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Use of SPOT Satellite Data for the Mapping of Floods in the Archaeological Site of Petra

Introduction

At the time when economic development in the Hashemite Kingdom of Jordan (HKJ) is the priority for a successful peace process, the Royal Jordanian Geographic Center (RJGC) is giving the utmost importance to the use of remote sensing and Geographic Information System (GIS) techniques in several areas of applications :

- Topographic maps updating
- Ground water recharge areas delineation
- Surface water management
- Dam sites location
- Desertification process monitoring
- Agricultural land suitability maps compilation

One of the vital components of the economic development in the HKJ is water resources management and the preservation of antiquities, cultural heritage and environment in the Petra region. Several times, the Wādī Mūsā area, including the archaeological site of Petra, was devastated by floods from heavy rains and/or snow. The most recent floods affected Petra in November 1994.

As a contribution to the large national action required for the preservation of the archaeological site of Petra, RJGC is carrying out a study for the delineation of areas subject to floods in the Wādī Mūsā Basin. The results of this study will consist of a map locating the extent of areas endangered by floods. Such a map constitutes an important input for decision makers to undertake measures in order to minimize damage and environmental degradation caused by eventual floods. This map is also very useful for other applications such as better resources management including location of sites suitable for dam implementation in order to supply water for Wādī Mūsā Basin inhabitants and tourists needs, as well as to protect areas endangered by floods in Petra

The delineation of areas endangered by floods in the Wādī Mūsā Basin is based on a mathematical model which takes into account the parameters affecting run-off potential. Investigations carried out until the writing of this paper are presented in the following sections. Final results and other investigations required for flood modelling will be published elsewhere.

Schultz (1993) mentioned fields of application of remote sensing in hydrology as being: rainfall, evapotranspiration, soil moisture, groundwater, surface water, snow and ice, sediments and water quality as well as hydrological modeling. A discussion of hydrological modeling is given by Schultz (1994). In this discussion, examples of the use of remote sensing data for the estimation of parameters and model input are given. Also, examples of models where remote sensing data and GIS play a dominant role are shown.

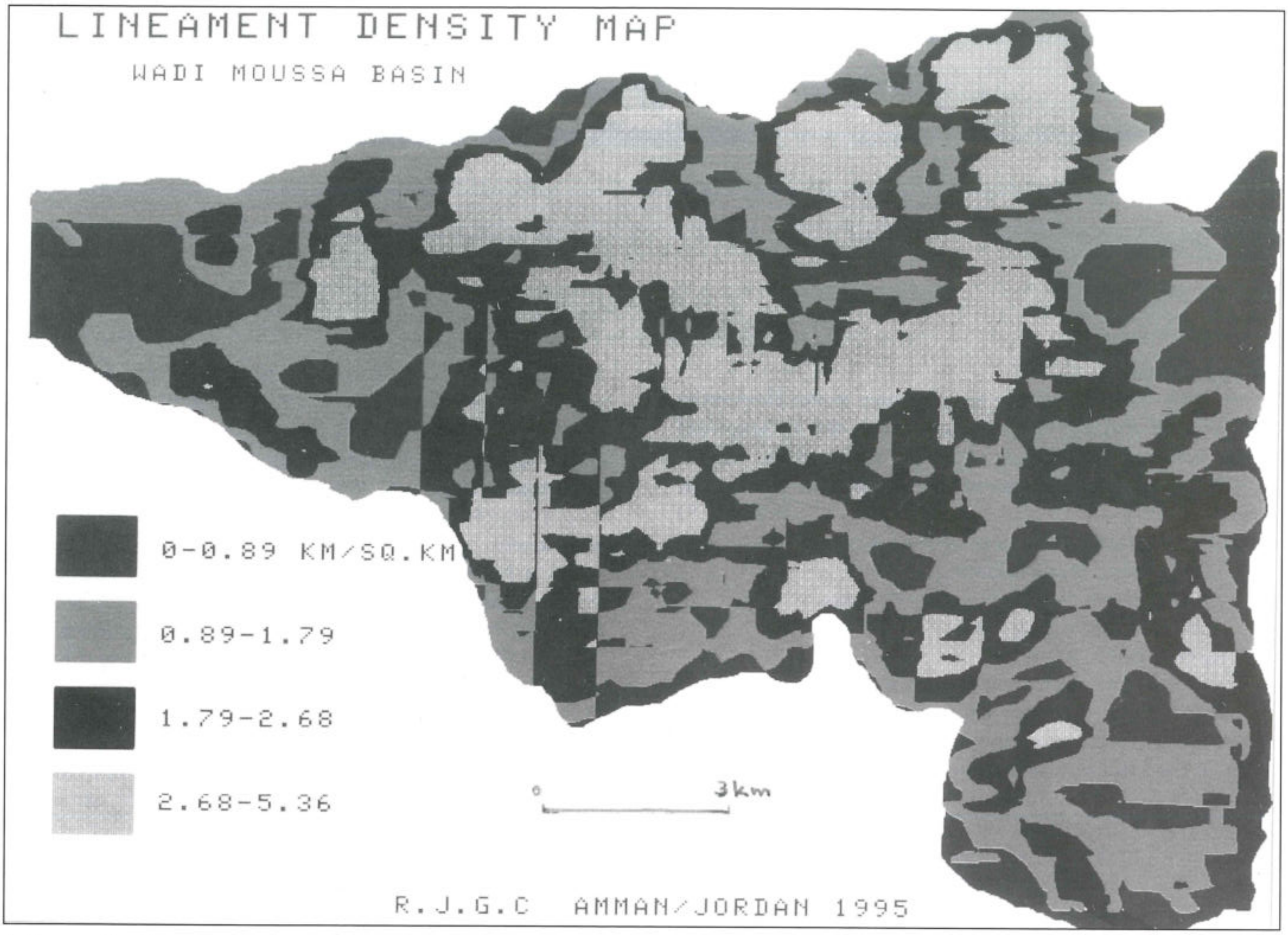
In a brief review of research in remote sensing of water resources, Rango (1994) stated that remote sensing data was being used operationally in precipitation estimates, soil moisture measurements for irrigation scheduling, snow water equivalent and snow cover extent assessments, seasonal and short term snow melt run-off forecasts, and surface water inventories. Rango (1994) indicated that the use of LANDSAT-MSS data as input to produce flood flow curves reduces the cost of obtaining required land cover data to one-third of the cost of conventional techniques for basins larger than 25 sq. km. It is also stated (Rango 1994) that the use of LANDSAT-TM and SPOT reduces the effective basin size to at least 10 sq. km-and possibly smaller. One of our study objectives is to determine the accuracy of SPOT-XS data for a basin size equal to 174 sq. km which is approximately the size of the catchment where the archaeological site of Petra is located.

Lineament Density Map Compilation

The lineament density map is obtained using SPOT-XS image band 2, on which a directional filtering is applied in 4 directions; north-south, east-west, north-east and north-west with a filter size of 3 X 3. These filters provide lineaments in different directions. A manual drawing of lineaments is done and then the lineament density map is compiled. Results show that the lineament density values vary between 0 and 5.36 km/sq. km. The lineament density values are subdivided into 4 classes of values. FIG.1 shows the resulting lineament density map and TABLE 1 contains the classes and percentage of the area corres ponding to each class relative to the total area of the catchment.

Land-Use Classification

The land-use map is produced from SPOT-XS imagery. The method consists of a manual classification on the



1. The resulting lineament density map.

Table 1. Lineament density values.

Class	Density (km/sq. km)	Percentage
1	0 - 0.89	46.77 %
2	0.89 - 1.79	20.42 %
3	1.79 - 2.68	18.98 %
4	2.68 - 5.36	13.83 %

principal component of the SPOT-XS three bands in order to extract rocky and alluvial land classes. Other classes are obtained by a supervised classification using maximum likelihood algorithm. A median filter of 5 X 5 size is applied in order to remove irregularities. FIG. 2 shows the resulting land-use map and TABLE 2 contains information relative to each land-use class.

Vegetation Cover Map Production

The vegetation cover map is produced by the extraction of a vegetation index from SPOT-XS imagery. A threshold of vegetation is done by a visual interpretation of the vegetation index combined with a false color composite of SPOT-XS bands 3, 2, 1. This threshold is done to separate

Table 2. Land use values.

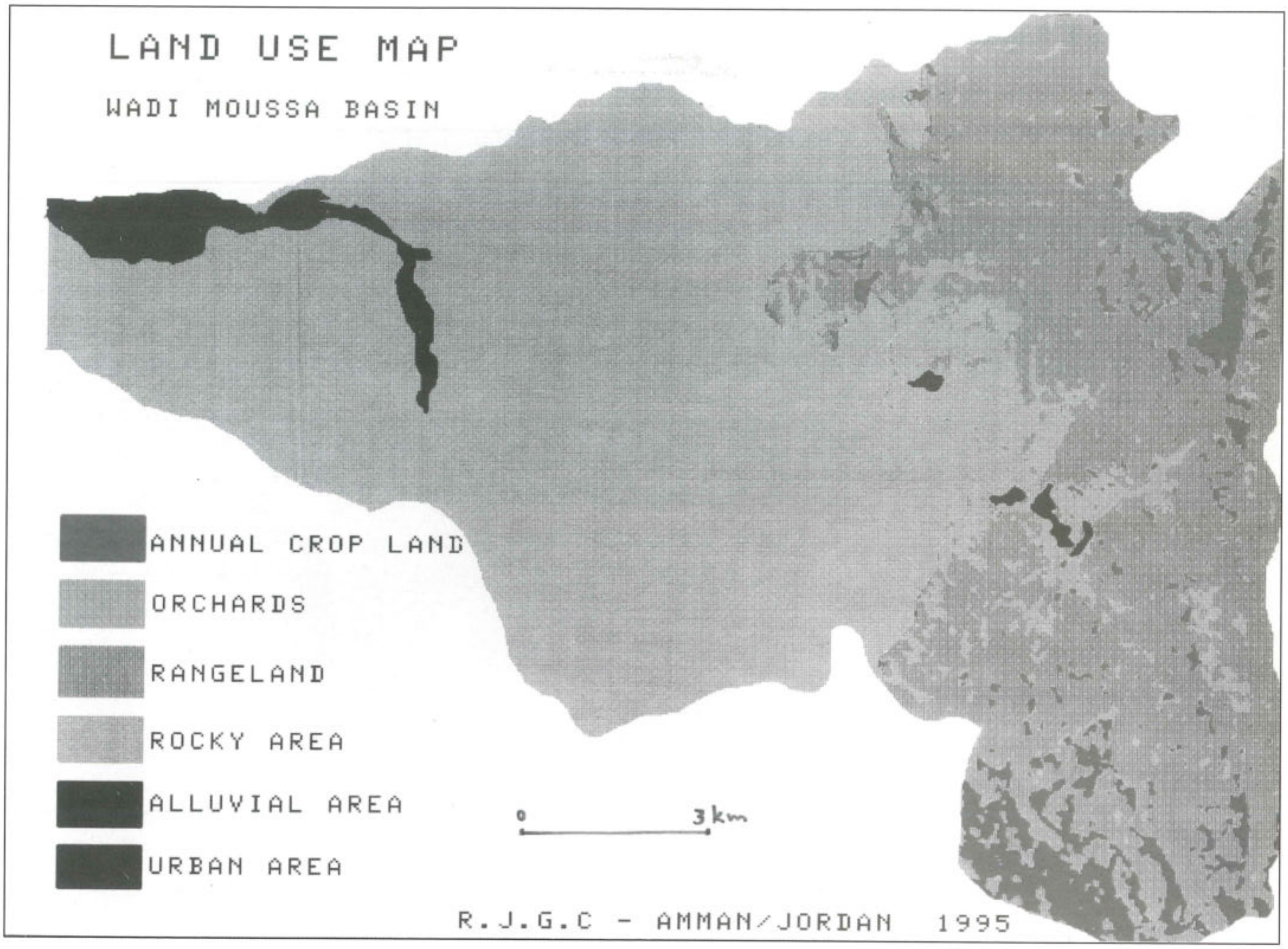
Class	Area (sq. km)	Percentage
Annual Crop	9.7	5.6 %
Orchards	2.5	1.6 %
Range Land	55.4	31.7 %
Rocky	101.0	58.0 %
Alluvial	4.5	2.7 %
Urban	0.5	0.4 %

lands covered by vegetation from other types of land. A density slices classification is then applied to land covered by vegetation in order to subdivide the land into 2 classes: low and high density vegetation. A median filter (5 X 5) is applied to generalize the classes. TABLE 3 provides information on the area corresponding to each class. The resulting vegetation cover map is shown in FIG.3.

DATA

Remote sensing data may be used by hydrological models in two distinctly different fashions (Schultz 1994) :

- as a basis for model parameter estimation



2. The resulting land use map.

Table 3. Vegetation cover values.

Class	Area (sq. km)	Percentage
Low Vegetation	11.8	7 %
High Vegetation	6.6	4 %
No Vegetation	155.2	89 %

- as model input

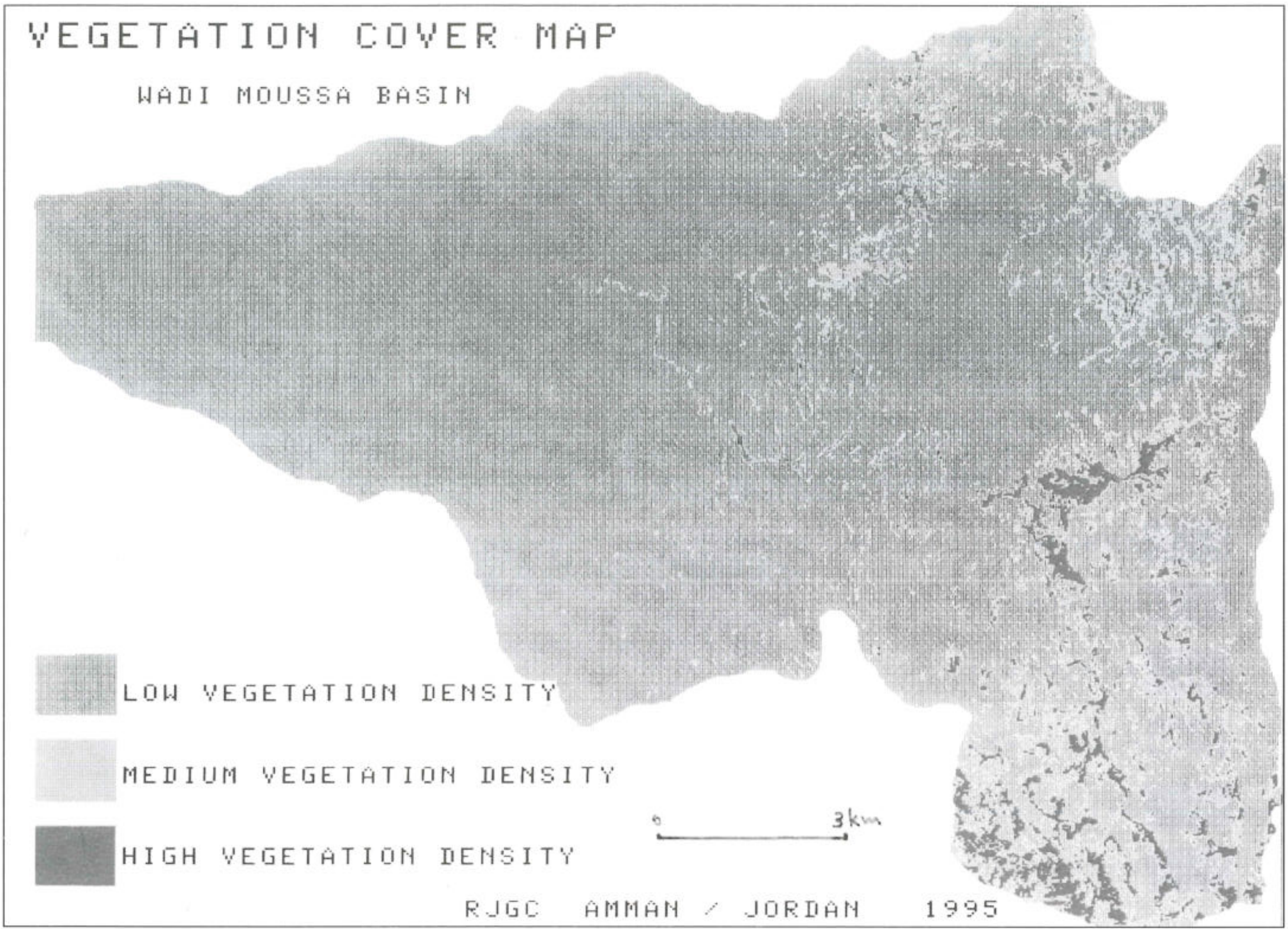
Satellite data, combined with other data derived from maps are used to specify catchment characteristics which are hydrologically relevant. The data which is used in this study consists of :

1. *Topographic Maps of Petra and Bi'r-Khdad (1:50,000):* A digital terrain model (DTM) is extracted from these maps. This DTM is used to derive hydrologically relevant information such as land slope (relevant for flow velocity) and exposure to the sun (relevant for evapotranspiration).

2. *SPOT Images :* A SPOT-XS image of 7 April, 1986 and a SPOT-P image of 18 August, 1990 are used to derive a land-use classification and a vegetation index which are both related to evapotranspiration and soil water storage model parameters. The SPOT-XS band 2 image is used to extract lineament information which is relevant for infiltration.

Flood Modelling

Flood mapping can be done using multitemporal analysis of satellite data recorded before and during/after floods, if such data is available. Satellite images (SPOT, LANDSAT, ERS-1) archives have been consulted for the period between January 1986 and February 1995, taking into consideration precipitation and run-off measurements collected over the Wādī Mūsā Basin during the same period. It was not possible to find any cloud-free image when floods occurred. It is not always easy to acquire a real-time image of floods, as clouds frequently are present when floods occur, and the use of Radar images may require to program the satellite before an eventual flood which increases image cost. Therefore, a flood modelling technique, which transforms rainfall input



3. The resulting vegetation cover map.

into run-off data must be made available in order to overcome the difficulties encountered when the multitemporal analysis method is adopted.

Generation of a Flow Direction Map

This map can be generated from elevation values of the DTM which is obtained from digitized contour lines of the 1/50,000 topographic map. The flow direction map is used to extract the water route downhill from pixel to pixel, eventually reaching the nearest wadi, and then reaching main wadis until arriving at the catchment outlet.

Hydrologically Similar Units (HSUs) Map Extraction

A HSUs map can be extracted from merging different hydrological parameters affecting the run-off potential. Pixels which behave in a similar way are aggregated into HSUs consisting of pixels which are similar in their land use, lineament density and other parameters. Run-off modelling for the catchement area is done by a combination of the direction flow data with the HSUs map. This results in the computation of the quantity of run-off in each wadi and the total flow in the outlet of the catchment area.

Conclusions and Possible Future Work

Remote sensing and GIS tools are used in flood modelling which results in speeding up the process of floods monitoring. SPOT satellite data are of a great benefit for the estimation of parameters required in flood modelling. GIS techniques allow linkage of data corresponding to different sources of information (images, maps, etc.).

The model for transforming rainfall data into run-off curves, which is the subject of this study, is in the final stage of development. Investigations for the study area are recommended in the field of the production of a flow accumulation map and a HSUs map and the use of measured rainfall/run-off data as input to the flood model for the computation of flood hydrographs and comparison with observed run-off values.

Acknowledgements

Dr Talal Akasheh of the Higher Council for Science and Technology supplied the SPOT-XS image used in this study.

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