

# Application of Remote Sensing and GIS for Modeling and Assessment of Land Use/Cover Change in Amman/Jordan

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## ABSTRACT

Modeling and assessment of land use/cover and its impacts play a crucial role in land use planning and formulation of sustainable land use policies. In this study, remote sensing data were used within geographic information system (GIS) to map and predict land use/cover changes near Amman, where half of Jordan's population is living. Images of Landsat TM, ETM+ and OLI were processed and visually interpreted to derive land use/cover for the years 1983, 1989, 1994, 1998, 2003 and 2013. The output maps were analyzed by using GIS and cross-tabulated to quantify land use/cover changes for the different periods. The main changes that altered the character of land use/cover in the area were the expansion of urban areas and the recession of forests, agricultural areas (after 1998) and rangelands. The Markov chain was used to predict future land use/cover, based on the historical changes during 1983-2013. Results showed that prediction of land use/cover would depend on the time interval of the multi-temporal satellite imagery from which the probability of change was derived. The error of prediction was in the range of 2% - 5%, with more accurate prediction for urbanization and less accurate prediction for agricultural areas. The trends of land use/cover change showed that urban areas would expand at the expense of agricultural land and would form 33% of the study area (50 km × 60 km) by year 2043. The impact of these land use/cover changes would be the increased water demand and wastewater generation in the future.

**Keywords:** GIS; Remote Sensing; Land Use/Cover; Jordan; Treated Wastewater

## 1. Introduction

Mapping of land use/cover and its change provides invaluable information for managing land resources and for projecting future trends of land productivity [1]. Modeling of land use/cover change can be achieved by integrating the contemporary tools of geographic information systems (GIS) and remotely sensed data [2-7]. Visual and digital analysis of remote sensing data can be used to derive historical and current land use/cover maps at reasonable costs. The output maps, in the form of digital layers, can be overlaid and analyzed within a GIS to provide information on percentage land use/cover and its change among or between a time-series of satellite images or aerial photography. Based on this knowledge, future land use trends can be postulated and action plans can be framed.

A good example on the ecosystem where land use/cover is dynamic and changing with time is the Mediter-

ranean region. The agricultural intensification and shift in land use, observed in this region, have resulted in more stress being put on the fragile land resources. These stresses are threatening biodiversity and ecosystem potential [8,9], as well as exacerbating the problem of climate change and its adverse impacts on food security in this region [1].

In Jordan, land use/cover includes a complex pattern of urbanization and agricultural activities to meet the demands of the growing population. The country, located in the eastern Mediterranean region (**Figure 1**), has limited renewable water resources, classifying the country as one of the four poorest countries worldwide, in terms of the per capita water share [10]. The country is also characterized by a high population growth rate, with an average of 3.7% during 1950-2010 [11], giving a population increase from 0.59 million in 1952 to 6.4 million in 2012. Due to the aridity of the climate and population growth, the current annual share of water is 146 m<sup>3</sup> per capita [1], compared to 3600 m<sup>3</sup> in 1946 [12]. In addition

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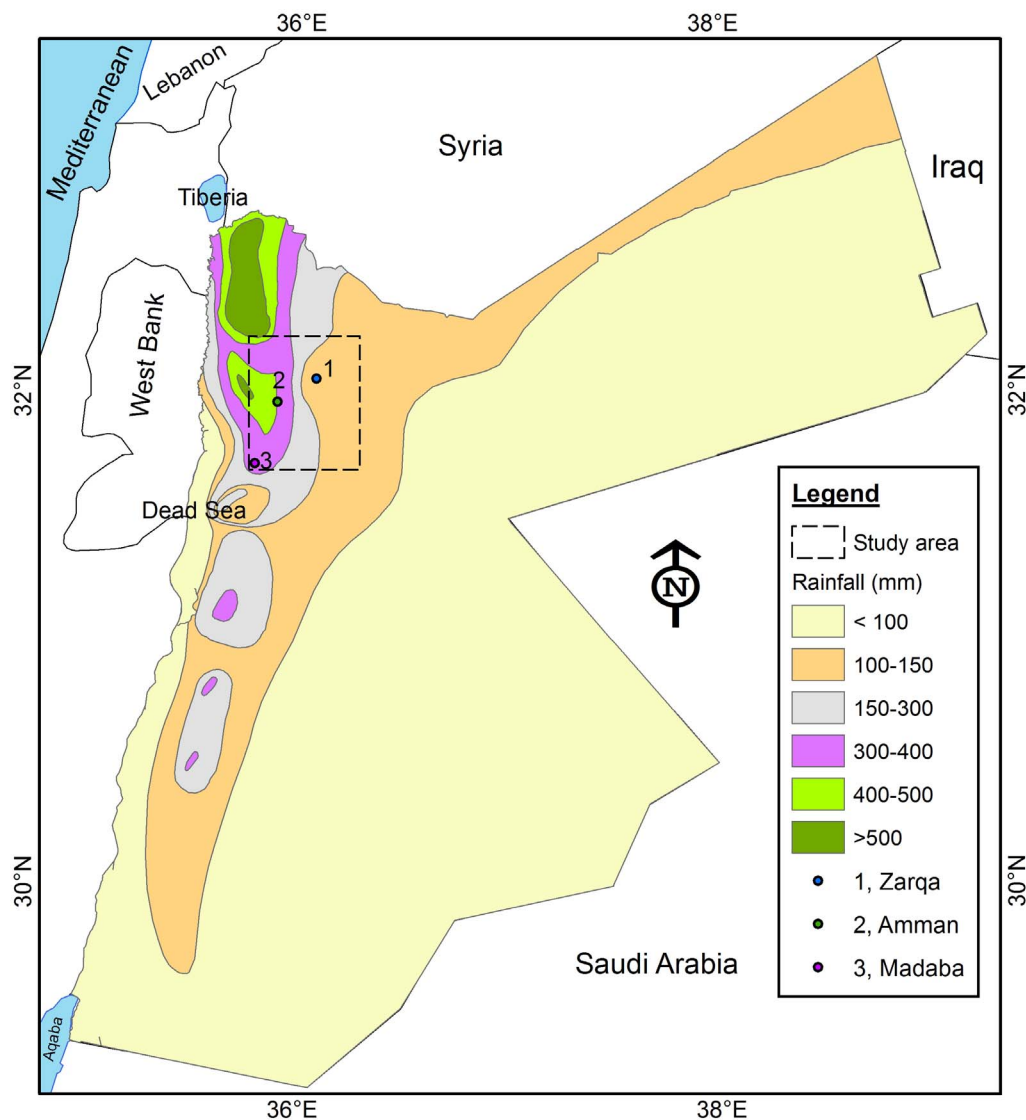


Figure 1. Location of the study area.

to its population, the political instability in the area surrounding Jordan has brought waves of refugees into the country. The most recent movements have included 0.45 million Iraqis [13], about 1.50 million Syrians, of which 0.25 million are registered as refugees (by end of 2012) [11,14].

The high increase in Jordan's population has resulted in unplanned land use/cover changes turning the limited agricultural lands into urbanized areas [1,15]. These trends are expected to exert more pressure on the country's limited resources of water and agricultural land. A quantitative prediction of land use/cover change, therefore, is needed to put future changes into context and to enable appropriate planning of the country's limited resources. This study aims to assess land use/cover and its change around Amman, where more than half of the country's population is living. The main impacts of land use/cover

change on available water resources are discussed in relation to possible future changes.

The use of remote sensing and GIS for mapping land use/cover and its change is well recognized and has been reported by many case studies and research projects. The use of certain models, however, is very important and will affect the predicted trends of change. Among these models is the Markov chain. The use of this model has been used to study vegetation dynamics and land use/cover changes in different ecological zones [16-23]. The advantage of this model is that the probabilities of all possible transitions between classes, given as a matrix, will permit a direct and unambiguous prediction of future land use/cover changes [22,23]. Results of predicting land use/cover change by this model, however, depend on the time interval from which the matrix of probability is derived. Therefore, from remote sensing and GIS per-

spectives, this study evaluates the effect of time-interval on predicting land use/cover change with the Markov chain model so that the time interval of satellite imagery with the highest accuracy of prediction will be recommended for predicting future land use/cover.

## 2. Study Area and Methodology

### 2.1. Study Area

The study area (50 km × 60 km) is located between 35.76°E to 36.29°E and 31.70°N to 32.24°N (**Figure 1**). A typical Mediterranean climate dominates the area. The mean monthly air temperature ranges from 6°C in January up to 22°C in August, with a mean annual air temperature of 15.0°C [24]. The annual rainfall gradient decreases from 500 mm in the west to 120 mm in the east. The area is characterized by undulating topography in the west and flat areas in the east and south, with altitude range of 700 - 1200 m. Aridic soils (Calcids and Cambids) with high carbonate contents dominate the eastern parts of the study area, while more developed soils (mainly Entic haploxererts, typic xerochrepts) with low salinity and high clay contents are found in the north and west [25].

The study area is characterized by intensive human activities, as 3.4 million people (half of the country's population) are living in this area [11]. Population densities are 326 and 200 persons per km<sup>2</sup> for Amman and Zarqa, respectively [26]. The high population densities are imposing serious stress on the available water resources in the study area, and in the country as well. In the study area, the annual extraction of groundwater increased from 8.5 million cubic meters (MCM) in the mid-sixties to 120 MCM in the nineties and reached about 140 MCM during 2000-2010, while the safe yield is about 70 MCM. Subsequently, the base flow of the Zarqa River has dropped from 5 to less than 1 m<sup>3</sup>/s [27].

The main wastewater treatment plant (WWTP) in the study area is As-Samra that receives wastewater from Amman and Zarqa cities. The WWTP started to operate in 1986 and treats about 20 MCM using waste stabilization ponds (WSP) primary treatment. Due to increased population and urbanization, the annual influent reached 60 MCM by the late 1990's [28]. The increase in influent resulted in a decrease of the efficiency of water treatment. Therefore, the WWTP was upgraded after 2004 to use mechanical treatment that improved the quality of effluent [29]. The effluent from this WWTP is used for irrigation on the floodplain of the Zarqa River and in the Jordan Valley (downstream area) after mixing with surface water from the King Talal Dam (KTD).

The main uses of land in the study area are urbanization and agriculture. Urbanization is taking place in the capital Amman and in Zarqa and Madaba cities. Urban

areas include residential units, educational facilities and industrial plants. Agricultural activities include the cultivation of rainfed crops of wheat, barley, summer crops, olives and fruit trees. Also, it includes irrigation of vegetables and fruit trees using groundwater in the southern and eastern parts of the study area. Irrigation is practiced on both sides of the Zarqa River using a mixture of treated wastewater and fresh water to irrigate fodder crops. Deciduous and evergreen oaks and pine forests are scattered in the western parts of the study area where rainfall is relatively high. The eastern parts, where rainfall is low, are used as open rangelands. Cultivation of barley is practiced in these areas to support the grazing herds of sheep with straw, as grain is not produced in most years.

### 2.2. Data Collection and Processing

The study was mainly based on collection and analysis of remote sensing data. The study also used ancillary data on population, obtained from the Department of Statistics (DoS), and water resources, obtained from Ministry of Water and Irrigation (MWI). Ground surveys were also used to collect data on land use/cover and to verify the results of visual interpretation of satellite imagery.

A time-series of Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Operational Land Imager (OLI) images were used to derive land use/cover maps of the area. The dataset included full scenes for the years 1983, 1989, 1994, 1998, 2003 and 2012. The selected datasets were cloud free images acquired between March and May, *i.e.* spring-time when vegetation growth or cover is at its peak. The dataset was mainly downloaded from the archive of the Global Land Cover Facility (GLCF) (<http://glcf. umiacs.umd.edu/index.shtml>) and the official website of Landsat 8

(<http://earthexplorer.usgs.gov>) at no cost. The images included the visible (bands 1, 2 and 3), the near infrared (NIR), the shortwave infrared (SWIR), and the middle infrared (MIR) bands with 30 m spatial resolution for TM and ETM+ images. The same bands were selected from the OLI of Landsat 8 for year 2013. Due to the problem of image striping in Landsat 7, Google Earth imagery were used to guide and verify land use/cover mapping of the study area in 2012.

Various image processing techniques were applied to prepare the images for visual interpretation of land use/cover. These included geometric correction, resampling, mosaicking and clipping of the images to the borders of the study area. The satellite images were geometrically corrected using 8 well-defined and distributed Ground Control Points (GCP's) collected during ground surveys using a Global Positioning System (GPS) with a positional error of 5 m. A second order polynomial transformation was used to calculate new coordinates for the

output image with a Root Mean Squared error (RMS) of less than one pixel. The images were then resampled using the Nearest Neighbour (NN) method [30]. For the purpose of comparison with the historical dataset of Landsat, the NN resampling was carried out with an output pixel size of 30 m. Mosaicking was then used to join the different images from 2012 and 2013. Histogram matching was used to improve the visual appearance and brightness of the output image [30,31].

The output image was used to carry out geometric correction for the historical satellite images of ETM+ and TM, using the image-to-image correction method [30]. The ETM+ and TM images were corrected using second order polynomial transformations with RMS values of less than one pixel. All images were resampled by the NN method to 30 m pixel size, registered in the Jordan Transverse Mercator (JTM) projection and clipped to the borders of the study area.

### 2.3. Mapping of Land Use/Cover

A visual interpretation of Landsat images was performed to derive land use/cover maps for each date of imagery. Although there were many digital classification techniques to derive land use/cover [2], visual interpretation was used to avoid classification errors that might result from spectral mixing at the 30 m spatial resolution, as indicated by previous research in the study area [32,33]. Therefore, visual interpretation was applied to derive all land use/cover maps following the same digitizing procedure so that human errors were the same for all maps.

On-screen digitizing was used to delineate land use/cover parcels using a false color composite (bands 4, 5, 3) for Landsat images. A classification scheme with six classes (**Table 1**) was identified to enable the interpretation of land use/cover with high accuracy and to enable the comparison between the different time series of satellite images. The classes were visually identified using

pattern, shape, size, location and GIS layers of ground-water wells that were used for irrigation. Results of interpretation were verified by several field visits, aided by the use of topographic maps and GPS. Accuracy assessment of the most recent image (2012) was made by selecting random samples from the land use/cover map of 2012 and comparing the interpretation results with the actual land use/cover on the ground, using the contingency table method [34]. All land use/cover were visually identified and delineated with high accuracy. Few errors of interpretation were observed among agricultural areas, forests and dense vegetation in the high rainfall zone. Corrections were made for all detected errors.

The results of mapping for the years 1983 and 1989 were compared with land use/cover maps reported by the 1:50,000 topographic maps of the Royal Jordanian Geographic Center (RJGC). Similarly, land use/cover in 1994 and 1998 were compared with historical land use/cover maps produced by previous work in the study area [25, 35,36]. Outputs from the visual interpretation were five digital maps (GIS layers) representing the land use/cover for each of the images. All land use/cover maps were analyzed within the GIS to determine the percentage of each land use class.

### 2.4. Modeling of Land Use/Cover Change

A first-order Markov model was used to represent the land use/cover change for different time intervals. Future land use/cover was predicted by multiplying the state vector (initial land use/cover) at a given time ( $V_{\text{initial}}$ ) by the transition matrix  $[p_{ij}]$  during a time interval  $t$  to yield the new state vector ( $V_{\text{initial}+t}$ ) or expected proportion of land use/cover after  $t$  years from the initial state as follows:

$$V_{\text{initial}} \times [p_{ij}]_t = V_{\text{initial}+t} \quad (1)$$

**Table 1. Land use/cover classification scheme.**

Class	Definition	Mapping Accuracy (%)
Urban (U)	All residential, commercial, educational and industrial areas, including villages and quarries.	100
Mixed agricultural areas (MAA)	Rainfed areas planted with one or more types of crops, including. field crops (wheat and barley), trees (mainly olives), summer crops and vegetables.	92
Irrigated farms (IF)	Permanently irrigated farms of vegetables, in open fields or under plastic houses, and fruit trees.	94
Forest (F)	Deciduous and evergreen oaks and coniferous, including both protected and open forests.	97
Open rangeland (OR)	Open shrub and herbaceous rangelands, including wadis cultivated with barley, where open grazing is practiced.	93
Water bodies (WB)	KTD, As-Samra WWTP, desert dams and ponds	100

This procedure could be used repeatedly, extending the forecast to distant future states. However, accuracy usually decreases with time steps [23]. In order to apply the model, the land use/cover maps were rasterized and cross-tabulated to calculate percentage land use/cover change between the different classes during the different time intervals. In order to consider positional shifts among maps and their impacts on estimating change, a buffer of 15 m on each side of the polygon's boundaries was created to exclude these areas from the analysis, as described by Reference [37]. The procedure was carried out for the combinations 1989-1994, 1989-1998 and 1983-1998. The aim was to evaluate the accuracy of prediction using 5, 9 and 15 years interval based on the rate of land use/cover change during the late 1980s to 1998. This period was considered representative for the rapid population growth in the country resulting from the political instability in the region, as the year 1990 witnessed the return of Jordanian labour from the Gulf region [15].

In order to construct the transition matrix, land use/cover maps were rasterized, overlaid and cross-tabulated to derive tables that represented transition matrices where the change of type  $i$  into type  $j$  was calculated. The set of all possible transitions  $i - j$ , divided by the total area of type  $i$  in the initial state, constituted the probability  $p_{ij}$  of type  $i$  changing into type  $j$  over the time period separating the two maps. Transition probabilities were expressed as a complete matrix of land use/cover classes ( $V_{\text{initial}}$ ), where the rows of the matrix sum to 1.0 (100%), and the diagonal cells represent the probability that a class remains what it was (*i.e.* did not change). This matrix was used to calculate  $p_{ij}$  by dividing the area of each row by the row's total. The transition matrix between 1983 and 2013 (row-wise) is shown in **Table 2**. In this matrix, for example, the probability of changing forests into other classes is 13% to urban, 41% to mixed agricultural areas, 2% to irrigated farms and 12% to open rangelands, while 32% of the forests remained unchanged. Similarly, transition matrices were derived for the different time intervals.

**Table 2. The matrix of percentage land use/cover change between 1983 (rows) and 2013 (columns).**

		Year 2013					
		U	MAA	IF	F	OR	WB
Year 1983	U	99.6*	0.0	0.0	0.0	0.4	0.0
	MAA	2.2	85.2	4.2	0.0	8.4	0.0
	IF	19.8	41.4	36.8	0.3	1.7	0.0
	F	13.3	40.6	1.8	32.1	12.2	0.0
	OR	27.5	10.9	1.3	1.3	58.8	0.2
	WB	0.0	0.0	0	0	12.4	87.6

\*Diagonal represents the unchanged proportion of the particular land use/cover class (Abbreviation is shown in **Table 1**).

Following the stage of deriving the transition matrices, the Markov model was used to predict future land use/cover using the time interval with the highest accuracy of prediction to predict future land use/cover (after 2013). Two statistical measures were used to evaluate the accuracy of prediction. These were the RMSE and the index of agreement ( $D$ ). The RMSE and  $D$  were computed as follows [38]:

$$RMSE = \left[ N^{-1} \sum_{i=1}^N (P_i - O_i)^2 \right]^{0.5} \quad (2)$$

$$D = 1 - \frac{\sum_{i=1}^N (P_i - O_i)^2}{\sum_{i=1}^N (|P_i| + |O_i|)^2} \quad (3)$$

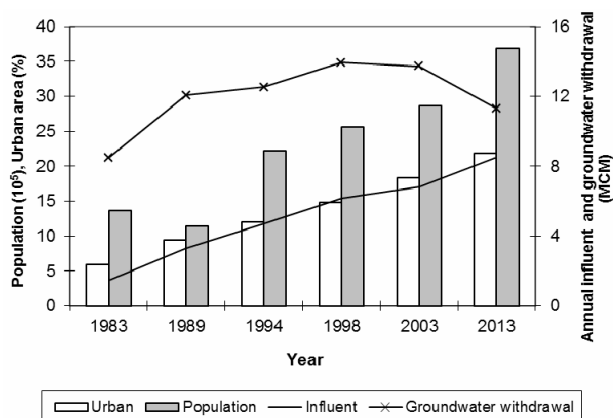
where  $N$  is the number of land use/cover classes,  $P$  is the predicted class and  $O$  is the observed class,  $P'_i = P_i - \bar{O}$  and  $O'_i = O_i - \bar{O}$ , and  $\bar{O}$  is the mean of the observed values of land use/cover. There is no higher bound on RMSE and it ranges from 0 to infinity. However, the lower the RMSE the better is the agreement. A value of 1 for  $D$  means a complete agreement between predicted and actual land use/cover while a value of 0 means a poor agreement. Prediction for future land use/cover was based on the initial map of 1998 ( $V_{\text{initial}}$ ) using the transition matrix of 5 and 15 years. The output land use/cover was predicted for years 2003, 2008 and 2013. Similarly, the transition matrix of 9 years interval was used to predict land use/cover of 2012 using the map of 1994 as the  $V_{\text{initial}}$  and the map derived from Google Earth images of 2012 for verification.

Two possible scenarios of future land use/cover were tested. The first scenario (Scenario A) assumed continuous change of land use/cover following historical trends. This was implemented by applying the transition matrix for the time interval with the maximum accuracy of prediction. The second scenario (Scenario B) assumed that previous and current land use/cover would affect water resources, which would determine future land use/cover. In this scenario, land use policy and plans of the MWI [10] were taken into consideration with the possible expansion in treated wastewater use in irrigation, while prioritizing groundwater for drinking water. This would imply the decrease in areas irrigated with groundwater by 1.5 thousand hectare or 0.5% of the total area, due to reduction in groundwater amounts (**Figure 2**).

### 3. Results and Discussion

#### 3.1. Land Use/Cover Changes

Results showed intensive urbanization and agricultural activities that changed the character of land use/cover in

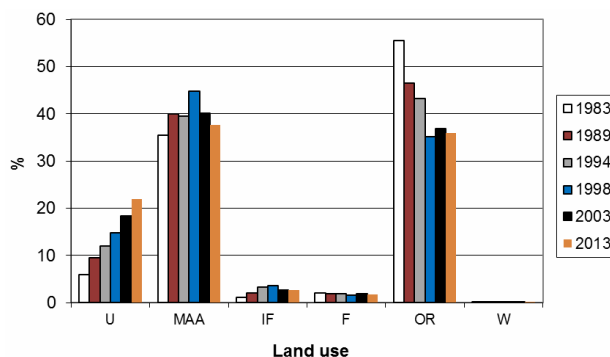


**Figure 2.** Changes in urban areas, population, annual influent to As-Smara WWTP and annual groundwater withdrawal from Amman-Zaqqa basin.

the study area. Analysis of land use/cover maps showed that urbanized areas doubled every 15 years (**Figure 3**). Agricultural activities were also practiced in about 40% - 45% of the total area. Irrigation was practiced in two main locations; the first was located between Amman and Madaba and mainly depended on groundwater for irrigation. The second location was on both sides of the Zarqa River (**Figure 4**) and mainly used treated wastewater mixed with surface water. Forests were scattered in the high rainfall zone in the western parts of the area, while open rangelands were distributed in the low rainfall zone in the east.

Results of cross-tabulating the 1983 and 2013 land use/cover maps (**Table 2**) showed important trends of land use/cover changes during the 30 year period. Part of the mixed agricultural areas was changing into urban or open rangelands. In terms of area, 2640 ha of the mixed agricultural areas were urbanized. Another important change that was noticed in the study area was the conversion of 13.3% of the forest into urban and 41% into mixed agricultural areas. According to Reference [37], this trend was seen as the major cause of land degradation in the high rainfall zone in Jordan. The change from mixed agricultural areas to open rangelands, and vice versa, was also noticed when the maps of land use/cover classes were cross-tabulated. This change could be attributed to the crop rotations and rainfall distribution that affected the spatial distribution of rainfed barley and other field crops in the study area. Changing the irrigated farms into open rangelands, on the other hand, would imply the abandonment of irrigated farms due to soil salinization as indicated by Reference [1].

Analysis of maps showed important changes in land use/cover in the study. An obvious expansion of urban areas occurred during the 1983-2002 period. The trend of change for mixed agricultural areas was different from that of urbanization. During 1983-1998, mixed agricul-



**Figure 3.** Percentage land use/cover in the study area during 1983-2013 (Class abbreviation is shown in Table 1).

tural areas increased from 35% to 40% while irrigated farms increased from 1.1% to 3.6%. This increase, attributed to the increased demand on food by the growing population, resulted also in converting 41% of the remaining forests in the areas into mixed agricultural areas.

Following 1998, agricultural activities recessed as urbanized areas expanded. Irrigated lands, on the other hand, started to decrease as prices of water and cost of pumping groundwater increased. Subsequently, during 2003-2013, the total irrigated area was 5400 ha, which represented 1.8% of the study area. Generally, the trends of urbanization were consistent with the increase of population in the study area. According to the official records of the Department of the Statistics [11], population of the study area increased from 1.4 million in 1983 to 3.6 million in 2012. This increase resulted in increasing urbanized areas from 6% in 1983 to 22% in 2013 (**Figure 2**). The increase in population and urbanized areas resulted in increasing the amounts of treated wastewater from 15 MCM in 1983 to 85 MCM in 2013. Therefore, population growth could be considered as the main driving force for land use/cover change in the study area and would call for future plans to cope with its adverse impacts on land resources.

### 3.2. Future Land Use/Cover

Results from land use/cover prediction showed variations in the future trends of land use/cover according to the time interval from which the probability matrix was derived (**Table 3**). The use of the 5 years interval resulted in underestimation of urban areas and overestimation of all other classes. The overall average RMSE for the prediction was 2%. The use of 9 years interval resulted in more accurate prediction for urban areas than for the 5 and 15 years interval. The 9 years interval overestimated the mixed agricultural areas and underestimated the open rangelands. The 15 years interval followed similar trends to the 9 years interval with less accuracy for predicting urbanized areas. Generally, the use of 9 - 15 years inter-



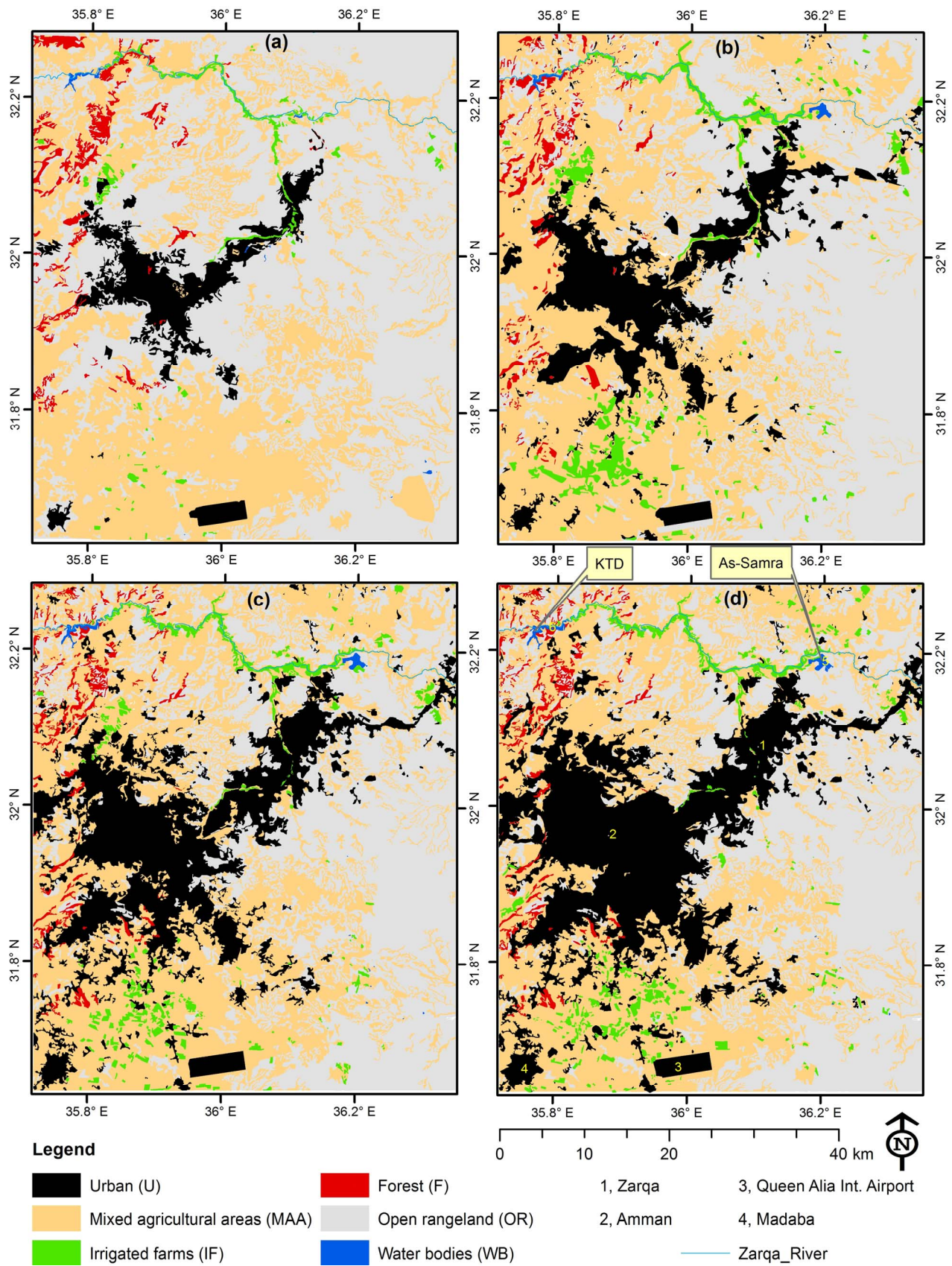


Figure 4. Land use/cover maps of the study area in 1983 (a), 1994 (b), 2003 (c) and 2013 (d).

**Table 3. Historical, current and future land use/cover in the study area using different time intervals and scenarios.**

Class	Land Use/Cover Prediction for 2013 Based on Different Intervals					Future Land Use/Cover (Scenario A)		Future Land Use/Cover (Scenario B)	
	1983	2013	5 years	9 years	15 years	2028	2043	2028	2043
U	5.9	21.9	18.1	21.4	20.6	26.3	33.3	26.3	33.3
MAA	35.4	37.6	38.3	43.6	45.4	44.1	37.8	43.1	37.1
IF	1.1	2.7	5.5	5.3	5.2	3.7	3.1	2.7	2.2
F	2.0	1.8	1.8	1.5	1.4	1.0	1.0	1.0	1.1
OR	55.5	35.9	36.1	27.9	27.1	24.7	24.6	26.6	26.2
WB	0.1	0.2	0.2	0.3	0.3	0.3	0.3	0.3	0.3
<b>Statistical Measure</b>									
RMSE	N/A	N/A	2.0	4.2	4.9	N/A	N/A	N/A	N/A
D	N/A	N/A	0.996	0.982	0.976	N/A	N/A	N/A	N/A

vals showed more accurate results than the 5 years interval for predicting urbanization in the study area. The low accuracy for predicting agricultural and vegetated classes from the 9 and 15 years intervals could be attributed to the accuracy of land use/cover interpretation, crop rotations and the rainy season which might affect the distribution of rainfed crops. Therefore, high RMSE values were obtained for predictions using both intervals for the vegetation classes of MAA, IF and F.

Results of land use/cover prediction showed that urban areas would expand in the future and would reach 33% in year 2043, under both scenarios of land use/cover change. Both scenarios expected a slight decrease in MAA and a considerable loss of forests. Assuming that irrigated farms in the southern and western parts of the study area will face the problem of groundwater availability, scenario B predicted the recession of irrigated farms by 30% of their present area. Most of the irrigated farms will be around the Zarqa River while irrigation in the western and southern parts might be supplementary for fruit trees. Both scenarios predicted the decrease of open rangelands, which would create serious problems for livestock owners who would lose important sources of browse for their flocks of sheep and goats.

The above results showed that land use/cover changes in the study area, particularly the unplanned expansion of urbanized areas, would result in altering the character of the Amman-Zarqa region with a deterioration of water quality in the area. This supports "Scenario B" in predicting future changes; which proposed that land use changes would affect water quality which in turn would limit further expansion in irrigation and would prioritize water allocation for urban use. Subsequently, encroachment of urban areas into more agricultural lands would continue in the future.

### 3.3. Impacts of Land Use/Cover Change

Urbanization was the most important character of land

use/cover in the study area. The trends of urbanization at the expense of agricultural land would be expected to impose serious stress on land and water resources. Results from intersecting the land use/cover map of 2013 with the existing soil map of the study area [25] showed that the main urbanized soil mapping units were the typic xerochrepts and entic chromoxererts in Amman and Madaba and the calcixerollic xerochrept in Zarqa. These fertile and deep soils would be highly suitable for rainfed arable land utilization including wheat and summer crops, as indicated by previous research in Jordan [9]. Therefore, the conversion of agricultural areas into urban units would imply an irreversible permanent loss.

Although the scenarios of land use/cover change expected little expansion of agricultural areas to meet the increased demand on food, however it would be unlikely for these lands to compete with urbanization. This would be expected as the price of land would increase and the competition between the different land uses would be for the benefit of urbanization. Another important factor that would also increase the competition on agricultural lands for urbanization would be the land fragmentation, which decreases the landholding size of agricultural lands. Reference [39,40] revealed that 25% of the rainfed landholdings, which accounted for 40% of the country's land area, were receiving less than 250 mm of annual rainfall. This rainfall amount would not sustain dry farming, particularly under the adverse impacts of future climate change in the country, as indicated by References [1] and [41].

The observed urbanization increased the influent of treated wastewater. Data from the MWI showed that As-Samra was receiving 170,000 m<sup>3</sup> of wastewater influent per day in the late 1990's, although its design capacity was half of this amount. This resulted in inefficient treatment of wastewater that increased the biological oxygen demand (BOD5) of the water to reach its maximum (234 mg/l) in 1996, much more than the Jordanian standards (JISM 2006) for reuse in irrigation [42]. The dis-



posal and the use of inefficiently treated wastewater would also result in many negative environmental impacts [42,43]. These could include the occurrence of waterborne and soil-borne diseases, salinization of water in the Zarqa River and KTD, salinization of the irrigated soils and contamination of wells used for irrigation and municipal supply, in addition to noxious odours near the WWTP.

The adverse environmental impacts resulting from the inefficient treatment of wastewater urged the MWI to upgrade the WWTP (after 2004) for influent quantity and effluent quality. Although the data of MWI, as indicated by Reference [29], showed obvious improvement in effluent quality, the challenge would be the future upgrade of the plant to receive higher wastewater quantities resulting from urbanization. Correlating results of urbanization with wastewater influent (**Figure 2**) revealed that the amount of wastewater treated by As-Samra WWTP would reach 105 and 135 MCM in years 2028 and 2043, respectively.

Another important impact of land use/cover changes in the study area was the increased abstraction of groundwater from 121 MCM in 1989 to 137 MCM in 2003, although the estimated safe yield was 65 MCM. Generally speaking, the over-abstraction from groundwater aquifers of the Amman-Zarqa was mainly to meet the growing human activities in all sectors. This, however, resulted in depletion of groundwater aquifers and increased salinity levels and pumping costs due to the drop in the water table. The recent water policy of the government prioritized groundwater for municipal and industrial uses [10]. The actions of the government also included the implementation of the Disi conveyor project [1,10] which started to supply Amman, Zarqa, and other cities, with drinking water since June 2013. The future challenge, however, would remain developing additional water sources to meet the demand of growing population.

#### 4. Conclusion

Results from this study showed that remote sensing data and GIS could provide useful information for modeling and assessing land use/cover in a country where land use/cover was highly affected by a high population growth resulting from the political instability in the surrounding countries. Prediction of future land use/cover by the Markov chain model showed that the use of multi-temporal satellite imagery with 9 years interval would provide accurate results for predicting trends of urbanization. The prediction of changes in other classes of land use/cover, particularly mixed agricultural irrigated areas, would require the implementation of scenarios that might consider sources of water and the availability of arable lands. The study also showed that the possible impacts of urbanization would be the increased amounts of wastewater

influent and the expansion of urbanized areas at the expense of agricultural land. Results of the study were alarming and emphasized the need for urgent future land use plans and legislations to alleviate the impacts of urbanization on water resources in the study area and in the country as a whole.

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#### REFERENCES

- [1] J. T. Al-Bakri, M. Salahat, A. Suleiman, M. Suifan, M. R. Hamdan, S. Khresat and T. Kandakji, "Impact of Climate and Land Use Changes on Water and Food Security in Jordan: Implications for Transcending 'The Tragedy of the Commons'," *Sustainability*, Vol. 5, No. 2, 2013, pp. 724-748. <http://dx.doi.org/10.3390/su5020724>
- [2] A. Alqurashi and L. Kumar, "Investigating the Use of Remote Sensing and GIS Techniques to Detect Land Use and Land Cover Change: A Review," *Advances in Remote Sensing*, Vol. 2, No. 2, 2013, pp. 193-204. <http://dx.doi.org/10.4236/ars.2013.22022>
- [3] A. Al Mashagbah, R. Al-Adamat and H. Al-Amoush, "GIS and Remote Sensing to Investigate Urban Growth in Mafraq City/Jordan between 1987 and 2010," *Journal of Geographic Information System*, Vol. 4, No. 4, 2012, pp. 377-382. <http://dx.doi.org/10.4236/jgis.2012.44043>
- [4] B. Quan, Z. Xiao, M. Römkens, Y. Bai and S. Lei, "Spatiotemporal Urban Land Use Changes in the Changzhutan Region of Hunan Province in China," *Journal of Geographic Information System*, Vol. 5, No. 2, 2013, pp. 136-147. <http://dx.doi.org/10.4236/jgis.2013.52014>
- [5] P. Raj and P. Azeez, "Land Use and Land Cover Changes in a Tropical River Basin: A Case from Bharathapuzha River Basin, Southern India," *Journal of Geographic Information System*, Vol. 2, No. 4, 2010, pp. 185-193. <http://dx.doi.org/10.4236/jgis.2010.24026>
- [6] N. Singh and J. Kumar, "Urban Growth and Its Impact on Cityscape: A Geospatial Analysis of Rohtak City, India," *Journal of Geographic Information System*, Vol. 4, No. 1, 2012, pp. 12-19. <http://dx.doi.org/10.4236/jgis.2012.41002>
- [7] R. Zaki, A. Zaki and S. Ahmed, "Land Use and Land Cover Changes in Arid Region: The Case New Urbanized Zone, Northeast Cairo, Egypt," *Journal of Geographic Information System*, Vol. 3, No. 3, 2011, pp. 173-194. <http://dx.doi.org/10.4236/jgis.2011.33015>
- [8] T. Lasanta, S. Beguería and J. M. García-Ruiz, "Geomorphic and Hydrological Effects of Traditional Shifting in Agriculture in a Mediterranean Mountain Area, Central Spain Pyrenees," *Mountain Research and Development*,

- Vol. 26, No. 2, 2006, pp. 146-152.  
[http://dx.doi.org/10.1659/0276-4741\(2006\)26\[146:GAHEOT\]2.0.CO;2](http://dx.doi.org/10.1659/0276-4741(2006)26[146:GAHEOT]2.0.CO;2)
- [9] J. T. Al-Bakri, M. Ajlouni and M. Abu-Zanat, "Incorporating Land Use Mapping and Participation in Jordan: An Approach to Sustainable Management of Two Mountainous Areas," *Mountain Research and Development*, Vol. 28, No. 1, 2008, pp. 49-57.  
<http://dx.doi.org/10.1659/mrd.0863>
  - [10] Ministry of Water and Irrigation, Jordan, "Water for Life: Jordan's Water Strategy 2008-2022," Amman, Jordan, 2009.
  - [11] Department of Statistics, "Jordan in Figures: 2012," Report No.14, DoS, Amman, 2012.
  - [12] Ministry of Water and Irrigation, "Special Report on Water Resources in Jordan," Amman, 2009.
  - [13] Department of Statistics, "Iraqis in Jordan: Their Number and Characteristics," DoS, Fafo and UNFPA, Amman, 2007.
  - [14] UNHCR (The UN Refugee Agency), "A Briefing Note on Syrian Refugees," 2013. <http://www.unhcr.org/>
  - [15] J. T. Al-Bakri, J. C. Taylor and T. R. Brewer, "Monitoring Land Use Change in the Badia Transition Zone in Jordan Using Aerial Photography and Satellite Imagery," *The Geographical Journal*, Vol. 167, No. 3, 2001, pp. 248-262. <http://dx.doi.org/10.1111/1475-4959.00022>
  - [16] R. Van Hulst, "On the Dynamics of Vegetation, Markov Chains as Models of Succession," *Vegetatio*, Vol. 40, No. 1, 1979, pp. 3-14. <http://dx.doi.org/10.1007/BF00052009>
  - [17] R. J. Hobbs and C. J. Legg, "Markov Models and Initial Floristic Composition in Heatland Vegetation Dynamics," *Vegetatio*, Vol. 56, No.1, 1984, pp. 31-43.
  - [18] K. Aaviksoo, "Changes of Plant Cover and Land Use Types (1950's to 1980's) in Three Mire Reserves and their Neighbourhood in Estonia," *Landscape Ecology*, Vol. 8, No. 4, 1993, pp. 287-301.  
<http://dx.doi.org/10.1007/BF00125134>
  - [19] H. Balzter, "Markov Chain Models for Vegetation Dynamics," *Ecological Modelling*, Vol. 126, No. 2-3, 2000, pp. 139-154.  
[http://dx.doi.org/10.1016/S0304-3800\(00\)00262-3](http://dx.doi.org/10.1016/S0304-3800(00)00262-3)
  - [20] Q. Weng, "Land Use Change Analysis in the Zhujiang Delta of China Using Satellite Remote Sensing, GIS and Stochastic Modelling," *Journal of Environmental Management*, Vol. 64, No. 3, 2002, pp. 273-284.  
<http://dx.doi.org/10.1006/jema.2001.0509>
  - [21] Y. Kurucu and N. K. Christina, "Monitoring the Impacts of Urbanization and Industrialization on the Agricultural Land and Environment of the Torbali, Izmir Region, Turkey," *Environmental Monitoring and Assessment*, Vol. 136, No. 1-3, 2008, pp. 289-297.
  - [22] B. Ahmed and R. Ahmed, "Modeling Urban Land Cover Growth Dynamics Using Multi-Temporal Satellite Images: A Case Study of Dhaka, Bangladesh," *ISPRS International Journal of Geo-Information*, Vol. 1, No. 1, 2012, pp. 3-31. <http://dx.doi.org/10.3390/ijgi1010003>
  - [23] G. R. Pontius and J. Malanson, "Comparison of the Structure and Accuracy of Two Land Change Models," *International Journal of Geographical Information Science*, Vol. 19, No. 2, 2005, pp. 243-265.  
<http://dx.doi.org/10.1080/13658810410001713434>
  - [24] Jordan Meteorological Department, "Annual Report of Jordan Meteorological Department," Amman, 2010.
  - [25] Ministry of Agriculture, Jordan, "The Soils of Jordan: Semi-detailed Level (1:50,000)," Ministry of Agriculture, Amman, 1995.
  - [26] Department of Statistics, "Demographic Statistics," DoS, Amman, 2013. <http://www.dos.gov.jo/>
  - [27] B. M. Al-Qaisi, "Climate Change Effects on Water Resources in Amman Zarqa Basin—Jordan," Individual Project Report for Climate Change Mitigation and Adaptation, MWI, Amman, 2010.
  - [28] Consolidated Consultant, "Environmental and Social Impact Assessment Study for the Expansion of As-Samra Wastewater Treatment Plant," Final ESIA Report Submitted to MWI, Amman, 2012.
  - [29] A. Al-Omari, Z. Al-houri and R. Al-Weshah, "Impact of the As Samra Wastewater Treatment Plant Upgrade on the Water Quality (COD, Electrical Conductivity, TP, TN) of the Zarqa River," *Water Science & Technology*, Vol. 67, No. 7, 2013, pp. 1455-1464.  
<http://dx.doi.org/10.2166/wst.2013.686>
  - [30] J. R. Jensen, "Introductory Digital Image Processing: A Remote Sensing Perspective," 3rd Edition, Prentice Hall, Upper Saddle River, 2005.
  - [31] R. A. Schowengerdt, "Remote Sensing: Models and Methods for Image Processing," 3rd Edition, Academic Press, London, 2006.
  - [32] M. M. Rababa'a and J. T. Al-Bakri, "Mapping Land Cover in the Dead Sea Basin from Landsat TM Satellite Imagery," *Dirasat*, Vol. 33, No. 2, 2006, pp. 103-113.  
<http://journals.ju.edu.jo/DirasatAgr/article/view/669>
  - [33] S. Al-Tamimi and J. T. Al-Bakri, "Comparison between Supervised and Unsupervised Classifications for Mapping Land Use/Cover in Ajloun Area," *Jordan Journal of Agricultural Sciences*, Vol. 1, No. 1, 2005, pp. 73-83.  
<http://journals.ju.edu.jo/JJAS/article/view/1290>
  - [34] R. G. Congalton, "A Review of Assessing the Accuracy of Classifications of Remotely Sensed Data," *Remote Sensing of Environment*, Vol. 37, No. 1, 1991, pp. 35-46.  
[http://dx.doi.org/10.1016/0034-4257\(91\)90048-B](http://dx.doi.org/10.1016/0034-4257(91)90048-B)
  - [35] University of Jordan, "Improvement of Agricultural Productivity in Arid and Semi-Arid Zones of Jordan (JAZPP)," Final Report to EU, SEM/O3/628/021, UOJ, Amman, 2002.
  - [36] L. Salameh, "Assessment of Land Use/Cover Changes in the Zarqa Basin Using Remote Sensing and Markov Model," Unpublished MSc Thesis, University of Jordan, Amman, 2006.
  - [37] S. Khresat, J. Al-Bakri and R. Tahhan, "Impacts of Land Use Change on Soil Properties in the Mediterranean Region of Northwestern Jordan," *Land Degradation & Development*, Vol. 19, No. 4, 2008, pp. 397-407.  
<http://dx.doi.org/10.1002/ldr.847>
  - [38] P. Krause, D. P. Boyle and F. Base, "Comparison of Different Efficiency Criteria for Hydrological Model As-

- essment,” *Advances in Geosciences*, Vol. 5, 2005, pp. 89-97. <http://dx.doi.org/10.5194/adgeo-5-89-2005>
- [39] United States Department of Agriculture, Soil Survey Staff, “Keys to Soil Taxonomy,” 4th Edition, SMSS, Technical monograph 19, Blacksburg, 1990.
- [40] A. S. Al-Rimawi, “A Classification of Farm Holdings in Jordan by Rainfall Zones: Implications for Agricultural Policies,” *Dirasat: Agricultural Sciences*, Vol. 30, No. 3, 2003, pp. 261-273.
- [41] J. T. Al-Bakri, A. Suleiman, F. Abdulla and J. Ayad, “Potential Impacts of Climate Change on the Rainfed Agriculture of a Semi-Arid Basin in Jordan,” *Physics and Chemistry of the Earth*, Vol. 36, No. 5-6, 2011, pp. 125-134.
- [42] M. M. Duqqah, “Treated Sewage Water Use in Irrigated Agriculture: Theoretical Design of Farming Systems in Seil Al Zarqa and the Middle Jordan Valley in Jordan,” PhD Thesis, Wageningen University, Wageningen, 2002.
- [43] M. Atasoy, R. B. Palmquist and D. J. Phaneuf, “Estimating the Effects of Urban Residential Development on Water Quality Using Microdata,” *Journal of Environmental Management*, Vol. 79, No. 4, 2006, pp. 339-408. <http://dx.doi.org/10.1016/j.jenvman.2005.07.012>