



The influence of the Land Use Land Cover (LULC) change on hydrological response in urbanized watersheds. Case study of Wadi Koriche and Wadi Kniss watersheds, northern Algeria

Samira Wissem Astite¹ · Saci Kermani² · Yacine Djediat³

Received: 8 September 2022 / Accepted: 8 March 2023 / Published online: 15 March 2023
© Saudi Society for Geosciences and Springer Nature Switzerland AG 2023

Abstract

The aim of the present study is to evaluate the impact of Land Use Land Cover (LULC) changes induced by urbanization on the hydrological response of the Wadi Koriche and Wadi Kniss watersheds, located in the urban area of Algiers (the capital of Algeria). Three land use scenarios were established by processing aerial and satellite images in three different periods (1959–1984–2019). These three scenarios were simulated with the flood of November 10, 2001, under the hydrological model Hydrologic Engineering Center-Hydrologic Modeling System. The results of this work show an increase in the built environment of 38% between 1959 and 2019 and a reduction in vegetation cover of 63%, accompanied by an increase in impervious surfaces of 48%, with an increase in runoff coefficients, a reduction in response times and water concentration times of the two watersheds, as well as an increase in peak flows of 30 m³/s and runoff volumes of more than 400,000 m³ between 1959 and 2019. The results indicate that LULC changes significantly impact the hydrological response of watersheds. They reduce infiltration and significantly increase runoff along the two wadis, causing flooding in the downstream parts of the studied watersheds.

Keywords LULC · Mapping · Runoff · Urbanized watersheds · Algeria

Introduction

The change in the land use pattern due to rapid urbanization adversely affects the hydrological processes in a watershed, leading to a deteriorating water environment

(Suriya and Mudgal 2012; Zope et al. 2015; Astuti et al. 2019; Hu et al. 2020). The most common effects are reduced infiltration and decreased travel time which significantly increase peak discharges and runoff (Tholin and Keifer 1959; Calomino and Veltri 1984; SCS 1986; Boyd et al. 1993; Banasik et al. 2008; Belihu et al. 2020). In addition, the urbanization of natural environments causes an artificialization of the flow axes and natural watercourses within urban areas (Bouvier 1989; Hingray 1999), which participates in the increase of runoff volumes and the development of flooding phenomena (Niu and Sivakumar 2014; Zhang et al. 2015; Xu and Zhao 2016; Li et al. 2018).

Algeria is concerned by these phenomena and, in particular, the region of Algiers, the political and economic capital of the country. The spread of urbanization on the foothills of the Hills and the Algiers Massif, in the presence of small watersheds, has led to significant changes in land use. The latter have modified the hydrological behavior of the existing watersheds, which is generally manifested by significant urban runoff and paralyzing storm floods in the Algerian municipalities.

Responsible Editor: Broder J. Merkel

✉ Samira Wissem Astite
astite-doc@hotmail.fr

- ¹ Laboratory of Research and Studies of Development and Town Planning, Faculty of Earth Sciences, Geography and Country Planning, University of Sciences and Technology Houari Boumediene (USTHB), Algiers, Algeria
- ² Laboratory of Geomorphology and Geo-hazards, Faculty of Earth Sciences, Geography and Country Planning, University of Sciences and Technology Houari Boumediene (USTHB), Algiers, Algeria
- ³ Laboratory of Geodynamic of Sedimentary Basins, Faculty of Earth Sciences, Geography and Country Planning, University of Sciences and Technology Houari Boumediene (USTHB), Algiers, Algeria

The different studies of floods in the province of Algiers (Burgeap 2005; Brgm 2006; SEAL 2007) have been carried out on the dysfunctions and the sizing of sewerage systems ignoring the hydrological behavior of existing watersheds. This is due to the strong presence of urbanization that makes the stream network invisible and difficult to identify and to the low topography of the land (Miller et al. 2014; Guan et al. 2016; Yao et al. 2018). According to the same studies mentioned above, this area presents a very high hydrological hazard requiring a detailed study of flood risk. It is drained by a dense river network covered by strong urbanization, causing significant floods during heavy rainfall events. Most of the watersheds of the study area have been urbanized. This study aims to model the hydrological functioning of the two urbanized watersheds of Wadi Koriche and Wadi Kniss. This modeling allows us to characterize the impact of the evolution of land use on the hydrological response of these two urbanized watersheds by calculating the runoff volumes, the peak flows and the hours of peak flows (Suriya and Mudgal 2012; Liu et al. 2014; Suribabu and Bhaskar 2015; Fehri and Yadh 2016).

A cartographic analysis based on the processing of aerial photographs and satellite images by the Geographic Information System (GIS) was also conducted. The objective of this treatment is the study of the evolution of land use and impermeable surfaces due to the evolution of urbanization. Moreover, a topographic and hydrographic analysis based on processing a Digital Terrain Model (DTM) using two geospatial hydrological models (HecGeoDozer and HEC-GeoHMS) coupled to ArcGis was established. This analysis's objective was to extract the hydrographic network and the physical characteristics of the urbanized watersheds. Finally, a hydrological model based on the use of the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) model was carried out to calculate the impact of urbanization on the hydrological response of the watersheds. The latter is calculated by applying the Soil Conservation Service (SCS) method proposed by the United States (US) Natural Resources Conservation Service (SCS 1986) for studying urban hydrology of small watersheds and runoff modeling. This study aims (1) to evaluate the main temporal and spatial variations of the land use of the Wadi Koriche and Wadi Kniss watersheds between 1959 and 2019 and (2) to evaluate the impact of these changes on the hydrological response of these two watersheds.

Materials and methods

Study area

The present study focuses on the urban watersheds of Greater Algiers, located in the North Center of Algeria, in

the province of Algiers. It includes the two small urbanized watersheds of Wadi Koriche and Wadi Kniss (Fig. 1). It is located between the geographical coordinates $X = 3^{\circ}08' E - 3^{\circ}00' E$ and $Y = 36^{\circ}48' N - 36^{\circ}42' N$. The Wadi Koriche watershed is a small watershed of a collected form located in the western part of Algiers. It covers a total area of 9 km² and a perimeter of about 55 km. It spreads over three municipalities: Bouzareah, Wadi Koriche and Bab El Wadi. A very dense hydrographic network drains this watershed. It takes its birth in the Massif of Bouzareah. It comprises seven sub-watersheds, from upstream to downstream (Baranes, Sidi Medjeber, Frais Vallon, Scotto Nadal, Chemin du Fort, Birtraria and Carriere Jaubert). Its main watercourse is Wadi Koriche, which has been transformed into a road, the expressway of Frais Vallon. The slopes of this basin vary between 0° and 48°. This basin was the subject of a catastrophic flood that caused immense material and human damage on November 9 and 10, 2001.

The second basin is the Wadi Kniss watershed, a small watershed of an elongated shape, with an area of about 12 km² and a perimeter of 31.5 km. It spreads over seven municipalities: El Biar, Hydra, El Madania, El Mouradia, Bir Mourad Rais, Belouizdad and Hussein-Dey. A very dense hydrographic network drains this basin. It takes its birth from the heights of the Massif of Bouzareah and The hills of Sahel of Algiers. It comprises seven sub-watershed areas (Kniss upstream West, Kniss upstream East, Hydra West, Hydra East, Kniss downstream, Kouba and Kniss's mouth). Its main watercourse is Wadi Kniss, the latter has been transformed into a communication road (*Rue de Frères Bouadou*). The slopes of this basin vary between 0° and 34°.

Topographically, the study area is composed of Massif of Bouzareah, characterized by rugged topography, with altitudes that vary between 250 and 450 m and slopes greater than 35°. The Sahel of Algiers is in the form of hills with altitudes that do not exceed 250 m and average slopes between 20 and 35°. The Eastern plain of the Mitidja is characterized by low altitudes that vary between 0 and 30 m and low slopes (less than 10°).

The study area has a complex geological formation, composed of the Primary bedrock in the form of metamorphic rocks, Tertiary formations, consisting of Pliocene upper, Pliocene lower, Miocene and Quaternary formations. The study area's soils are composed of Schists, Micashists and Gneiss on the Massif of Bouzareah, Limestones, Marls and Clays on the Sahel and the loose formations of sedimentary type on the Coastal Eastern Plain.

In terms of climate, the study region enjoys a Mediterranean climate, composed of two distinct periods, a wet period, which is spread for 9 months, characterized by events of short duration and strong intensities, and a dry period, which is spread for 3 months. The average annual temperature varies between 16 and 18 °C. Rainfall varies between

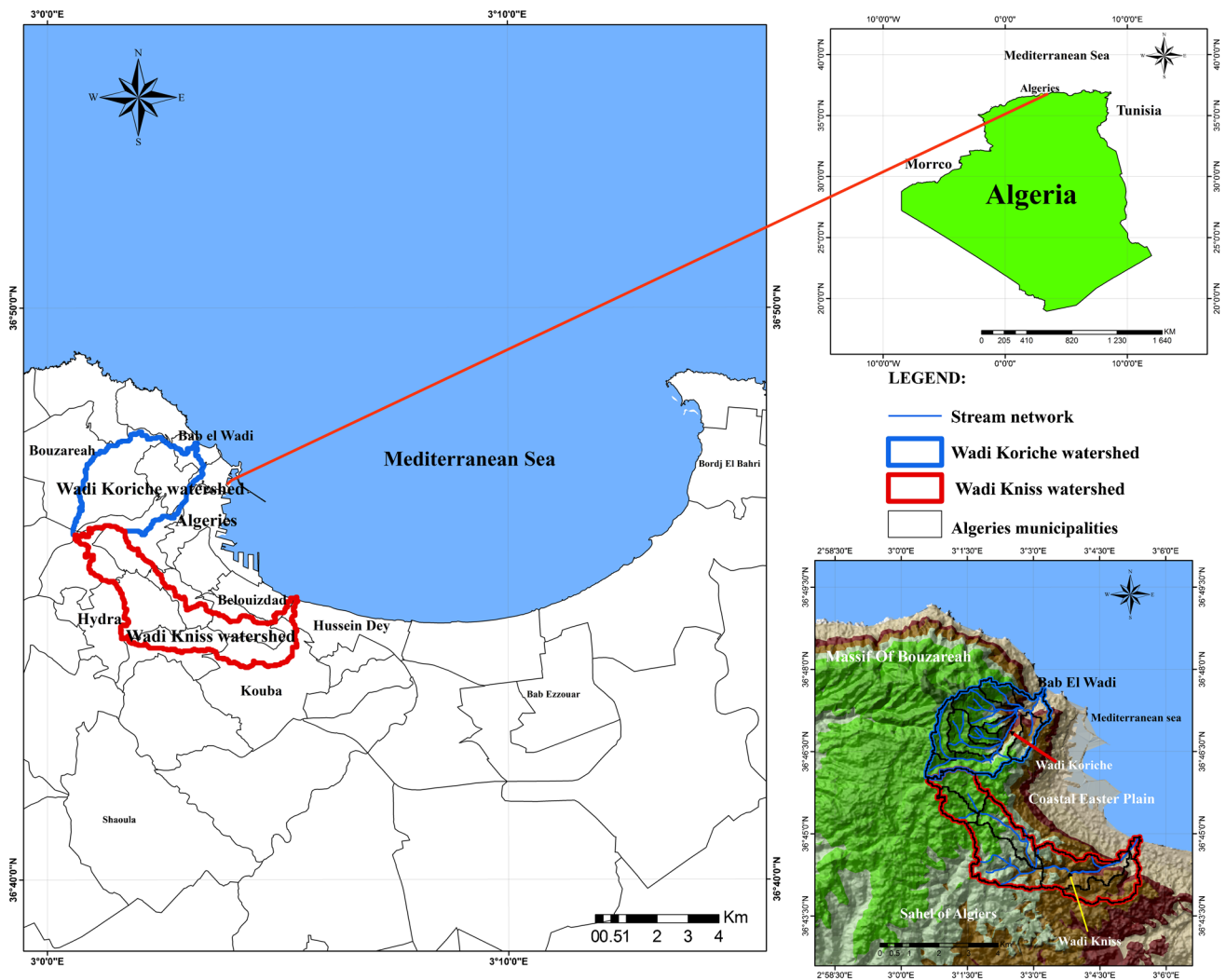


Fig. 1 Location map of the study area showing Wadi Koriche and Wadi Kniss watersheds

670 and 800 mm/year, with an excess of 100 mm/year in November, December and January.

From an urban point of view, the study area is characterized by a high urban density, especially in the downstream parts of the two watershed areas. The study area has recorded several remarkable events (with maximum daily rainfall ranging from 80 to over 260 mm). These events have caused devastating floods and significant material and human damage. The most spectacular and deadly were the floods of Bab El Wadi in Algiers (09 and 10 November 2001). The balance sheet of the disaster was very heavy. Huge losses in human lives were recorded (800 dead, 115 missing, 311 injured and more than 1454 families without shelter), and significant material damages were caused (infrastructures and various establishments).

Different data were used during this study. The 30-m Shuttle Radar Topographic Mission (SRTM) data obtained from the US Geological Survey (USGS) website ([https://](https://earthexplorer.usgs.gov/)

earthexplorer.usgs.gov/) was processed in ArcGIS from Environmental Systems Research Institute (ESRI) and used in this study for the extraction of the hydrographic network and the delineation of the watersheds. Old and recent cartographic documents, such as topographic, geological, hydro-geological maps and city plans, were used to map the study area's different physical and urban features. Corrected aerial photographs at different scales were obtained from different missions (1959 and 1984) and satellite images from 2019 used for mapping land cover dynamics. All these data were digitized, collated and geo-referenced in the North-Sahara-1959-UTM zone 31N projection system.

Extraction of physical characteristics of watersheds

The physical characteristics of the two watersheds were extracted by processing a 30-m resolution SRTM (Astite et al. 2015; Shahid et al. 2016). It was established under

GIS (ArcGis version 9.3) using two geospatial hydrological extensions (HEC-GeoDozer version 1.0 and HEC-GeoHMS version 5.0). The HEC-GeoDozer geospatial hydrological extension (Dartiguenav et al. 2009; Fleming and Doan 2010) is used for processing and correcting field data (SRTM). Moreover, the hydrological geospatial extension HEC-GeoHMS (Dartiguenav et al. 2009; Fleming and Doan 2010) defines the hydrographic network and watersheds the extraction of their physical characteristics, as well as the estimation of hydrological parameters. The interest of this approach is the automatic extraction of the hydrographic network within the areas with a high density of urbanization, as well as the evaluation and quantification of the morphological and physiographic characteristics of the watersheds. The different steps for the extraction of the hydrographic network and the physical characteristics of the watersheds are mentioned in the flowchart (Fig. 2).

Mapping land use changes between 1959 and 2019

The mapping of land use land cover changes was based on the study of the urban evolution of the study area between 1959 and 2019 by using aerial photographs and satellite images of three different periods (1959–1984–2019). A large number of researches around the world has been undertaken to study land use change using remote sensing and GIS (Tretitz et al. 1992; Suribabu and Bhaskar 2015; Fallati et al. 2017; Nan et al. 2020). These studies have widely recognized the integration of remote sensing and GIS as a powerful and effective tool for urban growth detection.

An ortho-photo plan construction was established. It was based on geo-referencing, correction and mosaicking of aerial photographs using GIS software (Crowell et al. 1991;

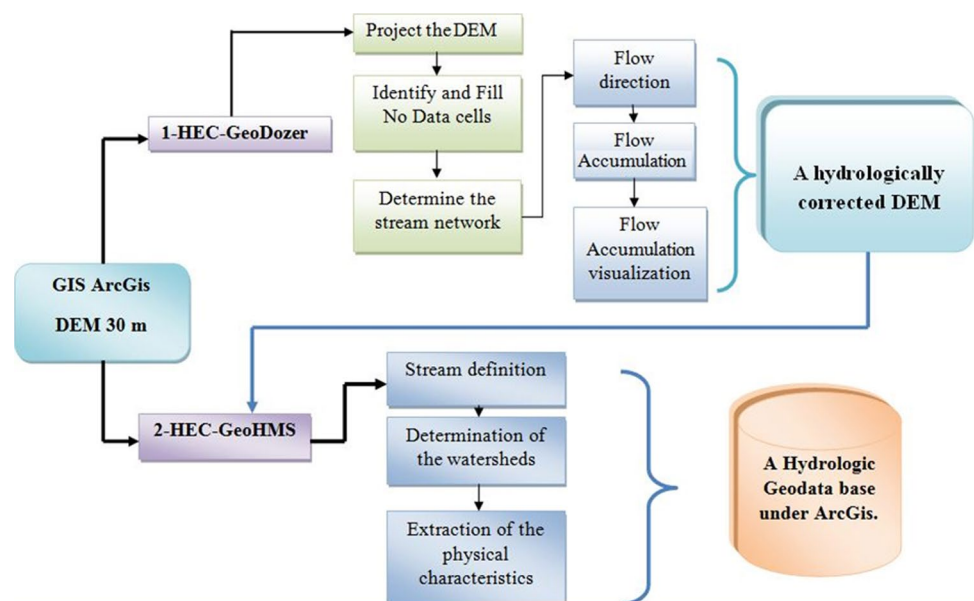
Moore 2000; Kermani et al. 2016). The main land use types were identified: built environment, roadway, vegetation and open land (unoccupied). The occupied spatial area of each land use type was calculated using GIS functions. Then, a calculation of impervious surfaces was performed. The latter is calculated by the sum of the surface areas of the built environment and the roadway. The interest of this part is to evaluate the main temporal and spatial variations of the land occupation of the study area during these three periods to quantify the rate of soil sealing induced by the changes in land occupation.

Hydrological modeling

Hydrological modeling is used in our study to determine the impact of land use changes induced between 1959 and 2019 on the hydrological response of small urbanized watersheds. This impact is determined through the calculation of several statistical parameters, namely, Watershed Runoff Coefficients, Stream and Watershed Concentration Times (T_c), Watershed Response Times (Lag time), Runoff Volumes, Peak Flows and Peak Flow Hours (SCS 1986). For this purpose, we used the hydrological model HEC-HMS version 3.5. This model contains a significant number of methods for simulating the behaviors of watersheds, streams and hydraulic structures, which allows for the prediction of flows, their volumes and their response times (Ford et al. 2008; Gao et al. 2019). It has been widely used for wet, tropical, subtropical and arid watersheds (Scharffenberg and Flemin 2010).

Many scientific researchers have conducted important hydrological studies using this model as an example: Chen et al. (2009); used the Soil Conservation Service-Curve

Fig. 2 Flow chart of the methodology for extracting the watersheds hydrographic network and physical characteristics



Number (SCS-CN) method under HEC-HMS to predict the impacts of land use change on surface runoff in the urbanized Xitiaoxi basin, China; Ali et al. (2011); combined an empirical land use change model and a single event-based rainfall-runoff model using HEC-HMS to quantify the impacts of land use change on runoff generation in the Lai Nullah basin in Islamabad, Pakistan; Abushandi and Merkel (2013); modeled Rainfall-Runoff relationships using HEC-HMS and IHACRES models for an arid region of Jordan. HEC-HMS is considered one of the most widely used hydrological models in water cycle studies (Wan and Yang 2007; Stehr et al. 2008).

The methods chosen for calculating the hydrological response of the watersheds in the study area are: (1) The SCS-CN model for calculating runoff-volume. Several research works have expressed its simplicity, ease and user-friendliness (Amini et al. 2011; Jiang et al. 2012; Birch et al. 2015; Fehri and Yadh 2016). It represents a useful tool for assessing runoff from ungauged watersheds and its adaptation to the characteristics of different environments. (2) The semi-empirical SCS unit hydrograph method for direct runoff estimation. It has been used by many researchers worldwide (Amini et al. 2014; Zope et al. 2015). This method requires the determination of the Times of Concentration (T_c) and response times (Lag time) of the watersheds as input to the model. (3) The lag method for the calculation of the routing function. This method models urban drainage (Shahid et al. 2016). The input parameters of this method are the time of concentration (T_c) and response time (Lag Time). For the meteorological model, the cumulative rainfall recorded during the event of November 9 and 10, 2001 (24 h cumulative rainfall) in the two rain stations of Bouzareah and Bir Mourad Rais were used (Table 1). This event is considered exceptional in cumulative rainfall (262 mm/ 24 h).

Table 1 Rainfall totals for the event of November 9–10, 2001 (Source: ANRH (2001), ONM (2002))

Days	Duration	Station of Bouzareah (mm)	Station of Bir Mourad Rais (mm)
09/11/2001 (6 am-6 pm)	12 h	0	26.0
09–10/11/2001(6 pm-6 am)	12 h	129.2	82.9
10/11/2001 (6 am-6 pm)	12 h	132.4	50.0
09–10/11/2001 (6 am-6 am)	24 h	129.2	108.9
09–10/11/2001 (6 pm-6 pm)	24 h	262	132.9
09–10/11/2001 (6 am-6 pm)	36 h	262	158.9

Results and discussion

Land use changes between 1959 and 2019

The results of the mapping of the dynamics of land use in the two watersheds of Wadi Koriche and Wadi Kniss show the temporal and spatial changes for 60 years (Table 2). At the level of the Wadi Koriche watershed (Fig. 3), the results show an increase in the area occupied by the built environment of 13.11% between 1959 and 1984 and 16.67% between 1984 and 2019, or an increase of 29.78% between 1959 and 2019, and a decrease in vegetation cover of 25.22% between 1959 and 1984, and 22.89% between 1984 and 2019, or a percentage of 48.11% between 1959 and 2019. We also recorded an increase in road space of 17.78% between 1959 and 2019. The sub-basins affected by this phenomenon are Baranes, Birtraria, Scotto Nadal, Chemin du Fort and Wadi Koriche. The results of processing aerial photographs also show the existence of a natural hydrographic network in the entire watershed in 1959 and its disappearance in 1984. The natural watercourse of Wadi Koriche was buried and transformed into a communication road, i.e. the expressway of Frais Vallon. These different changes result from anarchic urbanization, following the phenomenon of rural exodus and the orientations of the development plans and urbanism during this period.

The Wadi Kniss watershed has also experienced significant changes in land use (Fig. 4) due to urbanization resulting from the two development plans (General Orientation Plan and the Urban Master Plan), which have directed urbanization towards the Sahel Hills. The area occupied by vegetation cover was reduced by 37.91% between 1959 and 1984 and 24.33% between 1984 and 2019. At the same time, the built environment has increased by 22.33% between 1959 and 1984 and 15.67% between 1984 and 2019, an increase of 38% between 1959 and 2019. An important road system development has been made in all the watershed areas, with the construction of a road on the bed of Wadi Kniss, where the natural state of the wadi disappeared in 1984.

From these results, we find that both watersheds have been affected by the urban expansion of the city of Algiers from 1959 until 2019. During this period, the study area has experienced a considerable urban extension following the strong demographic growth, economic development and political actions maintained after independence. These socio-economic and political transformations have led to a significant increase in the surface area of the built environment to the detriment of the vegetation and the development of the road system to the detriment of the natural riverbeds.

These phenomena are seen on the slopes of the Hills and the Massif of Algiers, which have experienced

Table 2 Quantification of land use changes in the Wadi Koriche and Wadi Kniss watersheds between 1959 and 2019

Land use land cover	Wadi Kniss watershed				Wadi Koriche watershed					
	Km ² in 1959	% in 1959	Km ² in 1984	% in 1984	Km ² in 1959	% in 1959	Km ² in 1984	% in 1984	Km ² in 2019	% in 2019
Building	1.32	11	4	33.33	1.32	14.66	2.5	27.77	4	44.44
Vegetation	10.16	84.66	5.61	46.75	7.33	81.44	5.06	56.22	3	33.33
Roads	0.23	1.92	2	16.67	0.2	2.22	1	11.11	1.8	20
Other	0.29	2.42	0.39	3.25	0.15	1.66	0.44	4.88	0.2	2.22
Rate of imperviousness (Buildings + vegetation cover)	1.55	12.92	6	50	1.52	16.88	3.5	38.88	5.8	64.44
Total	12	100	12	100	9	100	9	100	9	100

significant changes in land use. Most of the natural slopes have been transformed into urbanized spaces covered by residential cities, individual housing and various facilities. The soils of these two basins show substantial changes in their land use. These changes are marked by a strong evolution of the areas occupied by the built environment and the road system and a strong decrease in the areas of vegetation cover. Both watersheds show a clear increase in paved areas (buildings and roads) between 1959 and 2019. These spaces have tripled in 60 years. The increase in asphalt surfaces participates directly in the increase in the rate of imperviousness. We can see that urbanization has caused a considerable increase in impervious areas, which promotes runoff in both watersheds.

The same findings have been observed in the different studies dealing with urban evolution and the different land use changes caused. According to Birch et al. (2015), the urban evolution of the Sydney Estuary in Australia between the period 1788 to 2010 caused a 46% increase in the built environment and an 18% increase in the roadway, as well as a 77% decrease in vegetation cover between 1788 and 2012. In another study by Liu et al. (2014), on the Jinjing watershed located in China, where he studied the different land use changes between the period 1933 and 2005, the areas of a built environment increased by 10.51% between (1933 and 1955) and 17.15% between (1955 and 1990), as well as 39.54% between (1990 and 2005).

Runoff coefficients

The results of calculating the runoff coefficient (CN) using the SCS-CN method showed an increase in this coefficient from 1959 to 2019 (Table 3). This increase is related to the land use changes in the basins caused by urban expansion, where we recorded a strong decrease in vegetation cover and a very strong increase in the built environment.

The comparison of the results between the Wadi Koriche and Wadi Kniss watersheds areas allows us to notice that the coefficients of runoff of the basin of Wadi Koriche were greater than those of Wadi Kniss in 1959 and 1984. This difference is due to the pedological cover of the soils, where 80% of the soils of the basin of Wadi Koriche are constituted of impermeable Schists. On the other hand, 80% of the soils of the basin of Wadi Kniss are constituted of permeable Limestone. The situation was reversed in 2019. We note that the sub-basins of Wadi Kniss have higher runoff coefficients than those of Wadi Koriche. This is due to the different changes in land use in the two watersheds.

Concentration time and response time

The application of the SCS unit hydrograph method also allowed us to estimate the water concentration times (of the

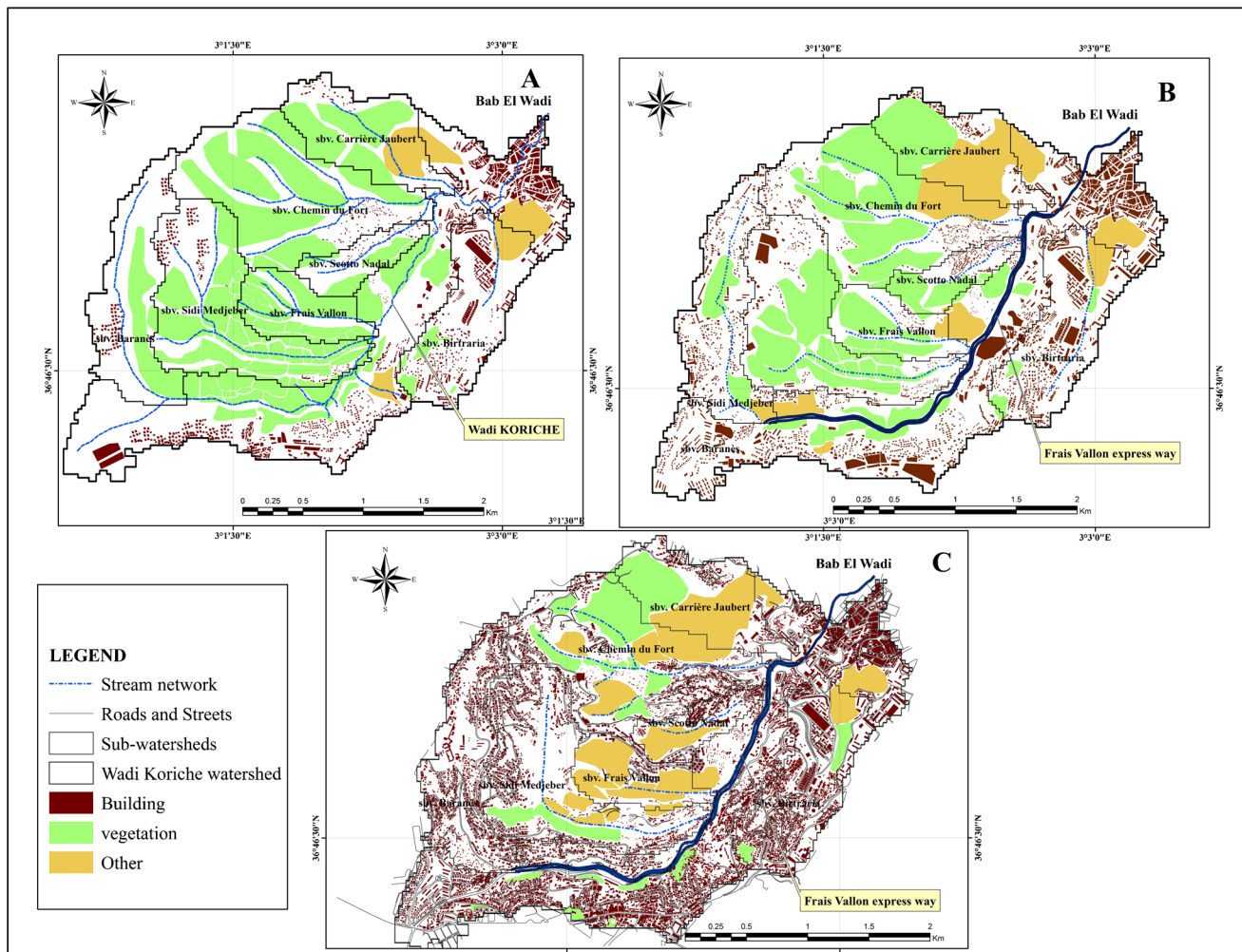


Fig. 3 Land use dynamics of the Wadi Koriche watershed, (A) Land use for the year 1959, (B) Land use for the year 1984 and (C) Land use for the year 2019

streams and sub-watersheds) and response times of the two watersheds. The results show a reduction in both times in most watersheds from the year 1959 to 2019 (Table 4). This is justified by the watersheds' urbanization and the watercourses' artificialization, which modifies the soils' roughness and impermeability.

Simulation of the event of November 10, 2001

We simulated the hydrological response of the Wadi Koriche watershed during the event of November 9 and 10, 2001, assuming that the land cover of the year 2019 represents that of the year of the disaster (2001). The model calibration was based on the runoff coefficient (CN) variation. The rainfall implemented corresponds to the 24-h cumulative rainfall, i.e. 262 mm. After the calibration and validation of the results, we simulated the hydrological response of the

two watersheds with this event in the three land use situations (1959, 1984, 2019).

The simulation results of the hydrological response of the Wadi Koriche watershed for the November 2001 event are presented in Table 5. The two important sites considered in this basin are the downstream confluence at Triolet and the basin outlet at Bab El Wadi (Fig. 5). We observe a variation in the hydrological response of the sub-watersheds of the Wadi Koriche. The peak flows and runoff volumes vary from one sub-basin to another due to the difference in their physical characteristics, such as area, perimeter, shape, slope, runoff coefficient, rate of imperviousness, and time of concentration and response times).

The peak flow simulated at the mouth of Wadi Koriche is 131.8 m³/s with a runoff volume of 2257.4 (10³ m³). At the level of the confluence of Triolet, located upstream of the Bab El Wadi district, we obtained a peak flow of 141 m³/s for a runoff volume of 2162.3 (10³ m³). The

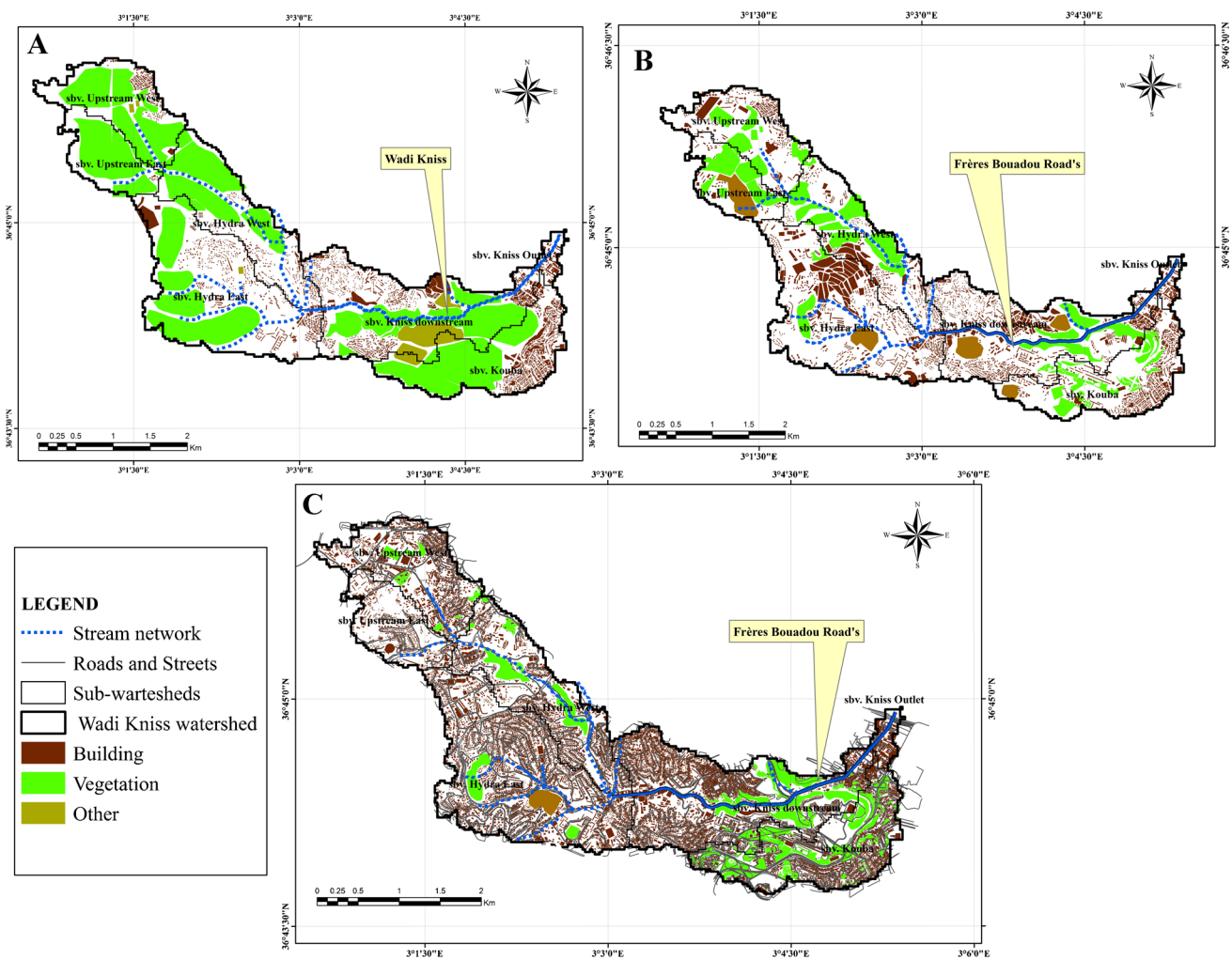


Fig. 4 Land use dynamics of the Wadi Kniss watershed, (A) Land use for the year 1959, (B) Land use for the year 1984 and (C) Land use for the year 2019

magnitude of these results explains the flooding that occurred in Bab El Wadi on November 10, 2001.

The runoff hydrograph at Triolet (Fig. 6) shows the existence of three peaks during the day of November 10, 2001. The first peak with a value of $102.7 \text{ m}^3/\text{s}$ was recorded at 07:30 am, the second peak with a value of $130.4 \text{ m}^3/\text{s}$ was recorded at 9 am and the third peak with a value of $141 \text{ m}^3/\text{s}$ was recorded at 10 am.

The first peak reflects the basin's response to the rains received during the night of November 09. It is caused by the arrival of the flows coming from the sub-watershed areas of Birtraria, Jaubert quarry and the main flow of Wadi Koriche (the latter collects all the waters of the upstream sub-watershed areas including Baranes, Sidi Medjeber, Frais Vallon, Scottu Nadal and Chemin du Fort). The second and third peaks reflect the basin's response to the heavy rains of the morning of November 10, 2001.

According to the simulated runoff hydrograph at the mouth of Wadi Koriche (Fig. 6), we also recorded three peaks of peak flow. The first peak is recorded at 9 am ($98.5 \text{ m}^3/\text{s}$), the second peak is recorded at 10:30 am with a value of $131.2 \text{ m}^3/\text{s}$ and the third peak is recorded at 11:30 am with a value of $131.8 \text{ m}^3/\text{s}$. The first peak reflects the response of the river inside the urban area of Bab El Wadi, following the first peak at the confluence of Triolet, and so on for the other peaks.

Comparing these results with those of previous studies and press articles shows certain conformity in the values of the peak flows. According to the Brgm study, the simulated peak flow at Triolet ranges from 120 to $160 \text{ m}^3/\text{s}$, while the one estimated by ANRH is $100 \text{ m}^3/\text{s}$. On the other hand, the results of Menad (2012) gave an underestimated peak flow of $89 \text{ m}^3/\text{s}$. Therefore, the results of this work are consistent with the results of the various studies and the press records. Nevertheless, the presence of triple peaks of rainfall

Table 3 Changes in the runoff coefficients (CN) between 1959- 2019

Watersheds	Sub-watersheds	Runoff coefficient (CN)		
		Year 1959	Year 1984	Year 2019
Wadi Koriche watershed	Baranes	74	83	95
	Sidi Medjeber	74	74	93
	Birtraria	79	85	93
	Frais Vallon	74	72	86
	CarrièreJaubert	76	78	81
	Chemin du Fort	74	74	80
	Wadi Koriche	82	87	94
Wadi Kniss watershed	Hydra East	58	81	96
	Kouba	57	85	92
	Kniss downstream	72	87	95
	Kniss Mouthpiece	77	84	93
	Hydra West	67	79.5	96
	Upstream East	55	65	94
	Upstream West	67	79.5	96

intensity (according to the data recorded at the Bir Mourad Rais station and the Hyetogram projected at the Bouzareah station) is consistent with the hydrological response of the watershed of Wadi Koriche.

The results obtained at Triolet and the outlet confirms the effectiveness of the methods chosen and the HEC-HMS hydrological model. The reconstruction of peak flows is satisfactory. From this, it can be noted that the hydrological model’s calibration for November 9 and 10, 2001, will be limited to verification of the order of magnitude of the peak

flow provided by the other studies. We, therefore, propose a simulation of this event with the other basins considered in this work.

Runoff volumes and peak flows of the Wadi Koriche watershed (1959–2019)

The simulation results of the hydrological response of the Wadi Koriche watershed for the event of November 9 and 10, 2001, under the effect of land use changes attributed between 1959 and 2019, show a strong increase in peak flows and runoff volumes.

The reading of the results shows that at the level of Bab El Wadi, the volume of runoff has increased from 1843 (10³ m³) in 1959 to 2043 (10³ m³) in 1984, to reach 2257 (10³ m³) in 2019. For peak flows, they increased from 104.2 m³/s in 1959 to 139.6 m³/s in 1984 to reach 131.8 m³/s in 2019. At the level of Triolet, the volumes of runoff have increased from 1773.1 (10³ m³) in 1959 to 1947.5 (10³ m³) in 1984, to reaching 2162.3 (10³ m³) in 2019, and the peak flows have increased from 111.2 m³/s in 1959, to 140.5 in 1984 to reach 141 m³/s in 2019 (Table 6).

The comparison of the results of the hydrological response of the basin between the state of land use in 1959 and that of 2019 shows an increase in runoff volumes of 414 (1000 m³) and 389.2 (1000 m³) in Bab El Wadi and Triolet respectively, as well as an increase in peak flows of 27.6 m³/s and 29.8 m³/s in Bab El Wadi and Triolet respectively. This increase is mainly due to the increase in runoff coefficients and soil sealing rates caused by land use changes resulting from this basin’s urban evolution. The latter has experienced

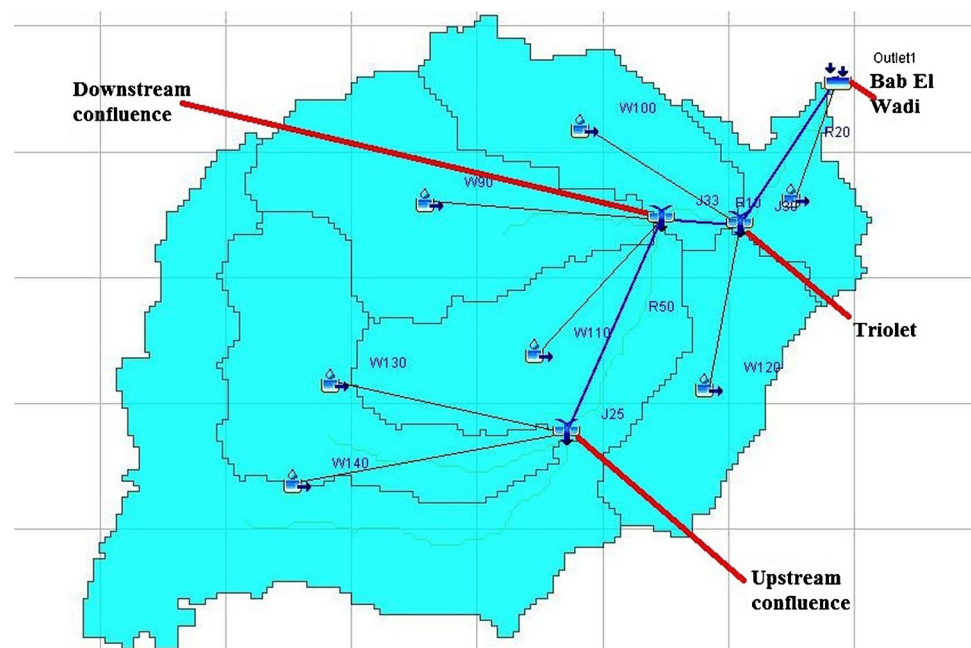
Table 4 Concentration and response times (lag time) of watersheds (1959- 2019)

Watershed	Sub-watersheds	Concentration time (minutes)			Response time (minutes)		
		Year 1959	Year 1984	Year 2019	Year 1959	Year 1984	Year 2019
Wadi Koriche watershed	Baranes	48	35.4	34.2	28.80	21.24	20.52
	Sidi Medjber	30	25.8	25.8	18.00	15.48	15.48
	Birtraria	18	18	18.6	10.80	10.80	11.16
	Frais Vallon	19.8	18.6	18.6	11.88	11.16	11.16
	CarrièreJaubert	21.6	21	19.8	12.96	12.60	11.88
	Chemin du Fort	19.2	18.6	14.4	11.52	11.16	08.64
	Wadi Koriche	14.4	11.4	10.2	08.64	06.84	06.12
Wadi Kniss watershed	Hydra East	73.8	61.2	48.6	44.28	36.72	29.16
	Kouba	59.4	48.6	46.2	35.64	29.16	27.72
	Kniss downstream	28.2	23.4	22.2	16.92	14.04	13.32
	Kiss mouthpiece	10.2	10.8	12	06.12	06.48	07.20
	Hydra West	45	29.4	25.8	27.00	17.64	15.48
	Upstream East	39	36	25.8	23.40	21.60	16.92
	Upstream West	49.8	46.2	39.6	29.88	27.72	23.76

Table 5 Simulation results of the hydrological response of the Wadi Koriche watershed to the event of November 9 and 10, 2001

Name	Drainage area (Km ²)	Peak flow (m ³ /s)	Time of peak flow	Runoff volume (10 ³ m ³)
S.Baranes	2.57	91.9	10/11 at 07:30 am	658
S.Sidi Medejber	1.32	55.2	10/11 at 07:30 am	332.8
S.Birtraria	0.94	39.9	10/11 at 07:30 am	238.4
S.Frais Vallon	1.33	57.2	10/11 at 07:30 am	350.3
S.Carriere Jaubert	1.06	44.9	10/11 at 07:30 am	273.3
S.Chemin du Fort	1.54	59.9	10/11 at 07:30 am	343.7
S.Koriche Wadi	0.5	21.7	10/11 at 07:30 am	133.1
Bab el Wadi	9.29	131.8	10/11 at 11:30 am	2257.4
Upstream Confluence	3.9	147.1	10/11 at 07:30 am	990.8
Downstream Confluence	6.78	160.7	10/11 at 08:30 am	1676
Triolet	8.78	141	10/11 at 10 am	2162.3

Fig. 5 Schematic of the Wadi Koriche watershed under the HEC-HMS hydrological model



an increase in paved areas (buildings and roads) of nearly 48% between 1959 and 2019.

The results also indicate variations in peak flood times between 1959 and 2019 at Triolet and the outlet. According to these results, in 1959, the flood arrived at the outlet at 12 pm with a peak flow of 104.2 (m³/s), while in 2019, it arrived at 11:30 am with a peak flow of 131.8 (m³/s). The travel time of the flood from upstream to downstream has thus decreased by 30 min between 1959 and 2019 (Table 6). These variations are mainly due to the reduction of water concentration times and watershed response times. The latter two are influenced by the artificialization of the majority of natural flows and their transformation into communication roads, thus causing changes in the slopes and roughness of the flows.

Runoff volumes and peak flows of the Wadi Kniss watershed (1959 and 2019)

The simulation results of the hydrological response of the Wadi Kniss watershed on November 10, 2001, show a strong increase in peak flows and runoff volumes from 1959 to 2019. The results are discussed at three important sites considered in this work. The first site is the upstream confluence of the two flows coming from the heights of Hydra (at the level of the Martyrs' Square). The second site is the downstream confluence at the level of Anassers, and the third is the mouth of Wadi Kniss at the level of Ruisseau between the two communes of Belouizdad and Hussein Dey (Fig. 7). Simulation results show that the highest values of peak flows and runoff volumes are

Fig. 6 Runoff hydrograph of the event of November 9 and 10, 2001

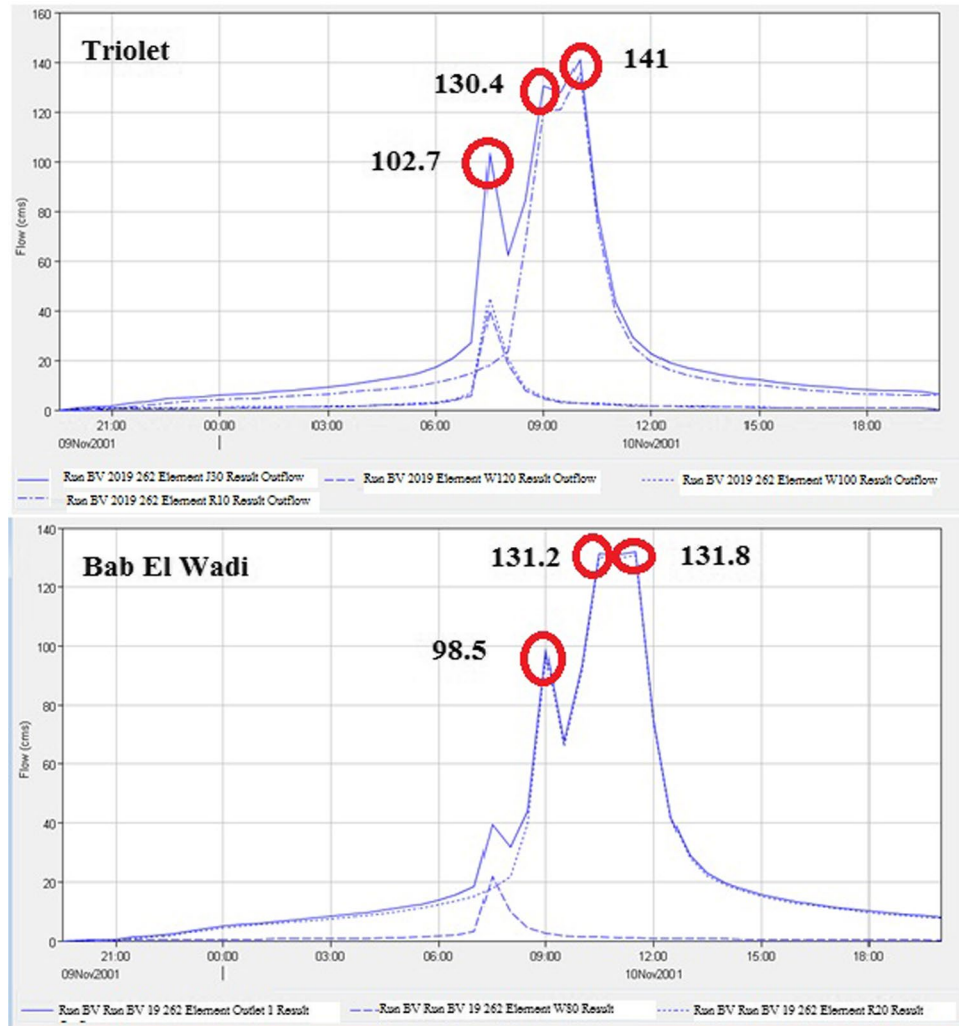


Table 6 Hydrological response of the Wadi Koriche and Wadi Kniss watersheds under land use changes (1959- 2019)

		Year 1959		Year 1984		Year 2019	
		Peak (m ³ /s)	Vol. (10 ³ m ³)	Peak (m ³ /s)	Vol. (10 ³ m ³)	Peak (m ³ /s)	Vol. (10 ³ m ³)
Wadi Koriche watershed	Bab El Wadi	104.2	1843.3	139.6	2034.6	131.8	2257.4
	Triolet	111.2	1773.1	140.5	1947.5	141	2162.3
Wadi Kniss watershed	Outlet	101.5	1,694.4	154.9	2,526	170	2,975.9
	Upstream confluence	79.9	1,035.3	119.6	1,531.3	162.4	1,876.9
	Downstream confluence	110.7	1,773.4	168.1	2,584.3	183.9	3,036.5

present at the downstream confluence, where all the water from the other sub-basins converge. The peak flows at this confluence increased from 110.7 m³/s in 1959 to 168.1 m³/s in 1984, reaching 183.9 m³/s in 2019. While at the outlet, they have increased from 101.5 m³/s in 1959 to 154.9 m³/s in 1984 and 170 m³/s in 2019.

The upstream confluence has lower flows than the downstream ones, with a peak flow of 79.9 m³/s in 1959, then 119.6 m³/s in 1984, and it reached 162.4 m³/s in 2019. The

downstream confluence point also has the highest runoff volumes, including 1773.4 (10³ m³) in 1959, 2584.3 (10³ m³) in 1984 and 3036.5 (10³ m³) in 2019, followed by the outfall of 1694.4 (10³ m³) in 1959, 2526 (10³ m³) in 1984 and 2975.9 (10³ m³) in 2019. As for the upstream confluence, the runoff volumes are 1035.3 (10³ m³) in 1959, 1531.3 (10³ m³) in 1984 and 1876.9 (10³ m³) in 2019 (Table 7).

Thus, from the runoff hydrographs of the three years (1959, 1984 and 2019) at the three points considered, the

Fig. 7 Schematic of the Wadi Kniss watershed under the HEC-HMS hydrological model

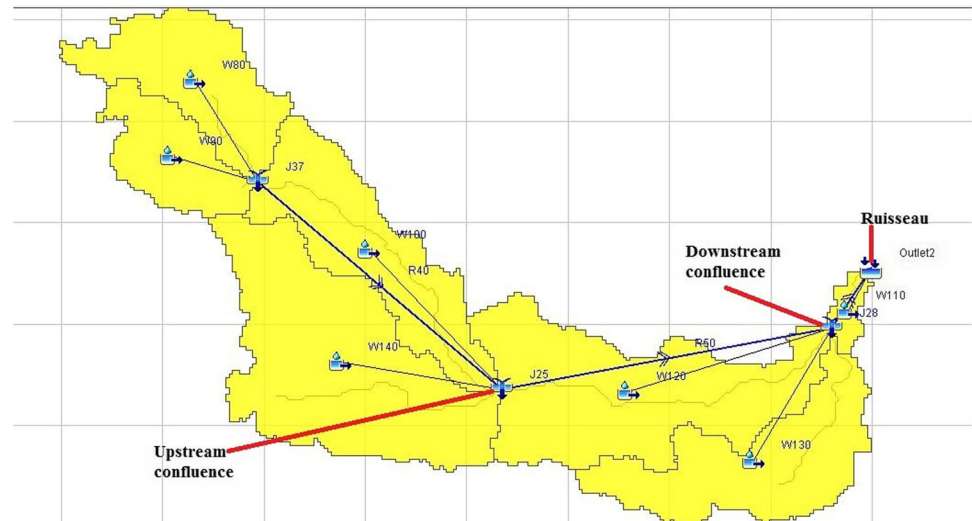


Table 7 Time of the Peak flow and the Peak flows of the Wadi Koriche and Wadi Kniss watersheds for November 10, 2001

		Peak Time (m ³ /s) in 1959	Peak Time (m ³ /s) in 1984	Peak Time (m ³ /s) in 2019
Wadi Koriche watershed	Outlet (Bab El Wadi)	11 am: 89.8 12 am: 104.2	10:30 am: 119.1 11:30 am: 139.6	10:30 am: 131.8
	Triolet	9 am: 111.2 10h30 am: 108	9 am: 118.5 10 am: 140.5	9 am: 130.4 10 am: 141
Wadi Kniss watershed	Outlet	10h30 am: 101.5 11 am: 84.2 2 pm: 85.1	10 am: 154.9 1 pm: 125.2	10 am: 170 12h30 pm: 162.1
	Upstream confluence	8 am: 79.9	10 am: 154.9 12h30 pm: 125.5	07h30 am: 162.4 09h30 am: 88.2
	Downstream confluence	07h30 am: 110.7 11 am: 86.7	07h30 am: 168.1 10 am: 133.2	07h30 am: 183.9 10 am: 172.2

results show a decrease in the travel times of the flood from 30 min to 1 h (Table 7). In 1959, the flood presented two peaks at the outlet, arriving at 10:30 am and 2 pm, while in 1984, the two peaks are recorded at 10 am and 1 pm. For the 2019 situation, the second peak is at 12:30. The same findings are recorded for the two confluences showing two peaks. This decrease in peak times is related to the decrease in water concentration times and response times of the sub-watersheds of Wadi Kniss between 1959 and 2019.

Although the Wadi Koriche watershed has physical characteristics such as geology, soil type and topography that are more conducive to runoff than the Wadi Kniss watershed, the latter has higher peaks and volumes of runoff. These findings confirm that imperviousness rates and runoff coefficient play an important role in generating runoff from small urban watersheds. These two parameters have increased significantly in this basin (Wadi Kniss) since the 1980s, following the development of urbanization on the Sahel hills after 1962.

The simulation results indicate that the Wadi Kniss watershed has a higher flood hazard than the Wadi Koriche watershed. However, if the same quantities of rainfall are recorded as those of November 09 and 10, 2001 (262 mm in 24 h) on the heights of the Sahel of Algiers, the watershed area of Wadi Kniss will present higher flood flows and runoff volumes than that of Wadi Koriche. This watershed area can thus be confronted with the phenomena of flooding, manifested by floods characterized by flows higher than 130 m³/s for a return period of about 100 years. The importance of torrential runoff (strong flow, steep slopes) can be seen in areas on the river's path. We point out that the Wadi Kniss will form a real torrent in case of important downpours and will surge on the lowest areas (Ruisseau district, *Rue des Fusillés* and *Rue Tripoli*), carrying away everything on its way (Fig. 8).

The results of this study show that land use changes are a major determinant of watershed hydrological response. These findings have been highlighted by several scientific works (Wan and Yang 2007; Wang et al. 2010; Jiang et al.

Fig. 8 Flooding of the Frais Vallon expressway, and the Road of “Frères Bouadou”



2012; Abushandi and Merkel 2013; Zope et al. 2015; Suribabu and Bhaskar 2015; Fehri and Yadh 2016; Mushtaq and Lala 2017; Das et al. 2018). For the same rainfall event, in different land use scenarios, an increase in peak flows and runoff volumes and a decrease in infiltration volumes were recorded. The same observations have been obtained in small urbanized watersheds in Poland, France, Italy, China and Australia (Boyd et al. 1993; Hingray 1999; Banasik et al. 2008; Albano et al. 2014; Niu and Sivakumar 2014).

Conclusion

The analysis of the different characteristics of the two watersheds of Wadi Koriche and Wadi Kniss revealed that they gather all the natural and anthropic factors favoring the formation of urban runoff.

The analysis of the hydrographic network and the delimitation of the small urban watersheds, based on the Digital Terrain Model (DTM), shows that the study area has a very dense hydrographic network formed from the heights of the Massif of Bouzareah and the Sahel of Algiers. These basins are characterized by strong and weak slopes upstream with an abrupt transition between these two degrees, increasing the runoff velocities. These increase the destructive power of water and its ability to carry objects, as happened in Bab El Wadi in 2001. The entire hydrographic network draining the study area has been artificialized, buried and replaced by communication roads, citing the example of the two important watercourses, Wadi Koriche and Wadi Kniss, which have been buried and replaced by the Frais Vallon expressway and the road “Frères Bouadou”, respectively.

The study of the land use dynamics of the two watersheds shows a significant change in the urban fabric, characterized by an increase of nearly 30% in the built environment and a decrease of 48% in vegetation cover between 1959 and 2019. These land use and occupation changes have led to an increase in impervious surfaces of about 49% between the same period. From these results, we confirm the effect of urbanization on the increase of impervious surfaces and, consequently, runoff.

The application of the SCS method for the study of the impact of urbanization on the hydrological response of the two watersheds of Wadi Koriche and Wadi Kniss shows that the various changes in land use induced by the evolution of urbanization between 1959 and 2019 have led to an increase in runoff coefficients, soil sealing rates, peak flows and runoff volumes of the watersheds as well as a reduction in water concentration times and response times of the watersheds. From these results, we reveal that both watersheds present a high vulnerability to flooding. This vulnerability results from the interweaving of several natural and anthropogenic factors.

Based on the findings, some recommendations can be highlighted to reduce the vulnerability of the populations of the study area to flood risks: (1) afforestation of the slopes of the hills and the Massif of Algiers; (2) prohibition of construction in the vicinity of watercourses; (3) temporary closure of the flow axes during large amounts of runoff; (4) integration of flood risk areas in the Land Use Plans (POS); (5) drawing up a flood emergency plan based on the flood risk areas and the flow axes within the urban areas; (6) raising awareness and informing the population of the existing dangers in the communication roads; (7) applying this

method to other small urban watershed areas. On the other hand, it is the first step towards better risk management, in particular by proposing cartographic tools for decision support to the competent authorities. It should encourage public authorities to block the extension of housing in sectors recognized as very vulnerable, (8) use of Geographic Information Systems (GIS) for the production of spatial analyses, as they facilitate the assessment of flood risk from hazard and vulnerability maps. We hope this work will contribute to managing flood risks in the Algerian municipalities.

It can be said that the analysis of urban flooding problems must lead local authorities to take an interest in the flow of water in the urban fabric. It is therefore essential to carry out a global study on the scale of the watershed area by simulating its behavior in the face of the various factors. This means that the control of runoff entirely conditions the organization of the city.

Data Availability The data that support the findings of this study are available from the corresponding author, ASTIT. S W, upon reasonable request.

Declarations

Conflict of interest The authors declare no competing interests.

References

- Abushandi E, Merkel B (2013) Modeling rainfall-runoff relations using HEC-HMS and IHACRES for a single rain event in an arid region of Jordan. *Water Resour Manage* 27:2391–2409. <https://doi.org/10.1007/s11269-013-0293-4>
- Albano R, Sole A, Sdao F, Giosa L, Cantisani L, Pascale S (2014) A systemic approach to evaluate the flood vulnerability for an urban study case in Southern Italy. *J Water Resour Prot* 6:351–362. <https://doi.org/10.4236/jwarp.2014.64037>
- Ali M, Khan SJ, Aslam I, Khan Z (2011) Simulation of the impacts of land use change on surface runoff of Lai Nullah basin in Islamabad, Pakistan. *Landsc Urban Plan* 102:271–279. <https://doi.org/10.1016/j.landurbplan.2011.05.006>
- Amini A, Ali TM, Ghazali AHB, Aziz AA, Akib SM (2011) Impacts of land-use change on streamflows in the Damansara Watershed, Malaysia. *Arab J Sci Eng* 36:713. <https://doi.org/10.1007/s13369-011-0075-3>
- Amini A, Ghazvinei PT, Javan M, Saghafian B (2014) Evaluating the impacts of watershed management on runoff storage and peak flow in Gav-Darreh watershed, Kurdistan. *Iran Arab J Geosci* 7:3271–3279. <https://doi.org/10.1007/s12517-013-0950-1>
- ANRH (Agence Nationale des Ressources Hydrauliques) (2001) Note Technique sur l'événement pluvieux du 09 et 10 novembre 2001, Région d'Alger (Wadi Koriche- Wadi Kniss, Département des eaux superficielles, Agence Nationale des Ressources Hydrauliques, 53p
- Astite SW, Medjerab A, Belabid NE, El mahmouhi N, El Wartiti M, Kemmou S (2015) Cartography of flood hazard by overflowing rivers using hydraulic modeling and geographic information system: Wadi El Harrach case (North of Algeria). *Revista de Tel-edeteccion*, vol.44, pp.67–79. ISSN:1988–8740. <https://doi.org/10.4995/raet.2015.3985>
- Astuti IS, Sahoo K, Milewski A, Mishra DR (2019) Impact of land use land cover (LULC) change on surface runoff in an increasingly urbanized tropical watershed. *Water Resour Manage* 33:4087–4103. <https://doi.org/10.1007/s11269-019-02320-w>
- Banasik K, Hejduk L, Barszcz M (2008) Flood Flow consequences of land use changes in a small urban watershed of Warsaw. 11th International Conference on urban drainage, Edinburgh, Scotland UK, 10p
- Belihu M, Tekleab S, Abate B, Bewket W (2020) Hydrologic response to land use land cover change in the Upper Gidabo Watershed, Rift Valley Lakes Basin, Ethiopia. *HydroResearch* 3:85–94. <https://doi.org/10.1016/j.hydres.2020.07.001>
- Birch GF, Lean J, Gunns T (2015) Historic change in watershed land use and metal loading to Sydney estuary, Australia (1788–2012). *Environ Monit Assess*, 187: 594. <https://doi.org/10.1007/s10661-015-4718-9>
- Bouvier C (1989) Contribution à l'étude du ruissellement urbain en Afrique de l'Ouest, Application à la simulation des écoulements sur petits bassins urbains. Mécanique, Génie Mécanique, Génie Civil. Université de Montpellier, Thèse de Doctorat, p 344p
- Boyd MJ, Bufill MC, Knee RM (1993) Pervious and impervious runoff in urban watersheds. *Hydrol Sci J* 38(6):463–478. <https://doi.org/10.1080/02626669309492699>
- Brgm (Bureau de Recherches Géologiques et Minières) (2006) Réduction de la Vulnérabilité du Massif de Bouzaréah aux Catastrophes naturelles, Rapport de tache 2, vol. 02-Risque d'inondation. Rapport ISL R 3114.doc. 225p
- Burgeap (Bureau d'Etudes en Environnement) (2005) Etude intégrée de réduction de la vulnérabilité des zones urbaines de la Wilaya d'Alger aux catastrophes naturelles (hors massif de Bouzaréah), Rapport n°4, Diagnostic de la vulnérabilité des zones pilotes aux aléas naturels et recommandations pour la mise en œuvre de plans d'aménagement urbain et péri-urbain durables. Rit. 4891/A.11197/C.104067. 228p
- Calomino F, Veltri P (1984) Rainfall-runoff in a small urban basin: experimental results from Luzzi. The 3rd International Conference on Urban Storm Drainage. Chalmers Univ. Technology; Göteborg, Sweden, pp 223–231
- Chen Y, Xu Y, Yin Y (2009) Impacts of land use change scenarios on storm-runoff generation in Xitiaoqi basin, China. *Quatern Int* 208:121–128. <https://doi.org/10.1016/j.quaint.2008.12.014>
- Crowell M, Leatherman SP, Buckley MK (1991) Historical shoreline change: error analysis and mapping accuracy. *J Coast Res* 7(3):839–852. <https://www.jstor.org/stable/4297899>
- Dartiguenav C, Sreedhar S, Fleming M (2009) HEC-GeoDozer user's manual. U.S. Army Corps of Engineers, Institute of Water Resources, Hydrologic Engineering Center (HEC). 609 Second St. Davis, CA 95616.4687
- Das P, Behera MD, Patidar N, Sahoo B, Tripathi P, Behaera PR, Srivastava SK, Roy PS, Thakur P, Agrawal SP, Krishnamurthy YVN (2018) Impact of LULC change on the runoff, base flow and evapotranspiration dynamics in eastern Indian river basins during 1985–2005 using variable infiltration capacity approach. *J Earth Syst Sci* 127:19. <https://doi.org/10.1007/s12040-018-0921-8>
- Fallati L, Savini A, Sterlacchini S, Galli P (2017) Land use and land cover (LULC) of the Republic of the Maldives: first national map and LULC change analysis using remote-sensing data. *Environ Monit Assess* 189(8):417. <https://doi.org/10.1007/s10661-017-6120-2>
- Fehri N, Yadh Z (2016) Étude de l'impact de l'extension et de la densification du tissu urbain sur les coefficients de ruissellement dans le bassin versant des Wadis El-Ghrich et El-Greb (Tunis) par l'application de la méthode SCS aux événements de septembre 2003. *Physio-Géo* 10:61–79. <https://doi.org/10.4000/physio-geo.4769>

- Fleming, MJ, Doan JH (2010) HEC-GeoHMS geospatial hydrologic modeling extension. U.S. Army Corps of Engineers, Institute of Water Resources, Hydrologic Engineering Center (HEC). 609 Second St. Davis, CA 95616–4687
- Ford D, Pingel N, Devries JJ (2008) Hydrologic modeling system application guide. U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC). 609 Second St. Davis, CA 95616–4687
- Gao Y, Chen J, Luo H, Wang H (2019) Prediction of hydrological responses to land use change. *Sci Total Environ*. 708: 134998. <https://doi.org/10.1016/j.scitotenv.2019.134998>
- Guan M, Sillanpää N, Koivusalo H (2016) Storm runoff response to rainfall pattern, magnitude and urbanization in a developing urban watershed. *Hydrol Process* 30:543–557. <https://doi.org/10.1002/hyp.10624>
- Hingray B (1999) Comportement et modélisation hydraulique des zones bâties en situation d'inondation: le cas des zones cloisonnées d'habitat individuel de Ouagadougou. Mécanique, Génie Mécanique, Génie Civil. Université de Montpellier II, Thèse de Doctorat, p 390p
- Hu S, Fan Y, Zhang T (2020) Assessing the effect of land use change on surface runoff in a rapidly urbanized city: a case study of the central Area of Beijing. *Land* 9(1):17. <https://doi.org/10.3390/land9010017>
- Jiang S, Ren L, Yong B, Fu C, Yang X (2012) Analyzing the effects of climate variability and human activities on runoff from the Laohahe basin in northern China. *Hydrol Res* 43(1–2):3–13. <https://doi.org/10.2166/nh.2011.133>
- Kermani S, Boutiba M, Guendouz M, Guettouche MS, Khelfani D (2016) Detection and analysis of shoreline changes using geospatial tools and automatic computation: case of Jijelian sandy coast (East Algeria). *Ocean Coast Manag* 132:46–58. <https://doi.org/10.1016/j.ocecoaman.2016.08.010>
- Li C, Liu M, Hu Y, Shi T, Zong M, Walter MT (2018) Assessing the impact of urbanization on direct runoff using improved composite CN method in a large urban area. *Int J Environ Res Public Health*. 15(4):775. <https://doi.org/10.3390/ijerph15040775>
- Liu X, Li Y, Shen J, Fu X, Xiao R, Wu J (2014) Landscape pattern changes at a catchment scale: a case study in the upper Jinjing river catchment in subtropical central China from 1933 to 2005. *Landsc Ecol Eng* 10:263–276. <https://doi.org/10.1007/s11355-013-0221-z>
- Menad W (2012) Risques de crue et de ruissellement superficiel en métropole méditerranéenne: Cas de la partie Ouest du Grand Alger. Thèse de Doctorat: Géographie. Université Paris Diderot-Paris, 330p
- Miller JD, Kim H, Kjeldsen TR, Packman J, Grebby S, Dearden R (2014) Assessing the impact of urbanization on storm runoff in a peri-urban watershed using historical change in impervious cover. *J Hydrol* 515:59–70. <https://doi.org/10.1016/j.jhydrol.2014.04.011>
- Moore L (2000) Shoreline mapping techniques. *J Coast Res* 16:111–124. <https://www.jstor.org/stable/4300016>
- Mushtaq F, Lala MGN (2017) Assessment of hydrological response as a function of LULC change and climatic variability in the watershed of the Wular Lake, J&K, using geospatial technique. *Environ Earth Sci* 76:760. <https://doi.org/10.1007/s12665-017-7065-z>
- Nan Y, Wang B, Zhang D, Liu Z, Qi D, Zhou H (2020) Spatial patterns of LULC and driving forces in the transnational area of Tumen River: a comparative analysis of the sub-regions of China, The DPRK, and Russia. *Chin Geogra Sci* 30(4):588–599. <https://doi.org/10.1007/s11769-020-1136-x>
- Niu J, Sivakumar B (2014) Study of runoff response to land use change in the East River basin in South China. *Stoch Environ Res Risk Assess* 28:857–865. <https://doi.org/10.1007/s00477-013-0690-5>
- ONM (Office National de Météorologie) (2002). Un résumé de la situation météorologique exceptionnelle ayant affectée le centre et l'ouest du nord Algérie et en particulier la zone urbaine d'Alger les 9 et 10 novembre 2001. Note technique, n°001, 6 p
- Scharffenberg WA, Flemin MJ (2010) Hydrologic modeling system HEC-HMS user's manual. U.S. Army Corps of Engineering Center (HEC). 609 Second St. Davis, CA 95616
- SCS (1986) Urban hydrology for small watersheds, technical release (TR-55). United States Department of Agriculture Washington, USDA, Washington, DC
- SEAAL (Société des Eaux et d'Assainissement d'Alger) (2007) Actualisation du Schéma Directeur d'Assainissement de la Wilaya d'Alger. Société d'Ingénieurs Conseils SAFEGE. Société des Eaux et de l'Assainissement d'Alger
- Shahid MA, Baccardo P, Usman M, Albanese A, Qamar MU (2016) Predicting peak flows in real time through event based hydrologic modeling for a trans-boundary river watershed. *Water Resour Manage*. <https://doi.org/10.1007/s11269-016-1435-2>
- Stehr A, Debels P, Romero F, Alcayaga H (2008) Hydrological modeling with SWAT under conditions of limited data availability: evaluation of results from a Chilean case study. *Hydrol Sci J* 53:588–601. <https://doi.org/10.1623/hysj.53.3.588>
- Suribabu CR, Bhaskar J (2015) Evaluation of urban growth effects on surface runoff using SCS-CN method and Green-Ampt infiltration model. *J Earth Sci Inform* 8:609–626. <https://doi.org/10.1007/s12145-014-0193-z>
- Suriya S, Mudgal BV (2012) Impact of urbanization on flooding: the Thirusoolam sub watershed—a case study. *J Hydrol* 412–413:210–219. <https://doi.org/10.1016/j.jhydrol.2011.05.008>
- Tholin AL, Keifer CJ (1959) The hydrology of urban runoff. *J Sanit Eng Div* 85(2):47–106. <https://doi.org/10.1061/JSEDAI.0000218>
- Treitz PM, Howard PJ, Gong P (1992) Application of satellite and GIS technologies for land-cover and land-use mapping at the rural-urban fringe: a case study. *Photogram Eng Rem Sen* 58(4):439–448
- Wan R, Yang G (2007) Influence of land use/cover change on storm runoff—a case study of Xitiaoxi River Basin in upstream of Taihu Lake Watershed. *Chin Geogr Sci* 17:349–356. <https://doi.org/10.1007/s11769-007-0349-6>
- Wang M, Qin D, Lu C, Li Y (2010) Modeling anthropogenic impacts and hydrological processes on a wetland in China. *Water Resour Manage* 24:2743–2757. <https://doi.org/10.1007/s11269-010-9577-0>
- Xu Z, Zhao G (2016) Impact of urbanization on rainfall-runoff processes: case study in the Liangshui River Basin in Beijing, China. *Proc Int Assoc Hydrol Sci* 373:7–12. <https://doi.org/10.5194/piahs-373-7-2016>
- Yao L, Wei W, Yu Y, Xiao J, Chen L (2018) Rainfall-runoff risk characteristics of urban function zones in Beijing using the SCS-CN model. *J Geogr Sci* 28:656–668. <https://doi.org/10.1007/s11442-018-1497-6>
- Zhang L, Nan Z, Yu W, Ge Y (2015) Modeling land-use and land-cover change and hydrological responses under consistent climate change scenarios in the Heihe River Basin, China. *Water Resour Manage* 29:4701–4717. <https://doi.org/10.1007/s11269-015-1085-9>
- Zope PE, Eldho TI, Jothiprakash V (2015) Impacts of urbanization on flooding of coastal urban watershed: a case study of Mumbai city, India. *Nat Hazards* 75:887–908. <https://doi.org/10.1007/s11069-014-1356-4>

Springer Nature or its licensor (e.g. a society or other partner) holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.