in January to about 325 mm in July with an annual total of 2400 mm.

**Table 1: Climatologically Parameters for Ras Muneif Station (AH03).**

| Parameter | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Avg. Daily Temperature [C] | 5.4 | 6.7 | 8.8 | 13.1 | 16.8 | 20 | 21.3 | 21.3 | 20.7 | 18.2 | 11.9 | 7.1 | 14.3 |
| Avg. Daily Relat. Humidity [%] | 73 | 62 | 62 | 54 | 43 | 43 | 55 | 58 | 56 | 54 | 65 | 74 | 58 |
| Avg. Daily Wind Speed [m/sec] | 3 | 3.3 | 3.2 | 2.8 | 2.2 | 1.7 | 2.6 | 2.1 | 2.1 | 2.4 | 1.2 | 3.1 | 2.5 |
| Abs. Max Wind Speed [m/sec] | 8.6 | 8.3 | 8.9 | 7.8 | 4.1 | 4.4 | 5 | 5 | 6 | 6.9 | 8.6 | 8.6 | 6.9 |
| Max Daily Rainfall [mm] | 45.5 | 69.5 | 61.6 | 67.5 | 9 | | | | | 22 | 81 | 68.5 | 53.1 |
| Avg. Class A Pan Evaporation [mm] | 93 | 100 | 142 | 192 | 267 | 282 | 325 | 322 | 264 | 207 | 123 | 80.6 | 2400 |

The soil texture types for this basin is close to be clay C to silt clay SIC or the two types together in the same section in the soil texture. There are different depths for the soil texture ranging from 30 cm to 100 cm but can reach 170 cm in some sections. Table (2) clears the soil parameters used in AGWA model environment. The hydrological group was close to be group C to D. Other soil parameters were studied carefully in logical estimation (Table 2).

*Ks* is the saturated hydraulic conductivity, *n* is the soil porosity. $S_{max}$ is the maximum soil saturation. *Soil_awc* is the soil effective water capacity. $K_{FF}$ is the soil erodibility factor. Based on these parameters, an average weighted value was determined and entered into AGWA. Contour lines for Kufranja basin from Jordan Valley Authority were used to prepare the Digital Electronic Map (DEM) map as shown in Figure (2). The land uses in Kufranja basin are divided into four types. The first type is agricultural land which contains rain fed and irrigated agricultural land with deciduous and non-deciduous trees. Other types are forest, natural vegetation and urban lands as seen in Figure (3). Table (3) clears a range for curve number based on soil group and land cover.

**Table 2: Main Soil Texture Parameters.**

| TEXTURE | $K_S$ | *n* | Soil_ AWC | $S_{MAX}$ | SAND % | SILT % | CLAY % | $K_{FF}$ |
|---|---|---|---|---|---|---|---|---|
| **C** | 0.600 | 0.475 | 0.04 - 0.08 | 0.810 | 27.000 | 23.000 | 50.000 | 0.340 |
| **SIC** | 0.900 | 0.479 | 0.06 - 0.11 | 0.880 | 9.000 | 45.000 | 46.000 | 0.310 |

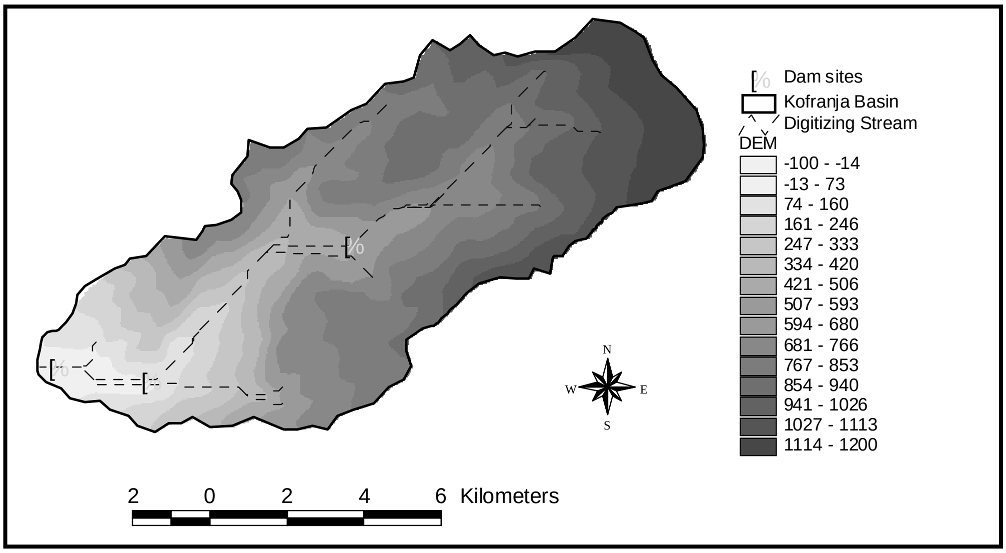


**Figure 2: Digital Elevation Map (DEM) of Kufranja Watershed.**

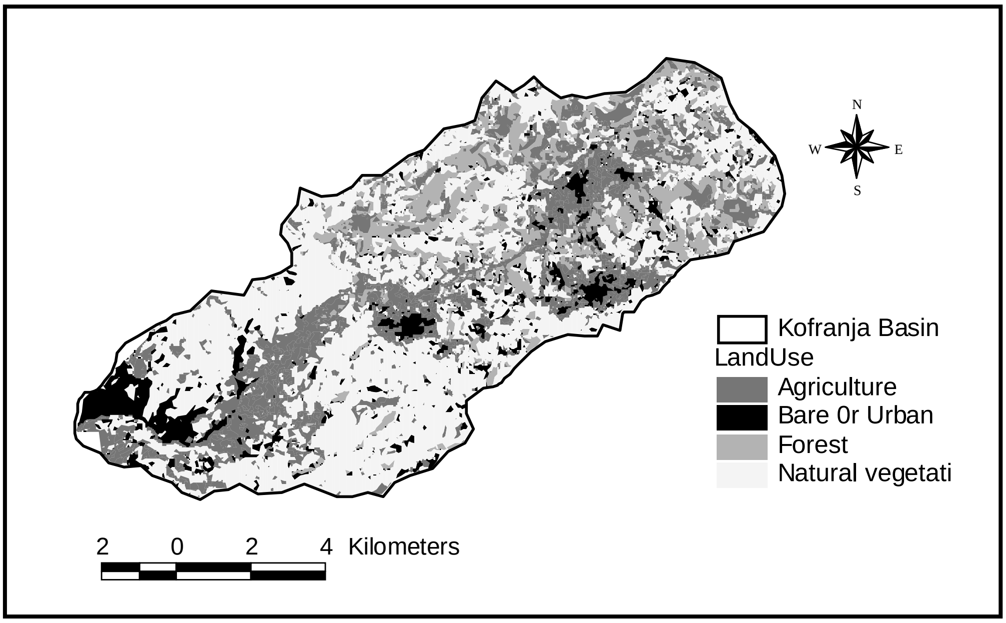


**Figure 3: Land Use Map of Kufranja Watershed.**

**Table 3: Curve Number Range Based on Soil Groups and Land Cover.**

| Land Cover | Suitable CN value range for Kufranja basin |
|---|---|
| **Agricultural Land**<br>Close-seeded Legumes or Rotation Meadow<br>Terraced | 76 - 83 |
| **Natural Vegetation** | 70 - 79 |
| **Forest**<br>Fair Conditions | 72 - 82 |
| Urban or Bare Land | 85 - 92 |

**Watershed Delineation**

AGWA delineated the Kufranja basin into small sub-basins to get a higher accuracy in the model results. AGWA made a digitizing stream depending on DEM map. In this process a database file was improved for subbasins, containing information such as area, slope, elevation and maximum flow length. Another database file was improved for streams, containing information such as stream length, slope, width, depth and cumulative area. AGWA prepared an input file to SWAT model based on land use map and soil data map as shown in Figure (4).

**Precipitation and Climate Data**

In the modeling process, a time series for daily rainfall for 52 years beginning at 1952 was used. Figure (5) clears the rainfall distribution in the sub-basins in (mm). Other daily climatic data could be simulated by SWAT model based on yearly climatic data with some statistical information for these data. Table (4) lists the daily rainfall stations used in the modeling.

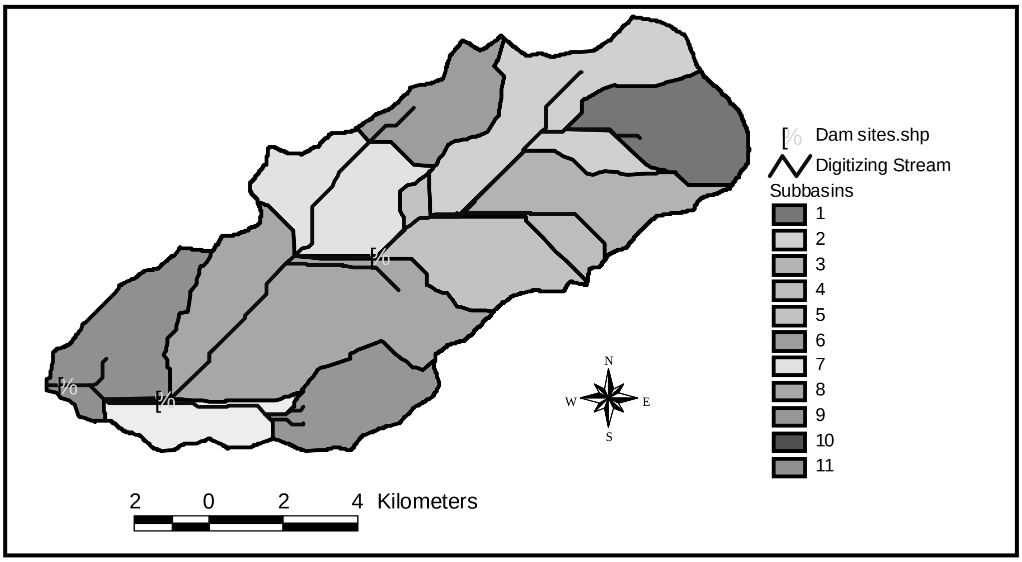


**Figure 4: Subbasions' Map of Kufranja Watershed.**

**Table 4: Rainfall Stations.**

| IDN No. | PGE | PGN | Elevation M.S.L |
|---|---|---|---|
| AJ01 | 221000 | 193500 | 760 |
| AJ02 | 216000 | 189400 | 640 |
| AJ03 | 206800 | 186000 | -200 |

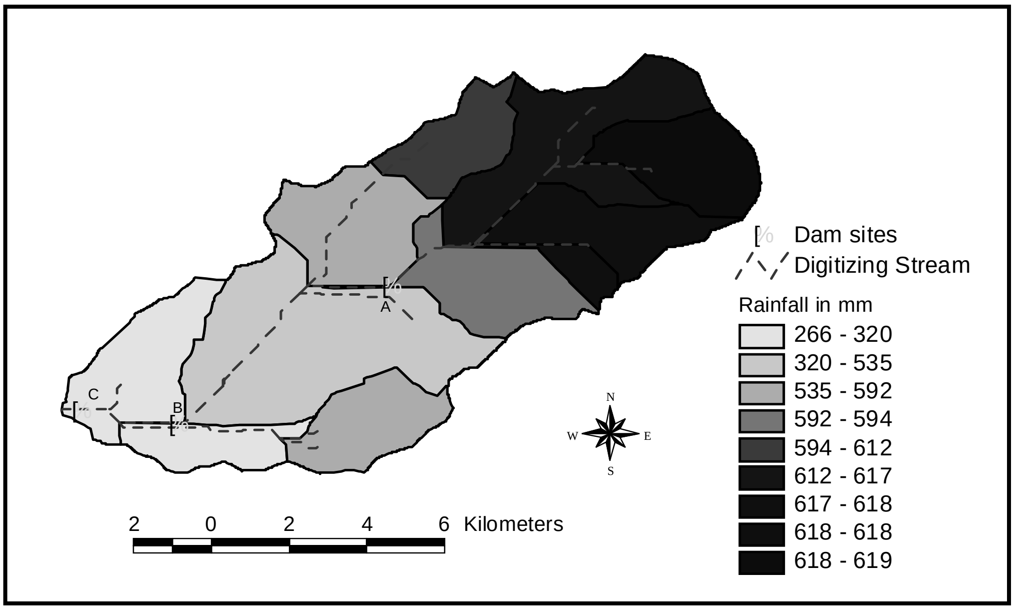


**Figure 5: Spatial Distribution of Annual Rainfall Distribution.**

**Table (5): The Final Calibrated Curve Number.**

| Land Cover | Suitable CN value range for Kufranja basin |
|---|---|
| Agricultural Land | 75 |
| Natural Vegetation | 70 |
| Forest Land | 73 |
| Urban or Bare land | 90 |

## MODEL RESULTS

AGWA cannot provide reliable quantitative estimates of runoff and erosion without careful calibration. It is also subject to the assumptions and limitations of its component models. So, the modeling process procedure depends on the calibration of the most sensitive parameters. The calibration is based on average yearly stream flow from the lager dam catchment area which represents the total studied area. For sediment yield, some information is available from water Master Plan of Jordan, prepared by the GTZ in 1977. That study evaluated the sediment transport for some of northern and southern side wadis. It was carried out on the basis of proper measurements of suspended solids, taken during different stages of flood flows. The relation is given as: $Qs= 4.45*Q^{1.653}$, where: $Qs$ = Sediment discharge (kg/s), $Q$ = Discharge ($m^3$/s). A hydrological study prepared by SSP estimated the average yearly stream flow based on some observed data of the Kufranja wadi to be 8.46 MCM for the total catchment area. This study used GTZ equation in sediment yield simulation by considering the estimated stream flow.

A careful manual calibration has been improved on stream flow and sediment yield. A sensitivity analysis was performed before the calibration process. The first sensitive parameter was the curve number (CN). Table (5) clears the calibrated CN for each landuse.

The other calibrated parameter was Soil_AWC and Soil layer thickness. For the weighted average value of soil parameter soil_awc is calibrated to be 0.05 and soil layer thickness was calibrated to be 700 mm. Also the

USCL_P factor used to be 0.3. Generally, AGWA with SWAT model give a good estimation for flow and sediment yield through the basin. Figure (6) clears the streams flow in the basin. The average simulated yearly stream flow for the total catchment area was 22636.8 $m^3$/ day or 8.29 MCM. This value reflects the model performance in the flow estimation. Figure (7) represents the average annual sediment yield through the basin in a unit ton/ hectare/ year. It shows the average annual sediment from the bed of channel in ton/year.

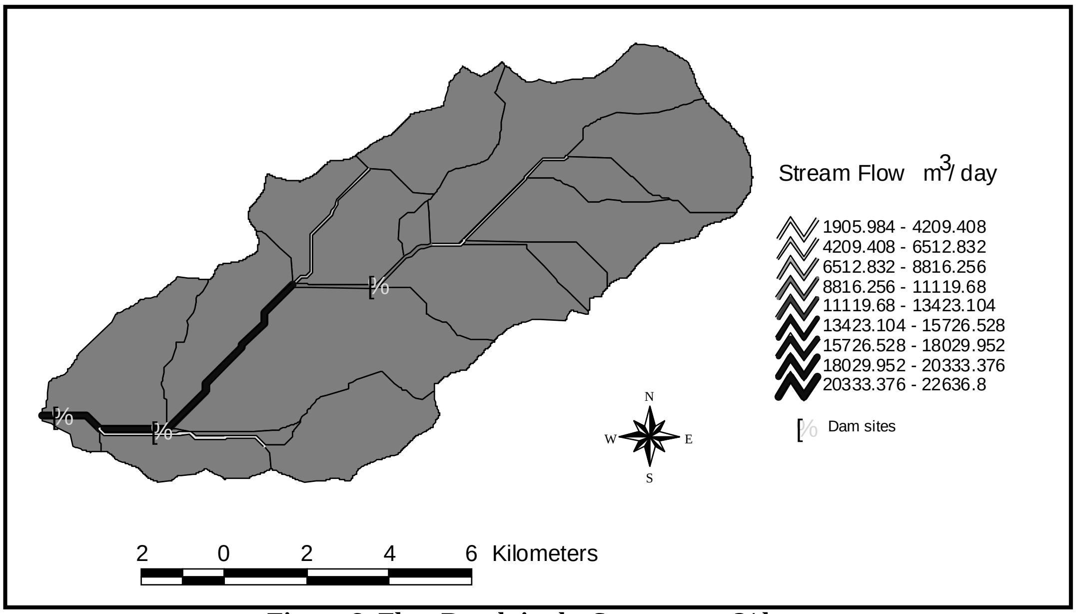


**Figure 6: Flow Result in the Stream as m3/day.**

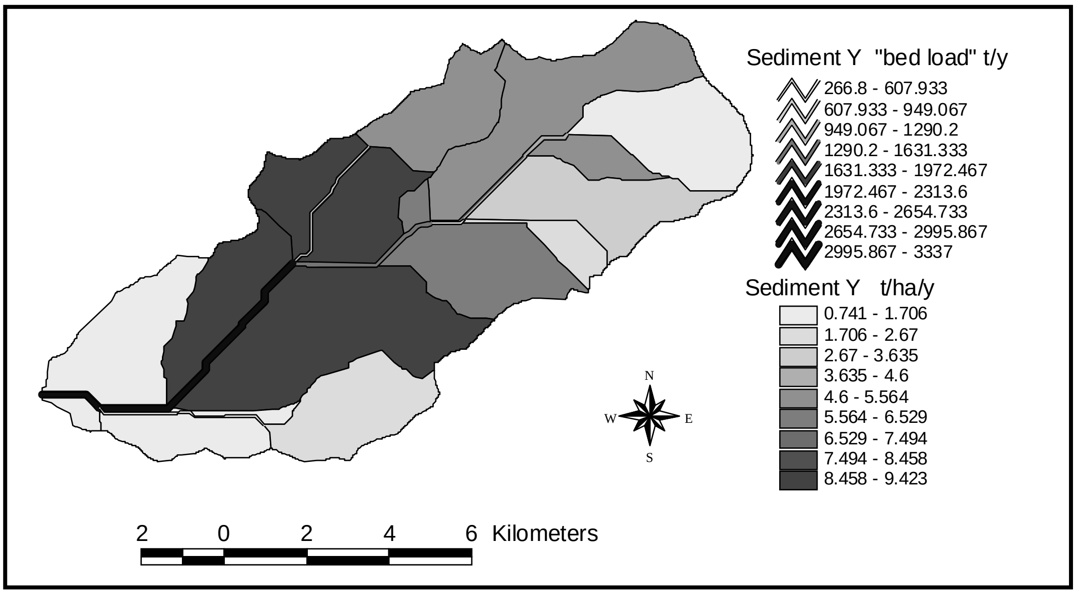


**Figure 7: Sediment Yield Result.**

Figure (8) shows the watershed for each proposed dam site. Table (6) summarizes the mean annual sediment yield for each dam site. The total annual sediment yield at dam site A is 433 t/km$^2$/yr. The annual sediment yield at dam site B is 600 t/km$^2$/yr and about 546 t/km$^2$/yr. The sediment yield obtained by this modeling approach compared well with previous studies in Jordanian dams.

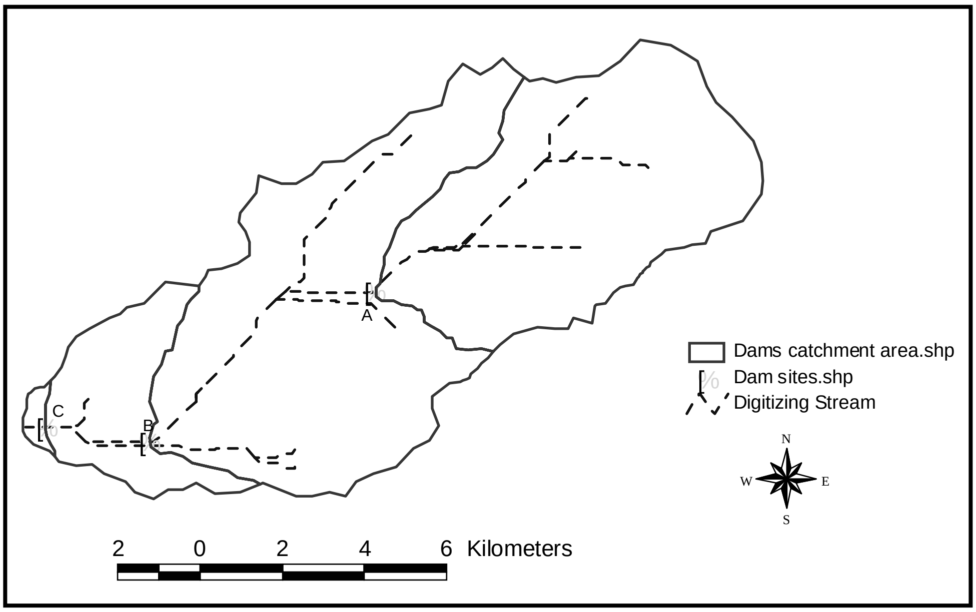


**Figure 8: Dams Catchment Area.**

**Table 6: SWAT Model Results.**

| Dam site | Catchment Area km$^2$ | Flow MCM | Yearly Sediment Y (t/ha) | Yearly Sediment Y (t/km$^2$) | Sediment Y bed load (t/y) | Sediment Y bed load (t/km$^2$/y) | Total sediment (t/km$^2$/y) |
|---|---|---|---|---|---|---|---|
| A | 40 | 3.65 | 3.93 | 393 | 1605 | 40.1 | 433.1 |
| B | 98 | 7.44 | 5.68 | 568 | 3156 | 32.2 | 600.2 |
| C | 110 | 8.29 | 5.16 | 516 | 3337 | 30.3 | 546.3 |

**Table 7: Summary of the Sediment Yield Estimation Compared with Previous Study.**

| Dam site | SWAT model result | | Previous study (SSP) | |
|---|---|---|---|---|
| | Annual Total Load (t/y) | 25 - year Dead Storage MCM | Annual Total Load | 25 - year Dead Storage MCM |
| A | 17324.0 | 0.33 | 18982.92 | 0.37 |
| B | 58819.6 | 1.13 | 60922.4 | 1.17 |
| C | 60093.0 | 1.16 | 61798.22 | 1.20 |

Table (7) summarizes the sediment yield calculation at the three dam sites using the empirical approach and SWAT model. The values of 25-year dead storage using the empirical approach (GTZ equation) from SSP study for dam sites A, B and C are 0.27 MCM, 1.04 MCM and 1.16 MCM, respectively. On the other hand, the SWAT model provides very close results, the values of 25-year dead storage for dam sites A, B and C are 0.33 MCM, 1.13 MCM and 1.16 MCM, respectively.

The most sensitive parameter in the calibration process was the curve number parameter (CN). An interesting relationship has been improved to evaluate the behavior of this parameter in the simulation process.

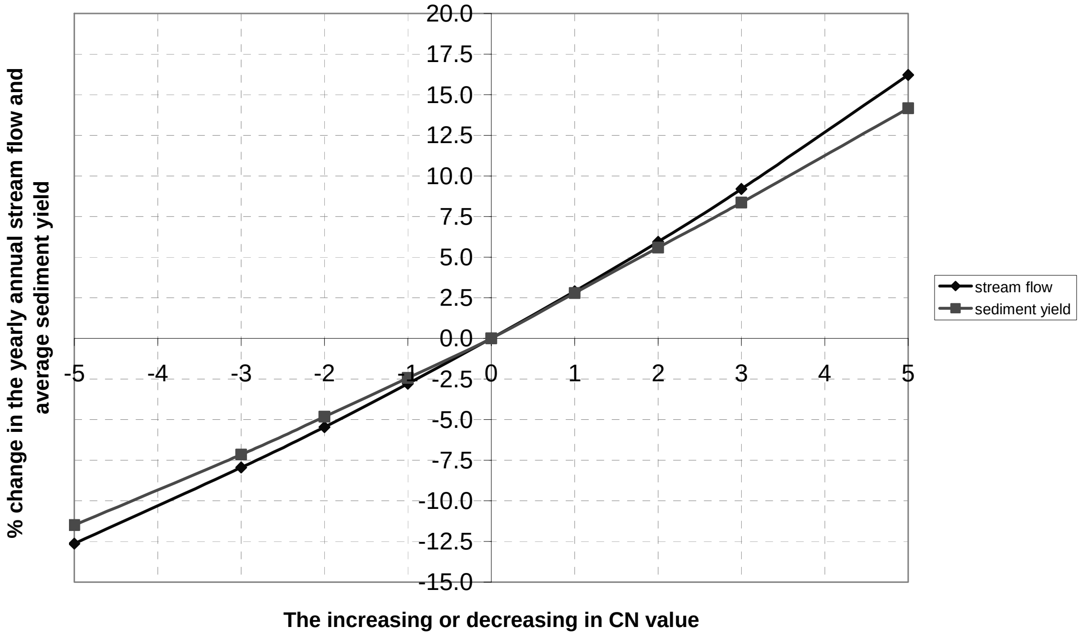


**Figure 9: CN Parameter Effect on Streamflow and Sediment Yield.**

Figure (9) shows that in this range in increasing or decreasing value of CN, for $\pm 1$ in CN value, the annual streamflow increases or decreases by 2.9% and the average sediment increases or decreases by 2.6%. This means that any improvement in the land cover to be controlled with good condition (decreasing CN value) can reduce the sediment yield from this catchment area and solve the increase in dead zone in the dam storage.

## CONCLUSIONS

Upon the findings of the study, the following conclusions can be made:

- The hydrological model SWAT under the Automated Geospatial Watershed Assessment Tool (AGWA) was applied to Kufranja basin in Jordan (semi-arid region).
- A careful manual calibration has been improved on stream flow and sediment yield. The calibration based on a hydrological study prepared by SSP estimated the average yearly stream flow based on some observed data of the Kufranja wadi. This study used special equations for Jordan to estimate the sediment yield from the streamflow.
- The model was successful in reproducing water flow and sediment yield; despite the detailed measurement data available were limited.
- The curve number (CN) parameter is the most effective parameter in the calibration process. A unique relationship representing the change in CN value with the percent change in the yearly annual stream flow and average sediment yield has been improved. CN value was based on the landuse and the soil group, so any improved scenario on this basin will be reflected on the sediment yield from the basin.
- The modeling environment AGWA has the ability to

evaluate water balance and sediment yield processes based on special calibrated parameters. In this paper, AGWA studies the change in the most sensitive parameter in SWAT model. The change in this parameter can be considered as different scenarios in Kufranja basin.

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