

GIS-based Analytical Modeling on Evaluating Impacts of Urbanization in Amman Water Resources, Jordan

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Abstract

Amman governorate is the largest governorate in term of population and urbanization in Jordan that is the third most water-scarce country worldwide. It has also limited water resources that were rapidly decreasing as results of groundwater over-pumping and climate changes that generates a serious water crisis. However, the population and urbanization focused on the Northwest of the governorate. The surface water and groundwater resources are available in the Northwest area as well. The overlaying between urbanization and population on one-hand and water resources on the other hand resulted in different environmental, hydrological, and hydrogeological problems. Our research investigated these problems using an integrated approach of remotes sensing and geographic information systems. Furthermore, our research suggested a spatial plan that would solve the conflict of urbanization impact on water resources in Amman. Accordingly, the catchment areas that span on the study area and their drainage network were defined.

1. Introduction

Amman governorate has an area of about 7,579 km² and about 4,007,000 inhabitants (Perdew 2014, Department of Statistics 2014). The population in Amman governorate has been increasing dramatically in the last 40 years. The population growth rate is at 5.8%. In addition to this growth, there is a continuous flux of migrations and refugees from neighboring countries like Palestine, the Arabian Gulf area, Iraq, and Syria which accelerates the urban expansion (Potter et al. 2009, Odeh et al. 2017). However, in 1921 Amman was generated as the capital city of Trans-jordan and has about 5,000 inhabitants whom are mostly from Circassian, Syrian origin and the surrounded cities such as Irbid and Al-Salt. During 1961–1979 the population has increased from 215,000 inhabitants to 777,800 by the population growth, second Palestinian refugee migration, and the Civil War in Lebanon. The first and the second gulf war in the 1990's forced more refugee waves to migrate to Jordan in general and to Amman specifically and the population becomes 851,000, and 1,017,000 inhabitants respectively. In 2014 the population of Amman become 1,698,000 after the migration of Syrians due to the civil war.

Urban area expanding because of inhabitants increasing is a common process in the capital cities such as Amman (Schneider et al 1973, Butler 2000,). However, previous studies show that urban expanding in Amman due to the population growth has increased the urbanized area from about 147 km² in the year 1987 to 237 km² in 2014 that means the urbanized area increased by almost 61% over the last three decades. During these decades urban expanding was at a high-rate stage during 1987–1997 and at a steady-rate stage during 1997–2007, and 2007–2014 (Al-Bilbisi 2019, Al-Bakri et al. 2013).

Geographically, Amman governorate is in the northwest of Jordan (Fig. 1). It is bounded from the east by Saudi Arabia and from the west by the Palestinian National Authority. Topographically, It has a significant variation in altitude, which ranges between (-143 m below sea level (absl.) – 1100 m absl.). It has different landforms (Fig. 2) which is influenced by the underlining geological features (Odeh et al. 2015). However, such a change in altitude and large spatial expansion combined led Amman to be influenced by

the three common climatic zones in Jordan (The Jordan Valley, The Mountain Heights Plateau, and The Desert or Badai region (Potter et al. 2009, Perdeu 2014). In general, northwest of Jordan is closer to the Mediterranean Sea where most of the atmospheric troughs comes and hence has more rainfall events, while the highlands are commonly the areas which receive the greatest amount of rainfall in general (Salameh and Bannayan 1993). However, The climate in Amman governorate is subtropical arid, with cold winter (November – April) in the northwest due to the high altitude that reaches up to 1100 m, and sunny in the summer (June – September) that is slightly hot and is controlled by the adjustment desert area (Salameh and Bannayan 1993, Potter et al. 2009, Perdeu 2014). Due to the topographic variation climate is changing spatially. The western highlands of the governorate are close to the Mediterranean Sea and thus affected by that climatic zone while the eastern part is close to the Arabian Desert and is affected by this climatic zone too (Berndtsson and Larson 1987, Bouraoui et al. 1999).

In our study, we selected rainfall pattern as a primary climatic indicator (Fig. 3) to simplify understanding the climatic patterns in the Amman Governorate. The rainfall patterns are integral to the quantity and quality of water resources (Salameh and Bannayan 1993 and Odeh et al. 2017, BGR 2017). The greatest rainfall pattern values (about 500 mm) are concentrated on the northwest and therefore most of its water resources are allocated in that area while the lowest values about 0 mm is in the south east of the study area (Salameh and Bannayan 1993, Potter et al. 2009).

Amman gets its water from both surface water and groundwater for agriculture, domestic, and industrial purposes. Both surface water and groundwater in Amman are solely fed by rainfall. The bank full discharge of the river and the recharge of groundwater is accounted for primarily by the receiving rain (Berndtsson and Larson 1987, Bouraoui et al. 1999, Saraf et al. 2004). However, the water resources of Amman mostly located in the northwest as a result of rainy climatic zones that prevailed in that area due to the geographic location (nearest area to the Mediterranean Sea) and landforms (mountainous area) where urbanization and population expansion is taking place (Salameh and Bannayan 1993, BGR 2017, Odeh et al. 2017).

From geological perspective, Amman is situated in a faulted zone because of the adjustment to the regional Dead Sea transform fault. The faults are mostly strike-slip faults that generate a conduits between the aquifers (Odeh et al. 2019). However, the rock units that are cropped out in the study area belong to three geologic periods which are form the oldest to youngest: pre-Cambrian, Cretaceous, and Tertiary. These rock units could be further classified into five hydrogeological units (Bender 1974, Odeh et al. 2017) as follows (Fig. 4):

- 1) Lower aquifer that consists of sandstone
- 2) Lower aquiclude that it consists of marl
- 3) Upper aquifer that consists of Limestone
- 4) Upper aquiclude that it consists of marl

5) Shallow aquifer that is consisted of chalk and limestone

However, the groundwater recharge of these aquifers are mostly allocated within the population and urbanization-expanding zone.

There are tens of water researches that carried on water resources on Jordan but there are no one them that correlated the effect urbanization expanding on the water resources of Amman. Therefore, the objective of this research is to investigate the effect of the urbanization expansion on the surface and groundwater resources of Amman. Such a study would enhance a sustainable water resources management by generating a spatial plan that recommends where the urban expansion must move to and where water resources enhancement project such water harvesting needs could carried out.

2. Methodology

The integrated approach of remote sensing (RS) and Geographic Information Systems (GIS) is now widely used to study environmental hydrology and hydrogeology and understand water resource problems (Chou 1997, Saraf et al. 2004, Odeh et al. 2015, Jahan et al., 2021). The integration of RS and GIS allow easy storing, overlaying and analyzing the geo-data spatially in form of layers (Berndtsson and Larson 1987, Chou 1997, Saraf et al. 2004). The data that are related to water resources and urbanization are mostly in form of geo-data. Therefore, Water resources and urbanization could be spatially analyzed and modeled by integrated approach of RS and GIS (Chou 1997, Saraf et al. 2004, Odeh et al. 2015). Accordingly, the mentioned approach (Fig. 5) was used to evaluate the impacts of urbanization on water resources in Amman. It could be divided into two parts as follows:

1) Estimation the water balance equation parameters where the runoff would be representative for the surface water resource and the infiltration be representative for the groundwater recharge. There would be two scenarios where in the first is to estimate the runoff and infiltration assuming that there is no urbanization and the second is to estimate the runoff and infiltration with the layer of urbanization in order to evaluate the influence of urbanization on surface and ground water resources.

2) Generate a digitized groundwater level map, drainage network and catchment area borders that would be used to recommend which directions that urbanization and water harvesting have to toward for. The estimation of groundwater recharge was according to water balance equation as follows:

$$\text{Infiltration (I)} = \text{Precipitation (P)} - \text{Actual Evaporation (AE)} - \text{Runoff (R)} \quad (1)$$

The precipitation (P) in the study area is mainly rainfall. The rainfall patterns are the driving force for the groundwater recharge in the study area (Berndtsson and Larson 1987, Bouraoui et al. 1999). They were generated according to interpolation by Inverse Distance Weighted (IDW) method as the following equation (Chou 1997):

$$V_i = \frac{\sum_{j=1}^n \frac{1}{d_{ij}^p} V_j}{\sum_{j=1}^n \frac{1}{d_{ij}^p}}$$

n :The Number of cells that is taken to obtained the unknown value

V_i :Known rainfall value

d_{ij} :Distance between unknown cell value and known cell value

p :power

The mentioned interpolation was done by ArcGIS 10.3 that is generated by ESRI (Environmental Systems Research Institute) and using the extension spatial analyst. Then the patterns were converted to vector, so we estimate the evaporation, runoff, and infiltration for each pattern in the attribute of the vector.

The average rainfall values (mm/yr) of 30 years of ten climate stations were used. However, the average recorded temperature (T) degrees (°C) for the same period was distributed to the rainfall pattern in order to estimate the actual evaporation (AE) (mm/yr) according to the Blaney–Criddle equation as follow:

$$(AE) = (p) \cdot (0.457 \cdot (T) \text{ mean} + 8.128) \quad (3)$$

However, (p) value in the above equation is the actual daily daytime hours to annual mean daily daytime hours expresses as a percent (Schneider et al. 1973).

For the runoff, we used a coefficient that changes by the land cover and landforms the main two factors that controls overland flow in our case study. Accordingly, we classified the studied area with different runoff coefficient as follows (Schneider et al. 1973, Butler and Davies 2000):

- 1) Multi-units, attached urban with a runoff coefficient of 0.65 in the NNW and NNE of the study area.
- 2) Multi-units detached suburban with a runoff coefficient of 0.50 in the west and SW of the study area.
- 3) Steep non-clastic hard rock (mostly limestone) with a runoff coefficient of 0.35 in the east and NE of the study area.

We obtained groundwater level map for the studied area for the Federal Institute for Geosciences and Natural Resources so-called BGR. By ArcGIS 10.3 software we georeferenced the map and then digitized the groundwater level of the study area in form of shapefile (vector). The National Aeronautics and Space Administration (NASA) generated through Shuttle Radar Topography Mission (SRTM) 2000 a 30 m resolution Digital Elevation Model (DEM) for the study area. We extracted the drainage network water

divide and drainage network density by the Spatial analyst extension according to approach that is described by Odeh et al. 2015.

The Landsat image is one of the most common satellite images that are used to detect the land cover over on the land surface (Chou 1997, McMaster 2002, Szypuła 2016). We used a Landsat image 2014 with 8 bands and 30-meter resolutions. However, only the visible bands were used in order to carry out a supervised classification by minimum distance method to classify the study area into three classes: urbanization, rock, and soil. In the minimum distance method, we depend on vectors of each class and calculate the Euclidean distance from each unknown cell on the satellite image to the vector for each class. The cells are classified to the nearest class. Classifying the satellite image into only three classes has the advantages of high accuracy classification (Odeh et al. 2015, McMaster 2002, Szypuła 2016, Odeh et al. 2017).

3. Results And Desiccation

The urban area expands for accommodating the growing local and migrated inhabitants is a common process in the capital cities and governorates (Potter et al. 2009). Amman is a capital city and governorate that its urban area was expanded rapidly during the last decades as a result of the migrations fluxes from the surrounding countries and high population growth rate of the native people (Potter et al. 2009, Department of Statistics 2014).

Water resources and moderately climatic conditions are attractive factors for urban expansion (Schneider et al. 1973, Stephenson 2003). In general, human beings in Jordan don't prefer neither hot weather nor cold one and need water resources for drinking, constructions, agricultural activities and domestic usages (Odeh et al. 2017). However, the three mentioned factors allocated in the north west of the study area (Fig. 6). The high elevations and nearing the Mediterranean Sea generates moderately climate conditions in the North West while the highest rainfall quantity as a surface water resource and nearest depth to the groundwater level (groundwater resource) (Fig. 7) is in the northwest too.

The influence of urbanization in the water resources has not been studied adequately in yet Amman. The urban landscape has common negative effects on the hydrological cycle and hence on the water resources (Schneider et al. 1973, Saraf et al. 2004). This include increasing runoff, evaporation, and decreasing the infiltration and hence decreasing the groundwater recharge too (Jyrkama 2005). The influence of urbanization does not stop on the quantity but extends to effect the quality too. This is because the urbanization as landscape units has point sources for pollution such as wastewater treatment plants; wastewater pipes defects, fuel stations and factories that might be within the frame of the urban landscape (Butler and Davies 2000, Stephenson 2003).

Land policy use regulations in order to restrict how land can be used. It has great importance to specify and orient in where the urban expansion should be carried out (Schneider et al. 1973, Butler and Davies 2000, Potter et al. 2009,). Amman governorate was established by unprofessional land policy according to weak urban planning that led there is a capital mistakes in generating the spatial distribution of the

land use. Accordingly, the urbanization was expansion in our case study over the area that has the highest amount of rainfall because the citizen and the refuses were searching for moderately climate conditions (Potter et al. 2009, Perdeu 2014, Odeh et al. 2017,). However, the urbanization in that area increases the overland flow and generate in some regions in the city of Amman a flash flooding even which caused tragic economical losses reach up to tens of million American dollars since part of the flash flooding were outlet in shopping area spots (Potter et al. 2009, Perdeu 2014, Odeh et al. 2017). Figure 8 shows how the urbanization covered aggressively the water resources in the studied where it mostly condensed in the North West. Before the urbanization, the runoff of water was carrying out rivers in the governorate during the winter seasons. A famous river was in the downtown that is so called Sayl Amman (The Amman Creek) was killed by the urbanization (Potter et al. 2009, Perdeu 2014). Tens of springs their discharges were stopped as a results of decreasing the groundwater recharges where the elevations of groundwater level becomes below the elevation level of the springs (Salameh and Bannayan 1993, Potter et al. 2009, Perdeu 2014). However, we evaluated the influence of urbanization on the surface rainfall and then on the groundwater recharge according to the techniques of overlaying layers and then erased in GIS (Fig. 9). We found that this approach is very useful although it is simple.

Figure 10 shows the estimated groundwater recharge quantity before and after the urbanization. The groundwater recharge rates that were estimated by water balance equation were multiplied by the area of each pattern in order to have quantity and converted to thematic maps within GIS environment.

The highest amount of groundwater recharges are on the area of highest amount of rainfall in the North West are the urbanization is condensed too. We found that there are tremendous loss of groundwater recharge because of urbanization reach up to 55.00 MCM/year. This loss has a several negative impacts on the groundwater resources such as decreasing the groundwater level and increase depth to water rapidly, increase the groundwater salinity and decrease the discharge of the remain springs (Odeh et al. 2019). A further transient numerical groundwater model for the study area is a must to achieve a sustainable groundwater management for the study area (Jyrkama 2005, Odeh et al. 2015, Odeh et al. 2019).

There are several decisions that has to be taken from the decision and policy maker in order to stop the degradation in water resources of Amman in addition to the sustainable water resource management according to transient groundwater modeling as follows:

- A) There must be a land policy protect the groundwater recharge area from the attacking of urbanization. The zone of groundwater recharge is the same zone approximately of soil, forest and agricultural activity so the recommended policy would enhance protection of soil and the eco systems too.
- B) A river restoration project could be carried out in the downtown of Amman city in order to reduce the influence of flooding and improve the water resources in Amman.
- C) A water harvesting project for the flash floods that run during the winter must be carried out in the area that has a limited water resources in order to generate a sustainable water resources development.

Figure 11 shows the catchment basins in the study area. There are two factors that increase the probability of flash flooding: the high rainfall intensity and the small catchment area size (Bue and Conard 1967, Butler and Davies 2000). The two factors are available in the North West catchment areas. Furthermore, most of these catchments are covered by urbanization that trigger the runoff and hence the flash flooding.

Drainage network density is the measurement of the length of river channel per unit area of the catchment. It has the unit of km^{-1} . The hydrologist and geomorphologist use it in order to give vision about the landscape shape and runoff potential respectively (Bue and Conard 1967, Butler and Davies 2000). In our research, recognizing the potential of the runoff has great importance in order to specify the location of water harvesting sites. However, Runoff magnitude and hydrograph peak increase with drainage density (Butler and Davies 2000, Saraf et al. 2004).

In the south east of the study area there are larger catchment areas that have strong drainage network density (Fig. 12) that encourage us to recommend a water harvesting project there because the intensity of the drainage network intensity increase the efficiency of water harvesting. Such a water project would improve the urban development where the groundwater recharge is minimum and furthermore the soil units and ecosystems are limited there therefore the optimized area for urbanization would be there too in terms of soil and ecosystems management too.

Conclusions

High Population growth rate and refugees are common reasons for urbanization. Water resources are an attractive feature for urbanization in the arid region because of water scarcity and stress. Urbanization expansion has negative impacts on water resources in term of quality and quantity. However, this negative is extended to effect the soil availability, ecosystems and landscape. Urbanization plays a major role in controlling the hydrological cycle in the cities through increasing the runoff and evaporation. As a result the infiltration that represent the groundwater recharge would decrease too. Sustainable water resources management needs a professional spatial plan that controls the attacking urban expansion on water resources and moving toward the area that has less rainfall quantity, far groundwater level, away from any water creek or spring discharge. We found that river restoration and overland flow harvesting projects are requested in Amman governorate in order to enhance the resilience of the water resources.

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Figures

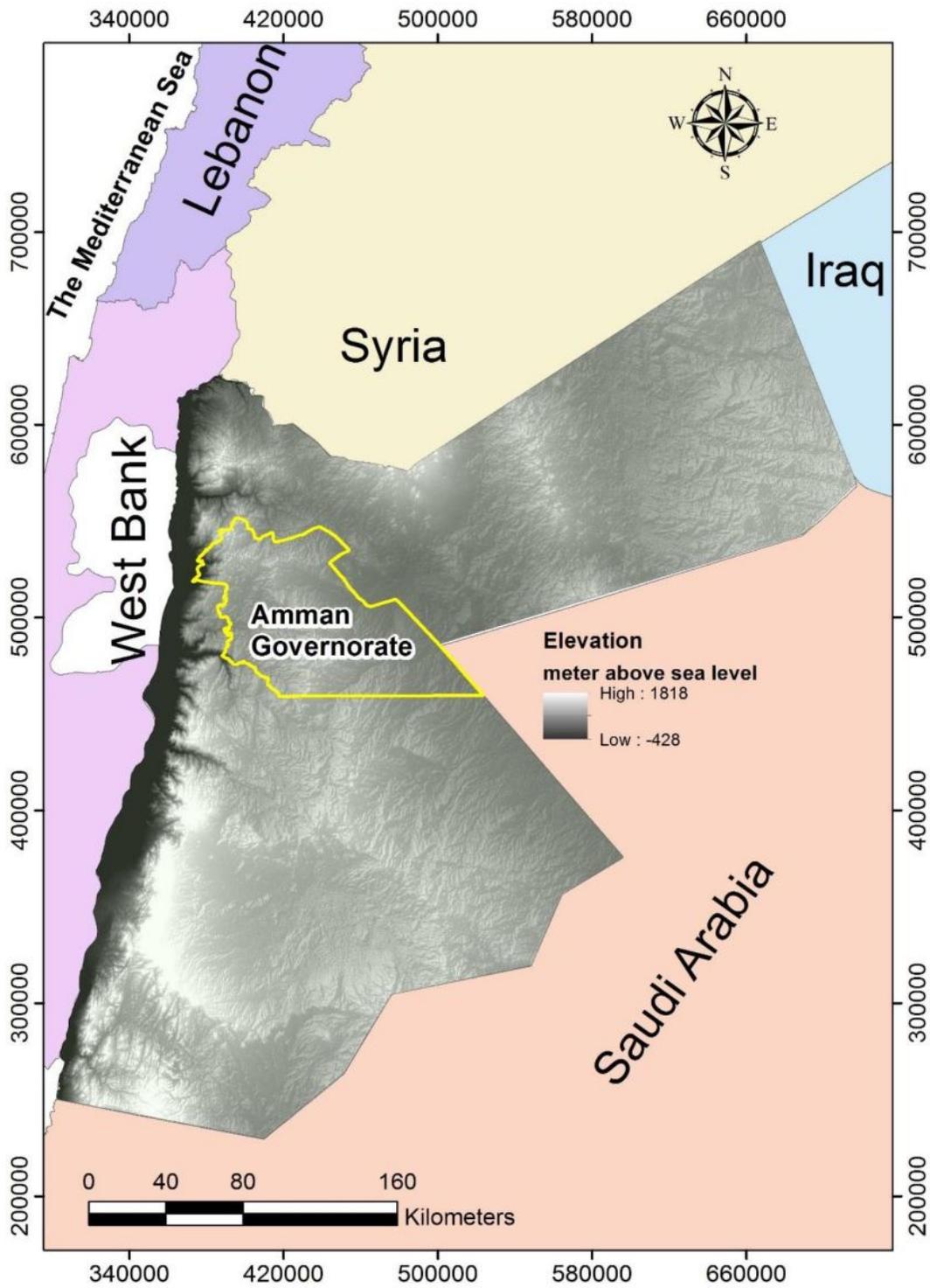


Figure 1

The location of the study area (Amman governorate). It is located in the north west of Jordan and has an area of about 7579 km².

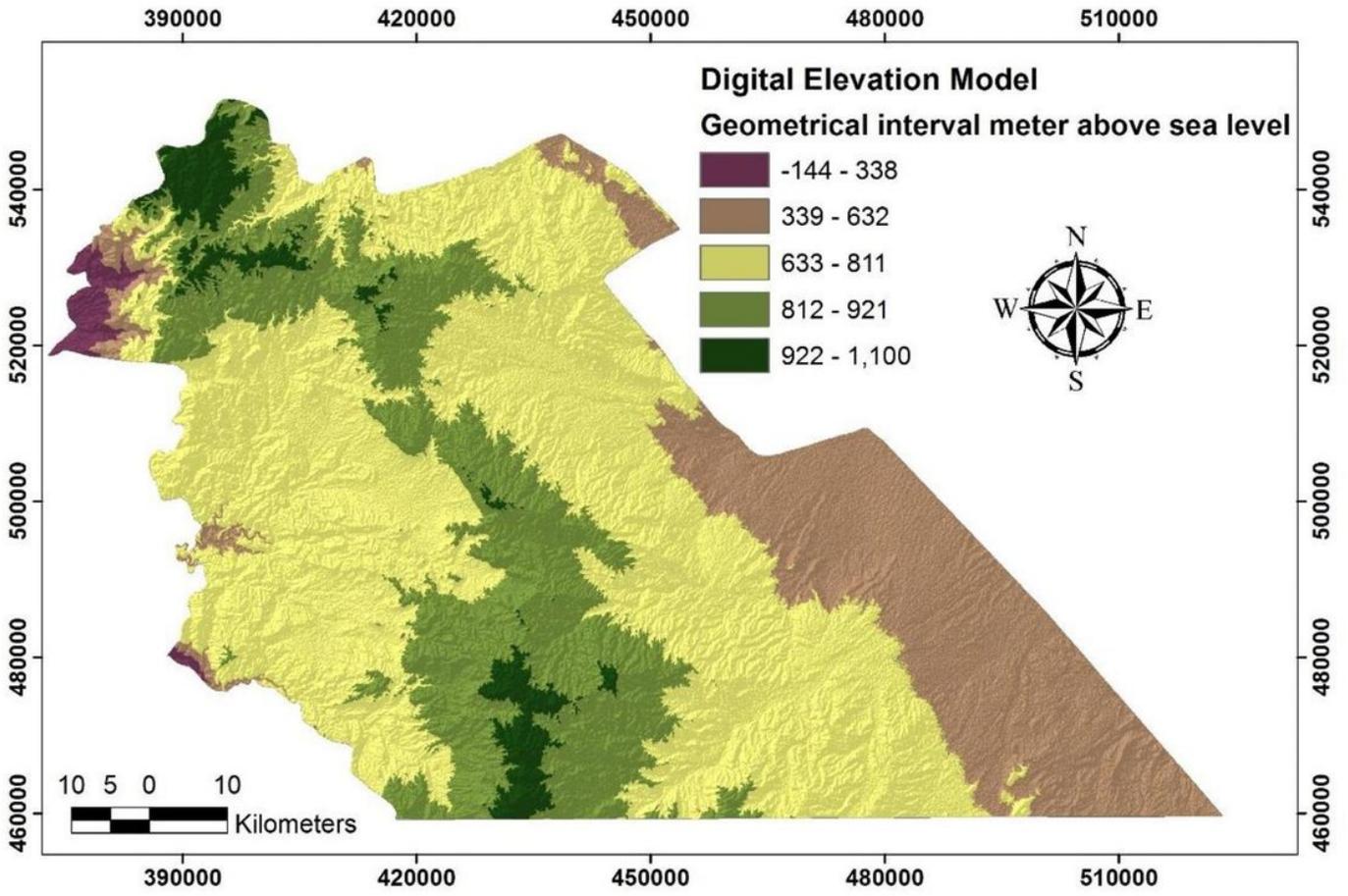


Figure 2

The topography of Amman governorate. It has a high relief topography and different geomorphological.

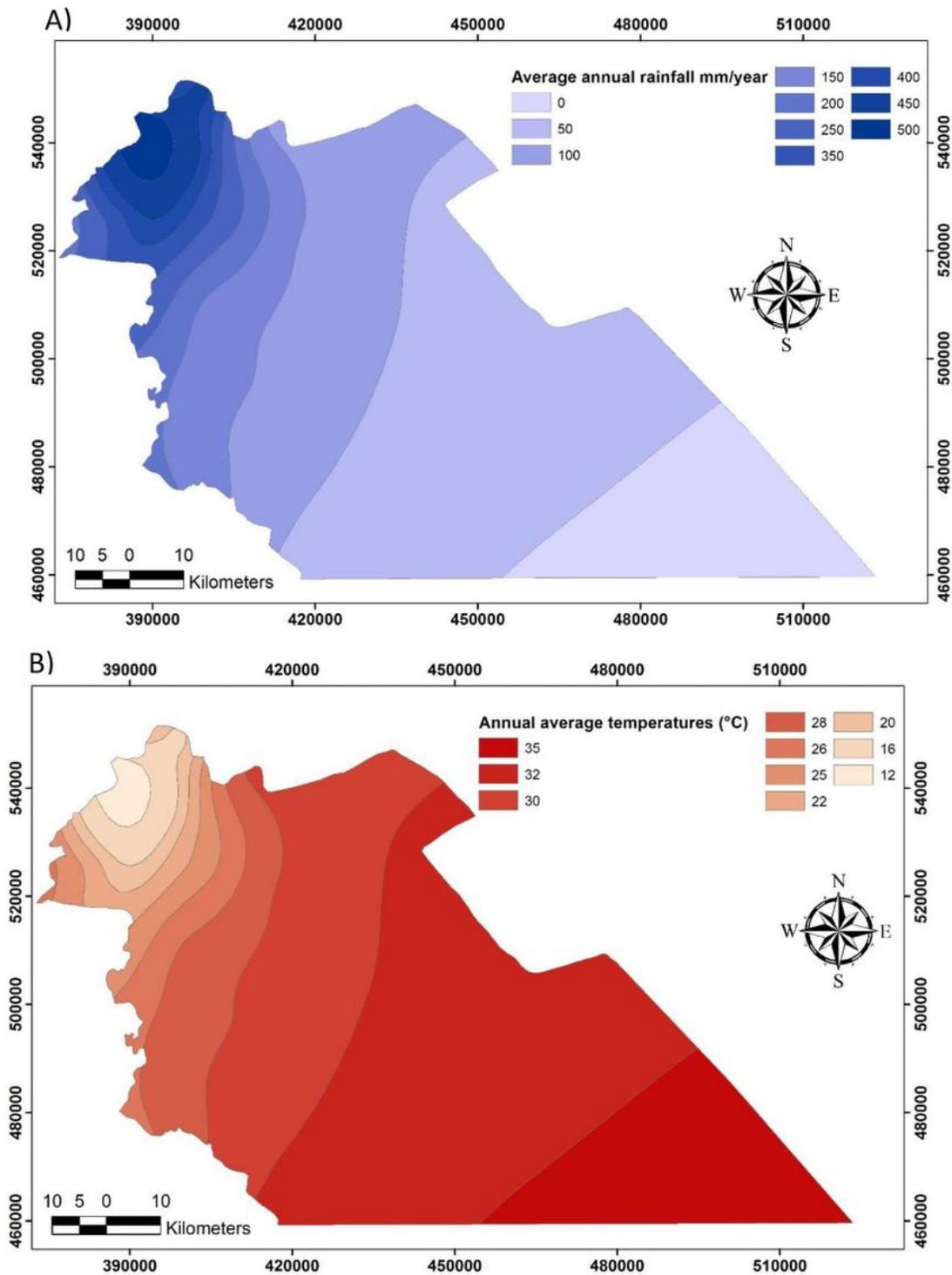


Figure 3

A) The rainfall patterns in Amman governorate. The highest amounts are in the northwest of the governorate. B) The temperature patterns in Amman governorate the highest values are in the southwest.

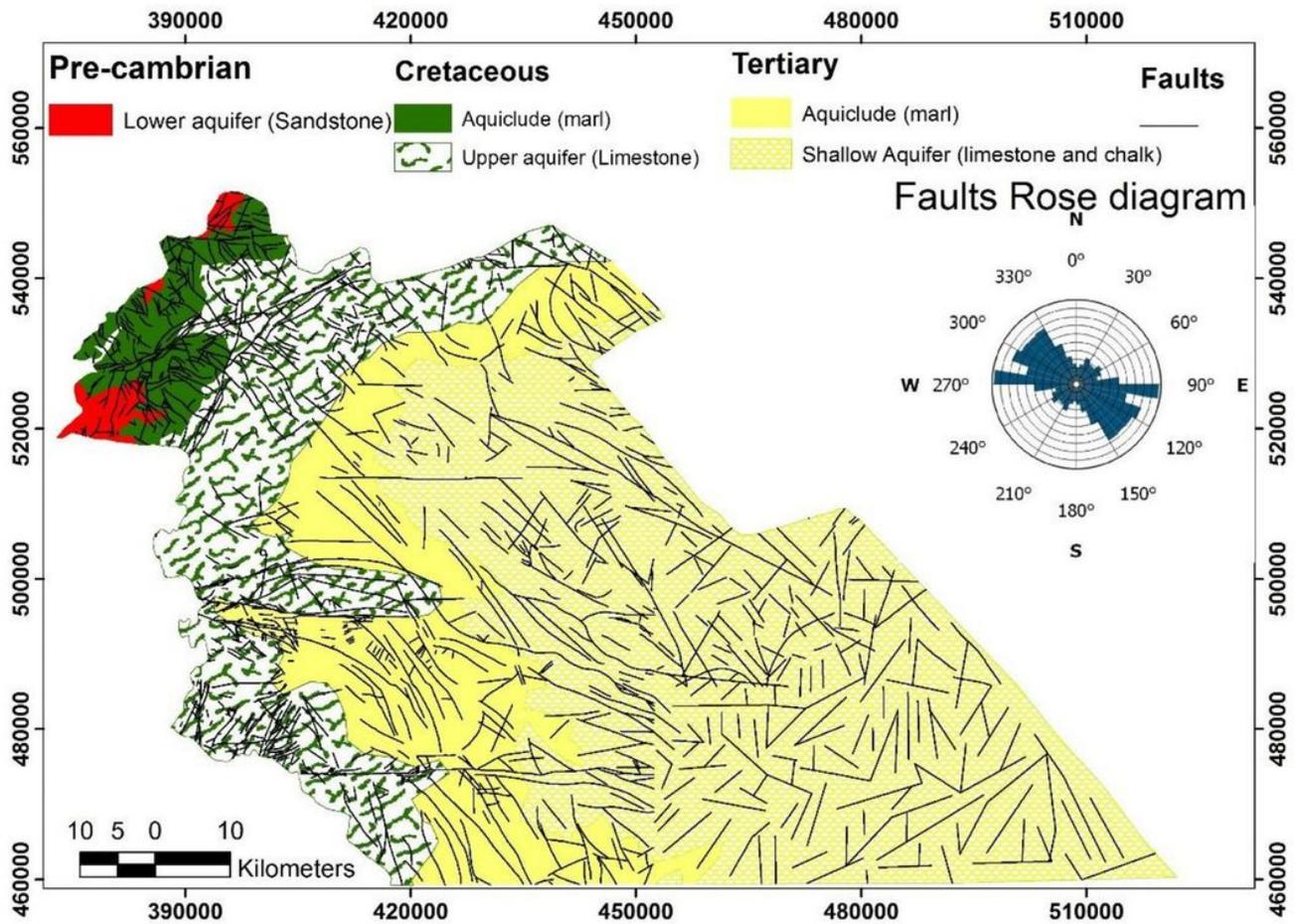


Figure 4

The hydrogeological map of Amman governorate (modified after NRA 2017). The hydrogeological units of the studied area are almost connected because of intensive faults.

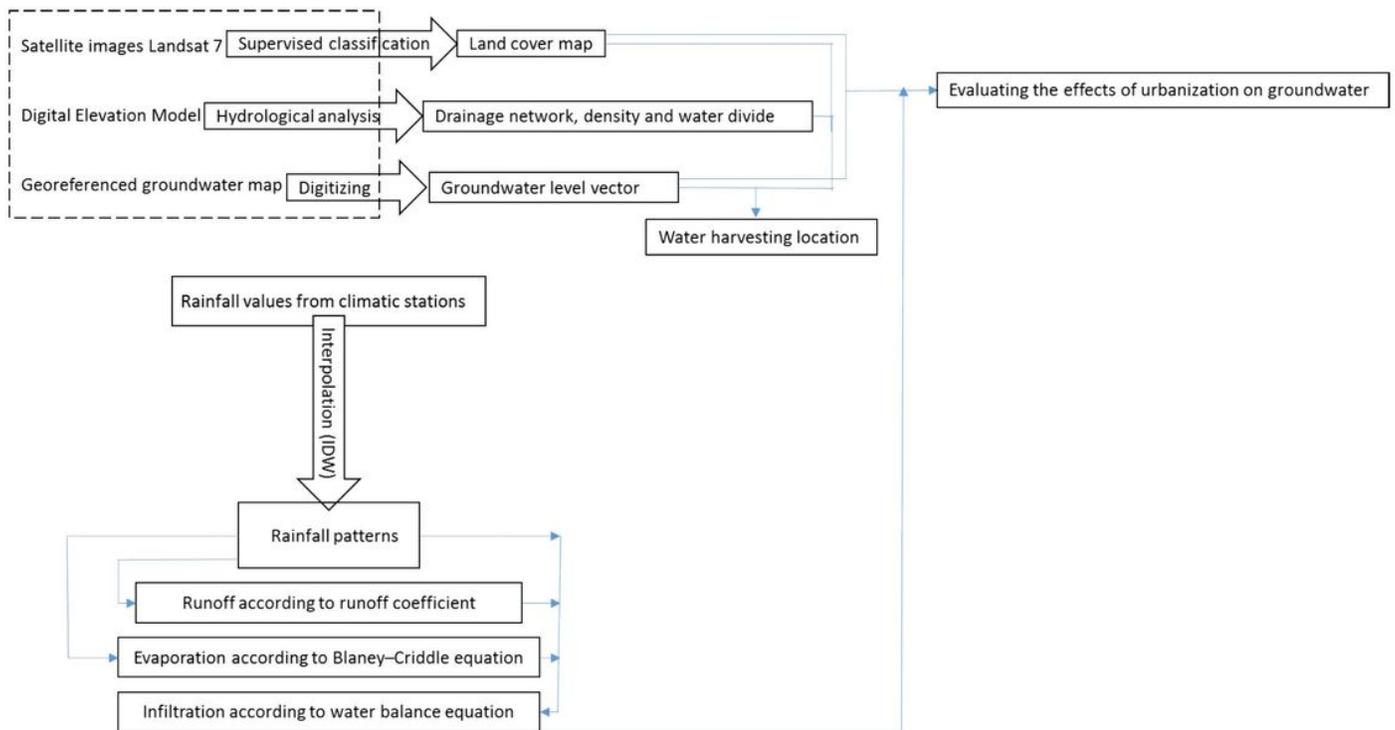


Figure 5

Integrated approach of remote sensing and GIS for evaluating the effects of urbanization on groundwater. ENVI 6 is the software that we used for supervise classification by minimum distance method for a landsat image 2016. ArcGIS 10.3 with spatial analyst-Hydrology extension was used for the hydrological analysis.

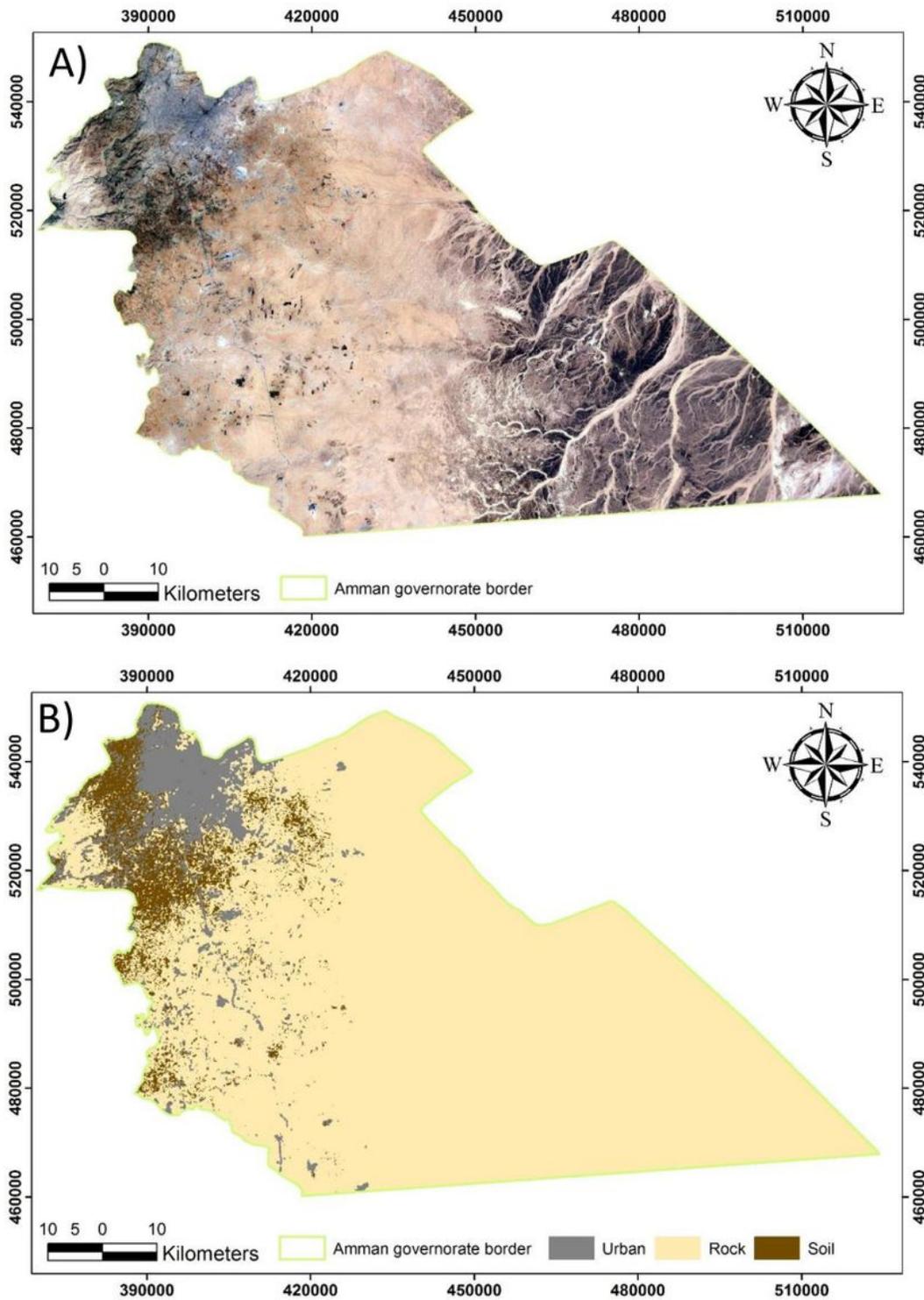


Figure 6

A) Landsat image 2019 for the study area. B) Land cover of the study area. The urbanization are expanding in the North West.

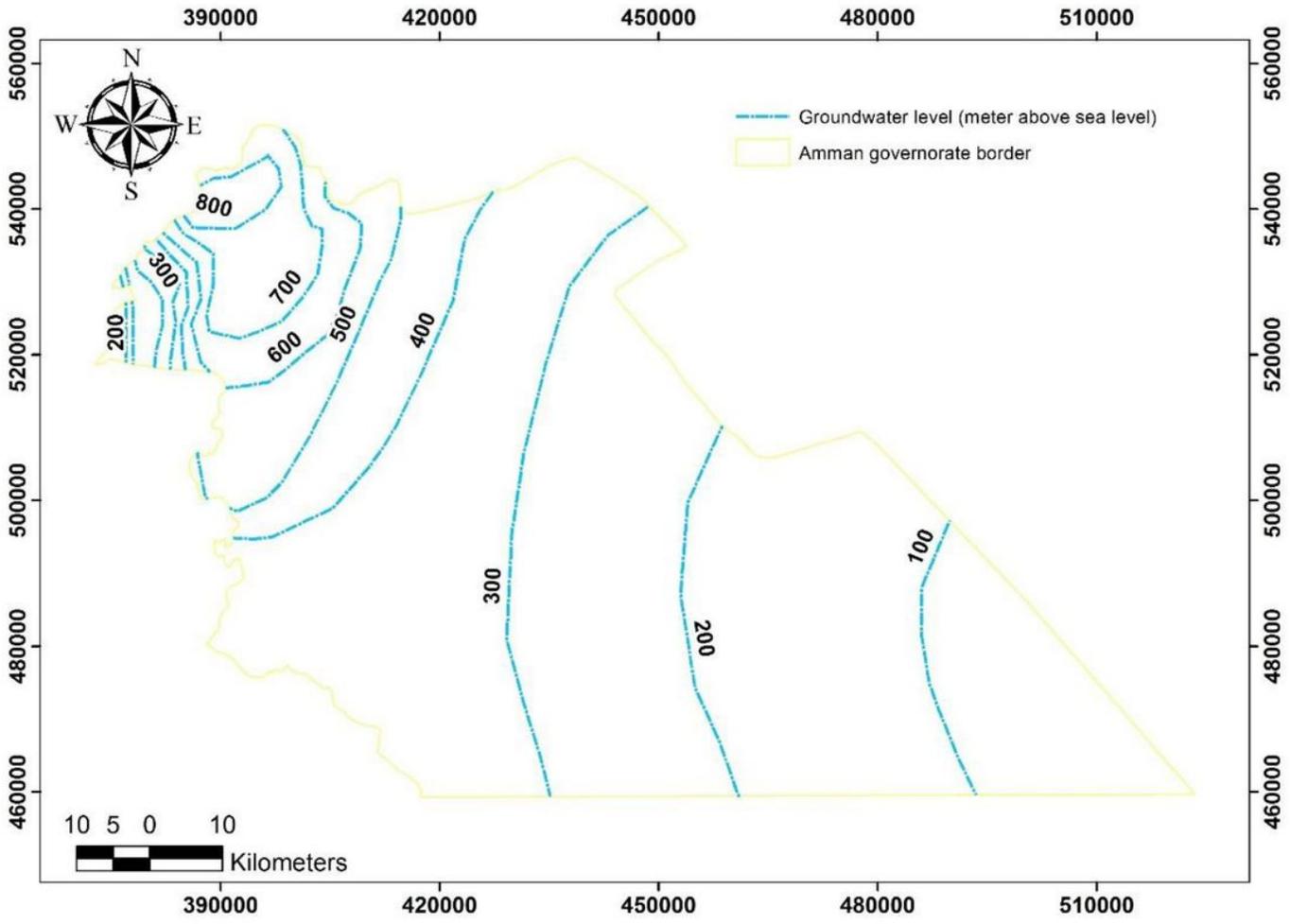


Figure 7

Groundwater level in the study area. The highest level of groundwater is located in the north west of the governorate.

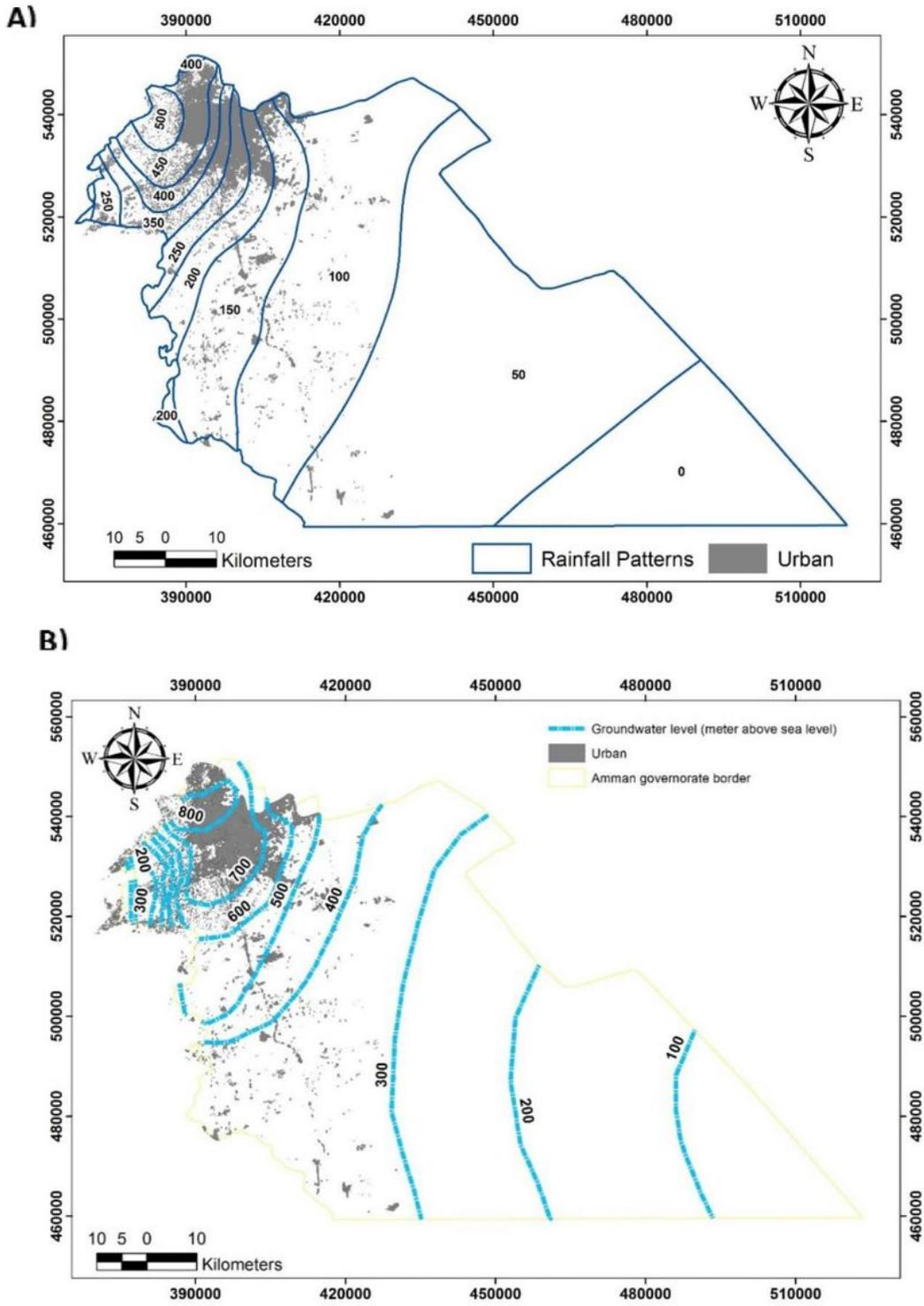


Figure 8

The attacking of urbanization on the water resources. A) Urbanization over the rainfall pattern and B) urbanization over the groundwater level.

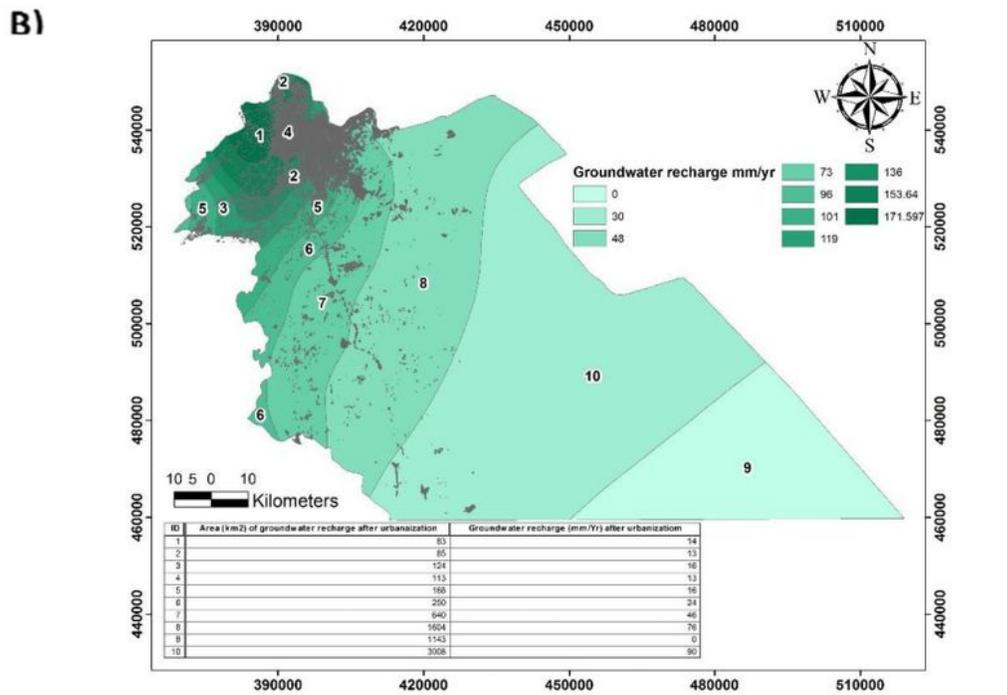
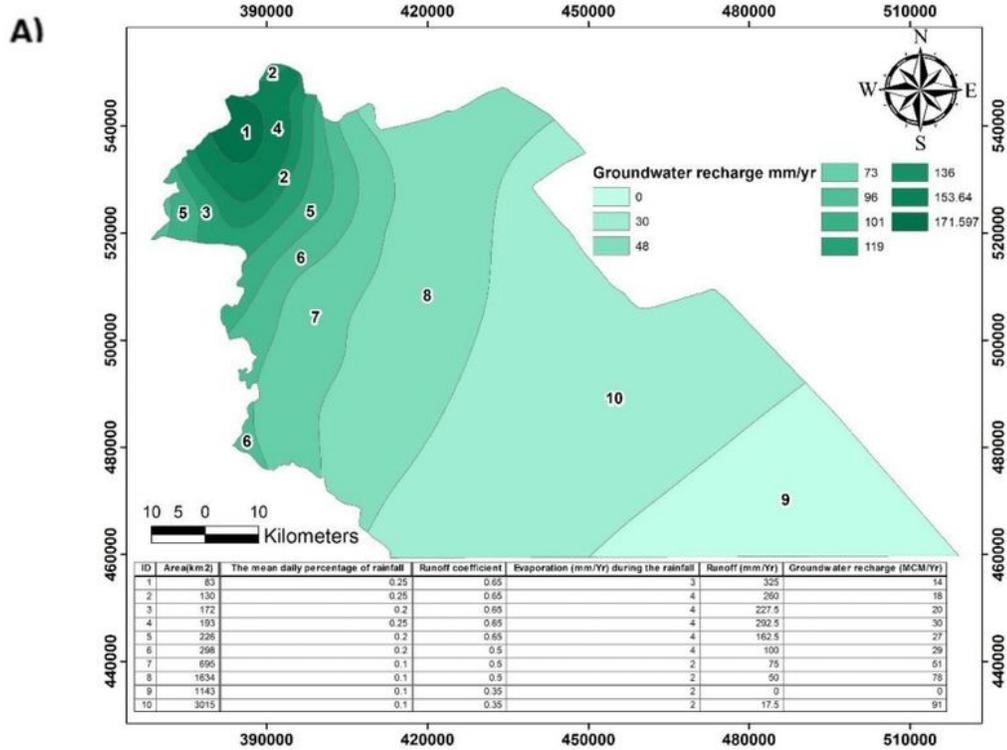


Figure 9

The influence of urbanization on the groundwater recharge quantity. A) The groundwater recharge quantity without urbanization and B) groundwater recharge quantity after the urbanization.

Groundwater recharge before and after the Urbanization

Total loss per year 50.00 MCM

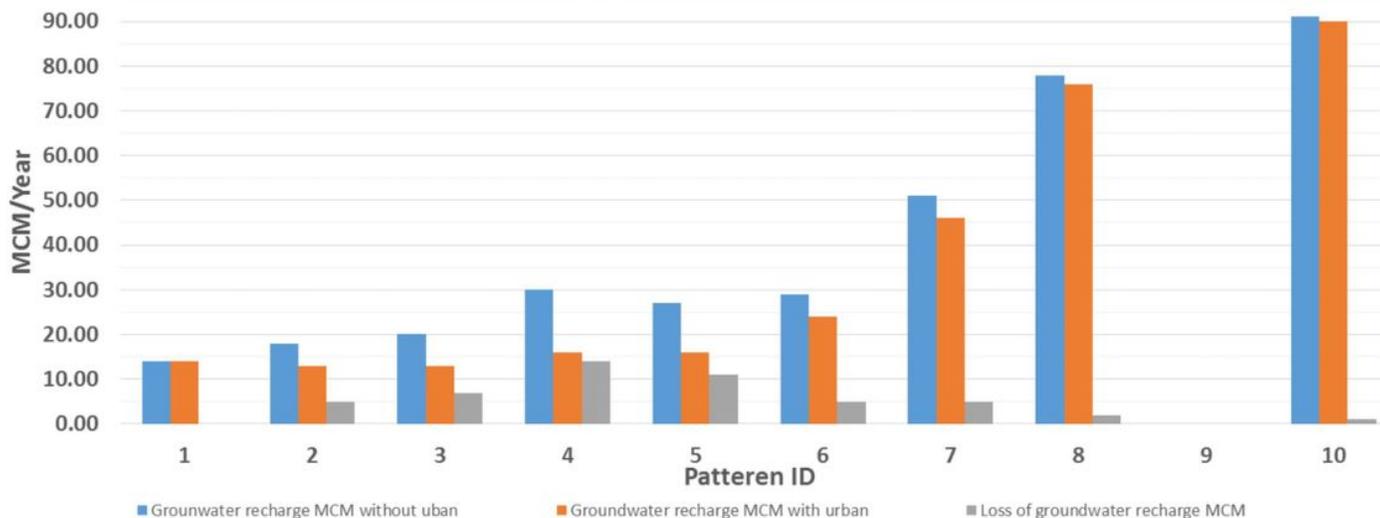


Figure 10

The groundwater loss over the groundwater recharge patterns because of the urbanization.

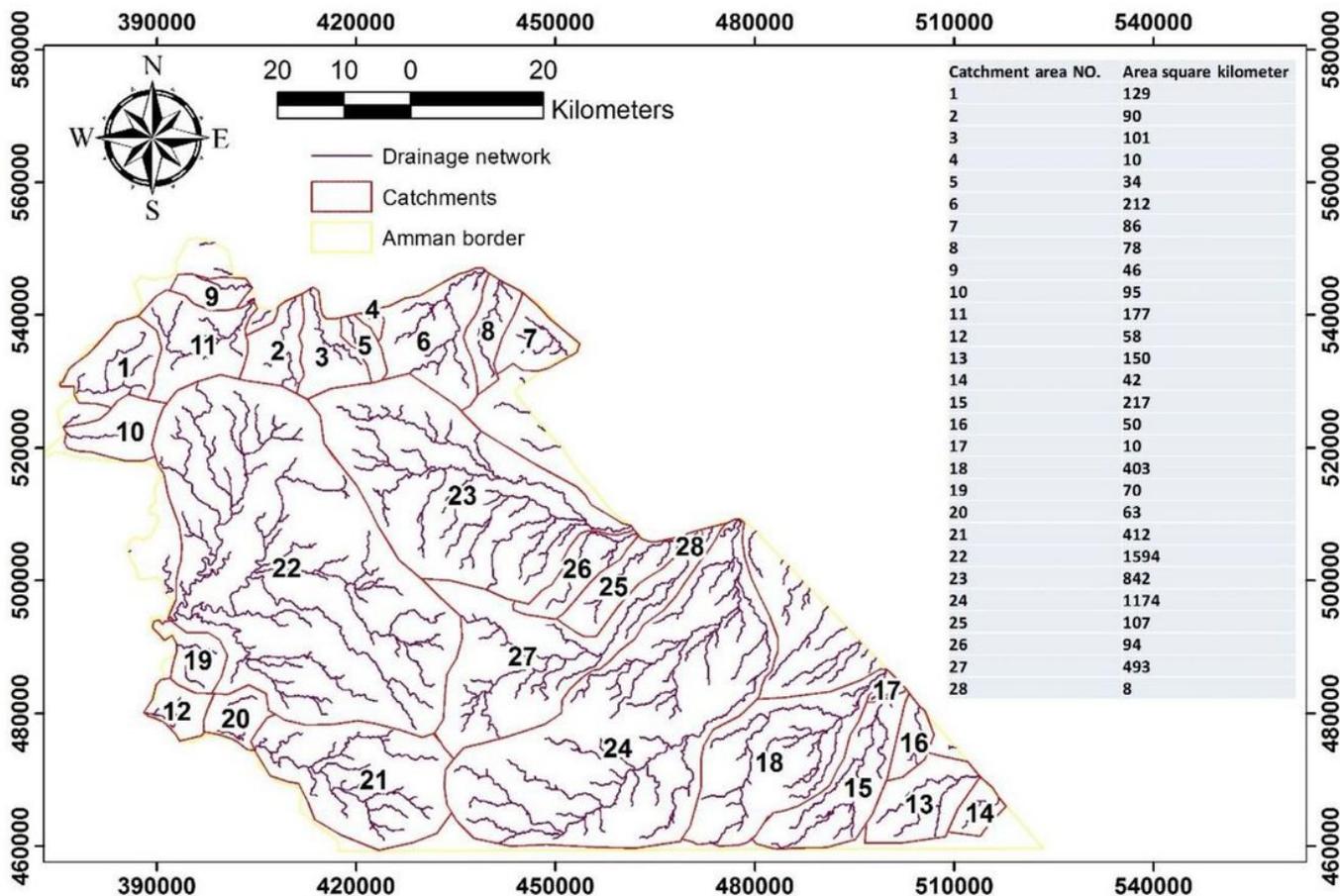


Figure 11

Catchment areas in the study area. The smallest catchment areas are mostly in the north of the governorate.

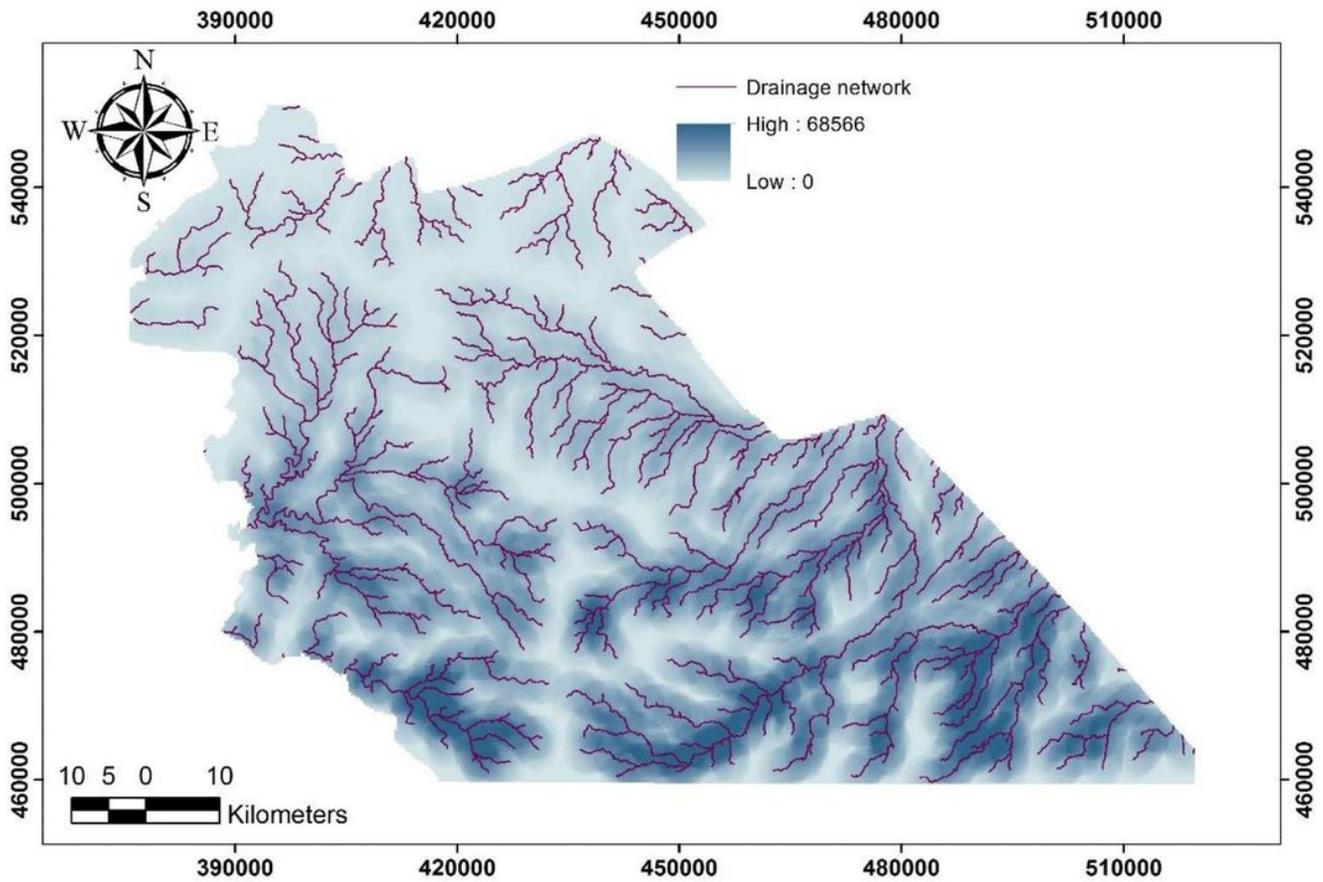


Figure 12

Drainage network density. The highest values of density is located in the south east of the governorate.