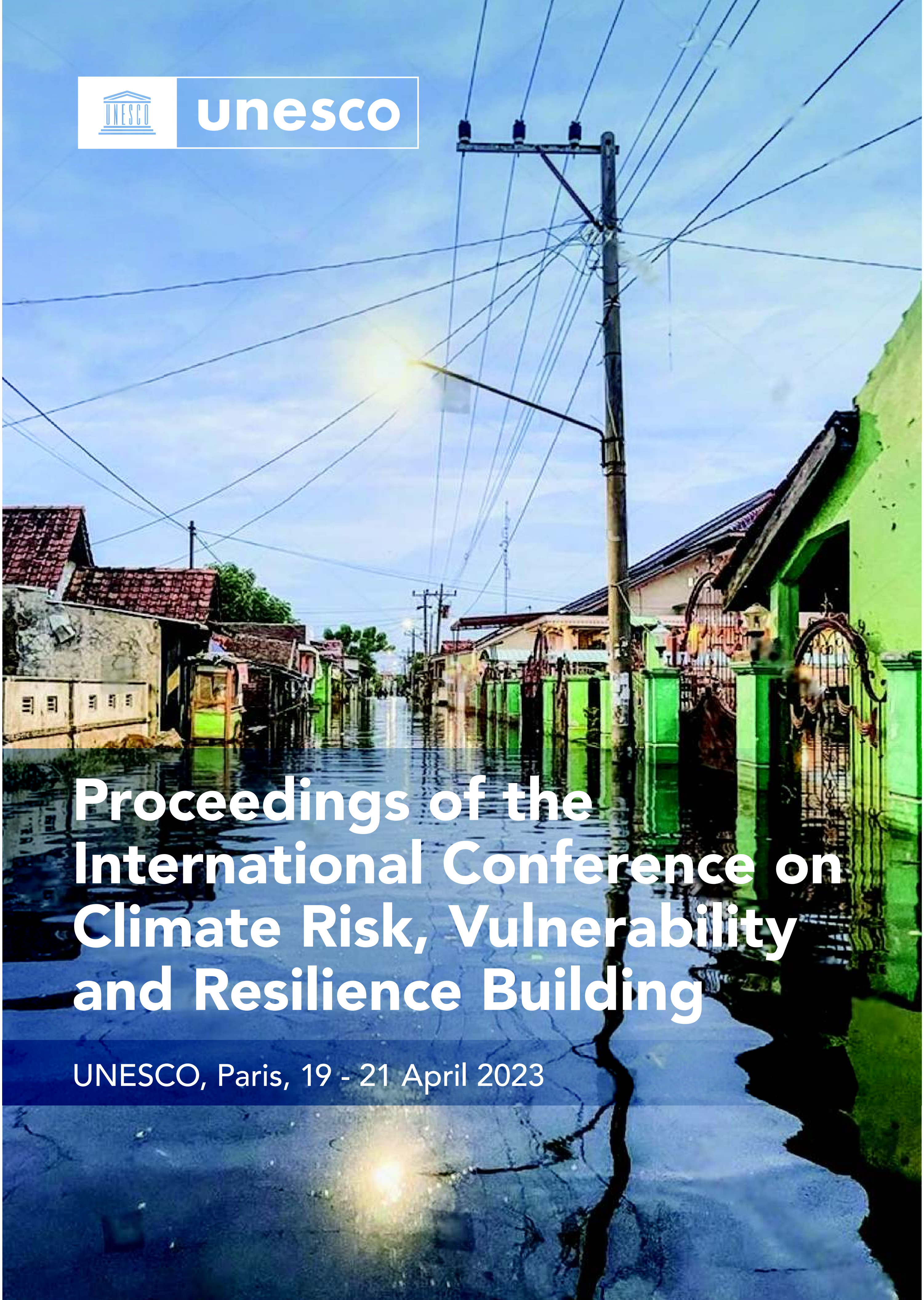

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Proceedings of the International Conference on Climate Risk, Vulnerability and Resilience Building

UNESCO, Paris, 19 - 21 April 2023

Published in 2025 by the United Nations Educational, Scientific and Cultural Organization, 7, place de Fontenoy, 75352 Paris 07 SP, France

https://doi.org/10.54677/ZCGQ8636

SC-2025/HYD/PI/8

This publication has been developed under the framework of project CliMWaR (Enhancing Climate Services for Improved Water Resources Management in Vulnerable Regions to Climate Change: Case Studies from Africa and Latin America and the Caribbean), made possible with the support of UNESCO/Flanders Fund-in-Trust for the support of UNESCO's activities in the field of science (FUST).

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Editor: Rita Marteleira, UNESCO

Acknowledgements: Paulina Marcela Ramírez Quevedo, UNESCO, Hong Huynh, UNESCO, Barbara Kavuma, UNESCO, Ruth Katui Nguma, UNESCO; Siying Tan, UNESCO; Natalia Tolochko, UNESCO; Annelies Martens, UNESCO

Graphic design: Sergio Baros

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The impact of urbanization expansion and land use change on flood peak discharge and vulnerability (case study: northeast Iran)

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Abstract

This research investigates the hydrological and human variables contributing to northeastern Iran's flooding. In the past few decades, the riverbed encroachment and urbanization increased the impervious area. This has increased exposure to floods and increased vulnerability. Due to the region's mild summer climate and fertile soil for the cultivation of rice, this region has experienced land use change, population growth, and urbanization in recent years. Furthermore, the number of reported flood incidents and subsequent damage has significantly grown. In order to achieve this purpose, we explored how changes in land use and precipitation affected the highest levels of discharge. We compared the peak flood flow volume before and after the city's expansion by using aerial photos and land use maps. Furthermore, the peak discharge's sensitivity to the curve number (CN) was examined. According to the results, variations in rainfall have far less impact on the peak discharge rate than variations in the CN. Peak flood discharge can grow between 2.7 and 4 times with a 10% increase in CN, according to the results of the sensitivity analysis. As a result, it can be concluded that an increase in CN and encroachment on the riverbed is the main cause of flood damage and increased vulnerability.

Introduction

Over the last 150 years, the world population has grown significantly, and this trend is expected to continue, putting tremendous pressure on local and global water resources (Yang *et al*. 2012). There is a competition for water between humans and ecosystems, giving rise to complex interrelationships between hydrological and social systems (Liu *et al*. 2015). Floods have caused the third greatest economic losses of the last twenty years, totalling $662 billion USD. The cost of hydrological disasters is expected to reach 59 billion USD in 2016 (Sermet *et al*. 2020). Floods can have serious socioeconomic implications, such as catastrophic damage to towns and cities (Jha *et al*. 2012, Alfieri *et al*. 2018). Human-environment interactions are more significant today than ever before (Blair and Buytaert 2016). Understanding the connections and feedback mechanisms between water resources and the social systems that rely on them becomes more crucial as human activity develops (Blair and Buytaert, 2016). Floods often stem from natural occurrences like heavy rainfall or river overflow, yet human activities can also exacerbate or induce them (Diaconu *et al*. 2021). Thus, floods represent a complex interplay of meteorological and hydrological elements influenced by human actions. Urbanization, expansion of cities towards the river's banks and land use changes increase flood frequency, storm flow volumes, peak discharge, and surface runoff, while decreasing infiltration, baseflow, and time lag (Smith *et al*. 2005, Dougherty *et al*. 2006, Ogden *et al*. 2011). It seems that urban flooding is much more common in developing countries (Chen *et al*. 2016), as the poor knowledge and fewer studies make it harder to predict the extent of flood impacts in most of these countries (Fewtrell *et al*. 2011). Often, in these countries, there are no reliable intensity-duration-frequency (IDF) relationships to estimate rainfall (Nkwunonwo, 2016). Climate change will only increase the magnitude and frequency of extreme storm events, while urbanization will increase the exposure and the effects of flooding (Green, 2018).

In several studies, humans are either depicted as an external factor acting on the system under investigation or as boundary elements (Milly *et al*. 2008, Peel and Blöschl 2011). As a result, our understanding of linkages and related feedback mechanisms between hydrological and social processes are mainly unexplored (Baldassarre *et al*. 2013). In order to analyse the reciprocal impacts of the hydrological and the human systems over time, it is necessary to construct a continuous human-water system to create a resilient city and minimize human and economic losses)Sivapalan *et al*. 2012, Kumar *et al*. 2020). For this purpose, the interaction between society and flood has been expressed by different approaches (Devkota *et al*. 2020; Haeffner and Hellman, 2020). But, in general, all these models simplify the effects of floods and, for example, ignore the complexities caused by the topography of the region or cultural aspects in vulnerability to floods (Schoppa *et al*. 2022). The interplay of several hydrological and social system components with flood occurrence is shown in Figure 1, along with the factors impacting flood damage.

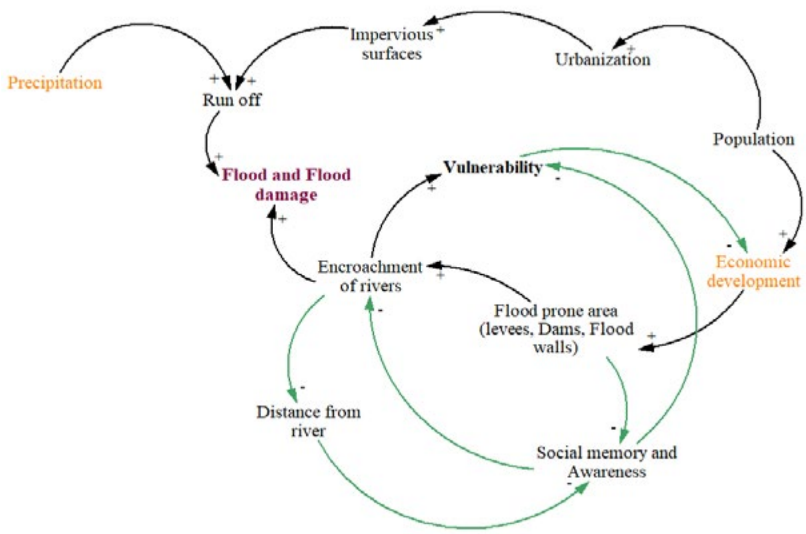

FIGURE 1. Interaction of different hydrological and human factors in flood and flood's effects on communities

Sensitivity analysis allows evaluating a situation response under several assumptions and examines the effects of each input variable on overall changes in model predictions (Beven and Hall, 2014). In this study we investigated the flood occurrences in a watershed in northeastern Iran. We studied the effect of land use changes and precipitation in two states, before and after urban development, and analysed the sensitivity to land cover and precipitation changes on peak flood discharge.

Studied Area

The city of Kalat, in the northeast of Iran, has existed for many years and was a prime place of Iranian rice cultivation (Figure 2). The fertile soil and the mild mountain climate in the summer have caused the population of Kalat to grow rapidly in the past years. As a result, urban areas have grown in this region during the last decade, with buildings being constructed beside the river's path, coming from the upstream tributaries. The studied basin lies in the semi-temperate mountainous climatic region. The mean annual precipitation is 340 mm, and the rainy season runs from winter to the middle of spring, with most rainfall occurring from February to May, and the highest flood frequency occurring in late May.

Consequently, the natural land cover (pasture) has been replaced by asphalt and impermeable surfaces.

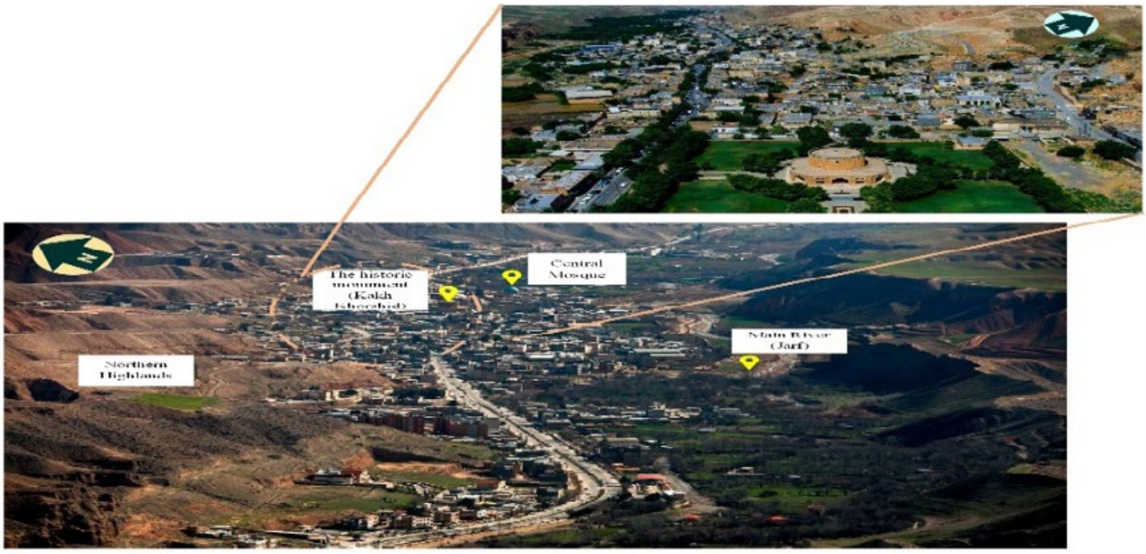

FIGURE 3. **Aerial view of the Kalat city and its historical monuments. The city was developed on the northern side of the highlands**

Figure 3 illustrates how the city is spread along the river and surrounded by mountains in the north. Nevertheless, since the population of this region has grown recently, houses have been constructed in the northern elevated areas, and the region's pastures have been completely destroyed.

Methodology

Data used in this study included:

1) Daily rainfall and discharge data of the hydrometric station located upstream of the city, the Darband Hydrometric Station, for the 28-year period (1991–2019)

2) Soil type and land use maps

3) Digital Elevation Model (DEM)

We used the Soil Conservation Service (SCS) method for estimating the runoff peak discharge (Ojha *et al*. 2008, Salami *et al*. 2017). In order to estimate the rainfall for a specific return period, the method by Ghahraman and Abkhezr (2004) was used, which presented the IDF equations for the eastern and northeastern regions of Iran (equations 1 and 2). Using daily rainfall records, the rainfall values with return periods of 2, 5, 10, 25, 50, 100 and 200 years were estimated.

$$P_{60}^{10} = 1.34 \text{ x } (P_{24})^{0.6490} \qquad (1)$$

$$P_{T}^{t} = (0.4524+0.2471n\ [T-0.6]) \text{ x } (0.3710+0.6184\text{x}t^{0.4484}) \text{ x } P_{60}^{10} \qquad (2)$$

Where is the one-hour rainfall with 10-years return period, is the average maximum 24-hour rainfall in the basin, T is the return period, and t is the duration of the precipitation event (min).

In order to estimate the water retention index, the curve numbers (CN) were analyzed, which depend on the permeability of the surface. The Soil Conservation Service Curve Number (SCS-CN) approach is the most widely used method for forecasting runoff depth from rainfall. This method quickly became a standard methodology utilized by many researchers and engineers worldwide in a variety of hydrological applications (Soulis, 2021; Hawkins *et al*., 2020). The factors affecting CN are shown in Figure 4.

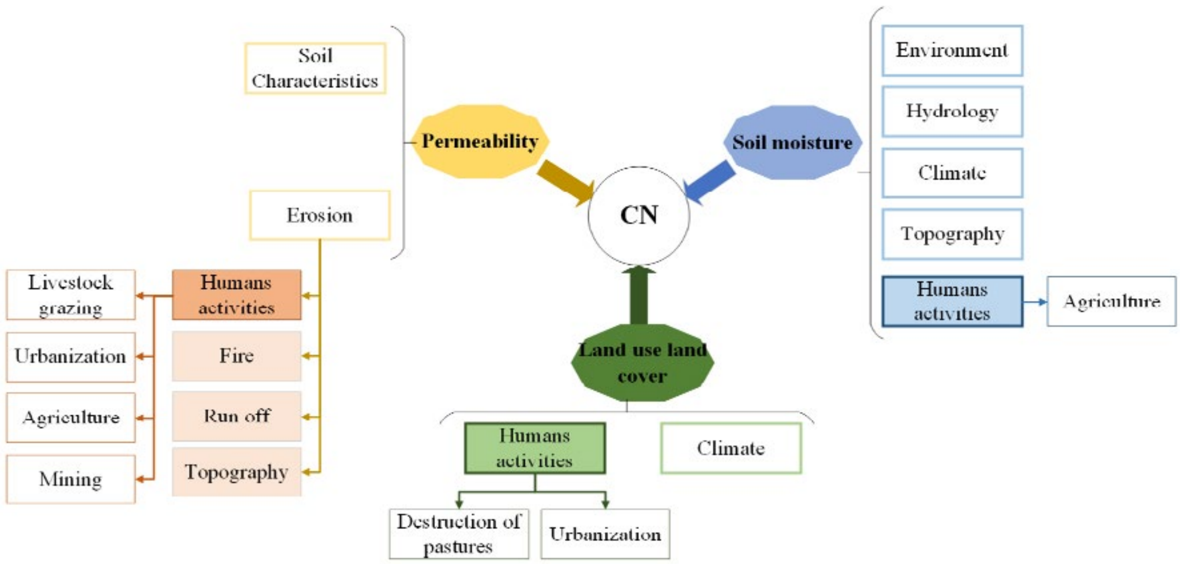

FIGURE 4. Factors affecting the curve number (CN)

Studies and field work conducted on the location revealed that land use/land cover (LULC) had been the most affected variable during the last few decades. This problem was caused by the inappropriate development in the city's northern region and the rise in the encroachment of the river's banks. In order to determine how changing the CN and precipitation will affect the peak flood discharge, a sensitivity analysis was conducted.

Results and Discussion

Based on aerial photos and land use/land cover maps of the study area, the CN before and after the urbanization of sub-basins (SB) 2, 3, 4 and 5 is given in Table 1.

TABLE 1. **Curve number values in sub-basins 2, 3, 4 and 5 before and after urban development**

CN \ SB	2	3	4	5
Pre-development	90	84	88	86
Post-development	94	92	95	92

According to the CN before and after the urbanization, the peak flood discharge values were generated from the precipitation estimated using the equation (2). The difference in the peak flow rate (Qp) is shown on Figure 5 in two states.

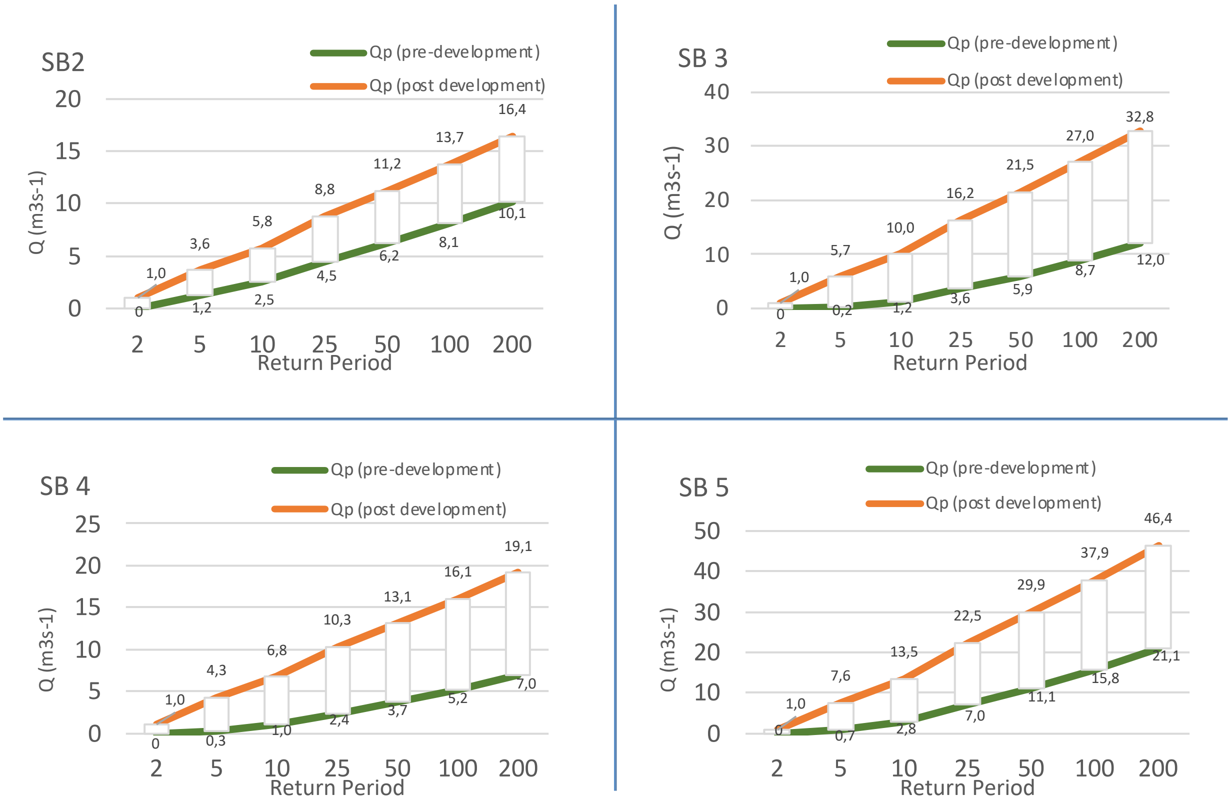

FIGURE 5. **The influence of the curve number on the amount of peak discharge before and after urban development**

As shown in Figure 5, increasing the CN due to increased impervious surfaces and inappropriate expansion of the city creates a very significant increase in the flood peak flow. This problem becomes more severe in smaller sub-basins (e.g. sub-basin 4). The rise in flood peak flow following urban development, produces an increase in the flood areas and exposure, mostly felt in sub-basins with higher population density and impervious surfaces.

The change in CN has caused the floods that used to occur with a longer return period, to see their return period decreased. This difference is shown in Figure 6 for all four subbasins, where we evaluated the return period of several peak flow values of 0.5, 1, 2, 4, 6, 8, and 10 before and after urban development.

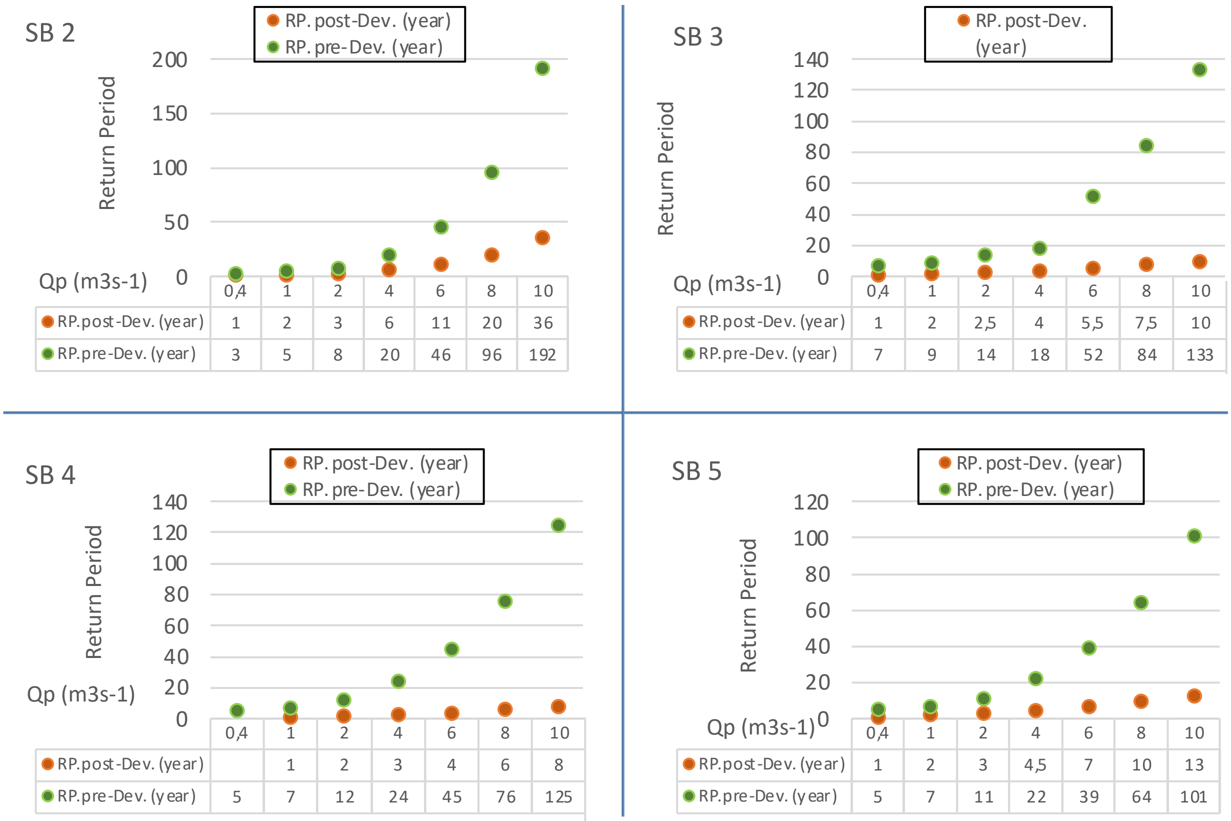

FIGURE 6. The effect of changing the CN on the flood return period (RP) with a certain flow rate

As shown in Figure 6, flooding with a certain peak discharge with longer return periods before development, occur at shorter intervals after the city's development, due to an increase in impervious surfaces and land use changes over the last decade. In sub-basin number 4, the return period of the discharge peak of 0.4 after development is less than 1 year, that is why no value is mentioned, while the return period of this specific discharge is estimated to be of about 5 years before the intensification of the urbanization rates which illustrates the great effect of reducing permeability on increasing runoff.

Conclusions

Our results show that the increased urbanization in the study area has strongly affected the number of flood events and the exposure of communities and assets. This confirms previous results (Eriyagama *et al*, 2017; Rahman *et al*. 2021). The city has grown in an inappropriate way in the northern highlands due to the growing population and the region's suitable agricultural circumstances. Buildings have been constructed close to riverbanks that flowed naturally before, increasing exposure as this region does not have appropriate flood control infrastructure and warning systems. The lack of deployment and management programs has made the community become more vulnerable to flooding hazards.

According to the results of the sensitivity analysis of peak flood discharge to rainfall and CN, the peak flood discharge can rise between 2.7 and 4 times with a 10% increase in CN, which is caused by the limited area and high population density. On the one hand, encroachment of riverbeds and land use changes has reduced the return period of floods with a certain discharge after urban development, but on the other hand it has increased the vulnerability of the city's residents.

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