ORIGINAL ARTICLE

Urban Flooding in the Northern Part of Kabul City: Causes and Mitigation

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Abstract

Urban flooding is a big challenge in the northern part of Kabul city. Urban flooding during monsoon has become common in recent years. Urban flooding occurs due to excessive rainfall and inadequate drainage, which can be exacerbated by unsustainable urban expansion, changes in catchment topography, and increase of impervious surface. Over a decade, drainage systems of Kabul had been undesirably upgraded in proportion to population growth, causing an increase in the frequency of urban flooding. However, studies to address this issue are not known to have been conducted in Afghanistan. Therefore, the objective of the study was to evaluate pre and post-development land-use changes and hydrological modeling for identification of the factors causing the floods. The land-use changes of between 1964 and 2009 were evaluated using CORONA 1964 and update 2009 imagery of Kabul city. Climate Hazard Group InfraRed Precipitation with Station (CHIRPS) rainfall data was used as input in a one-dimensional hydrological model for the simulation of floods. The simulated data were analyzed together with landuse change data for identification of driving factors of floods and the possible mitigation measures. The study revealed that green land (pervious surface) within the study catchment in Kabul City has reduced from 21 to 5.71%, while the impervious land has dramatically increased from 7.1 to 58.57% during 1960 − 2009. Simulation of runoff using hydrological model revealed less runoff volumes generated floods in recent years which may be due to large changes in landuse. The study concludes that unsustainable development, a poor link between the main canal and existing drainage structures, and undesirable combined drainage structures are the major contributors to urban flooding of Kabul.

Keywords Urban flooding · Land-use · Urbanization · Modeling

1 Introduction

Urban areas are important in regional development, as they provide services including education, transportation links, energy supplies, and are major sources of employment. The occurrence of floods in these areas; termed urban flooding can disrupt activities and can cause damages to private properties and public infrastructures, erosion of stream and river banks, contamination of water sources, loss of lives and prevention of day to day activities (Rahman and Rob 2019). Consequently, the socio-economic activities of urban areas can be significantly impacted and huge economic losses can occur due to flooding. Flooding is generally caused by intense rainfall, site topography, soil characteristics, and surface permeability (Rahman et al. 2019; Baky et al. 2019). There is much difference between urban and rural flooding in that urban flooding is influenced by the development of catchments and in the event of a heavy/high intensity rainfall, higher runoffs are generated which increases the flood peaks and flood volumes (National Disaster Management Guidelines) (NDMG 2010). Due to this, an area is inundated within a shorter time, sometimes in minutes. Adnan et al. (2019) reported that the geomorphology of an area, e.g., the deltaic geographical settings of Bangladesh can

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affect and increase the vulnerability of flooding. Studies have also reported the inducement of floods by changes in hydrology and anthropogenic activities (Hooke 2016; Adnan et al. 2020). Flood is a universal phenomenon and there has been an increasing trend in its occurrences and intensity in many parts of the globe (Douglas et al. 2008; Asdak and Supian 2018; Boudiaf et al. 2020) and have been attributed to changes in climatic variables (Shiru et al. 2019a; Sa'adi et al. 2019; Homsi et al. 2020). This has generated further interest in research on past floods and their causes.

Devastating effect of urban floods in different parts of the world has been reported in numerous studies (Li et al. 2017; Hall et al. 2005; Shiru et al. 2015; Zope et al. 2016) Devastation of urban floods are much severe in arid regions compared to other climatic zones due to their rapidness (Mohamed 2019). Afghanistan with a predominantly arid climate is often faced with periodic threats from flooding as a result of intense rainfall, snow melting or a combination of both, causing several fatalities and destruction of thousands of homes (NATO 2009). The report of the EMDAT (2015) showed that flooding accounts for 54.3% of the frequency of occurrence of disasters in Afghanistan, 26% deaths occurrences, and 33.5% losses to the economy between 1990 and 2014. In 2012, a sudden downpour in Kabul; Afghanistan's capital city caused severe flash flooding which affected many areas of the city, particularly the districts 6 and 13 which are the most congested areas (Hakimi 2012). The flood inundated the Kabul River, washing away several houses near the river bank and contaminating water sources. Similarly, in 2019, eight provinces including Kandahar were affected by floods that left 20 people dead, thousands of homes swept away and many families, which had already been displaced by drought, to leave their homes for the second time (Janjua and McVeigh 2019).

It has been suggested that a continuous increase in urban population and climate change will increase the rate of urban flooding (Hammond et al. 2015). The report of the United Nations Department of Economic and Social Affairs/Population Division (UNDESAD 2012) showed that between 2011 and 2050, population of the world is projected to increase from 7.0 billion to 9.3 billion. In the same vein; urban area population is expected to increase from 3.6 billion in 2011, to 6.3 billion by 2050. This movement of people from rural to urban areas exacerbates the expansion of construction land and cement roads that leads to serious soil compaction and larger areas of impervious surfaces (Wu et al. 2012). This will further have a severe impact on the hydrological cycle causing extreme runoff (Wang and Guo 2019) and further aggravating the flood hazards in many urban areas. The urban area population growth of Afghanistan has been projected to be about 15% between 2018 and 2050 (Masood et al. 2018). Like many other parts of the globe, reports of the erratic nature of rainfall and increase in temperature have been reported in the country (Bokhari et al. 2018; Sediqi et al. 2019; Qutbudin et al. 2019). These will have significant influence on the frequency and intensity of flooding in some parts. Understanding urban flooding in Afghanistan is, therefore, crucial for sustainable development of the area.

Unlike in developed parts of the globe, where many studies have been conducted on urban flooding, such studies have not been widely conducted in Afghanistan. More so, the combined approaches presented in this study are not known to have been applied in other studies in the country. In this study, the urban flooding in the northern part of Kabul City was investigated. The study evaluates urbanization and land use changes between 1964 and 2009 for the study catchment in the northern city of Kabul. Study involves the digitization of CORONA imager for the period of 1964 and 2009, land-use changes analysis using geographic information system (GIS), validation of MEW and CHIRPS daily rainfall data for the period 2008–2018, and the use of HEC-HMS hydrological model for the generation of discharge from rainfall for each urban flooding event obtained from Pajhwok Afghan news network.

2 Materials and Methods

The urbanization and land-use changes have been evaluated between 1964 and 2009 for the study catchment in the northern part of Kabul city. For land-use changes, the pre and post-development changes were assessed. The general procedure used in the study is outlined as follows.

1. The CORONA imager of 1964 for green area (pervious), constructed area (impervious) and compacted soil area (bare soil) are digitized with different highlights as well as imagery from 2009 digitized for the study area.
2. The land-use changes as pervious and impervious area were analysed and estimated in percentages using geographic information system (GIS).
3. Analysis of the digital elevation map (DEM) and storm water flow map of the study area for their possible impacts on urban flooding.
4. The CHIRPS daily average rainfall data was validated using the MEW gauge data for the years 2008–2018.
5. The hydrological model HEC-HMS was used for generating discharge from rainfall for each urban flooding event.
6. Analysis of results for understanding the factors causing urban flooding within this study catchment in the Kabul city.

2.1 Study Area

Afghanistan, covering an area of 652,000 km² falls within 29°350 N–38°400 N latitude and 60°310 E–74°550 E longitude, in the southwestern part of Central Asia. The topography of the country is very undulating with 75% area occupied by mountains.

The climate of Afghanistan is subtropical and continental, with hot and sunny summers and cold and rainy winters. The climate zones of the country are five according to Köppen–Geiger climate classification: arid desert, arid steppe, temperate dry summer, cold dry summer, and polar tundra. Annual average rainfall in the country is 300 mm. There is, however, variation in rainfall within the country based on the area and the altitude. The south is very dry, covered mostly by desert, and because of altitude, many areas are cold. The far eastern part of the country receives relatively more rainfall partly due to the effects of the Indian monsoon. Temperature in the area also varies widely. Mean temperature on the plains ranges from 0 to 8 °C in July with minimum temperature of between −20 and −25 °C.

This study was conducted in the northern part of Kabul within the coordinates of Lat: 34°32′47.92″N, Long: 69°8′33.32″E and Lat: 34°32′23.25″N, Long: 69°09′11.77″E in Afghanistan. The area comprises of four districts: 4, 10, 11 and 15 (Fig. 1) with flood-prone locality of Taimani (T), Market (M), Proja e Jadid (P) and Sarsabzi square (S).

This catchment has a total area of 70 Km² and is mostly for residential and commercial purposes. Flood occurrence is a common event in this area and understanding the occurrences of the past events is crucial for development of mitigation measures against future floods in the area.

2.2 Data Sources

The land use data was obtained from CORONA imagery 1964 and the new RGB imagery of 2009 with (10 × 10) cm resolution obtained from geospatial faculty of Kabul Polytechnic University. The daily rainfall satellite data from the Climate Hazard Group (CHIRPS v2) and the rain gauge daily rainfall data from the ministry of energy and water (MEW) of Afghanistan for the periods 2008–2018 were used in this study.

2.3 Rainfall Data Validation

The data validation was conducted to assess the ability of the CHIRPs data in replicating the properties of the MEW rainfall data. In second step, screened data for both types was compared to each other. In third step, validation of CHRIPS and MEW rainfall data was conducted based on the empirical root mean square error (RMSE) equation.
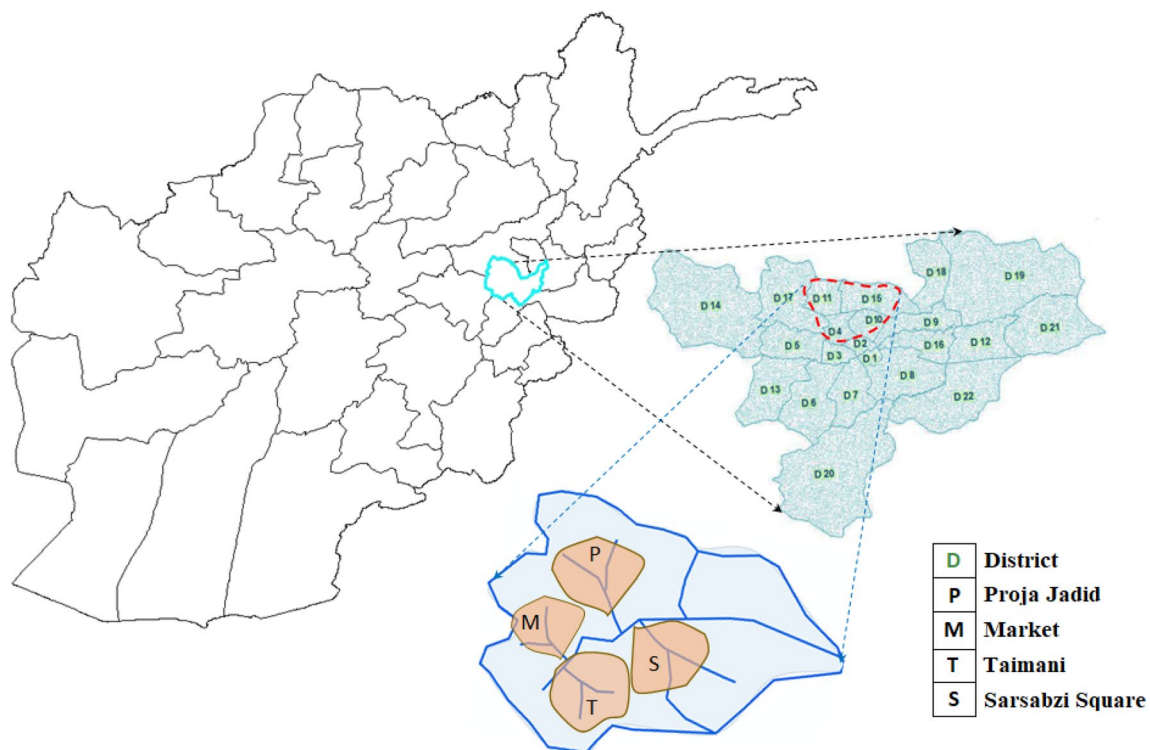

Fig. 1 Study catchment in the northern part of Kabul city

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\text{Pi} - \text{Oi})^2}{n}}, \tag{1}$$

Pi is the CHIRPS data, Oi is the observed (MEW) data, and n is the number of the data.

In fourth step, a correlation between CHIRPS and MEW data was estimated using Pearson correlation method.

2.4 Land-use Change Analysis

In the pre-development scenario, the urban land-use (developed) area as well as natural stream line and its reserved area based on CORONA imagery data of 1964 were delineated. The CORONA imagery maps were the only old imageries used by the military of the United States of America (USA) for military purposes, which were made public in 1995 for archaeological use and non-military purposes (Dashora et al. 2007). The percentage of land-use (constructed areas), pervious surface (green area), and impervious surface (bare soil) such as roads, rooftops are estimated and highlighted through digitizing using GIS know the land-use changes.

In post-development period, the study catchment images from 2009 with 10×10 cm resolution were evaluated for the land-use changes. The land use of year 1964 was compared with the land-use changes in 2009 as well as changes in imperviousness.

2.5 Modelling Urban Flooding

2.5.1 Hydrologic Model HEC-HMS

The Hydrologic Modelling System (HEC-HMS) was designed by the US army corps of engineers for simulating of the rainfall-runoff processes in branched stream watershed system (HMS 2000). Before simulation using HEC-HMS, it is required to do pre-calculations of some parameters including, time of concentration (Tc), lag time, rainfall data, soil type and infiltration rate, initial and constant lose, and the length and area of the sub-basin of the catchment.

The Tc is a key catchment response time parameter needed for forecasting the peak discharge rate and the timing of the flood event. The Kirpich (1940) method was used in this study.

$$Tc = 0.0195L^{0.77}S^{-0.385}, \tag{2}$$

$$\text{Lag time} = 0.6Tc. \tag{3}$$

The initials and constant loss were used for modelling the HEC-HMS. These two parameters were included for initial and constant loss rate that shows the physical characteristics of soil, land use and antecedence condition of the basin (Arekhi et al. 2012). The constant loss 0.1 mm/hr is entered to the model.

The soil type data with its infiltration rate was obtained from (Rahmani 2014). Based on soil texture, the soil infiltration rate was obtained from (Arekhi et al. 2012). These were used in the development of the hydrologic model in this study.

2.5.2 Estimating Canal Capacity

A 7 km Wazerabad canal with a cross-section of 7 m width and 3.5 m height (Fig. 2) passes through the middle of the catchment. The canal was recently upgraded to desirable capacity. The canal accommodative capacity is enough to carry generated stormwater in this catchment. Based on manning formula the discharge capacity of the canal was calculated using the following equations:

$$Q = VxA, \tag{4}$$

$$V = \frac{1}{n}R^{\frac{2}{3}}S^{\frac{1}{2}}, \tag{5}$$

where A is the area in (m^2), S is the slope of the canal (m/m), n is the manning coefficient, R is the hydraulic radius (m), P is the cross section wetted perimeters (m), v is the velocity
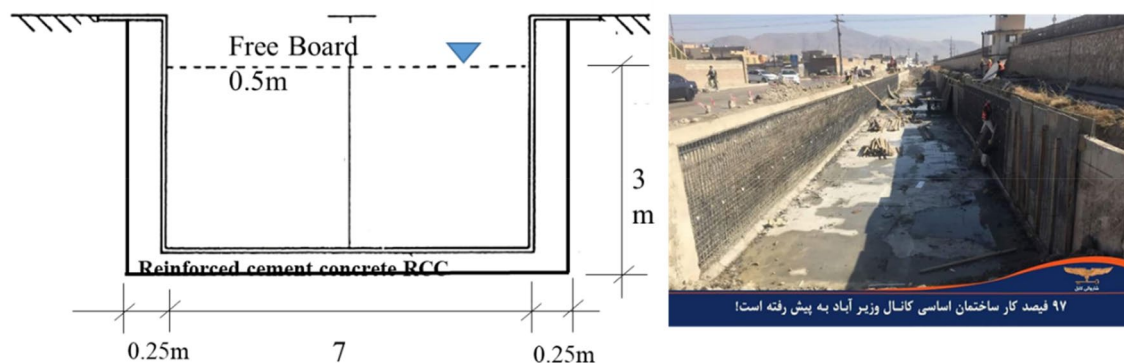

Fig. 2 Existing Wazerabad canal cross sectional details

(m/sec), and Q is the discharge cubic meter per second (cms).

3 Results

3.1 Data Validation and Urban Flooding Event

Validation of CHRIPS rainfall and MEW rainfall data was achieved based on the empirical root mean square error (RMSE) equation. The results showed RMSE = (0.3 mm/month) which is small amount change and is near to zero. Meanwhile, a good correlation of 0.9 R^2 was achieved between the two data sets. Afterward, the urban flooding events record was obtained from Pajhwok Afghan news for Kabul city. The CHIRPS and MEW rainfall data set were checked from 2011 to 2018 for the exact dates of urban flooding events. The rainfalls for the urban flooding dates were used to determine the surface runoff. Urban flooding occurs about (2 ~ 5) times annually. Due to 3 decades of warfare, the urban flooding data record was quite limited before 2011. It was only possible to get an urban flooding events data for 8 years commencing from 2011 to 2018. The comparison of the two rainfall datasets shows the CHIRPS was closely able to replicate the properties of the MEW gauge based rainfall data (Fig. 3).

January and February have high volume rainfalls, but because of the low temperatures during these months, rainfalls come as snowfalls. Due to this, for these months, the average between the daily min–max temperature from Global Summary of the Day (GSOD), where the temperature is very low (− 1 to − 17.5 °C) degrees Celsius were taken (Fig. 4).

3.2 Land-use Change Analysis

The pre-development (1964) map (Fig. 5), digitized in brown shows there were small developments of residential areas, schools and some government places. The green areas were agriculture land (Green land) that can be categorized as pervious area of the catchment. The land use (home constructions) totally occupied 5 km^2 which

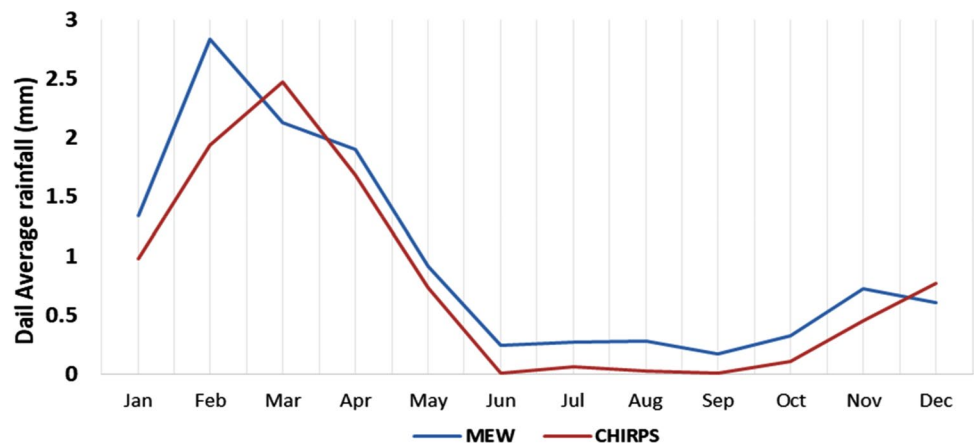**Fig. 3** MEW and CHIRPS daily average rainfall data for all months for the period 2008–2018
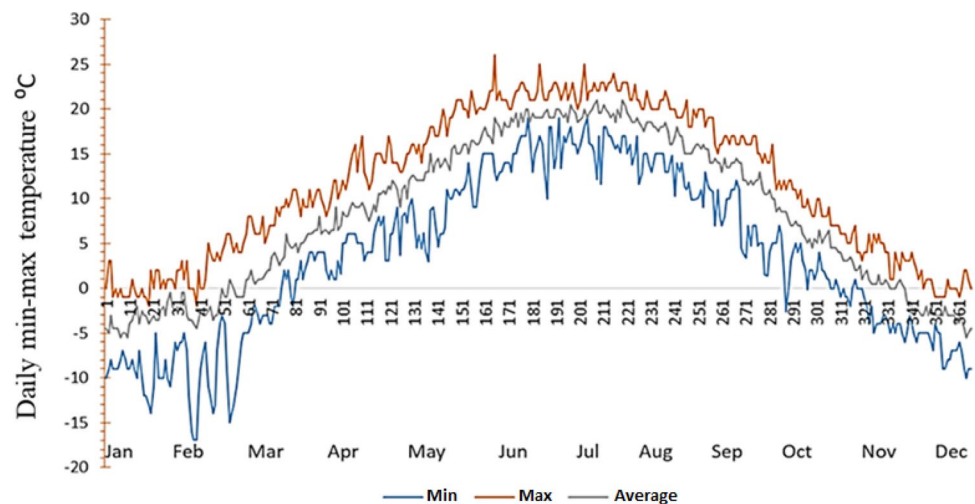

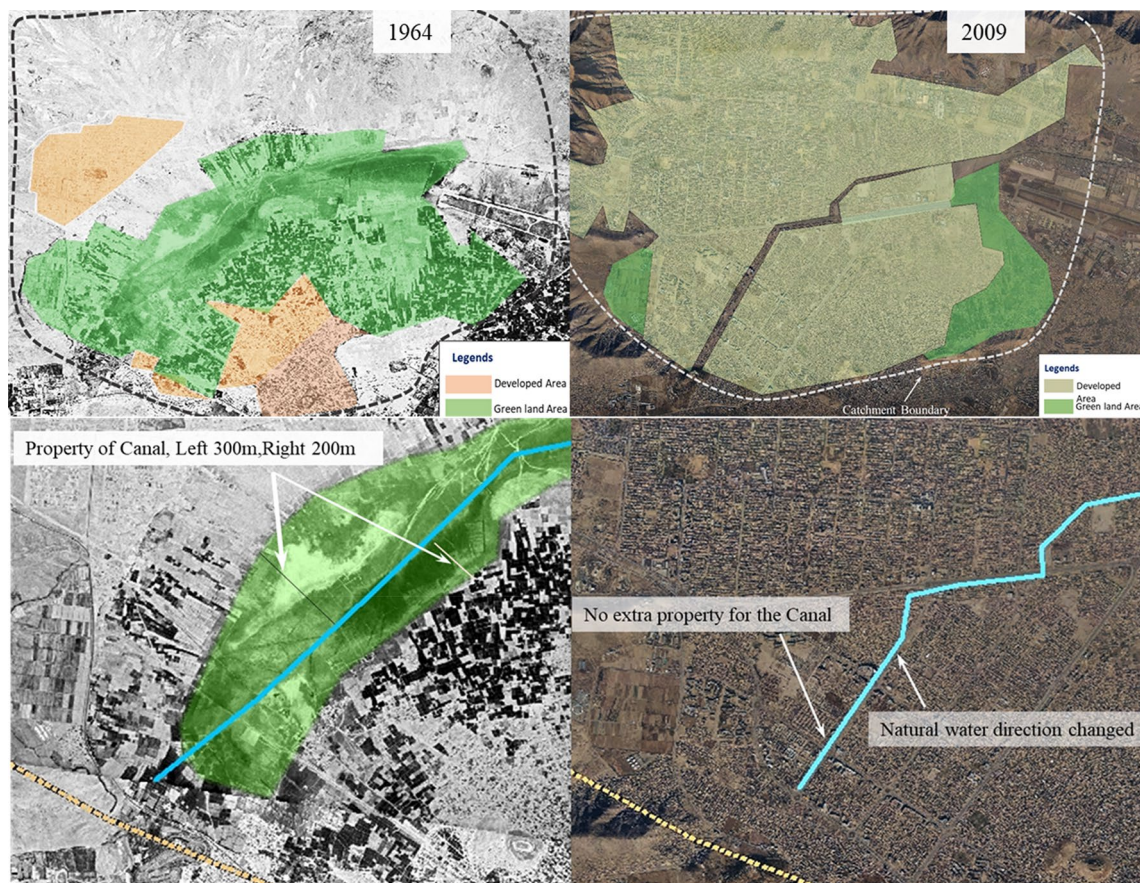**Fig. 4** Daily minimum, maximum and average temperature (°C) for the study area

Fig. 5 Pre and post-development land-use changes from 1964 to 2009

was about 7% of the catchment land. The green area was 21 km^2 which represents about 30% of the total catchment land. The remaining areas (in grey) represent natural bare soil with natural topography. Bared soil area was 44 km^2 which represent 62.9% of the catchment. In the (bare soil) portion, the water flow was based on gravity and natural waterway to the catchment with sufficient river capacity to accommodate the accumulated runoff without any flooding. Furthermore, there is existence of a swamp near airport area accommodating extra water in time of rainfalls and serving as a retention pond. This area was famous for hosting temporarily migrating wild ducks, especially in the spring times.

After 45 years of manmade activities, huge changes occurred on this catchment. Due to migration of rural population to the capital Kabul city, a rapid urban expansion had taken place. The digitized map of 2009 (Fig. 5) shows the percentage of land use (home, building constructions), and green area changes. The land use (home construction) after development was observed to have occupied an area of 41 km^2 amounting to 58% of the catchment area. The green area had reduced to 4 km^2 which represents 5.71% of the total catchment. The remaining 32.72% represents

the natural bare soils which are hillsides and unusable compacted places.

The numerical and percentage land use changes of the pre and post-development changes are presented for the study area in Table 1.

Based on the different types of land-use, green area comprises of wheat, corn and vegetable plantations as well as public parks. However, there are places that remained undeveloped such as hillsides and open spaces which are neither vegetative surfaces nor concrete. These areas mainly bare soils or exposed lands have lesser infiltration rates because they are compacted. Fifty percent (50%) of the bare soil area is hilly that contributes to direct runoff and the remaining fifty percent (50%) is open area for future government use.

The initial and constant loss, which shows the physical characteristics of soil, land use and antecedence condition of the basin used in the model to assess flood hazard show that there is an influence of land use on runoff generation and urban flooding. The model showed that changes in land use influences the rise in the level of accumulated runoff resulting in urban flooding in the study area.

Table 1 Land-use changes in during 1964 and 2009

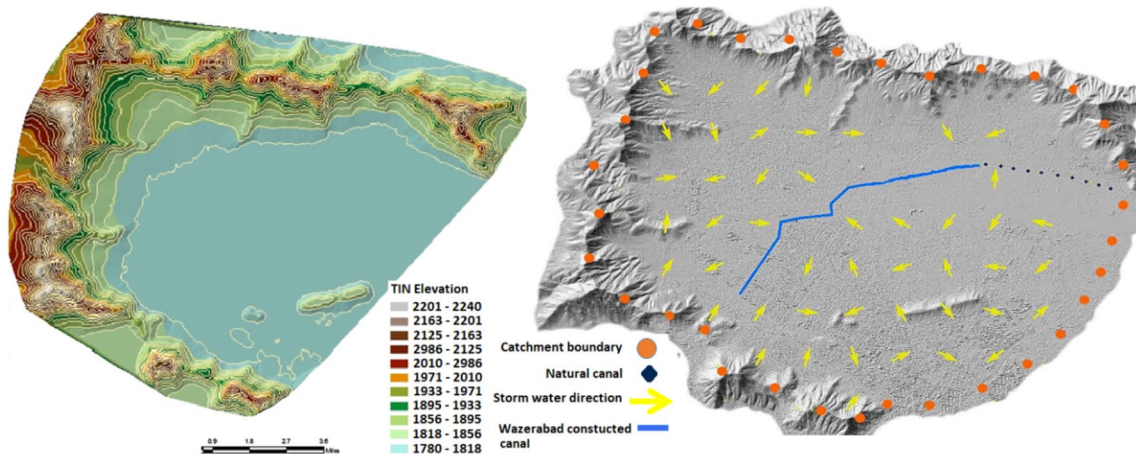| Land use	Pre-development		Post-development	
Type of land	Area in km^2	Percentage %	Area in km^2	Percentage %
Catchment area	70	100	70	100
Impervious land (roofs)	5	7.1	41	58.57
Pervious land green area	21	30	4	5.71
Bare soil surface	44	62.9	25	35.72
Swamp and wetland	1	>1	0	0.00

Fig. 6 Digital elevation model and storm water flow map of the catchment

3.3 Topography of the Catchment

Topography is one of the most important parameters for urban drainage structures for maintaining and giving desirable inclination for storm water flow. The result from the analysis/interpretation of the digital elevation map (DEM) and storm water flow map for the study area is presented in Fig. 6. The figure shows that unsustainable urban developments, such as unplanned houses and building constructions over the period of 45 years within the study catchment have resulted in increased percentage of impervious areas. The changes in the topography of the catchment have reduced the slope of many areas in the catchment. These urban developments altered the steep slope to smooth and gentle. In the middle of the catchment, there was a swampy area which had been filled with debris and soil after development, that the catchment became more flat (Fig. 6). The steepness of the area originates from the hillside upward to the mountainous area, where the most developed area laid in a gentle gradient area of the catchment Fig. 6. Additionally, the Catchment has a concave shape like a flat saucer. Urbanization changed and narrowed the natural waterway which causes slow movement and stagnation of the storm water.

Table 2 Urban flooding events record in Kabul city (www.pajhwok.com)

Year	Month	Urban flood date	Rainfall (mm) (daily max)
2018	April	20	19.13
2017	February	17	26.82
2016	April	2	22.95
2015	May	10	9.93
2014	March	16	42.19
2013	March	16	22.82
2012	March	12	23.08
2011	April	16	18.92
2011	Oct	7	9.24

3.4 HEC-HMS Model

To determine the discharge for each urban flooding event (Table 2) within the study catchment, the seven (7) consecutive day's rainfall data were entered into the hydrologic model. The discharge hydrograph with peak flow was generated for 8 years from 2011 to 2018.

The time of concentration is calculated based on Kirpich (1940) formula by considering the slope of the catchment 1:2000 in Table 3.

From the eight model simulation we have considered four models with maximum generated discharge for presentation in this section. Those events took place in 2012, 2014, 2017 and 2018 with peak flow of 10.4, 27.1, 15.9 and 11.2 cms respectively. The generated discharge hydrograph results (brown lines) (cms) and the rainfall hyetograph depth (blue bars) (mm) are presented in Fig. 7 for the four periods.

Overall results from the HEC-HMS model for this study catchment are presented in Table 4.

Table 4 Urban flooding events with generated discharge by HEC-HMS from (2011–2018)

Year	Month	Flood event date	Rainfall (mm) Max (daily)	Discharge (cms)
2018	April	(14–20)	19.13	11.2
2017	Feb	(12–18)	26.82	15.9
2016	Mar/Apr	(29 Mar–3 Apr)	22.95	12.6
2015	May	(5–11)	9.93	6.3
2014	March	(12–18)	42.19	27.1
2013	March	(10–16)	22.82	11.1
2012	March	(10–16)	23.08	10.4
2011	April	(10–16)	18.92	8.5
2011	Oct	(2–8)	9.24	3.4

Table 3 Calculated time of concentration (hrs) at study locations

Sub catchment	Sarsabzi square	Taimani	Market	ProjaeJadid
Length (m)	2119	2200	3000	2700
Tc (Hr)	2.2	2.3	2.9	2.7

3.5 Canal Capacity Estimation Against Generated Discharge

Based on continuity and manning formula, the estimated capacity of the canal within the study catchment is presented in Table 5.
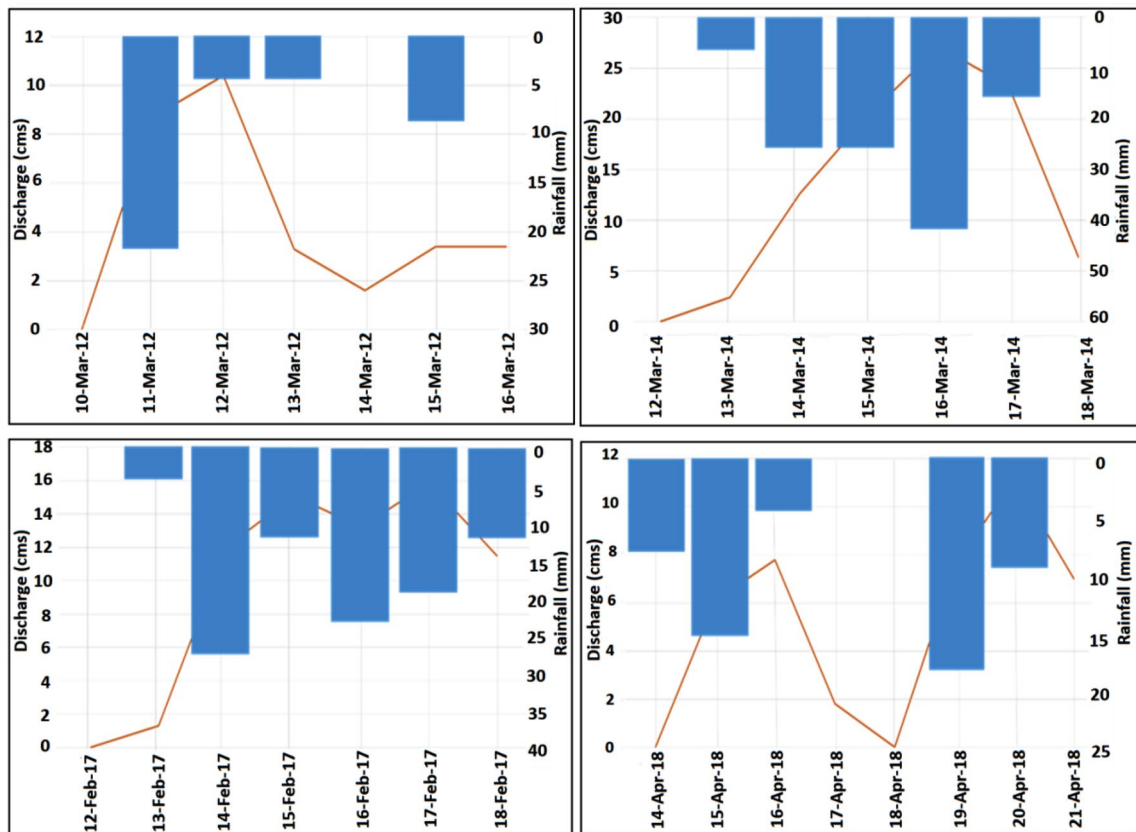

Fig. 7 Generated rainfall hyetograph (blue colour) and discharge hydrograph brown colour

Table 5 Calculation of existing Wazerabad canal

Average width	Height	A (m²)	S (m/m)	n	R (m)	P (m)
7 m	3.5 m	24.5	0.0005	0.02	1.75 m	14 m
$Q = \frac{A}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$	= 39.78 cms					

Based on hydrologic model generated, maximum discharges of 15.9 and 27.1 (m³/s), of two events were obtained and were less than the Wazerabad canal capacity as indicated in (Table 5). Calculation result shows that Wazerabad canal can accommodate around 39.78 (m³/s). In other words, existing constructed Wazerabad canal have sufficient capacity to accommodate and transfer all catchment generated runoff/discharge. Therefore, the urban flooding is not just due to the rainfall but other factors that contribute to it, such as sub-drainage structures poor linkages to Wazerabad canal, characteristics of the catchment, unsustainable urban expansion, combined drainage structures, absence of law enforcement and less attention to maintenance.

4 Discussion

Urban flooding constitutes a major problem in many parts of the world and has led to the loss of many lives, damages to properties, affected agriculture among other havocs. While major advances had been achieved in understanding floods, the major factors that will play significant roles in increased flooding in urban areas are continuous rural urban migration and climate change. On the Asian continent and Africa, where urbanization has been projected will increase the most (UNDESAD 2012), climate change is already having significant impacts (Alamgir et al. 2019; Ahammed et al. 2019; Salman et al. 2020; Khan et al. 2020) and projections have shown that these impacts may be aggravated in the future. For example, while rainfall has been projected to decrease in some parts of Nigeria, it is expected to increase in the most populated city of the country; Lagos, under all RCPs (Shiru et al. 2019b). This will have significant impacts on the city due to expected increase in population and poor infrastructural development and management. Similarly, Januriyadi et al. (2018) evaluated the future flood risks of Jakarta, with one of the fastest growing population in Asia. The mean future flood risk was amplified by 322–402% due to a combination of urban development and climate change. Aich et al. (2017) projected the future climate change in Afghanistan, and found that temperatures are expected to increase over the country and will significantly influence the rates of evapotranspiration. This may affect the patterns of rainfall in many areas of the country in the future and may have effects on the frequencies and intensities of both droughts and floods.

This study though not conducted for future assessment of floods, the study was conducted to understand changes in land-use and urbanization in relation to flooding. Study was motivated by the incessant occurrence of floods in many areas including the urban areas of Afghanistan particularly the highly populated Kabul city of the country. Flood occurrences have become an issue of major concern in the area due to the severe threats it poses to the social lives and economic activities in the area. As reported by Hagen and Teufert (2009), though there is a long history of occurrences of floods in Afghanistan, they are not well documented, except for short situational reports, thus little was known about the issues of floods in the country. This was confirmed by recent literature search which showed that studies relating to flooding and in particular urban flooding have still not been widely conducted. However, the frequency, intensity and devastating impacts of floods have been reported by some studies. Brakenridge et al. (2006) noted that the 1988 flood of Afghanistan resulted into displacement of 3000 people and causing an estimated damage of about US$260 million for the country. Hagen and Teufert (2009), reported the destruction of agricultural lands, livestock and infrastructure, and homelessness due to the 2005 and 2006 severe flooding in the country. As reported by Khalid (2018), two third of the city of Kabul population lives in informal settlements' and does not put into consideration design protocols, standard construction practices, and urban planning. These informal settlements are contributors to the problems of flooding in the city. In the neighboring Pakistan, Rana and Routray (2016) reported increasing frequency and intensity of floods in some cities, causing damage to infrastructures and loss of lives. Yasmeen et al. (2016) used HEC-HMS with HEC-GeoHMS combined with remote sensing and geographic information system (GIS) for hydrologic modeling of Tarbela catchment for the 2010 flood event in the area. The study revealed that the large surface runoffs occurrence in the area was due to the monsoon precipitation at the downstream area. This study supports the findings of the occurrences of urban flooding in the region.

There are several sources of uncertainties in hydrological rainfall-runoff models including initial conditions, model structure, parameters, and observational data (Lehbab-Boukezzi et al. 2016). There are several methods of analyzing these uncertainties based on the quantification of the errors between the observed and the predicted values (Mediero et al. 2011; Quintero et al. 2012; Fonseca et al. 2014). They include generalized likelihood uncertainty estimation

(GLUE) (Beven and Binley 1992; Freer et al. 1996; Mirzaei et al. 2015), shuffled complex evolution metropolis algorithm (SCEMUA) (Vrugt et al. 2003); sequential uncertainty fitting (SUFI2) (Abbaspour et al. 2004; Mousavi et al. 2012); parameter solution (ParaSol) (Van Griensven and Meixner 2007), and Markov chain Monte Carlo (MCMC) (Vrugt et al. 2008). Of the methods, the GLUE which is applied during calibrating and validating of the distributed or semi-distributed model is more widely used. The method also considers multiple simulations with different parameter sets in the model, which are generated randomly from a fixed prior distribution (Lehbab-Boukezzi et al. 2016). Each result is given a likelihood based on the comparison of the observed and simulated behavior.

Though the GLUE method has been criticized for not being formally Bayesian, giving unreliable and incorrect parameter estimation and predictive uncertainty (Mantovan and Todini 2006; Stedinger et al. 2008), other studies (Vrugt et al. 2009; Jin et al. 2010) found that both the method and the Bayesian can generate very similar estimates of stream flow under certain conditions. In Afghanistan, the area considered for this study, there are no observed discharge data. Therefore, the validation of the model using observed discharge data could not be conducted. Likely sources of uncertainty in this study may originate from the rainfall data due to errors in measuring equipment and in preparation of datasets. It is anticipated that such validation would be possible for future studies in the area when discharge data may be available.

5 Conclusions

This study investigates urban flooding in the northern part of Kabul city between 1964 and 2009. Digitization was conducted on CORONA imager and analysis of land-use changes using GIS. Validation of MEW and CHIRPS daily rainfall data for the period 2008–2018 was conducted and HEC-HMS hydrological model was used for generation of discharge from rainfall for each urban flooding events' obtained from Pajhwok Afghan news network.

This study is significantly important as the finding of factors causing urban flooding is crucial for developing best-suited management practices (BMPs) for mitigation of flooding in the area. This study reveals that during the last 45 years (1964–2009), a large change in land-use has occurred in urban catchment area. The green area has been reduced from 21 to 5.71%, and the bare pervious soil reduced from 62.9 to 35.72% and also the impervious land (construction) has dramatically increased from 7.1 to 58.57%. Though the capacity of the existing canal which passes through the middle of the catchment was sufficient to accommodate runoff waters, flood occurrence persists in

the area. This suggests that rainfall is not the only cause of flooding within the catchment. With advances in modelling approaches and future global climate models, it is hoped that a study on the future expected changes in land-use, population growth and climate change is conducted to assess the occurrence and impacts of floods in the study area. It is also anticipated that findings from the study would be of use to policy makers and developers in better planning of the urban area of Kabul and other urban areas and infrastructural developments and management. In view of this, the study recommends the following as some of the measures that can be applied in the management and flood control of Kabul city or other urban areas.

1. Reconstruct and upgrade aged drainage structures using standard drainage structure considering the BMPs, Considering reasonable slope (1:1000–1:500) to maintain a desirable link with Wazerabad canal.
2. Urban development should be put in city master planning agenda with a focus on the planning of standard drainage structures, sewage treatment facilities and water supply for newly developing areas.
3. Law enforcement by the government and public awareness of the impacts of improper waste disposal which can cause flooding. As the study area has no single sewerage system, construction of centralized sewage treatment facilities (CSTP) is recommended for the area for storm water management.

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