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The impacts of land-use change on the runoff characteristics using HEC-HMS model: A case study in Wadi Al-Mulaikhy sub-watershed in Sana’a basin, Yemen

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Abstract

Runoff is affected by several parameters such as climatology, soil type, and Land-use/cover, which includes vegetation cover and level of urbanization. The current study assesses the impact of Land-use/cover change between 1994 and 2018, on the runoff characteristics of Wadi Al-Mulaikhy Sub-watershed in the Sana'a basin, Yemen by integrated GIS, HEC-GeoHMS extension, and HEC-HMS model. Remote Sensing data, land-use/cover, soil type, and rainfall are the main input data were 3used. The study results showed that the agricultural area was reduced by 5.67%. Conversely the surface runoff and the maximum (peak) value of runoff for the overall study area have been increased by 1.65% and 1.27% respectively. It was found that there is no significant change in runoff volume relative to Land-use/cover change due to some agricultural general class changes to other classes (shrubs/brush), which has similar runoff characteristics, while the second change, agricultural general class changes to urban classes (high urban density, medium to low urban density and roads) which occurred north of the study area at the boundary of the city of Sana'a which has an urban expansion The changes in runoff parameters were found in the sub basin (W300, W310 and W320) which located in the north of the study area due to the changes of agricultural general class changes to urban classes (urban high density, urban medium to low density and roads).

Key Words: Runoff, Land-use/cover, GIS, HEC-HMS, Agriculture, Runoff, Sanaa basin, Yemen

1. Introduction

Water is the most essential natural resources for living species. Since the available amount of water is limited, scarce, and not spatially distributed in relation to the population needs, proper management of water resources is essential to satisfy the current demands as well as to maintain sustainability (Geremew, 2013).

Water availability in Sana'a City, capital of Yemen, is one of the scarcest in the world. The region has no perennial surface water runoff, and is practically entirely depend on the use of groundwater. Over-exploitation in Sana'a Basin is causing the groundwater table to deplete at an alarming rate with a water table drawdown of about 3 meters per annum, is amongst the worst affected areas in the country (Al-Derwish, 2014).

Change in runoff characteristics induced by urbanization is important for understanding the effects of Land-use/cover and cover change on earth surface hydrological processes. With urban land development, impervious land surfaces expand rapidly, the capability of rainfall detention declines sharply and runoff coefficient increases. Urbanized land usually leads to a decrease in surface roughness; hard road and drainage system can greatly shorten the time of runoff(Shi et al., 2007).

Remote Sensing and Geographic information system(GIS) provide effective tools for Land-use/cover planning and modeling. Land-use/cover is an indicator of human interaction with nature. Therfore, it is necessary to discover and monitor Land-use/cover changes in order to either protect the environment or ensure sustainable development(Mousazadeh et al., 2015).

Hydrological modeling is a commonly used tool to estimate the basin's hydrological response due to precipitation. It allows to predict the hydrologic response to various watershed management practices and to have a better understanding of the impacts of these practice (Choudhari et al., 2014).

Several studies have been conducted using the HEC-HMS model in different regions under different soil and climatic conditions. The model was found accurate in spatially and temporally predicting watershed response in event based and continuous simulation as well as simulating various scenarios in flood forecasting and early warnings(Choudhari et al., 2014). From regional perspective there have been abundant researches on the impact of land-use change on runoff. Some of them used lumped models and the others used distributed and semi-distributed models to estimate the runoff characteristics, and each of these models has their own merits and demerits. (Mistry et al., 2017; Köylü and Geymen, 2016; Nachshon et al., 2016; Ajmal et al., 2015; Tiwari et al., 2014; Ramakrishnan et al., 2009; Shi et al., 2007; Noman, 2016) calculate the surface runoff by using SCS-CN method. Other studies calculated runoff volume by using semi-distributed models(Maisa'a et al., 2017; Sajikumar and Remya, 2015; Ngo et al., 2015; Maalim et al., 2013; Hundecha and Bárdossy, 2004).

In this study the impact of Land-use/cover change on surface runoff characterstics in Wadi Al Mulaikhy sub-watershed in Sana'a basin between 1994 and 2018 by using Land-use/covers digitized manually from aerial photo and satellite image with high spatial resolution. HEC-GeoHMS extension was used to create and export SCS curve number Method to HEC-HMS model. HEC-HMS model. Most of the previous studied used SCS-CN method separately or with other models. In this study we used SCS curve number losses method with HEC-HMS model because It is semi-distributed model, which mean the spatial geographic variations of characteristics and process are considered explicitly, It is an empirical model built up on observation of input and output, without seeking to represent explicitly the process conversion, their structure is more physically-based than the structure of lumped models, they are less demanding on input data than fully distributed models, it is an event model simulate single storm and the model is partially allowed to vary in space by dividing the basin into a number of smaller sub-basins. The objectives of the current paper can be summarize as flows: (1) Produce Land-use/cover maps of the Wadi Al Mulaikhy sub-watershed in Sana'a basin, (2) Assess the change in land-use between 1994 and 2018, (3) Assess the change in surface runoff volume between 1994 and 2018 by using HEC-HMS model.

2. Data and methods

2.1. Study area and data acquisition

Study area is located in Wadi Al Mulaikhy in the southern part of the Sana'a Basin and it shows in (Figure1). The total area is (63.2) km^2 . The wadi is located in the upstream of Sana'a Basin and has one major stream that extends from south to north. Its coordinates between (1687890 to 1675760 N) longitude and (407908 to 418001 E) latitude. The average monthly temperature from National Water Resource Authority (NWRA) records 1989-1997 ranges between about 15 and 25 C. The annual rainfall elevation is249 mm (JICA, 2007). The data analysis of the present study was carried out using available data:

- Aerial photo (1994) with spatial resolution one meter was obtained from General Authority of Land, survey and Urban Planning and satellite image (2018) with spatial resolution 60 cm from google earth.

- Digital Elevation Model (DEM) map at a resolution of 20*20 m was obtained from Yemen Remote Sensing Center.
- Soil map with spatial resolution 30 second was obtained from Harmonized World Soil Database (HWSD).

The processing of images was made using ArcGIS version 10.4.1 software and HEC-GeoHMS extension was used to create the basin model.

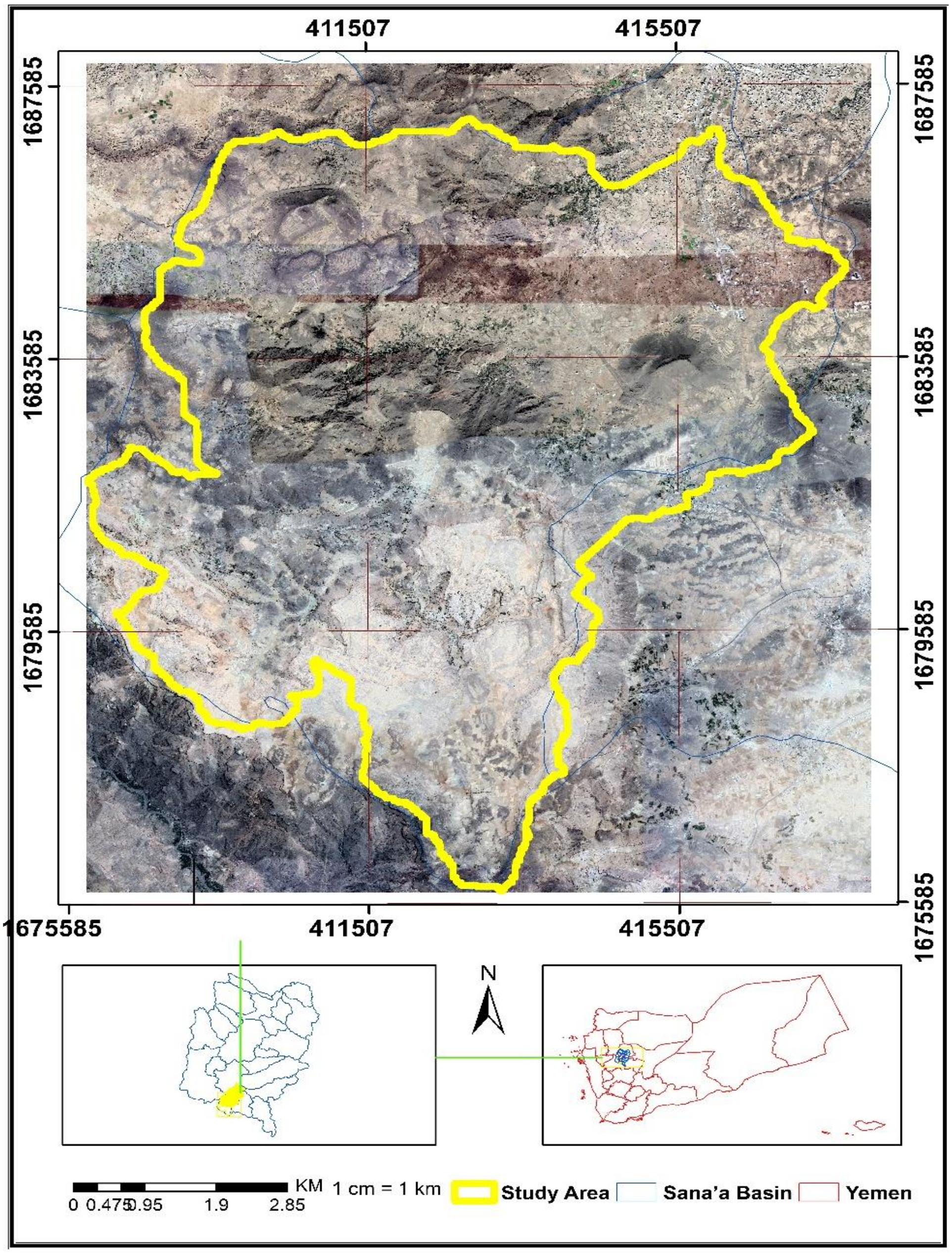

Figure1 . Location map of the Wadi Al Mulaikhy sub-watershed in Sana’a basin

2.2. Land-use/cover classification and mapping

The geo-referencing operation for the aerial photo (1994) and satellite image (2018) of the study area was performed depend on the digital map of the Republic of Yemen. The coordinate system was set on Universal Transverse Mercator (UTM) zone 38 north WGS84. Land-use classification was digitizing manually, and classified the study area into six Land-use/cover classes including: Urban High Density, Urban Medium to Low Density, Agriculture General, Barren/Minimal Vegetation, Shrub/Scrub, and Roads. The total area of each Land-use/cover category for the year 1994 and 2018 were calculated.

2.3. Creation the basin model

The basin model was created by using HEC-GeoHMS GIS extension functionality in ArcMap. The first step was delineating the stream network and watershed boundaries of the study area. This process is commonly referred to as terrain preprocessing and is entirely based on the input digital elevation mode (DEM). The GRID files which were derived from the DEM Fill Sink Grid, Flow Direction Grid, Flow Accumulation Grid, Stream Definition Grid, Stream Segmentation Grid, and Catchment Grid. The vector layers were created based on the previous computational steps which was divided Wadi Al Mulaikhy into seven sub basins in layers catchment polygons, Drainage line, and Adjoint Catchment (Figure 2). The hydrologic modeling was based on the SCS Curve Number Loss Model. This method only requires the definition of a single input parameter curve number (CN). The CN depends on the land-use, the hydrologic soil group, and the hydrologic condition of the top soil. The Land-use/cover classification, the semi-arid climatic characteristics of the area, the CN table for arid and semi-arid rangeland were used with hydrologic soil group map for creating CN grid numbers. The basin model file contains the hydrological data structure which includes the hydrologic elements, their connectivity, and related parameters. HEC-GeoHMS can export some of the hydrologic parameters to HMS basin model file. Background map, basin file, and meteorological model file were created by generate rainfall gage grid layers and import it to HEC-GeoHMS geodatabase.

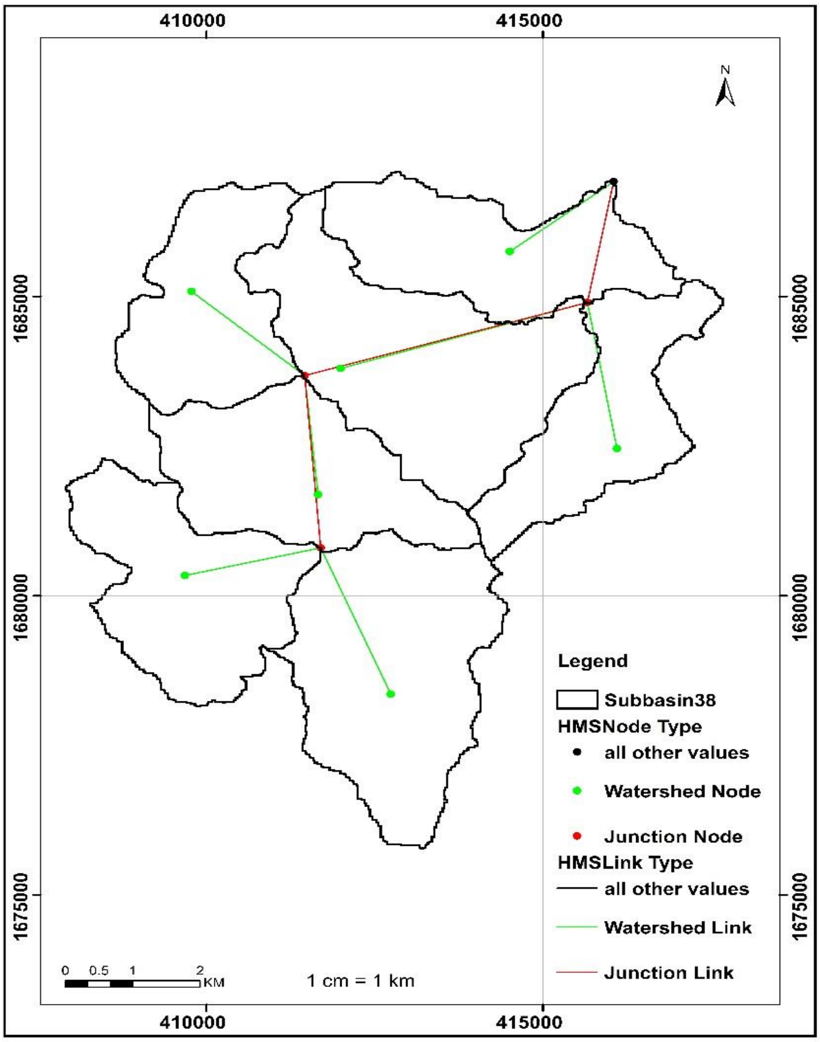

Figure 2. Model representation of Wadi Al Mulaikhy Watershed in HEC-GeoHMS

2.4. Model completion in HEC-HMS Model

The basin model was imported into a HEC-HMS project by using the HEC-GeoHMS data export to HMS function. The model consists of 7 basin, 8 junctions, 4reaches, and the basin outlet. In addition to the basin model the meteorological model, the performance of simulation of runoff volume for the years 1994 and 2018 in HEC-HMS by using SCS curve number losses method. The basic runoff equation of the CN method is shown in Eq (1).

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \qquad (1)$$

Where, Q = runoff (mm), P = rainfall (mm), S = potential maximum retention after runoff begins (mm), Ia= initial abstraction.

The initial abstraction includes all the losses that occur before surface runoff begins. According to the NRCS (2004), it contains water retained in surface depressions as well as water intercepted by vegetation, evaporation and infiltration. In the CN model, Ia is assumed to be correlated to S through Eq (2).

$$I_a = 0.2\,S \qquad (2)$$

The maximum retention S is further related to the soil and cover conditions of the analyzed watershed through the CN by Eq (3).

$$S = \frac{25400}{CN} - 254 \qquad (3)$$

In the HEC-HMS modeling process, the incremental excess rainfall for each computation time interval is calculated as the difference between the accumulated excess at the end of and the beginning of the period. The cumulative excess Pe is computed with Eq(4).

$$P_e = \frac{(P - 0.2\,S)^2}{P + 0.8\,S} \qquad (4)$$

3. Results and discussion

3.1. Land-use change

Land-use/cover maps of the study area in 1994, and 2018 which was generated manually, include land-use categories for agriculture general, barren/minimal vegetation, Shrub/Scrub, roads, urban high density and urban medium to low density. The area of each Land-use/cover type of different years and the changes procedures over 24 years are shown in (Table. 1)which indicates that most of the area of Wadi Al Mulaikhy covered by barren/minimal vegetation distributed throughout the basin for the two periods of time 1994 and 2018 and agriculture general also distributed throughout the study area. Shrub/Scrub areas are covering a small area and spread in the north and middle of the basin. The low, medium and high density of urban areas are located in the northeast of the study area. The land-use classification of 1994 (Figure 3) was compared to the Land-use/cover classification of 2018 (Figure 4) to identify the area where the main changes between 1994 and 2018 occurred. The results of land-use changes showed a decrease in the agriculture general Land-use/cover category. (Table. 1) shows that the area of Wadi Al Mulaikhy sub-watershed under the land-use classes Urban High Density, Urban Medium to Low Density, Barren/Minimal Vegetation, Shrub/Scrub and roads increased (1.5%, 0.22%, 0.53%, 2.84%, 0.55%) respectively with total increase 5.65km^2 about 8.96%. Whereas the agriculture general has decreased by about 5.65% over 24 years period. The major changes within agriculture general class changes to Shrub/Scrub and urban with high and medium to low-density classes (2.8% and 1.7%) respectively. The major increased of the urban area occurred on the north at the boundary of the study area due to urban expansion of Sana,a city, that entered Wadi Al Mulaikhy sub-watershed in addition to the simple conversion of agricultural general Land-use/cover class to roads, Shrub/Scrub and Barren/Minimal Vegetation.

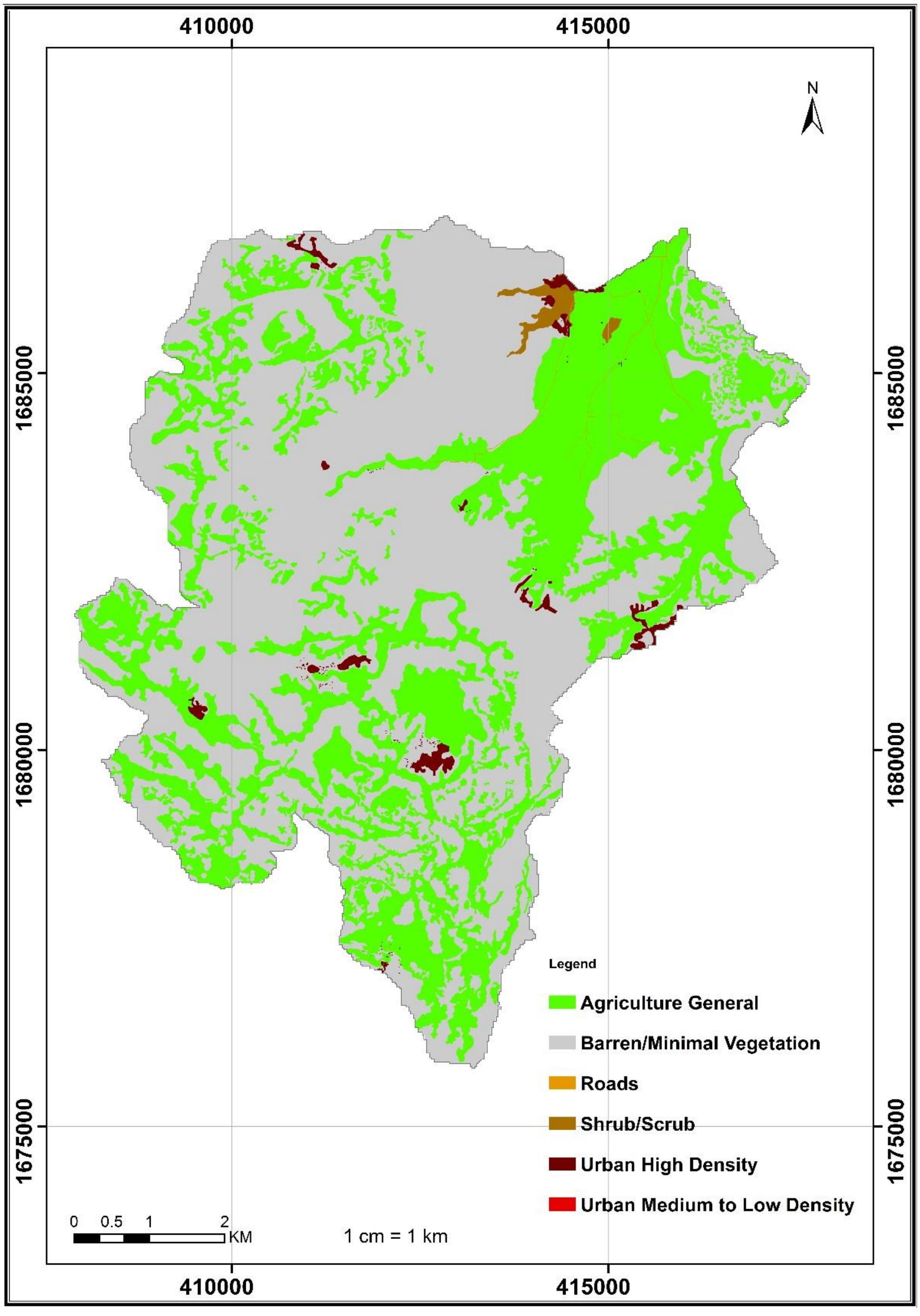

Figure 3. Land Use Map of Wadi Al-Mulaikhy Sub-watershed in 1994

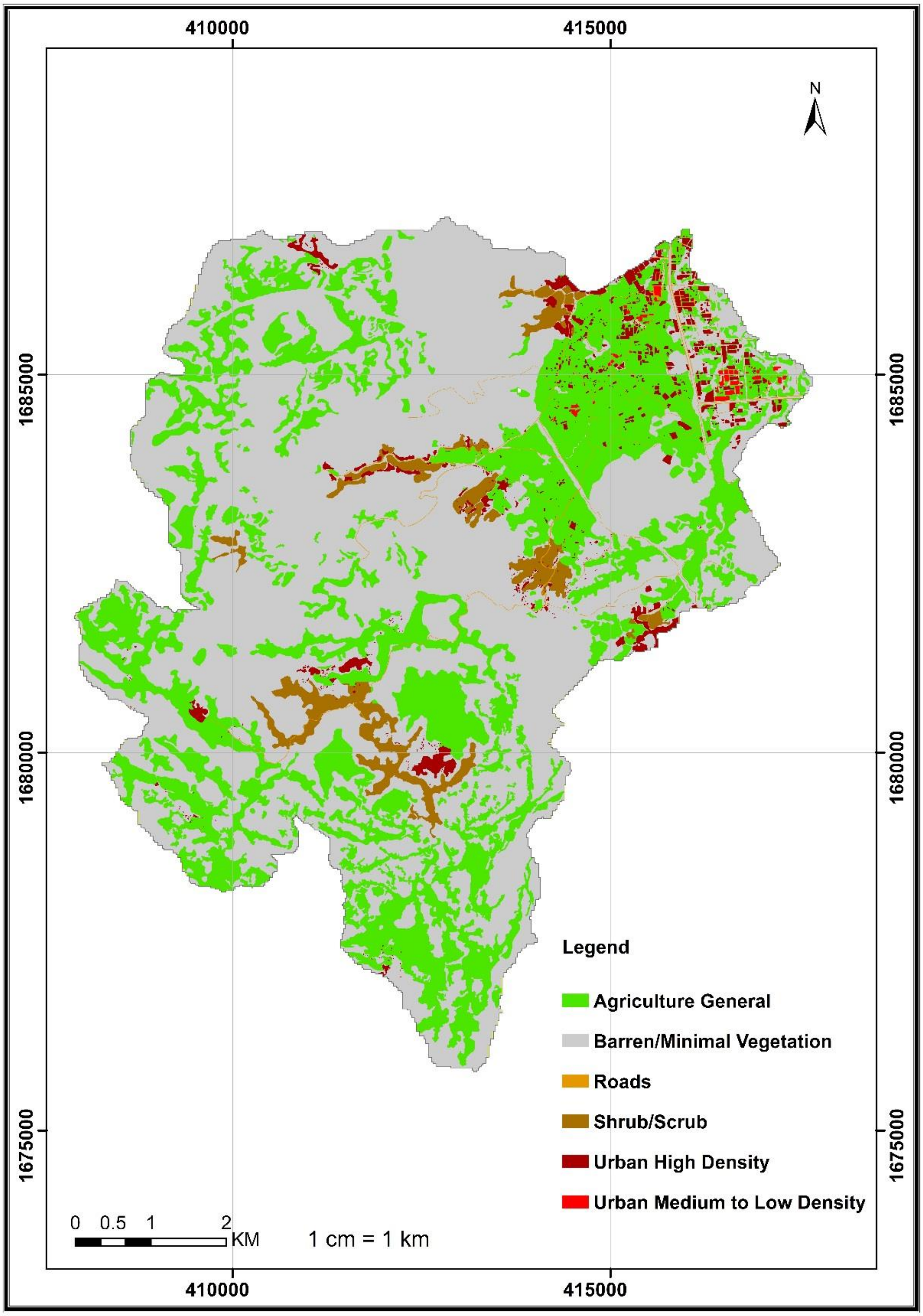

Figure 4. Land-use/cover Map of Wadi Al-Mulaikhy Sub-watershed in 2018

Table. 1 Total estimated area of each Land-use/cover classes in Wadi Al-Mulaikhy Sub-watershed in 1994 and 2018

N	Land-use classes	Area 1994 in(km^2)	Area 1994 %	Area 2018 in (km^2)	Area 2018 %	Change percent
1	Urban High Density	0.62	0.98	1.57	2.49	1.51
2	Urban Medium to Low Density	0	0	0.13	0.22	0.22
3	Agriculture General	24.14	38.32	20.57	32.65	-5.67
4	Barren/Minimal Vegetation	37.86	60.09	38.19	60.62	0.53
5	Shrub/Scrub	0.32	0.50	2.11	3.35	2.84
6	Roads	0.05	0.089	0.40	0.63	0.55
Sum		**63.00**	100	**63.00**	100	

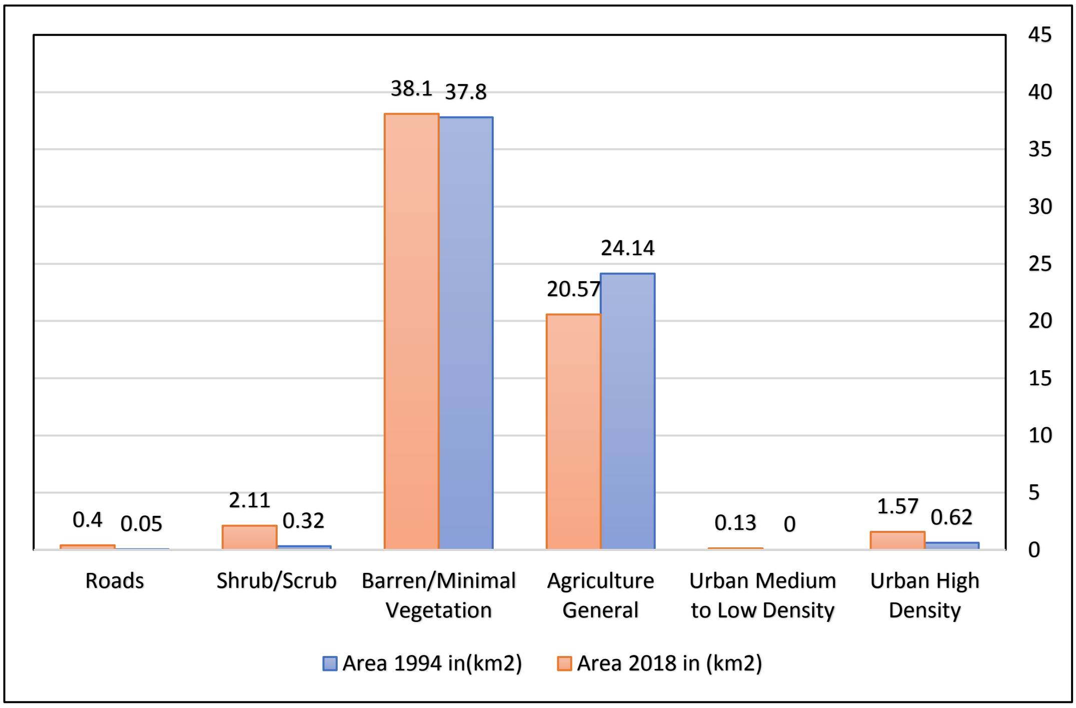

Figure 5. The comparison of land use classes area in Wadi Al-Mulaikhy Sub-watershed between 1994 and 2018

3.2. Runoff changes

As previously mentioned, the HEC-HMS model was used to calculate runoff volume for the two Land-use/cover periods (1994, 2018). The results of runoff changes are related to Land-use/cover changes for the periods 1994, 2018 are presented in Table*2* . Modeling results indicated that the largest volume of runoff in 2018 ($129.2*10^3$ m^3/year), and the volume of runoff in 1994 ($127*10^3$ m^3/year). Thus, it increased by 2100 cubic meter about 1.652% over 24 years (Figure *7*). The peak discharge in the outlet in 1994 is 1319.5 m^3/s increased to 1336.5 m^3/s in 2018 about 1.27% (Figure. 6). The results of land-use changes between the two periods, indicating that the total change in Land-use/cover categories increased by 5.66% in the categories (urban high density, urban medium to low density, barren/minimal vegetation, Shrub/Scrub, and roads) by (1.5%, 0.22%, 0.53%, 2.84%, and 0.55%) respectively, and 5.66% decreased from agriculture general. Since the increased in urban high density and urban medium to Low Density 1.7% and in roads to 0.5% and 3.6% increase in barren/minimal vegetation and shrub/scrub. The decrease in agriculture general 5.66% means an increase in the volume of runoff 1.652% and peak discharge 1.27% due to the increase in Urban High density and urban medium to Low density 2.06.

Table2 . Total Runoff Volume Wadi Al-Mulaikhy Sub-watershed in 1994 and 2018

Ser No	**Sub-Basin**	**Drainage area km^2**	**Peak discharge (m^3/s) 1994**	**Runoff volume (1000 m^3) 1994**	**Volume (mm)**	**Peak discharge (m^3/s) 2018**	**Runoff volume (1000 m^3) 2018**	**Volume (mm)**
1	W300	7.9154	147.1	138.5	17.42	158.8	153.1	19.24
2	W310	12.6014	250.4	240.6	19.10	251.2	241.7	19.18
3	W320	6.9156	125.8	118.3	17.11	132.5	126.5	18.29
4	W330	6.9256	155.6	152.2	21.85	155.4	151.9	21.81
5	W340	8.4888	193.3	189.5	22.32	192.7	188.8	22.24
6	W350	8.5128	197.1	191.0	22.44	196.6	190.3	22.35
7	W360	11.6458	250.2	240.7	20.67	249.4	239.6	20.58
Outlet			1319.5	1270.9	20.15	1336.5	1291.9	20.48

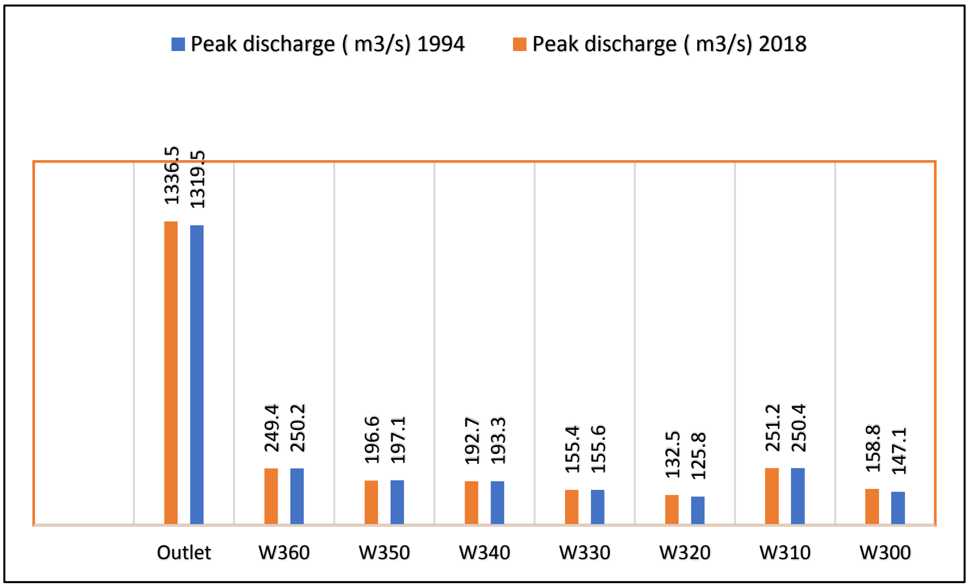

Figure. 6 The comparing of peak discharge in Wadi Al-Mulaikhy Sub-watershed in 1994 and 2018

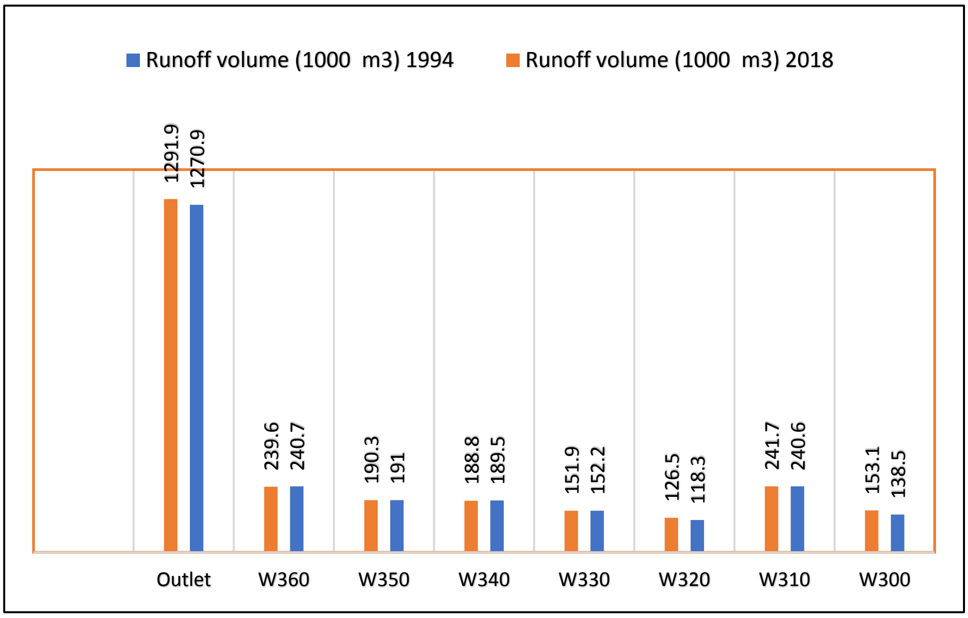

Figure 7. The comparing of Runoff Volume in Wadi Al-Mulaikhy Sub-watershed in 1994 and 2018

3.3. CN Values

The average of the curve number (CN) values for Land-use/cover in the years 1994, 2018 (88.69, 89.46) respectively (Table*3*). The increase in CN values from 88.69 in 1994 to 89.46 in 2018 an increased in surface runoff values Table*3* . A comparison of CN values for each sub-basin showed that there is an increase in CN values in sub-basins W300, W310, and W320 which were agricultural general lands converted to the urban area due to the urbanization of Sana'a city due to its location at the boundary of the study area.

Table3 The Comparing of CN for Land-use/cover classes in Wadi Al-Mulaikhy Sub-watershed in 1994 and 2018

Ser No	Sub-Basin	Area (km^2)	CN (1994)	CN (2018)
1	W300	7.9154	86.17	89.56
2	W310	12.6014	89.02	89.19
3	W320	6.9156	86.11	88.37
4	W330	6.9256	90.97	90.92
5	W340	8.4888	91.13	91.01
6	W350	8.5128	89.02	88.90
7	W360	11.6458	88.43	88.30
Average			88.69	89.46

3.4. S Values

This parameter describes the state of water-saturated soil after runoff begins. So, the factor S is related to soil type and Land-use/cover, which is reflected in the CN values. Near-zero S values indicate the low potential for soil water retention after the surface runoff, increasing surface runoff (Table4). S values decreased from 32.5 in 1994 to 29.94 in 2018. Thus, Low S values lead to a decrease in the water retention potential of soil after surface runoff. By comparing S values in the sub-basins, we found a decrease in S values in the sub-basin W300, W310, and W320, which is converted from agricultural general to urbanization.

3.5. Ia Values

Reflects the initial abstraction, which means that water loss by evaporation, plants, and infiltration. The low value of initial abstraction (Ia) that is close to zero indicates low water losses before surface runoff, which helps to generate the surface runoff quickly (Table*5*).

Table4 . The Comparing of the Maximum Retension(S) for Land-use/cover classes in Wadi Al-Mulaikhy Sub-watershed in 1994 and 2018

Ser No	Sub-Basin	Area (km^2)	S (1994)	S (2018)
1	W300	7.91	40.76	29.60
2	W310	12.60	31.32	30.78
3	W320	6.91	40.97	33.42
4	W330	6.92	25.21	25.36
5	W340	8.48	24.72	25.09
6	W350	8.51	31.32	31.71
7	W360	11.64	33.23	33.65
Average			32.50	29.94

The average value of Ia increased from 13 in 1994 to 11.97 in 2018, resulting in a decrease in water loss and an increase in surface runoff. The comparison of Ia with Ia, which calculated from global Land-use/cover. The Ia for global Land-use/cover has increased to 22.84, resulting in increased water loss and decreased the surface runoff.

Table5 The Comparing of the Initial Abstraction (Ia) for Land-use/cover classes in Wadi Al-Mulaikhy Sub-watershed in 1994 and 2018

Ser No	Sub-Basin	Area (km^2)	Ia (1994)	Ia (2018)
1	W300	7.9154	8.15	5.92
2	W310	12.6014	6.26	6.15
3	W320	6.9156	8.19	6.68
4	W330	6.9256	5.04	5.07
5	W340	8.4888	4.94	5.01
6	W350	8.5128	6.26	6.34
7	W360	11.6458	6.64	6.73
Average			13.00	11.97

4. Conclusions

The impact of Land-use/cover change of the years 1994, 2018 for Wadi Al Mulaikhy sub-watershed in Sana’a basin on surface runoff using HEC-HMS model shows that.

1- The major change in Land-use/cover classes were identified agricultural general class converted to other classes (urban high density, urban medium to low density, barren/minimal vegetation, Shrub/Scrub and roads)

2- The impact of Land-use/cover change on runoff characteristics is only exists through the conversion of 5.65% from agricultural general class to the classes (urban high density, urban medium to low density, barren/minimal vegetation, Shrub/Scrub and roads) by (1.5%, 0.22%, 0.53%, 2.84% and 0.55%) respectively.

3- The runoff volume increased from 1270900 million cubic meters of the year 1994 to 1291900 million cubic meters in the year 2018 about 1.625% over 24 years period. The peak discharge increased from 1319.5m^3/s to 1336.5 m^3/s about 1.27%.

4- It was found that there is not big change in runoff volume comparing with the change in Land-use/cover due to some of agricultural general class changes to other classes (Shrub/Scrub), which has the similar runoff characteristics, while the second changes from agricultural general class changes to urban classes (urban high density, urban medium to low density and roads) which occurred in the north of the study area at the boundary of Sana'a City which has urban expansion.

5- The average of CN values increased from 88.69 in the year 1994 to 89.46 in the year 2018. The average of S values decreased from 32.5 in the year 1994 to 29.94 in the year 2018. While, the average of Ia values decreased from 13 in the year 1994 to 11.97 in the year 2018.

6- The changes in runoff parameters were found in the sub basin (W300, W310 and W320) which located in the north of the study area due to the changes of agricultural general class changes to urban classes (urban high density, urban medium to low density and roads).

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