ANALYZING THE LAND-USE IMPACT ON FLOOD REGIME IN SOAN BASIN

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Abstract- Increase in population results in rapid urbanization. As a result, imperviousness increases, infiltration decreases, runoff discharge, and flood peak rise. Different patterns of urbanization and understanding its impact on flood responses are getting the attention of researchers. This study focuses on the changing urbanization impact on the flood peak of the Soan basin (SRB) using HEC-HMS v. 4.9 (Hydrologic Engineering Center - Hydrologic Modeling System). The input variables for the HEC HMS model were estimated using the Digital elevation model, Land use/ Land cover maps, and Soil and rainfall data. The urbanization trend has been increasing in the 20th century and the Soan river basin (SRB) has been experiencing an expansion from 3% to 17% from 1997 to 2020. The response to land use land cover (LULC) change on the calibrated event of 1997, simulated peak discharge for 1997 land use land cover (LULC) was 2383 m^3/sec, for 2010 land use land cover (LULC) it was 2442 m^3/sec and for 2020 land use land cover (LULC) LC it was 2462 m^3/sec. HEC- HMS modeling shows an elevated increase in simulated peak discharges (flood flow) and runoff volume as shown in (Table 1) due to an increase in a built-up area in (SRB) between 1997 and 2020. The study showed that urbanization has a larger impact on flood peaks rather than flood volume.

Keywords Flood intensity, Flooding, HEC-HMS, HEC Geo-HMS

1. INTRODUCTION:

Due to the rise in imperviousness, sudden changes in land use in emerging economies and an increase in extreme rainfall events may be significantly raising the danger of flooding, especially in metropolitan areas [1]. Extreme storm occurrences that cause urban floods are of great interest to several scholars worldwide. The likelihood of severe rainfall occurrences rises as the world's temperature rises. The changing patterns of rainfall events demonstrate the need for flood modeling. Changes in land use land cover (LULC) have a significant effect on the watershed ecosystem, economic activity, and hydrological processes. In addition to environmental vulnerabilities, land use land cover (LULC) shifts are important drivers of environmental change on a global scale, with potential negative effects on human well-being and way of life [2]. Land-use changes within a basin have a wide range of temporal and spatial effects on hydrological processes. It may have an effect on hydrological processes including interception, infiltration, evaporation, and an increase in runoff.

The rapid increase in the built-up area has adverse effects on the hydrological, it increases perviousness as a result increases surface runoff, and decreases groundwater flow, and lag time. The changes in land use with climate change have negative impacts not just on environments but on urban infrastructure in South Asia's tropical region [1]. On -average, metropolitan basins lose 90% of their storm precipitation to surface flow, while nonurban, wooded basins retain 25% of their rainwater. It is well known that increased impervious surface areas contribute to the effects of urbanization on hydrological processes [3].

The identification of appropriate techniques to analyze the influence of land-use change on storm runoff generation remains a critical issue. In various case studies, land-use patterns and rainfall events were inputs to an event-based hydrological model to evaluate the basin's hydrological responses to actual or expected precipitation events. These strategies have provided a warning of the likelihood or severity of future hydrologic reactions. Few methodologies exist for estimating peak discharges from projected land use patterns [4].

HEC-HMS describes the spatial patterns of a basin using a basin model by dividing a basin into relatively homogeneous sub-basins. The HEC-HMS system of hydrological modeling techniques aims at identifying sub-basin peak discharge hydrographs and directing flows through channels to the study outlet. In this study, the Curve Number (CN) was employed to find surface flow and peak discharges as land use distribution at the regional scale, and the curve number (CN) could be created and hydrologically validated. Similarly, Du et al., 2019 [3] in the Xiang River Basin, China, employed SCS CN to anticipate the effects of LULC change on flooding behavior caused by shifting urban patterns.

Kumar et al. 2022 [5] carried out a study on the combined effect of hydrological variations and Land use land cover change in the USRI watershed, India, and found out that due to increasing urbanization and reduction in water bodies and green cover there has been an increase in streamflow.

Umukiza et al. 2021 [2] employed an event-based method to explore the effects of fast LULC change on peak discharge and flow volume and observed that peak flow/ discharge depends on the curve number (CN), which relies on the LULC scenario. If growth in built-up areas is pursued, strategic countermeasures that do not enhance the area's susceptibility must be implemented.

Younis et al. 2018 used a lumped model and event-based model (HEC-HMS) and LANDSAT data to study the evaluate the impacts of LULC changes on hydrology in the upper Indus basin, including forest area, bare land, and impervious increases. The LULC change research was conducted on a small scale in the Mansehra metropolitan district (16 km2). Soil and built-up area rose from 69 percent and 8.2 percent in 2000 to 78 percent and 13.76 percent in 2010, respectively, while river flow increased by 33.61 percent from 2000 to 2010, suggesting a significant positive relationship between LULC and river discharge on a regional scale [6].

The flood response to the built-up area by utilizing the HEC HMS model was done by Emam. et. al 2016 [1]. The peak discharge based on precipitation to a 50-year return period in 2030 increased by 130%, due to land use cover and change.

The aims of this research are to (1) analyze the flooding process and identify the significant land-use changes and their spatial distribution from 1980-to 2020; (2) investigate the land-use pattern changes effects on the flood regime of the Soan basin.

2. DATA AND METHODOLOGY:

2.1 Study region:

The Soan River is a significant tributary of the Indus River and a key hydrological unit of Pakistan's Potohar plateau, with its source in the Murree Mountains. The Soan River passes via the Chirah and Dhoke Pathan hydrological gauging stations before flowing into the Indus River. Both the Chirah sub-basin and the Dhoke Pathan sub-basin are located above the hydrological gauging stations at Chirah and Dhoke Pathan, respectively. The Soan basin as shown in (Figure 1) is 6842 km^2 in size and has an elevation range of 262 to 2264 m. The basin's slope ranges from mild to severe, and monsoon-fed streams account for virtually all of the basin's flow. Simly dam being the primary drinking water supply for Islamabad, the capital of Pakistan, receives water from the Soan River. It also serves as the Potohar plateau's primary irrigation water supply [7].

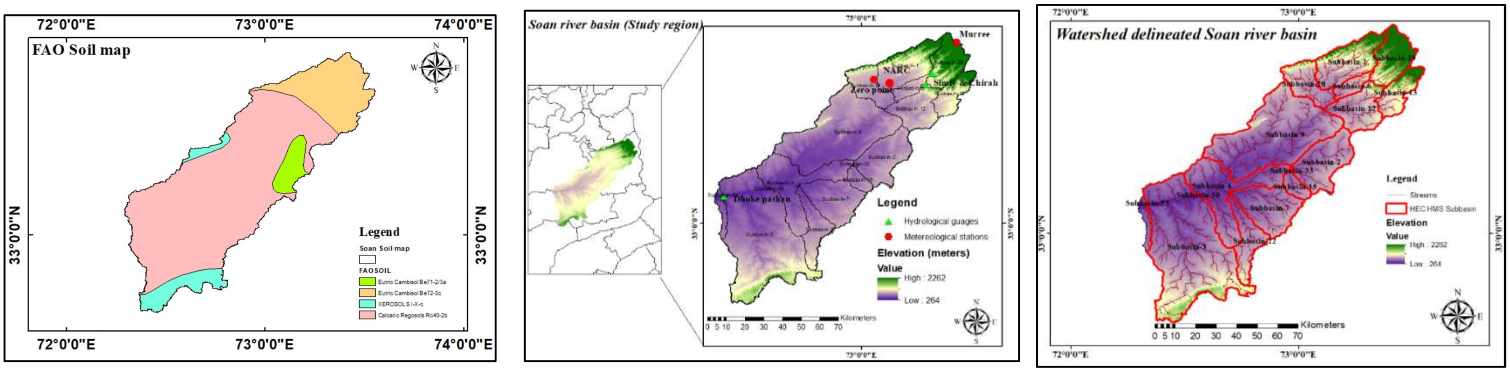


Figure 1 a) FAO soil map of study area. b) Study area map of SRB (Soan river basin) c) Delieated Soan basin

2.2 Data sets:

The daily precipitation data is provided by PMD (Pakistan meteorological department), WAPDA, and NARC of three gauging stations, and stream flow data at two gauging stations (Chirah and Dhoke Pathan) from 1960 to 2013 were collected. The two flood events were identified in July-1997, and July 2010, and the precipitation data and flow data have been used.

The soil types as shown in (Figure 1) were extracted from the data-sharing site of the Food and Agriculture Organization soil map. The HSG (hydrologic soil group) A, B, C, and D classifications, are used to represent high to low permeability rates when the soils are fully saturated and not have vegetation cover, and experiencing a high-intensity rainstorm

The Land Use and Land Cover data for 1997 and 2010 were extracted from a data-sharing site of glovis.org and re-classified into a water body, bare land, Vegetation land, forest, and Built-up area. The hydrologic soil group "D" covers most of the area of the Soan basin, followed by the group "C" [3].

2.3 Hydrological engineering center- hydrologic modeling system rainfall-runoff simulation procedure:

In contrast to fully-distributed hydrological models, HEC-HMS separates an entire basin model into homogenous sub-basins basis on the area threshold established in the model. It takes various sub-basins changing surface conditions into account. Evapotranspiration and snowmelt have not been considered in the HEC-HMS model since short-term flood events are depicted as being driven by high-intensity rainfall. To estimate the hydrological impact of LULC modifications solely, LULC maps are employed in conjunction with the precipitation data [8]. As a result, the semi-distributed model is preferable for simulating flood occurrences at a broad basin size. HEC HMS v4.9 was used in this work to predict surface runoff using different LULC maps.

HEC-HMS uses the following steps to run the simulation:

1. Basin model shows the physical characteristics of the study area.
2. Meteorological model takes rainfall data as input associated with each sub-basin.
3. Control specifications show the start and end and a time step of the simulation.
4. Time series data manager has observed discharge data and rainfall gauge data.

All of the above-mentioned models are combined to simulate by defining the following parameters:

1. *SCS-curve number- excess precipitation or runoff*: The SCS-CN (Soil Conservation Service Curve Number) is a function of total rainfall, land cover, soil characteristics, and moisture. CN value ranges from 30 for permeable soil to 100 for water bodies, being the most important parameter CN value is used to represent the urbanization level. CN (Curve number) grid was created to extract individual curve numbers for each sub-basin, using the LULC maps and FAO soil maps in conjunction with the HEC-Geo HMS extension of Arc Map and using the CN lookup table, provided by the SCS report [9] and Juan Du. et.al 2019 [3] in Xiang River Basin, China.

2. *SCS-UH (Soil Conservation Service Unit Hydrograph):* SCS unit hydrograph was used to calculate the direct runoff, the average UH resulting from runoff, and rainfall at gauges in agriculture basins.

3. *Baseflow method:* The Recession Model is used as a tool to explain the drainage processes from natural retention in basins. The river depth where additional runoff accumulates is defined by the baseflow parameter in flood studies.

Results:

3.1 Land-use land-cover change analysis:

Supervised classification of LANDSAT images of 1997, and 2010 (Figure 2) and applied algorithm of maximum likelihood. The images were classified into; Waterbody, Bare-land, Forest, Vegetation, and Settlements. LULC analysis was carried out by estimating the areas of LULC in 1997, and comparing them to the areas of land cover in 2010 and 2020 as shown in (Figure 3). As of 1997 the bare land covered most of the Soan river basin, forest, and vegetative land covered 25%, Built-up area covered 3% and water body covered approx. 1% of the total Soan basin. In the year 2010, vegetative and bare land covered most of the area by 39%, and 38% respectively, with 13% of the area as forest and built-up area covered 9% and water bodies covered approx. 1% of the total Soan basin. In 2020, 55% of vegetative land covered most of the area of the Soan Basin, the built-up area has slightly increased to 17% of the total area, and forest and bare land covered 14% and 13% of the total Soan river basin area.

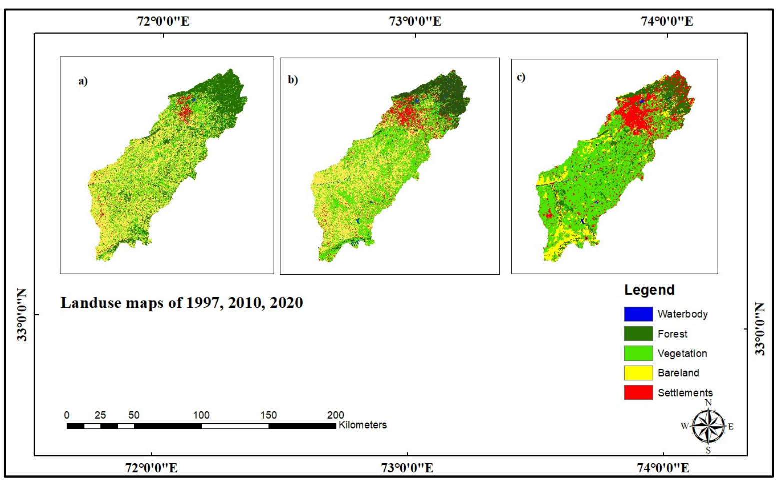


Figure 2 Land use maps a) 1997b) 2010 c) 2020

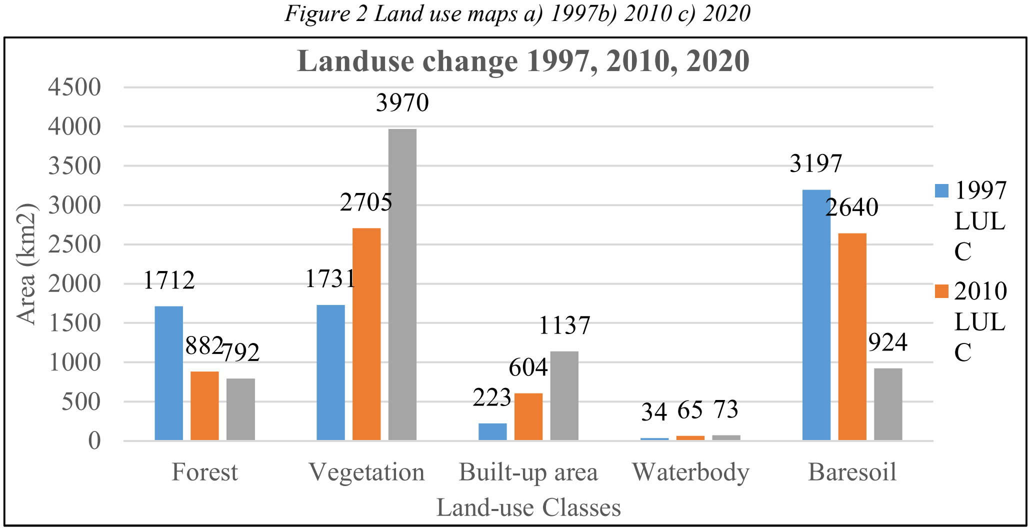
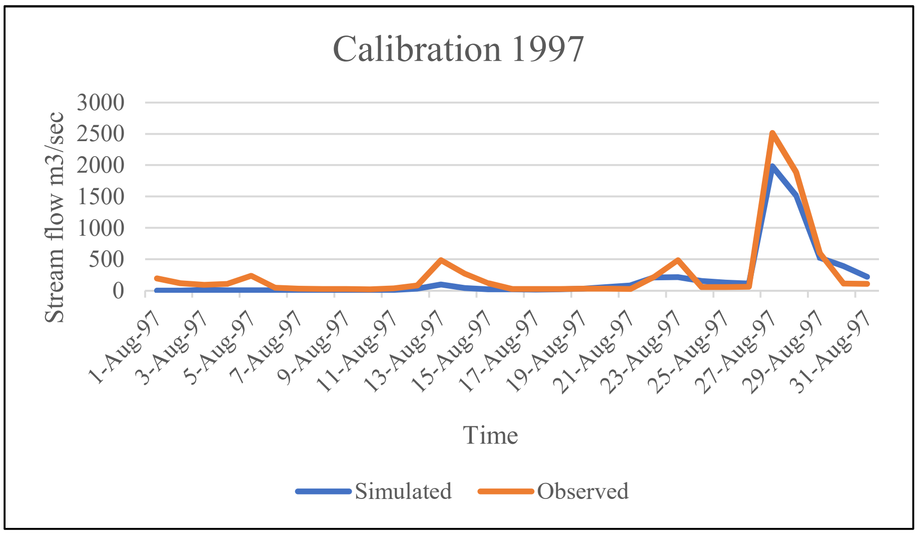


Figure 3 LULC comparisons (1997, 2010, 2020)

3.2 Impact of land use/land cover change on peak flood flows:

The rainfall-runoff is the result of a combination of climatic and topographical conditions. The HEC HMS model was calibrated for the event of July 1997 (Figure 4) and validated for the event of 2010 as shown in (Figure 5). The calibrated HEC HMS model for the 1997 event is used to simulate the flood responses to different LULC conditions (Curve number and impervious percent) of 1997, 2010, and 2020 as shown in (Figure 6).

Split sample methodology and streamflow observation data gathered at the watershed's outlet were used in the calibration and validation of the HEC-HMS model.

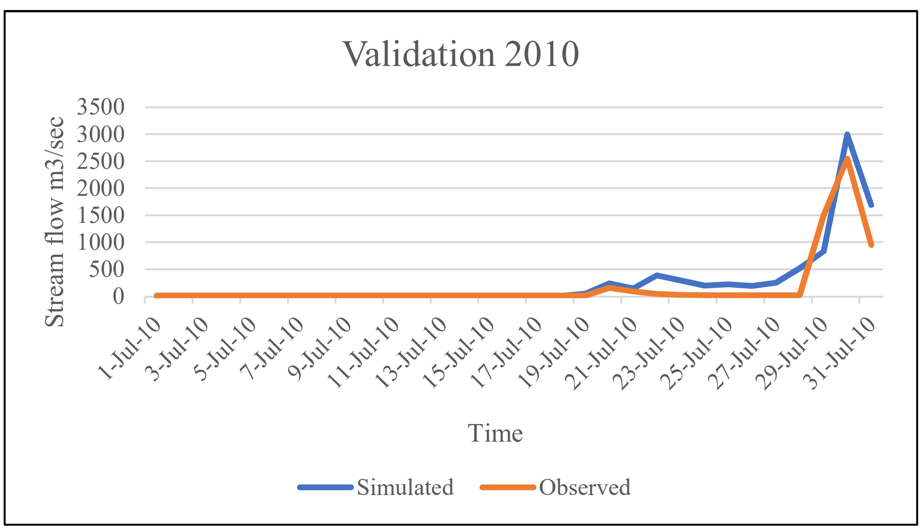


NSE: 0.886

R^2: 0.94

RMSE: 0.3

Figure 4 Calibration run for event 1997



NSE: 0.790

R^2: 0.86

RMSE: 0.5

Figure 5 Validation of 2010

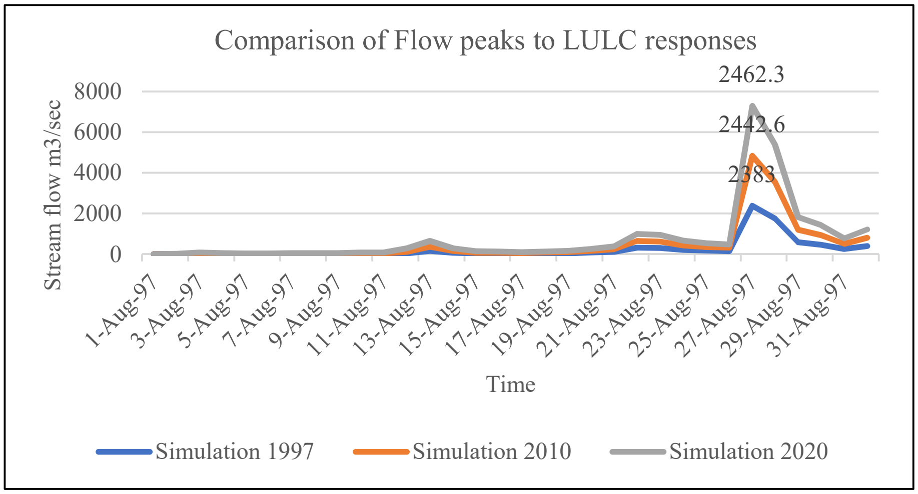


Figure 6 LULC change impact on flow peak

Table 1Responses of the peak flood flow to the land use changes of 1997, 2010, 2020

Catchment	LULC conditions	Impervious percent	Simulated peak flow m^3/sec	Increase m^3/sec	Flow volume (mm)
Soan River basin	1997	3	2383	0	95.5
Soan River basin	2010	9	2442	59	102.68
Soan River basin	2020	17	2462	79	108.77

Conclusions

The following conclusion has been drawn from this study:

1. The Land-use land cover change varied spatially such as the artificial surfaces increased from 1997 to 2020 i.e., from 3% to 17%. The significant land-use change in SRB was vegetative cover (Agriculture, grass, etc) increased from 25% in 1997 to 55% in 2020. The major urbanization or urban area expansion rate occurred at Rawalpindi and Islamabad of approximately 500 km2 in 2020.
2. The peak flood flow and flood volume increased from 1997 to 2020 by 79 m3/sec and 13 mm with increasing urbanization and the flows were observed at the outlet. Soan river basin has most of the area covered by an arable or vegetative cover which is why it had little effect on the elevated peak. Acknowledgments:

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