Impact of Land Use/Cover Changes on the Flow of the Zarqa River in Jordan

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ABSTRACT

This paper investigated the impact of land use/cover changes on the flow of the Zarqa River in Jordan over a period of twenty-eight years. The land use/cover maps were derived using a set of medium spatial images with full scenes for the years 1989, 2002, 2011 and 2017. These images correspond to the river flow data for the same hydrological rainy seasons. The component of the river flow consists of the base-flow, flood and contribution of effluent from treatment plants. Base-flow was separated from hydrographs and effluent contribution was obtained. Runoff coefficient was determined as the ratio of flood volume to rainfall volume. The land use/cover maps were classified as urban fabrics, bare rocks, open rangelands and bare soils, agricultural areas, agro-forestry, and water bodies. During the study period, urban areas increased from 4.87% to 16.14%, and agricultural areas increased from 21.69% to 31.66%. The areas of rangelands and bare soil decreased from 34.91% to 22.57% and bare rocks from 35.98% to 27.57%, respectively. The increase in urban and agricultural areas resulted in runoff coefficient improvement from 1.89% in 1989/1990 to 2.72% for 2016/2017. The results could be useful for planners and decision makers for future flow management in the Zarqa River Basin. The approach and results of this study confirm the findings of similar studies for land and water management.

Keywords: river flow, flood, land use/cover changes, runoff coefficient, planners and decision makers

INTRODUCTION

The land use/cover information is the basic pre-requisite for land and water resource utilization, conservation and management. It is used to protect the water resources necessary for sustaining human life (Demir et al. 2007). The information on land use/cover are available today in the form of thematic maps, where earth features such as water, urban, forest, exhibit typical spectral response pattern that enables for target identification, such as assessing the impact of land use/cover changes on river flow (Cook 1945; Gautam et al. 2000; Shammout 2003). Land use/cover change and climate variability are two major

factors controlling the hydrological responses, but the dominant role in the hydrological responses is played by the land use/cover change (Berihun et al. 2019). It is widely known that changes in land-use/cover, such as conversion of forest land into cropland or grazing land, and urbanization, can increase surface runoff (Chow et al. 1988).

Land use/cover change is a major challenge facing the global environment (Kates and Torrie 1998). This change in land use/cover, when coupled with climate change, could potentially lead to an increased risk of flooding in urban catchments. The influence of land use/cover change on surface runoff has been investigated in many studies. They examined the impacts of land use/

cover changes on floods, e.g. in Australia (Chen and Yu 2013), and in south-eastern United States (Nagy et al. 2011) as well as studied the water resources and land use and cover, indicating that the forest removal leads to more variable flow. In Italy, the results of land use change impact on flooding areas showed an increase in flood peak and a decrease of the rangelands, forests, and bare lands, indicating a good correlation between flooding areas and land use changes (Apollonio et al. 2016). In the city of Ghent, the results showed that grasslands contribute the most to storm water runoff reduction, and forests controlled the lowest runoff (Li et al. 2020). (Shanableh et al. 2018) confirmed that the expansion of built areas progressively increased the impervious land cover in the coastal city of Sharjah, and significantly increased the runoff coefficient.

In developing countries, the rapid increase in population pressure has pronounced effects on the land use/cover dynamics, mainly through deforestation aimed at increasing agricultural production (Maitima et al. 2009). These changes are causing alterations of the land surface and also have a great impact on hydrological processes such as surface flow, groundwater recharge, infiltration, interception, and evapotranspiration (Costa et al. 2003; Shammout et al. 2013). Most of the studies agree that the expansion of agricultural lands and the growth of urban areas at the expense of vegetation cover and forest significantly increase the surface runoff potential in a given watershed. (Yin et al. 2017) showed that the water resources subjected to land use/cover and climate changes, affected surface runoff differently between decades due to the combined effects of land use/cover and climate changes. The impact of urbanization through assessing the relationship between urbanization, runoff, floods and rainwater harvesting provides a basis for developing sustainable urban storm water management practices for the cities. Hence, proper land management may increase the amount of surface storage, rate of infiltration, and capacity of the soil to store water. Without proper land use management, the alterations of the land surface on hydrological processes will be continued and mainly exhibited in river flow. Moreover, the amount of surface storage, rate of infiltration, and capacity of the soil to store water will be also decreased (Chow et al. 1988; Shammout et al. 2013; Chen et al. 2017; Xu et al. 2017).

This study was conducted for the Zarqa River Basin (ZRB). It investigated the impact of land use/cover changes of ZRB on the flow of the Zarqa River over a period of twenty-eight years. This basin is located in Jordan, where surface water resources in Jordan are mainly scattered between 15 basins. One of the major basins is ZRB and it is well recognized as one of the most important basins with respect to its economic, social and agricultural importance. It is the second main tributary to Jordan River. ZRB is the most affected area suffering from several quality and quantity water problems. These problems are due to the scarcity of water which is a result of the wide fluctuations in annual rainfall and climate change, population growth, urbanization, and inappropriate land uses which resulted in watershed degradation. Accordingly, management tools should be adopted by planners to minimize this degradation. For this purpose, the translation of available real historical data of land use/cover images into responses of change for the river flow is essential for understanding, assessing, and managing the ZRB. The specific objectives were (1) to analyse the land use/cover distributions of the years 1989, 2002, 2011 and 2017, (2) to assess the impact of land use/cover changes on the responses of the river flow for the hydrological rainy seasons; 1989/1990, 2001/2002, 2010/2011, and 2016/2017, and (3) to compare the change in runoff coefficient as a result of land use/cover changes over the targeted years.

METHODOLOGY

Study Site

The Zarqa River Basin (ZRB) drains an area of 4120 km², about 95% of which is within Jordan and only 5% is in Syria. The basin extends from the Syrian city of Salkhad in Jebal al-Arab with an elevation of 1,460 m to south of Amman. Administratively, ZRB is located in five governorates, namely; Amman, Balqa'a, Zarqa, Jerash, and Mafraq. The ZRB hosts more than 50% of Jordan's population (10.5 millions). The basin discharges its water at the confluence of the Zarqa River with the Jordan River at an elevation of about –350 m. The streamflow of the Zarqa River is impounded at King Talal Dam (KTD), the largest Dam in Jordan, South-West of Jerash town. There are several

wadis draining in the ZRB, such as Wadi Dhuleil, and Wadi Zaatari. The runoff gauge station at Jerash Bridge on the Zarqa River is the only gauge station in the whole basin (Al-Qaisi 2015) which has the continuous long recorded database and possibly sufficient to be suitable for flood evaluation, as it is located at the entrance of the KTD from the east (Shammout 2003). Figure 1 shows the Zarqa River Basin.

The soils of the ZRB differ widely according to the rainfall and climate. The basin is mainly located in northern highlands dissected limestone and the north Jordan basalt plateau (Al-Bakri 2008). In the west, the prevailing soil textures are clay and clay loams. Toward the east, the soil becomes more immature with silty loam to loamy in texture with very high carbonate content. These soils have weak structure and suffer from low infiltration rate, resulting from the presence of surface crust. Land and water use in the ZRB has undergone considerable changes. Recently, the expansion of Amman and the surrounding towns

has been enormous, thus reducing the grazing land and fertile agricultural lands between Amman and other towns. The expansion was developed into a large urban conglomerate. In the north and north western parts, the ZRB is capable of supporting forests and agricultural activities. Natural forests occur in the mountainous part and agriculture within the basin is divided into agroforestry, rain-fed orchards and olives, field crops as well as irrigated agriculture. Historically, irrigation was practiced on the banks of the river, while during the last three decades, it expanded in the northern and middle parts of the basin, particularly in the Mafraq governorate where the irrigated areas nearly tripled during 1990–2014 (Al-Bakri 2008). The total irrigated area of the basin reached 18 thousand ha in year 2014 (Al-Bakri 2016). This resulted in increasing the demand and pressure on the limited groundwater resources of the basin.

The basin includes four municipal wastewater treatment plants (TPs), namely, Khirbet es-Samra
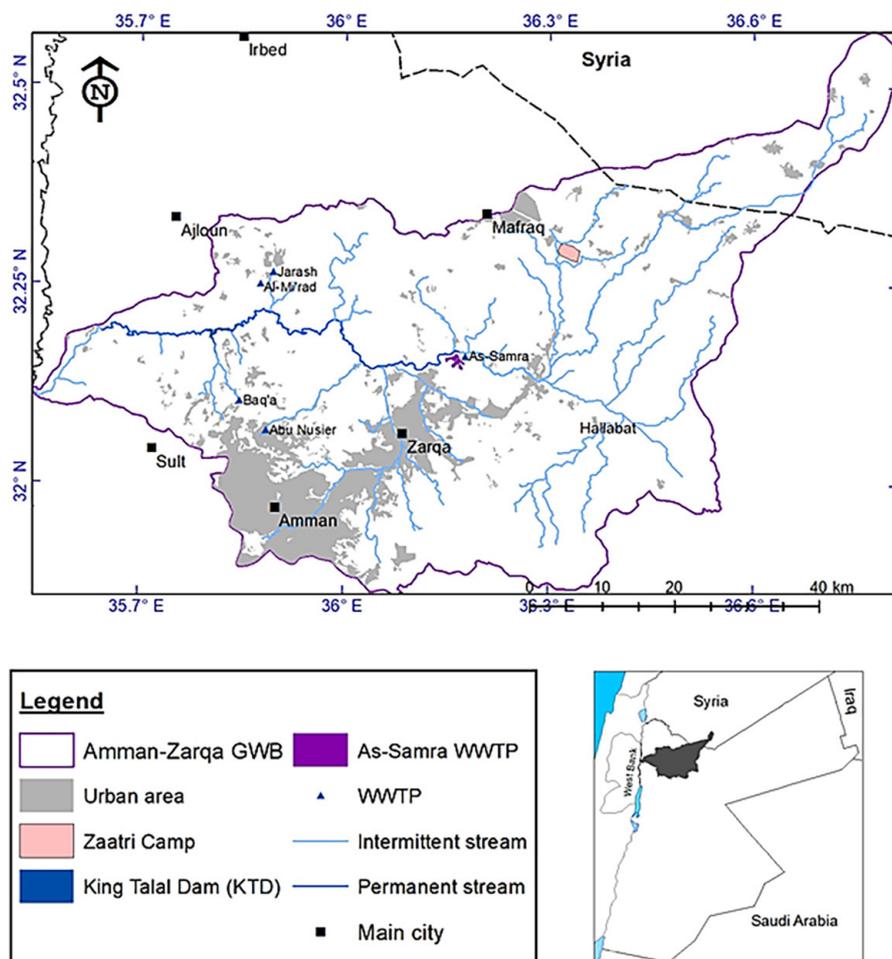

Figure 1. The Zarqa River Basin

Treatment Plant (KSTP), Abu Nusair, Baqa'a, and Jerash. KSTP is the largest wastewater treatment plant located in the ZRB. The treated wastewater discharged from KSTP to Wadi Dhuleil flows downstream to join the Zarqa River near Sukhna. The volume of effluent discharged from the TPs to the Zarqa River is expected to reach 180 MCM by the year 2025, which will lead to the needed of a set of strategies for the expansion, sanitation and storm water management (Heller et al. 2014). The water system in ZRB is characterized by complex characteristics, where its flow mixed with treated effluents from treatment plants and finally stored in KTD, which is located at the outlet of the basin where the dam's water is used for irrigation in the Jordan valley. Only 50 MCM surface fresh water is pumped to the basin from the Jordan Valley for domestic use and the groundwater from different basins is transferred to meet the growing domestic demand (Shatanawi and Shammout 2011). The heavy utilization of the water resources of the ZRB has resulted in reducing the base flow of the Zarqa River from 5 m³/s to less than 1 m³/s and the discharge of the springs reduces from an of average 317 MCM/year prior to 1985 to less than 130 MCM/year after 2000 (Shammout 2003).

Assessment of land use/cover changes

A set of medium spatial resolution images of Landsat Thematic Mapper (TM), Enhanced Thematic Mapper Plus (ETM+) and Opera-tional Land Imager (OLI) images were used to derive land use/cover maps of the basin. The dataset included full scenes for the years 1989, 2002, 2012 and 2017 for the path/row 173/38 and 174/38. These images corresponded to the same hydrological rainy seasons, except the 1989/1990 season which was only based on the 1989 image instead of the 1990, which was not available. The selected datasets were cloud free images acquired during March – May, when natural vegetation and rain-fed crops are usually at their peak growth. The dataset was mainly downloaded from the official website of Landsat 8 (http://earthexplorer.usgs.gov) at no cost. The data used for mapping land use/cover included the visible and the near infrared (NIR) bands with 30 m spatial resolution. Various image processing techniques were applied to prepare the images for digital and visual interpretation of land use/cover. This included the transformation of images to derive normalized

difference vegetation index (NDVI), visual interpretation for urban areas and forests, mosaicking of output layers and clipping of the images to the borders of the study area.

The first step of deriving the land use/cover maps was the derivation of NDVI layers to represent all vegetated areas in the basin. The second step was the use of visual interpretation of images in order to derive layers of agroforestry in the high rainfall areas and urban areas all over the basin. The method of visual interpretation was preferred over the digital classification techniques to avoid classification errors that might result from spectral mixing at the 30 m spatial resolution. Following this step, different functions within the geographic information system (GIS) were applied to append the layers derived from the visual interpretation onto the layers of NDVI. The results of land use/cover mapping for year 2017 were verified using field visits and the high-resolution images of Google Earth. The historical map of 1989 was verified and corrected using the hardcopy topographic maps of the Royal Jordanian Geographic Centre (RJGC), while the maps of 2002 and 2011 were verified by the maps produced by the previous research carried out on the basin (Al-Bakri et al. 2013). The land use/cover maps included seven classes that were selected to serve the objective of this study, while ensuring high accuracy of mapping as no subdivisions for the main classes were included in the maps. The land use/cover classes are continuous urban fabrics, discontinuous urban fabrics, bare rocks, agricultural areas, agroforestry, open rangelands and bare soils, and water bodies.

The flow responses to land use/cover changes

Four hydrological rainy seasons were considered in this study, the first one represents an average rainy season in 1989/1990 (from 1 October 1989 to 30 September 1990), the second year represents a wet rainy season in 2001/2002 (from 1 October 2001 to 30 September 2002), the third year 2010/2011(from 1 October 2010 to 30 September 2011), and the fourth season 2016/2017 (from 1 October 2016 to 30 September 2017). All the data of rainy seasons related to the river flow (base-flow+ flood) records of the only gauging station at the New Jerash Road Bridge are available on a daily basis (m³/sec). This station is the most

essential gauge with a complete flow record and is used for assessing the river flow amounts. The daily Zarqa River flow data of the gauging station was obtained from the Ministry of Water and Irrigation (MWI, 1989–2017) for the selected rainy seasons. Similarly, the daily effluents from KSTP were also acquired from the records of the Ministry of Water and Irrigation (MWI 1989–2017).

The hydrographs of daily flow in m³/sec were constructed in order to separate the base-flow from the flood flow. This was carried out by using the above mentioned flow data. The total base-flow in the Zarqa River consists of one portion of KSTP reaching the gauging station, and the second portion, it is the flow that would exist in the stream without contribution of direct flood (runoff). The separation of the total base-flow was done using the straight line method for each event (Chow et al. 1988), from which the time point of direct surface flood begins to the point where normal base-flow resumes. Between these points, surface flood and base-flow can be separated. This was done by using the stream flow hydrograph in Excel. Once the beginning and ending of each flood were even, the total base-flow were determined and their values were recorded. The actual base-flow was separated from the portion of KSTP effluent. This portion is an equal from effluent of KSTP effluent minus the portion of effluent that has been used upstream of the gauging station for irrigation. The flood flows were determined by integrating the areas of each hydrographs above the base-flow and summing them all to determine the annual flood for each targeted year.

The rainfall data from 10 gauge stations was obtained from Ministry of Water and Irrigation that allow studying the responses of the Zarqa River flow. The ZRB was outlined to define its boundaries, drainage network and outlet using the Digital Elevation Model (DEM). There are 33 rainfall gauges in the ZRB. Only 10 of them have long records over the years from 1989 to 2017. For the selected rain gauges, Thiessen weighted average method was used (Chow et al. 1988) to determine the influence of each rain gauge to the whole basin. Average rainfall was computed according to the following equation (Chow et al. 1988):

$$Average\ Rainfall = \frac{1}{A}\sum_{j=1}^{J} A_j P_j \qquad (1)$$

where: J: gauges,
Aj: gauge area,
Pj: rainfall recorded at jth gauge,
A: $\sum Aj$.

The computed area in km² for each gauge by applying the Thiessen method; Balama 390 km², Jerash 291 km², Zarqa 566 km², Suweileh 61 km², Amman Hussein College 308 km², Rumeimin 39 km², Qasr el Hallabat 718 km², Um el Jimal 475 km², Wadi Es-Sir 21 km², and Um el Quttein 640 km². The total area of delineated ZRB till the gauging station at the New Jerash Road Bridge is about 3509 km². The rainfall-runoff relationship for each rainy season; 1989/1990, 2001/2002, 2010/2011, and 2016/2017 in terms of runoff coefficients were determined by dividing direct flood volume by the total corresponding rainfall volume above the gauging station (Chow et al. 1988). In order to study the effect of land use/cover on the Zarqa River flow, each class of the land use/cover was compared with the runoff coefficient.

RESULTS AND DISCUSSION

Land use/cover changes

Land use/cover maps of the years 1989, 2002, 2011, and 2017 (Figure 2) showed that the ZRB was dynamic in terms of land use character. Table 1 summarizes the percentages of each land use/cover class during the period of 1989–2017. The map of 1989 showed that the main land use/cover classes were distributed as: 35.98% bare rocks, 34.91% open rangelands and bare soils, 21.69% agricultural areas, 4.87% urban, 2.28% agroforestry and 0.3% of water bodies. By the year 2017, land use/cover classes were distributed as: 27.57% bare rocks, 22.57% open rangelands and bare soils, 31.66% agricultural areas, 16.14% urban, 1.79% agroforestry and less than 0.3% of water bodies (Table 1). The main trends of the land use change were expansion in both urban and agricultural areas and the recession of

open rangelands and non-cultivated areas. These results were confirmed in the previous findings in the basin and in similar areas in Jordan (Al-Bakri et al. 2013).

In comparison with the land use distribution from 1989 to 2017, the land use changes have shown that continuous urban fabrics class has increased by 12.23%, and agricultural areas class has increased by 9.97%. On the other hand, there has been a reduction in agroforestry by 0.5%, and a reduction in open rangelands and bare soils by 12.34%. Part of the changes in agricultural areas

could be attributed to the differences in rainfall amounts and distribution among the four seasons. This would be expected under the Mediterranean environment, which had variability in rainfall during the season and among the seasons. Urbanization in the basin was seen as an important change that would reflect the water supply and demand. Urbanization was mainly on the expenses of agricultural areas in the high rainfall zones, particularly in the area of Amman, while expansion of agricultural areas was on the expenses of open rangelands in suburban areas. The previous
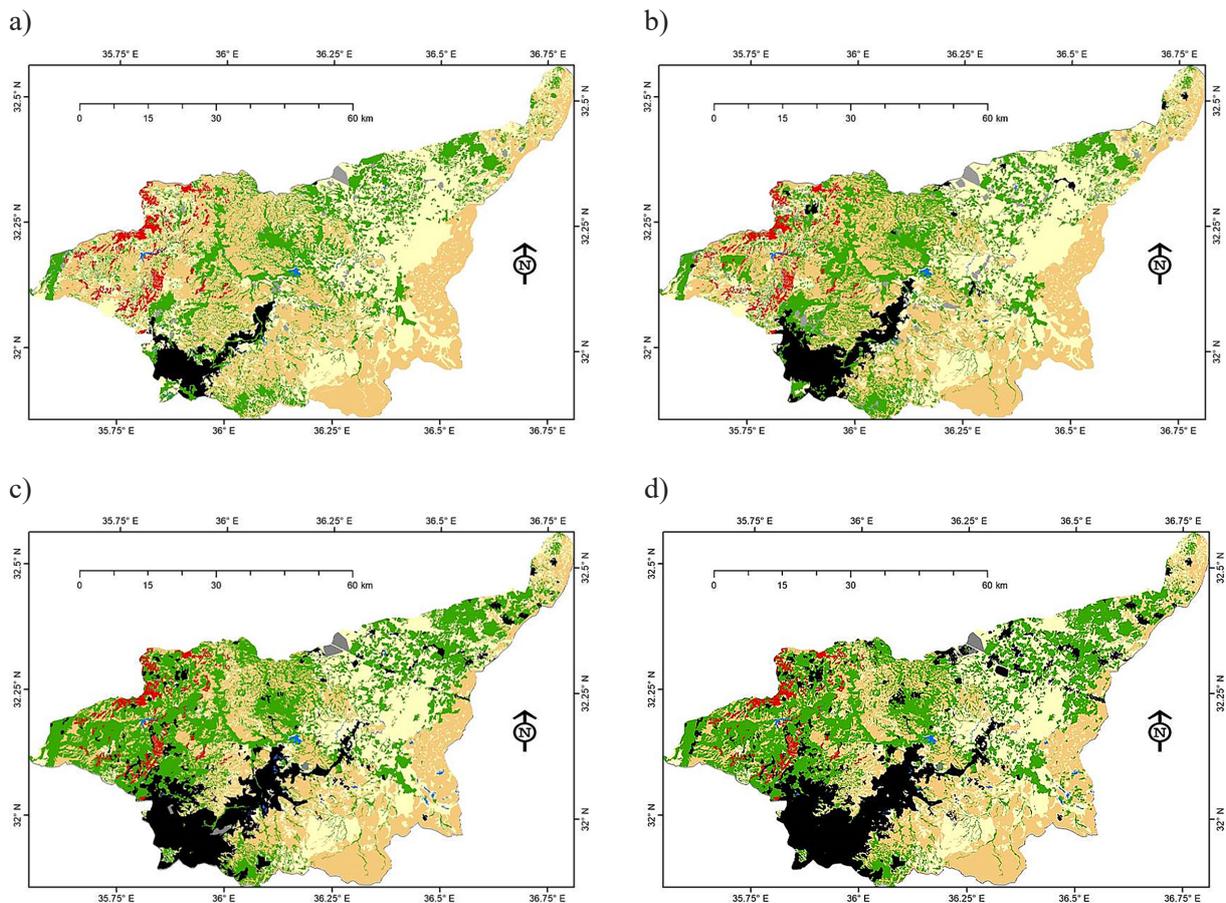

Figure 2 Land use/cover maps of the Zarqa River Basin during 1989–2017: (a) 1989; (b) 2002; (c) 2011; (d) 2017

Table 1. Land use/cover distribution in % of the Zarqa River Basin for the years 1989, 2002, 2011 and 2017

Land Use Distribution (%)	1989	2002	2011	2017	% Change 1989–2017
Continuous urban fabrics	3.52	6.06	12.43	15.76	+12.23
Discontinuous urban fabrics	1.35	2.13	0.52	0.38	-0.97
Bare rocks	35.98	36.73	28.84	27.57	-8.41
Open rangelands and bare soils	34.91	29.02	24.56	22.57	-12.34
Agricultural areas	21.69	23.72	31.49	31.66	+9.97
Agroforestry	2.28	2.04	1.82	1.79	-0.49
Water bodies	0.27	0.30	0.33	0.27	0.00
Total	100	100	100	100	

research in the basin showed that irrigation has expanded in the low rainfall zones in the north, north east and in the middle parts of the basin (Al-Bakri et al. 2016). These trends of land use change resulted in over pumping of groundwater and the increased amounts of treated wastewater effluents of KSTP

Flow responses and land use/cover changes

Figure 3. shows the flow responses of the Zarqa River for the rainy seasons 1989/1990, 2001/2002, 2010/2011 and 2016/2017. Figure 4 shows the effluent of Khirbet es-Samra Treatment Plant (KSTP) for (a) 1989/1990, (b) 2001/2002, (c) 2010/2011 and (d) 2016/2017. On the basis of the land use change distribution, the values of flow amount generated have been affected accordingly, as shown in Figure 3. This is indicated scientifically for the basins concerning their land uses and flow responses (Bakir and Xingnan 2008). In comparison with the water bodies

since 1989 till 2017, there has been no considerable change, whereas the direction of flow change was clearly observed and considerable in the Basin. Table 2 shows the average rainfall, average river flow gauged, average KSTP effluent, reuse of reclaimed water upstream gauging station, contribution of reclaimed wastewater to river flow, average river base-flow, average river flood, and runoff coefficient for the years 1989/1990, 2001/2002, 2010/2011 and 2016/2017, respectively. The flow has been increasing, reaching about 1.95 m^3/s in the year 1989/1990, 3.09 m^3/s in the year 2001/2002, 2.9 m^3/s in the year 2010/2011, and 3.67 m^3/s in the year 2016/2017. Generally, the trends of land use change were in favour of increasing flow due to urbanization and degradation of vegetation and soils in the basin. The increase in flow, however, would not compensate for the increased demand resulting from irrigation and urbanization and therefore, the problem of water scarcity would increase in the future, as indicated by the
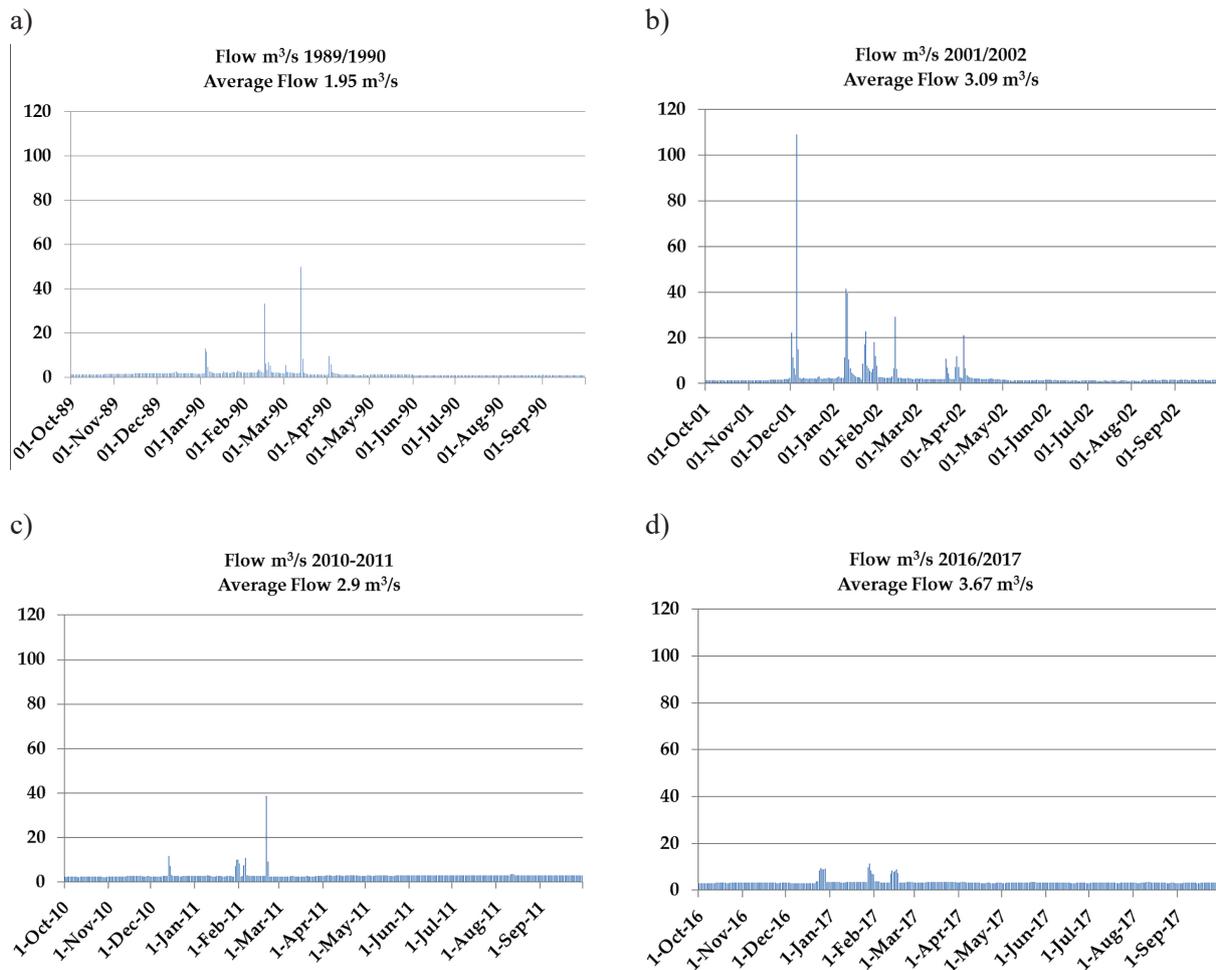
a)

b)

c)

d)

Figure 3. The flow responses of the Zarqa River for the rainy seasons 1989/1990, 2001/2001, 2010/2011 and 2016/2017: **(a)** Flow of 1989/1990 **(b)** Flow of 2001/2002 **(c)** Flow of 2010/2011 **(d)** Flow of 2016/2017
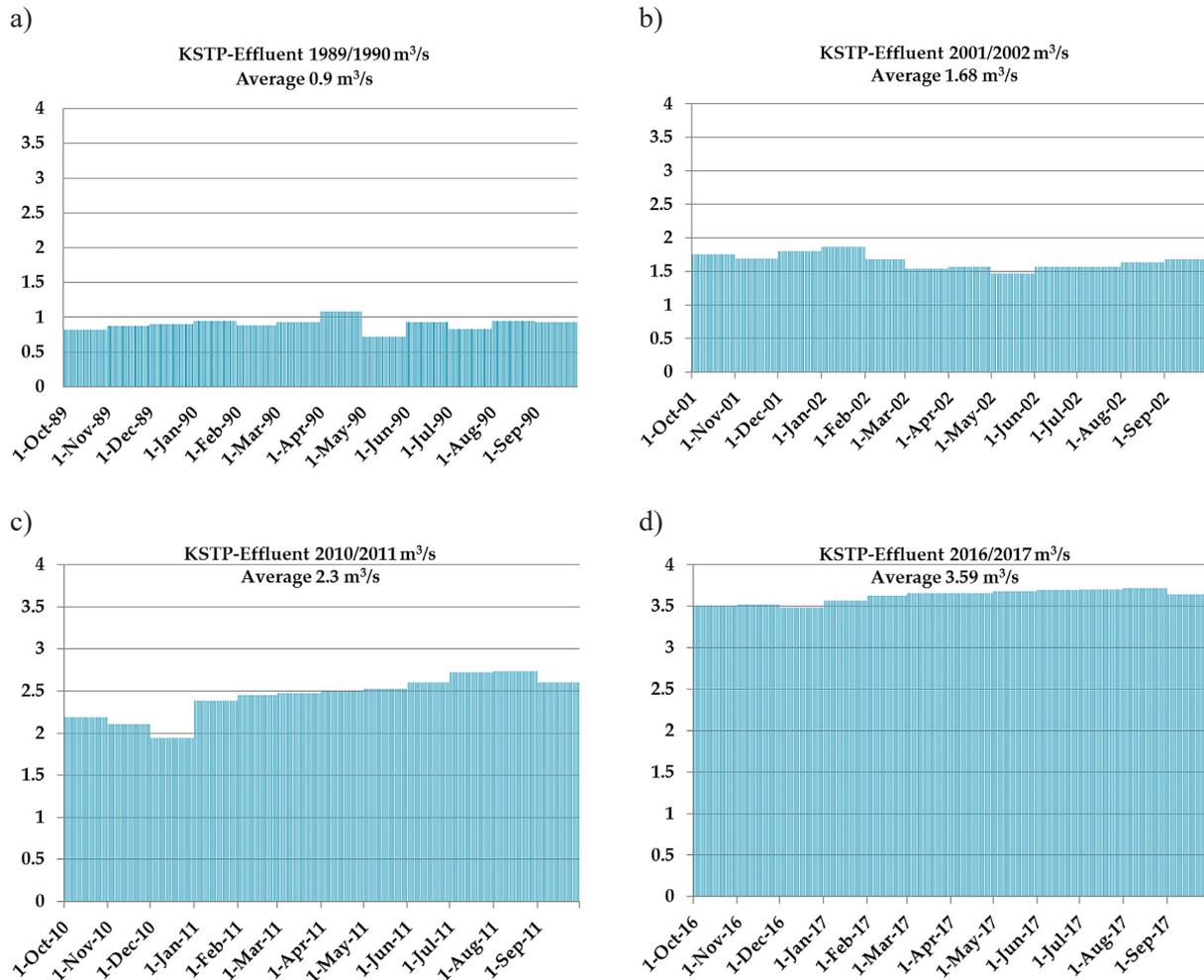
a)

b)

c)

d)

Figure 4 The effluent of Khirbet es-Samra Treatment Plant (KSTP) for **(a)** 1989/1990, **(b)** 2001/2002, **(c)** 2010/2011 and **(d)** 2016/2017

Table 2. Average rainfall, average river flow gauged, average Khirbet es-Samra Treatment Plant (KSTP) effluent, reuse of reclaimed water upstream gauging station, contribution of reclaimed wastewater in river flow, average river base-flow, average river flood, and runoff coefficient for the years 1989/1990, 2001/2002, 2010/2011 and 2016/2017

Parameter	1989/1990		2001/2002		2010/2011		2016/2017	
Unit	mm or m³/s	MCM	mm or m³/s	MCM	mm or m³/s	MCM	mm or m³/s	MCM
Average rainfall	176	617.6	244	856.2	157	550.9	180	631.6
Average river flow gauged	1.95	61.5	3.09	97.5	2.9	91.4	3.67	115.8
Average KSTP effluent	0.9	28.4	1.68	52.6	2.3	74.8	3.59	113.2
Reuse of reclaimed water upstream gauging station	0.13	4	0.25	8	0.32	10	0.79	25
Contribution of reclaimed wastewater in river flow	0.77	24.4	1.41	44.6	2.05	64.8	2.8	88.4
Average river base-flow	0.81	25.4	0.52	16.3	0.43	13.4	0.32	10.2
Average river flood	0.37	11.7	1.16	36.6	0.42	13.2	0.55	17.2
Runoff coefficient		1.89		4.28		2.4		2.72

previous studies in the basin (Al-Bakri et al. 2016). The water demand is increasing rapidly due to high population growth rates, and prolonged drought periods over the past decades which have reduced the surface and groundwater resources. However, the treated wastewater has become an ever-increasing percentage of the Zarqa River flows since the construction of the KSTP (González 2018). Therefore, due to high population growth rates, the treated wastewater constituted about 39.7% of the total flow of the Zarqa River in 1989/1880, about 45.7% in

2001/2002, 70.9% in 2010/2011 and 76.3% in 2016/2017 as shown in Table 2.

These above-mentioned results demonstrate that the impact of land use changes on flow is an issue of considerable importance for land use management (Chow et al. 1988; Archer 2007) that can increase the amount of surface storage, rate of infiltration, and capacity of the soil to store water (Shammout et al. 2013), as water harvesting either for surface storage or for artificial recharge will assist in the sustainable management of water resources (Bakir and Xingnan 2008). Decision makers are challenged to secure more water for an increasing population and agricultural activities. They may implement the land use practices to manage the behavior of the Zarqa river flows (Farajad et al. 2017).

Table 2 shows that the years 1989/1990 and 2016/2017 are similar in rainfall amount and pattern and were considered as average years. The year 2001/2002 was considered as wet year while the year 2010/2011 was dry. The magnitude of flood depends on the timing of the rainfall. If soils are already saturated, the likelihood of flooding increases (Wrzesien and Pavelsky 2020). Part of the reclaimed water from KSTP was used upstream of the gauging station correlating 4, 8, 10, and 25 MCM for the four seasons, respectively. In 1989/1990, there was restriction on the use of reclaimed water for agriculture and therefore only 4 MCM (0.13 m³/s) was used upstream of KTD. The volume of reclaimed water used for irrigation was increased to 8 MCM (0.25 m³/s) in 2001/2002. Due to the increase of the volume of effluent, the water authority encourages farmers to reuse the reclaimed water in irrigating forage crops and trees, fulfilling the Jordanian Standards (González 2018). This amount increased from 10 MCM (0.32 m³/s) in 2010/2011 to 25 MCM (0.79 m³/s) in 2016/2017.

As far as base-flow is concerned, it is clear from Table 2 that the base-flow has gradually dropped from 25.4 MCM (0.81 m³/s) in 1989/1990 to 10.2 MCM (0.32 m³/s) in 2016/2017. This is because of the over-utilization of groundwater upstream and using water for irrigation (Shatanawi and Shammout 2011; Shammout et al. 2013). The base-flow in 1989/1990 was normal, originating from the discharge of the springs along the valley of the river. In the 1990s and afterwards, there was heavy pumping from the groundwater of the basin to the extent that the discharge of

springs has dropped and others were completely dried. For the two average years which were similar in rainfall amount and pattern, Table 2 shows that the river flood increased from 11.7 MCM (0.37 m³/s) in 1989/1990 to 17.2 MCM (0.55 m³/s) in 2016/2017. The increase in flood may be attributed to the land use/cover change, especially the increase in urban and agricultural areas on the expense of range land and forest. This also reflects the runoff coefficient which has increased from 1.89% to 2.72% for the two years, respectively. These results confirmed the previous findings as in (Sriwongsitanon and Taesombat 2011; Li et al. 2020), where, they have shown the influence of land cover on runoff coefficient. It can be useful for land use, flood management of the river basin, and the importance for efficient scenario practices for various aspects of river flow management.

CONCLUSIONS

The Zarqa River Basin (ZRB) is under the pressure of various agricultural, industrial, and commercial activities. The water demand is increasing rapidly due to high population growth rates, and prolonged drought periods over the past decades, which have reduced the ZRB water resources. Hence, the translation of the available real historical data into the river flow responses to land use/cover changes is highly needed. This allows understanding, assessing the river flow and finding the ways towards ZRB management.

It was clearly observed that there was a direction of change of the Zarqa River flow in the basin since 1989/1990 till 2016/2017. The river flow was variable according to land use/cover changes; the increase of urban and agricultural areas, the reduction in open rangelands and bare soil, and the reduction in agroforestry, resulted in the increase of the river flow. This also influenced the runoff coefficient. On the basis of these conditions, decision makers are challenged to secure additional water for an increasing population and agricultural activities. Nevertheless, the change in land use/cover approaches will allow the validation of future scenarios for flow management, which is an issue of significant importance that can increase the amount of surface storage, rate of infiltration, and capacity of the soil to store water.

Acknowledgments

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