MODELLING OF SEDIMENT TRANSPORT IN THE AQABA ROAD BACK AREA, SOUTHERN JORDAN
MODELISATION DU TRANSPORT DE SEDIMENTS DANS LA REGION DE LA ROUTE D'AQABA DANS LE SUD DE LA JORDANIE

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ABSTRACT: This study presents an evaluation of the geomorphology of the Aqaba Road Back area in Southern Jordan. It aims at showing the environmental hazards for the study area, also compatibility and response of engineer structure to the hazards. This has been achieved through a theoretical and practical method which includes: topographical and geological maps, photography and aerial image, soil survey maps, land use maps, measured climate data. In addition to field measures and photographs, laboratory work to analyze soil samples, we took field measurement such as erosion and sediment for wadies, gullies and rills. Several programs have been used as: ARCGIS, ENVI, AVSWAT, Google Earth. All these maps, photos, equipments and programs helped in production of special maps, such as geological map for catchment area, soil map, land use map, network discharge map. SWAT model has been used to calculate the average of sedimentation in two main catchment areas, which are wadi Mobark and wadi basin, because their surfaces largely cover the study area. Both of them have an area approximately of 90.3 km², out of 146 km² for the study area (60%). In 1994 the sediment yield raised to 0.14/t/ha in wadi Mobark basin and to 2.5/t/ha in wadi basin. Dated back to meteorological data station for international king Hussein airport station we found that on 1/1/1994 the amount of rain in the region reached 21 mm whereas, on the other years the rainfall amount was much smaller, therefore affecting the sediment yield. Annual average for the sediment yield during the period 1980-2008 for wadi Mobark basin is 0.007/t/ha and 0.14/t/ha for wadi (9) basin. The study recommends to protect houses, tourism recreation infrastructures, and fences that are located in the middle of the wadi, to prevent them from flash flood, through making water channel to drive water discharge away from the structures. It is also needed to protect culvert from soil erosion located on shelter road. The study recommends to put suitable culvert in suitable clean places and maintain them after flooding, and also protect road from landslide and rock fall through barriers.

Keywords: Sediment transport modeling, Jordan, GIS

RESUME : Cette étude présente une évaluation de la géomorphologie de la région d'Aqaba dans le sud de la Jordanie. Elle vise à montrer les dangers environnementaux pour la zone d'étude, et également la compatibilité et la réponse des ingénieurs contre les dangers. L'étude a été réalisée à l'aide de méthodes théoriques et pratiques, qui comprennent : des cartes topographiques et géologiques, la photographie et imagerie aériennes, des cartes pédologiques, des cartes d'utilisation des terres, des données climatiques mesurées. En plus des mesures de terrain, des photographies, et des travaux de laboratoire pour analyser les échantillons de sol, des mesures d'érosion et de sédimentation ont été réalisées sur le terrain dans des oueds, des ravines et des rigoles. Les logiciels utilisés incluent ARCGIS, ENVI, AVSWAT, Google Earth. Toutes ces cartes, photos, équipements et programmes ont contribué à la production de cartes spéciales, telles que la carte géologique pour le bassin, la carte des sols, la carte d'utilisation des terres, la carte du réseau hydrographique. Le modèle SWAT a été utilisé pour calculer la moyenne de la sédimentation dans deux bassins versants principaux, qui sont l'oued Mobark et le wadi du bassin, parce que leurs surfaces couvrent largement la zone d'étude. Tous les deux ont une superficie d'environ de 90,3 km ², sur 146 km ² pour la zone d'étude (60%). En 1994, le transport de sédiments a été de 0.14 t/h sur le bassin de Wadi Mobark et de 2.5 t/ha sur le wadi. A partir des données de la station météorologique de la station de l'aéroport international du roi Hussein, nous avons constaté que le 01/01/1994 la quantité de pluie dans la région atteint 21 mm alors que, sur les autres années, la quantité de pluie était beaucoup plus faible, affectant la production de sédiments. La moyenne annuelle pour la production de sédiments au cours de la période 1980-2008 pour le wadi Mobark est de 0.007 t/ha et 0.14 t/ha pour le wadi. L'étude recommande de protéger les maisons, les infrastructures de tourisme, et les clôtures qui sont situées au milieu de l'oued, pour les protéger des crues éclair, en construisant un canal de dérivation de l'eau loin des structures. Il est également nécessaire de protéger les ponceaux contre l'érosion. L'étude recommande de réaliser des ponceaux appropriés dans des lieux adaptés et de les maintenir en état après les inondations, et également de protéger les routes des glissements de terrain par des barrières.

Mot clefs : modélisation des transports solides, Jordanie, SIG

INTRODUCTION

Several models can be used for estimating the sediment yield from watersheds (Morgan, 1996); some of them are for erosion modeling but can be used for sediment yield modeling by applying the delivery ratios, such as Revised Universal Soil Loss Equation (RUSLE)(Renard *et al.*, 1997), and Water Erosion Prediction Project (WEPP) models. All these models are computerized but determine the erosion rates in small areas, also the complexity of estimating delivery ratio decrease their use for sediment yield modeling. Other models were linked to geographic information system (GIS) which is relational database system that allows management of multiple layers of spatially distributed information to help synthesis and interpretation by users. So GIS does not generate new data but help manipulating the database to get the relationships 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 and modify attribute tables; and (6) analyze and display the results (Morris and Fan, 1997; Haimmouri, 2002). Examples of these models which were linked to GIS: AEGIS (Agricultural and Environmental Geographic Information System) model developed in 1993, and SWAT (Soil and Water Assessment Tool) model which is used in the present study (Neitsch *et al.*, 2002).

The coastal infrastructures are very sensitive to flood damages and in past years several rainfall events led to massive sediment transport in the Aqaba Road area, and had disastrous effects on infrastructures (ARA, 1987; ACR, 1993).

DESCRIPTION OF STUDY AREA

Location and area

The study area is located at the north shore of the Gulf of Aqaba, in the southwestern part of Jordan. It lies between latitudes 29°23’-29°32’ and longitudes 34˚57’- 35˚70’ E. Aqaba is a coastal city with a population of 90,295 inhabitants in 2004. The modern city of Aqaba is the only seaport in Jordan and is a vital commercial, economic, and tourist center, best known as a diving and beach resort. However, industrial activities remain important to the area, and the city is an exporter of phosphate, cement, potash, and petrochemicals, as well as an important commercial shipping center.

In 2001, Aqaba was renamed to Aqaba Special Economic Zone (ASEZ), complementing its historical role as a regional hub for trade, tourism, and culture. After being renamed, Aqaba’s population has grown rapidly during the last 5 years and is projected to reach 165,524 in 2010 according to the ASEZ master plan (Dweiri and Badranb, 2002).

The city of Aqaba is located about 330 km from Amman (Highway Aqaba-Ma'an-Amman)(Figures 1 and 2). Aqaba commercial and residential centers occupy the inner part of the city. Two geological formations occur predominantly in and around the investigated area. The oldest rocks (pre-Cambrian age, 570 million years old) are the main component of the mountain behind Aqaba. They mainly consist of granite, which is crisscrossed with sheets of intruded igneous rock, known as dykes. At the time of dyke formation, the granitic rocks were deep below the surface. In this area, sandstones are present and composed primarily of fine and medium sized quartz grain and small amounts of kaolinite (Bender, 1974).

Climate and Hydrology

The climate of the Aqaba area is classified as hyper arid, with low mean annual rainfall and moderately high temperature. The mean annual rainfall in Aqaba is 37 mm. Seventy percent of the rain falls between December and February. Maximum annual rainfall of 84.2 mm was recorded in 1975. The rainstorm of 21 March 1991, and 20 December 1993, which caused heavy damage to the road, resulted in 17 mm and 19.2 mm of rainfall respectively. During the March 1991 storm, the maximum rainfall intensities achieved were 9.5 mm (20 mins), 9.6 mm (30 mins), 13.5 mm (1 hour), 15.5 mm (2 hours), and 16.2 mm (3 hours).

Since culverts were designed to accommodate the 50 year flood, and the damaging March 1991 flood has only a 6-7 year return, it is quite apparent that damaging and dangerous rainstorms/flood are far more frequent than designed for.

Most of the rainfall in the area is convective, with some orographic effect. Convective rain usually occurs during October, March, and April and is characterized by intense rainfall of short duration, similar to the storms of 21 March 1991 and December 1993. Despite the low annual rainfall average, the spatial and temporal distribution of rainfall in Aqaba area is such that flooding may be a serious problem, even from very small catchments.

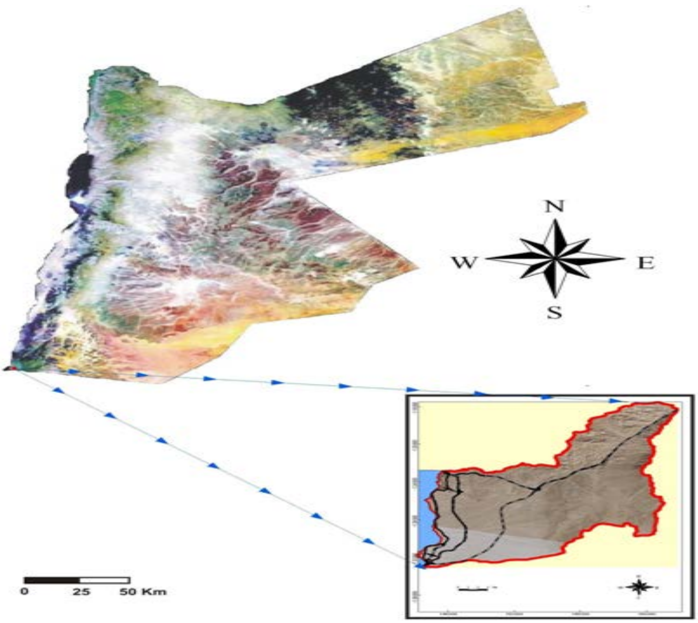

Fig. 1. Location of the study area

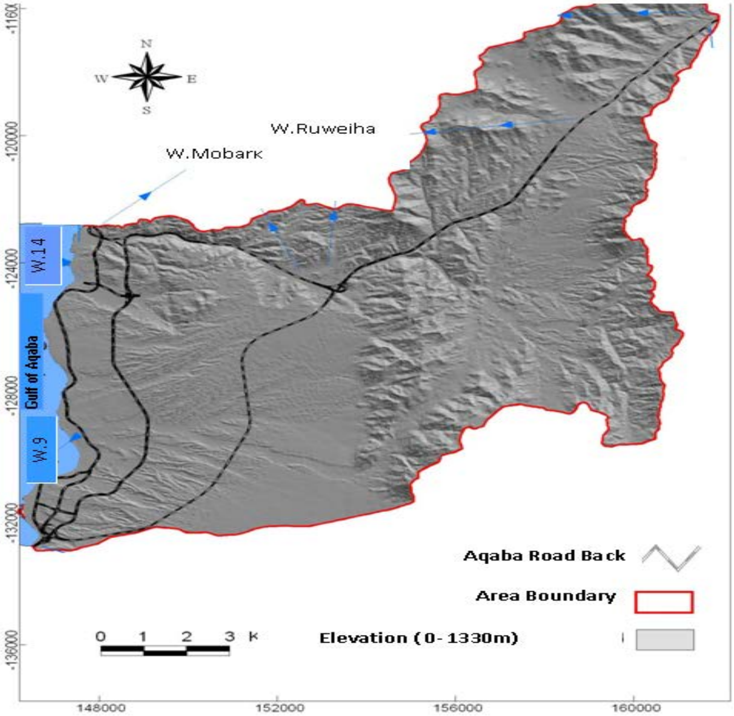

Fig. 2. Map of Shaded Relief

Soil Properties

During the field study 53 soil samples have been collected, at a depth of 25 cm, representing the study area (Figures 3, 4 and 5).

Readings were recorded after the measurement process as in Table 1, where these readings were used in the equation of soil erosion, to calculate the amount of erosion, and also used in the SWAT program to calculate the sediment yield. Then after that was measured moisture in the soil.

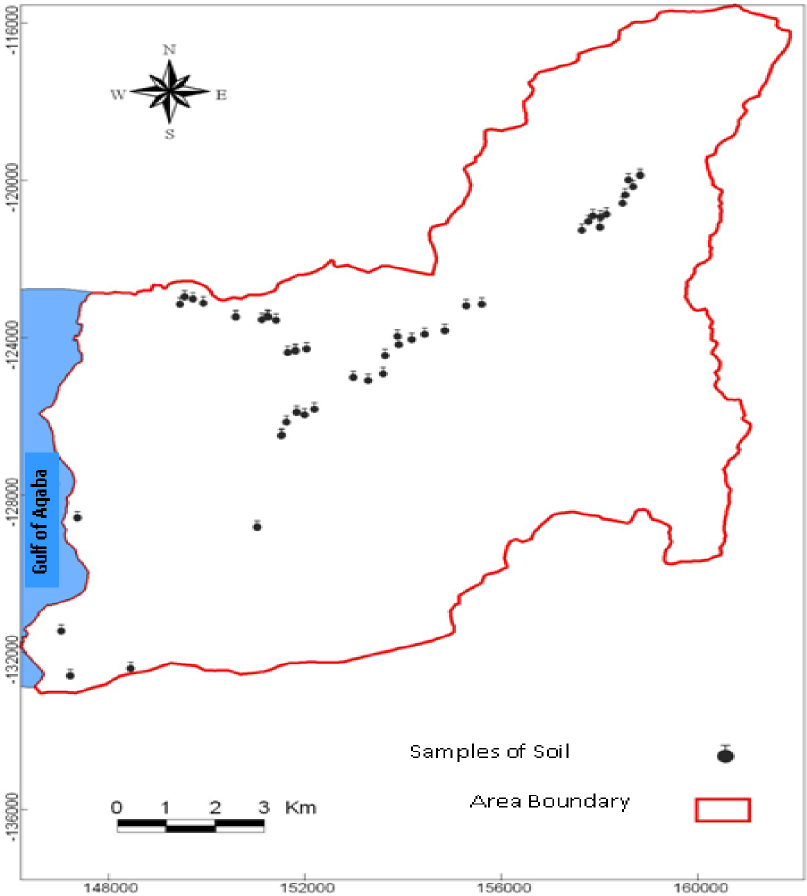

Fig. 3. Location of soil samples

Fig. 5. Samples shaked by a Shaker

Fig. 4. Samples of soil

Table 1. Results of analysis of granular soil samples.

Number of samples	Sand %	Silt %	Clay %	Number of samples	Sand %	Silt %	Clay %	Number of samples	Sand %	Silt %	Clay %
1	93	5	3	18	90	6	4	37	93	5	3
2	93	4	4	19	93	5	3	38	85	8	8
3	88	8	5	20	95	0	5	39	95	3	3
4	85	9	6	21	85	6	9	40	93	1	6
5	75	16	9	22	93	5	3	41	88	8	5
6	88	10	3	23	93	5	3	42	88	8	5
7	85	8	8	24	88	10	3	43	75	18	8
8	93	5	3	25	93	5	3	44	85	9	6
9	93	5	3	26	83	13	5	45	93	4	4
10	90	5	5	27	88	10	3	46	75	18	8
11	88	8	5	28	90	5	5	47	95	3	3
12	88	8	5	29	96	1	3	48	93	5	3
13	93	4	4	30	95	3	3	49	93	3	5
14	90	6	4	32	93	5	3	50	95	1	4
15	88	6	6	33	83	13	5	51	93	5	3
16	93	3	5	34	83	13	5	52	93	5	3
17	93	1	6	35	95	3	3	53	95	3	3
				36	88	8	5				
Average									89.4	6.2	4.4

SWAT MODEL

SWAT is the acronym for Soil and Water Assessment Tool, a river basin, or watershed, scale model developed by Arnold for the USDA Agricultural Research Service (ARS)(Arnold *et al.*, 1995). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields, in large complex watersheds with varying soils, land use and management conditions over long periods of time. To satisfy this objective, the model is physically based. Rather than incorporating regression equations to describe the relationship between input and output variables, SWAT requires specific information about: weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. The physical processes associated with water movement, sediment movement, crop growth, nutrient cycling, etc, are directly modeled by SWAT. It is computationally efficient. Simulation of very large basins or a variety of management strategies can be performed without excessive investment of time or money. It enables users to study long-term impacts. Many of the problems currently addressed by users involve the gradual build-up of pollutants and the impact on downstream water bodies. To study these types of problems, results are needed from runs with output spanning several decades.

Since SWAT was created in the early 90's, it has undergone continued review and expansion of capabilities, so there are many versions of SWAT: 94.2, 96.2, 98.1, 99.2, and 2000. The SWAT 2000 is the newly available version using ARCVIEW interface, so it is called AVSWAT 2000. AVSWAT 2000 was selected to model the sediment yield for The Aqaba Road Back Area.

OVERVIEW ON AVSWAT 2000

As shown in figure (4-8) the AVSWAT 2000 model contains main processes or steps to run as following:

- Input Data: AVSWAT 2000 model needs an input data for the study area, which must be prepared before starting the model these data are: DEM (Digital Elevation Model) as GIS layer of region, land cover layer, soil properties layer, and weather stations data base files. There is also an optional layer that can be loaded to the model such as mask map and stream map to be superimposed on the DEM.
- Watershed delineation: depending on the DEM model then, delineates the watershed and divides it into sub-regions and defines the streams.
- Hydrologic Response Unit (HRU): this step means that the model will subdivide the watershed into areas having unique land use and soil properties called as HRU to reflect differences in the hydrologic conditions for different land cover and soils.
- Weather stations definition: depending on weather stations location; each sub-region in the watershed will be linked to one weather station or gauge by the model.
- Parameterization: in this step the model will be linked to the results from previous steps to SWAT data base, which contains information about soils,

weather stations, and land cover, to find all hydrological and physical parameters for each HRU.

- Run SWAT: depending on previous steps the model can be run to find the final results as maps, tables, and charts, after that the calibration tool can used.

SWAT 2000 uses the Modified Universal Soil Loss Equation (MUSLE) for estimating the sediment yield for each HRU, the model will estimate or read these parameters as follows.

MODELING OF THE STUDY AREA

Data Preparation

The study area is divided into two basins by the model (wadi Mobark (62 km^2), wadi (9) (28 km^2), these basins cover 62% (90 km^2) from the study area (142 km^2) (Figure 6).

The data required for the model contain maps or layers and data base files; all the data preparing steps are discussed below.

- DEM grid layer: depending on the contour map for the study area (Fig.7), the digital elevation model was created using Arc-View GIS 3.1.

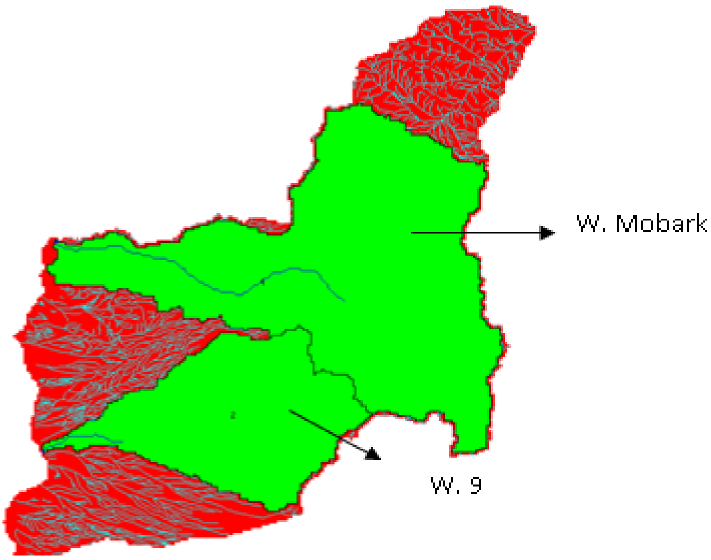

Fig. 6. Wadi Mobark and Wadi (9) in the study area

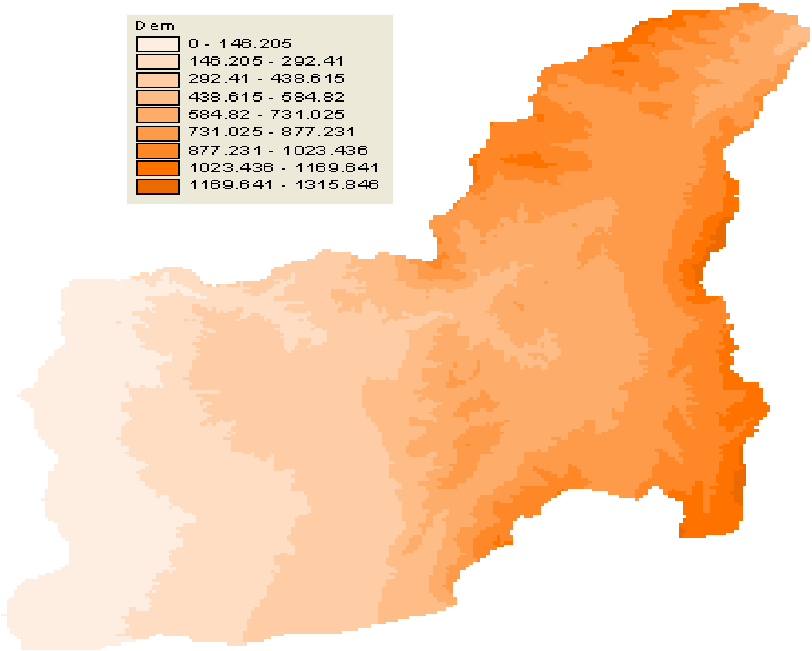

Fig. 7. Digital Elevation Model for Study Area (in m)

- Depending on the previous steps, the model defines the main streams in the study area, and generates a new layer for streams as shown in (Fig.8).

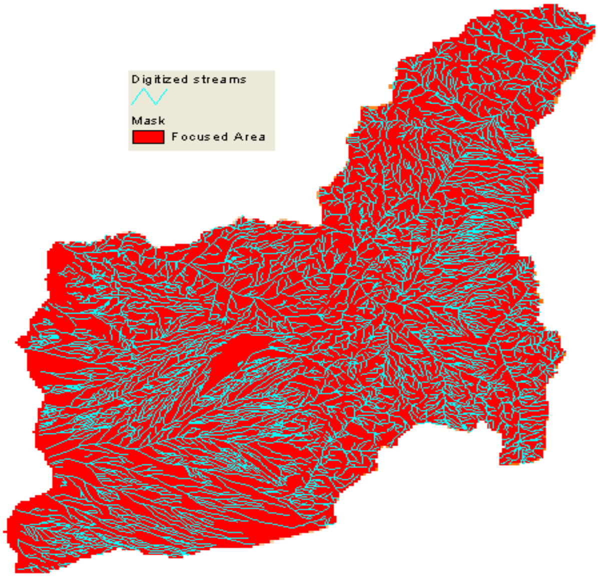

Fig. 8. Generated streams layer by model

- Loading the land cover layer (fig.9) into the study area

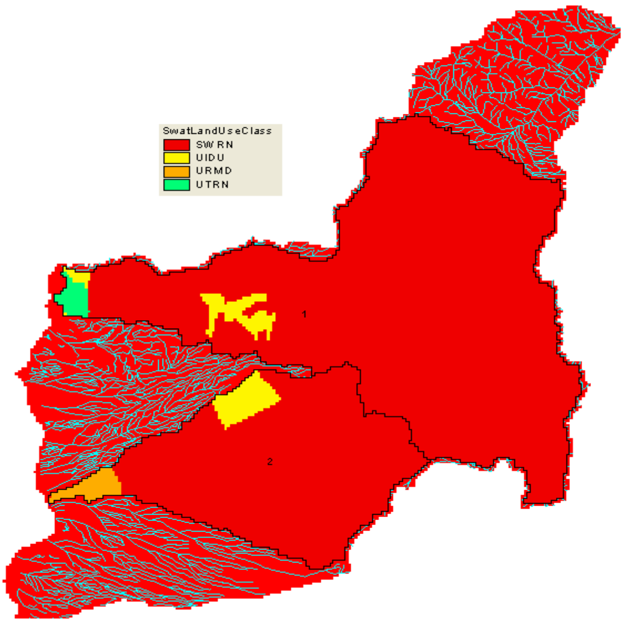

Fig. 9. Generated land cover layer by model

- Loading the soil layers (fig .10) into the project. The study area contains four types of soils types: Torriorthents, Camborthids, Torripsamments,and Calciorthids. The soils data were estimated previously from the national map and were calculated as Table (1), were loaded into SWAT database, so the model joined these data to the layer basing on sub regions names.

- Weather Data: the weather data required from the model to run contain daily precipitation, maximum / minimum air temperatures, solar radiation, wind speed, and relative humidity.

SEDIMENT YIELD RESULTS

The yearly total sediment yield from basin of wadi Mobark and basin from wadi (9) resulted from the model shown in fig. 11 and 12. These figures show that the maximum sediment yield value occurred in 1994 which reached 0.14 t/ha in the wadi Mobark while in the wadi (9) it reached 2.5 t/ha. Dated back to meteorological data station for international king Hussein airport station we found that on 1/1/1994 the amount of rain in the region reached 21 mm, whereas on the other years the rainfall was much lower and therefore affect the sediment yield. Annual average for the sediment yield during the period 1980-2008 for wadi Mobark basin is 0.007 t/ha and wadi (9) basin is 0.14 t/ha.

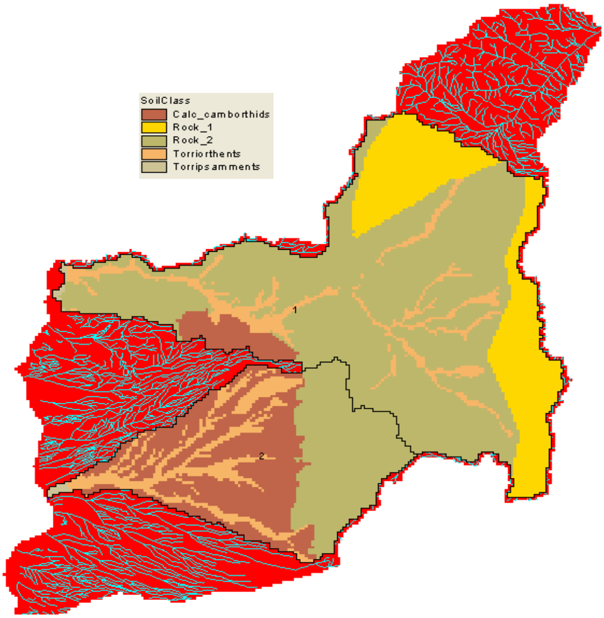

Fig.10. Soil map of the region.

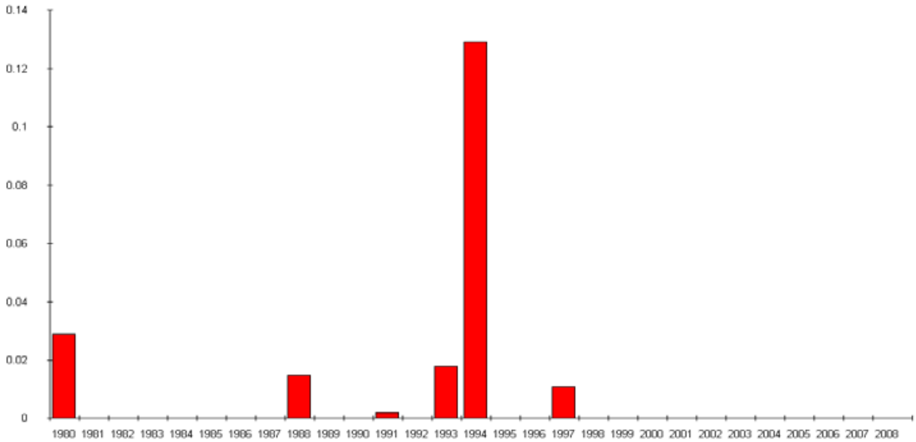

Fig.11. The annual rate of sediment yield to the basin wadi Mobark in the period 1980-2008

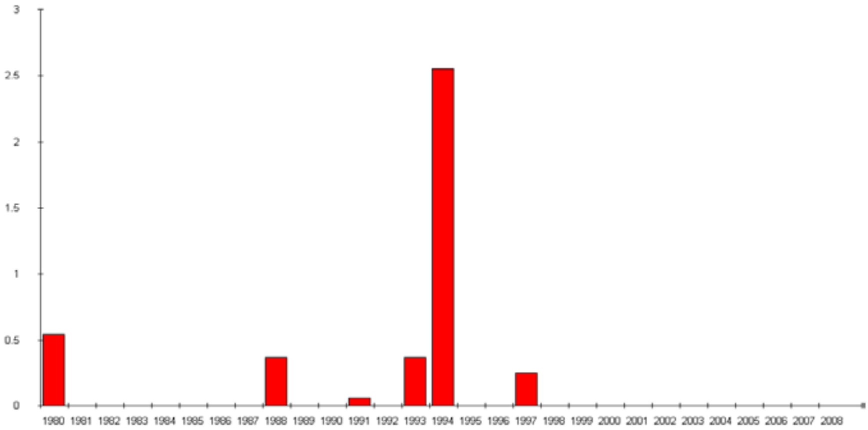

Fig.12. The annual rate of sediment yield to the basin wadi (9) in the period 1980-2008 (in tons/year)

In the wadi (9) valley (fig. 12) the amount of sediment yield has reached 2.5 t/year in 1994. In comparison with the basin of Wadi Mobark, we find that it is high and probably due to the nature of the deep sandy soil in the basin region of the wadi valley (9), (Fig. 13), while in the basin of Wadi Mobark, most of the area is rocky.

Fig. 13. Deep sandy soils in the basin of the wadi (9) valley

RECOMMENDATIONS

Following this work several recommendations can be addressed:

- Develop master plan for the city and land use based on geomorphological indicators illustrated by the detailed geomorphological maps.
- There are areas in need of culverts, whether pipe or boxes (Fig.15).

- protect house, recreation tourism, and fences that are located in the middle of wadis, from flash flood, through making water channels to divert water discharges away from structures.
- Cleaning and maintenance of hydraulic structures after the flood (Fig. 16, 17, 18 and 19).
- Protect culvert that are located on shelter roads from soil erosion (Fig.20).
- Protect roads from landslide and rock falls through barriers.

Fig. 15. Sites needed to culvert

Fig. 16. Culvert before the flood

Fig. 17. Culvert after the flood

Fig. 18. Bridge before the flood

Fig. 19. Bridge after the flood

Fig. 20. The lack of protect culvert from soil erosion

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