



Impact of soil sealing on the genesis of pluvial flood in Peshawar, Pakistan

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Abstract

Anthropogenic activities are consistently modifying surface covers changes. Such alterations have been producing negative impacts on surface and groundwater sources by escalating surface runoff and reducing infiltration to recharge the aquifers. In this research, an attempt has been made to explore the rapid expansion of the built environment, its trend, and impacts on the increasing surface runoff and the genesis of pluvial flood in Peshawar, Pakistan. The study area has been experiencing rapid population growth and urban expansion, which has been continuously consuming the fertile farmland and replacing the natural ground with artificial impermeable surfaces. The required data for this study was acquired through primary and secondary sources from various organizations. Remote sensing (RS) and geographic information system (GIS) were used to monitor and detect the development of the built environment and its probable impacts on the accelerated surface runoff. Analysis reveals that physical, infrastructural, and socio-economic developments were the major factors of land take and conversion of natural ground into impervious surface covers (ISC). Such modifications have been producing negative effects on the urban environment and water resources of the study area. The finding of the study reveals that rapid population growth is responsible for the increase in built-up areas, urban expansion, and infrastructural developments during the study period (1981–2014) that have increased the impermeable surfaces from 3.70 to 16.27%. Consequently, surface runoff has also been intensified, which has in certain cases created pluvial and flash floods. Rapid urban growth and the resultant physical and infrastructural developments need to be properly checked and monitored. The adverse impacts on the generation of pluvial and flash floods could be minimized if the existing land use regulations and urban policies are implemented in its true spirit.

Keywords Built environment · GIS · ISC · Land use land cover · RS · Soil sealing · Surface runoff

Introduction

Globally, flood is a major environmental calamity and occurs when enormous precipitation and the resultant runoff overflow the flood plain (Malik et al. 2020; Malik and Pal 2020). The most common types of floods are fluvial and coastal; the least common pluvial flood occurs as an invisible hazard in areas which are not actually prone to it (Houston et al.

2011). Torrential rainfall is considered to be the major factor of all types of floods; however, anthropogenic factors have also been triggering the situation (Minh et al. 2018; Malik et al. 2020; Malik and Pal 2020). Pluvial type usually occurs when rainwater is converted to surface runoff and is usually evacuated by the drainage system, often overflowing the impermeable surfaces. It usually occurs when the rainfall rate exceeds the capacity of stormwater drains to evacuate the water and the capacity of the ground to absorb it. Human involvements related to the natural system through deforestation, urbanization, and encroachment toward the riverside by the settlement have progressively resulted in reducing flood plain relations with river and increasing flood frequency and duration (Costache et al. 2021; Saha et al. 2021). Such human-induced interventions can be seen anywhere over the earth's surface; however, cities around the globe are generally favored. Impervious surface covers (ISC) and contiguous built environment are the common and most frequently

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occurring characteristics of urban centers and are resulting in surface cover changes as well as sealing the soil (Turok and Mykhnenko 2007; Wessolek et al. 2008; Prokop et al. 2011; Rubinato et al. 2019). In urban areas, pavements and buildings are the major physical developments often associated with infrastructural and socio-economic improvements contributing to the process of soil sealing (Breuste 2011). The adverse effects of such impervious surfaces are commonly observed on human health and urban environment in the form of increasing surface as well as atmospheric temperature and accelerating runoff which often augment the risk of an urban flash flood (Paul and Meyer 2001; Konrad 2003; Yuan and Bauer 2007; Scalenghe and Marsan 2009; Imhoff et al. 2010; Niemelä et al. 2010; Salvati et al. 2011; Myint et al. 2013). Likewise, the increasing trend of built-up areas has used up the fertile farmland and produced serious implications to urban food security and ecology near the major urban centers (Burghardt 2006; Montanarella 2007; Samiullah 2013; Khan 2019; Rahman et al. 2019; Samiullah et al. 2019).

The resultant soil sealing from surface cover changes have been fluctuating and intensifying surface runoff since human evolution and revolution. In such cases, attempts have always been furnished to measure the quantitative relationship between land use land cover (LULC) and the escalated surface runoff. However, a reliable and general model has to be developed for predicting the LULC impact with runoff generation (Kokkonen and Jakeman 2002). Historically studies have always been carried out to know the relationship between urban LULC changes and their probable effects on hydrological imbalance. It has been generally recognized that usually frequently occurring small-scale floods are often triggered by the urban infrastructural developments rather than the larger rare ones which are affected to a lesser extent by LULC changes (Hollis 1975).

For a reference period, the observed and modeled runoffs were compared by using lumped calibrated models (Schreider et al. 2002). It has been investigated that changes in land use have affected runoff generation of the catchment areas. Similarly, correlating runoff with land use changes, several other approaches have also been adopted (Braud et al. 2001; De Roo et al. 2000; Fohrer et al. 2001; Wooldridge et al. 2001). The essence of such approaches was that any changes in land use patterns have always impacted surface runoff generation. Predictions on the basis of certain methodologies have been made that the increasing trend in the built environment has intensified surface runoff.

The application of different models and approaches is probably helpful on small and meso scale rather than large scale for which such methods become impractical and other approaches could be adopted (Hundechea and Bárdossy 2004). To assess the impact of land use change on the catchments at meso scale, certain hydrological models

have been described by Bronstert et al. (2002), Brath et al. (2003), and Ranzi et al. (2002). The main theme of all these methods and approaches is that changes in land uses and the development of sealed surfaces have been accelerating runoff and generating pluvial and urban flash floods.

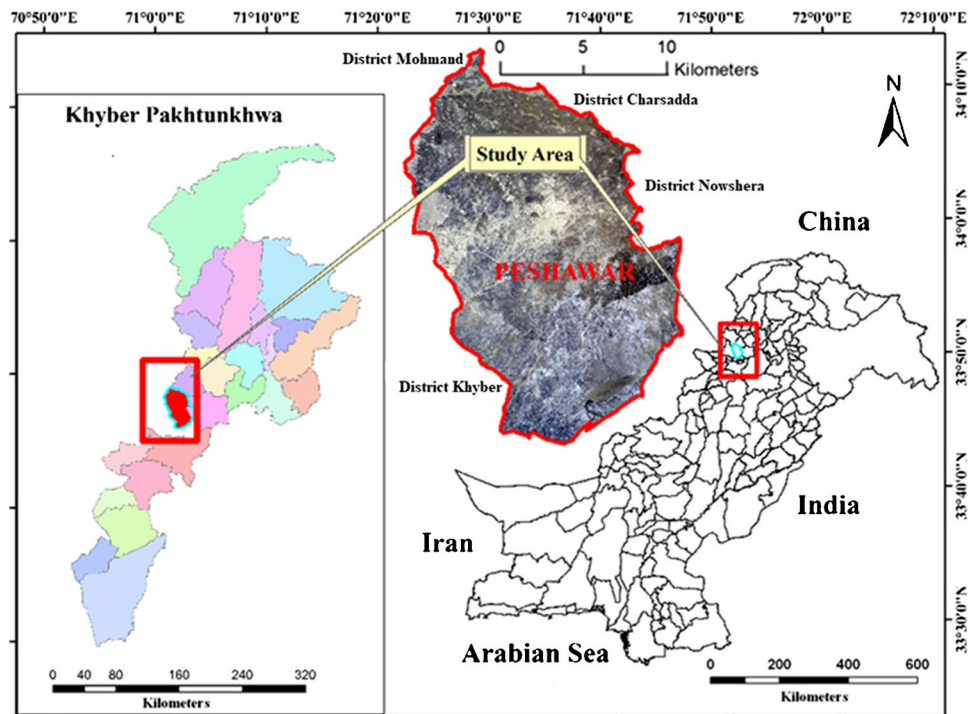
The novelty of this research is that anthropogenic activities regarding land use land cover changes have been linked with the generation of pluvial floods in the study area. It was found from the analysis that rapid population growth and urbanization have been continuously increasing sealed surfaces in Peshawar. Impervious surface covers have the capacity of water flowing over them rather than seeping and percolating to recharge the aquifer and generating problems to both surface and groundwater sources. In the study area, surface runoff has enormously been escalated and subsequently generated pluvial and urban flash floods.

District Peshawar: the study area

The rapidly growing and physically expanding district of Peshawar is not only the provincial capital of Khyber Pakhtunkhwa (KP) province but also the integral part of Peshawar valley. The total area of the district is 1257 km². Peshawar is among the historical cities of the world with geostrategic and socio-economic importance. Geographically, Peshawar is surrounded by the district of Mohmand in the north and the Khyber district from the west. District Kohat is located to the south. Charsadda and Nowshera districts are in the north and east of the study area. The latitudinal and longitudinal extension of the study area is from 33° 44' N to 34° 15' N and 71° 22' E to 71° 42' E (GoP 1999; Samiullah 2013; Rahman et al. 2016; Khan 2019; Khan et al. 2019; Rahman et al. 2019; Samiullah et al. 2019; Fig. 1).

The major factors of land take and soil sealing identified in Peshawar are rapid population growth, urban expansion, and physical and infrastructural developments. Soil sealing by impervious materials has accelerated surface runoff and resulted in pluvial floods (Rahman et al. 2016, 2019; Khan 2019; Khan et al. 2019). Peshawar is a fertile featureless plain consisting of fine alluvial deposits mainly in its central part. The cultivable land of the district consists of porous, light, and rich soil with a mixture of sand and clay and is favorable for cultivating a number of crops. The soil of the district has been classified into river alluvial, flood plain, piedmont, and loess plains (Fig. 2). The climate of Peshawar is a subtropical continental type where both winter and summer seasons experience severity. The average annual rainfall recorded at Peshawar Met Station and Agriculture Research Institute (ARI) Tarnab is over 400 mm.

Fig. 1 Location of District Peshawar, Pakistan (The Study Area)



Materials and methods

Data for this study were obtained from both primary and secondary sources. Data regarding average daily, monthly, and annual rainfall were collected from ARI Tarnab and Regional Meteorological Department, Peshawar. Topographical maps of the study area were obtained from the Survey of Pakistan (SoP). Digital elevation model (DEM; of 30-m resolution) of the Shuttle Radar Topographic Mission (SRTM) and LANDSAT images of 1981 and 1991 were downloaded from the open source of the United States Geological Survey (USGS) database. SPOT images of 2009 and 2014 were acquired from the Space and Upper Atmospheric Research Commission (SUPARCO).

The collected data were analyzed through statistical and cartographic techniques. Geographical information system (GIS) was used to carry out spatio-temporal changes in the built-up environment and to quantify the surface runoff of all the six urban drainage basins using the curve number (CN) method. ArcGIS 10.2 and ERDAS imagine 2014 were used to prepare various maps of land use land cover (LULC) and watershed delineation of the rivers and streams in district Peshawar.

Satellite images of LANDSAT (1981 and 1991) and SPOT (2009 and 2014) were analyzed to extract built-up areas, and consequently, LULC maps were prepared. Supervised maximum likelihood classification (SMC) technique was applied to classify the multi-spectral temporal images of 1981, 1991, 2009, and 2014 into different LULC classes

(Fig. 3). The multiple LULC classes provided excellent results; however, these classes' signatures were further analyzed using the histogram technique to separate the bands used in the LULC classes. The study area was cropped, and signatures were created for LULC classes. Histogram equalization was performed to evaluate the training samples of LULC. SMLC was also used to classify and calculate the statistics of LULC classes. Finally, a raster calculator was used to calculate the statistic of LULC in terms of area and percentages.

Watershed delineation of rivers and streams of district Peshawar was carried out in ArcGIS 10.2 using the Arc Hydrology tool. Digital Elevation Model of Shuttle Radar Topographic Mission (SRTM) of 23rd September 2014 was used. Four DEMs of 30 m resolution were added to ArcGIS, which were merged into a single mosaic to cover the entire drainage basins (Fig. 4). Curve number (CN) values depend upon the watershed cover conditions and soil type. In the model, the same are represented as cover type, hydrologic soil groups (HSG), and hydrologic and moisture conditions. HSG is a group of soil having similar runoff potential under similar storm and cover conditions associated with runoff CN (Table 1). The same was assigned certain CN values as per the guidelines of the Natural Resource Conservation Service (NRCS) of the United States Department of Agriculture. Based on infiltration rate and runoff potential, NRCS has classified soil into four hydrological soil groups (HSG) as A, B, C, and D (USDA 1986; NEH-4 1997; Hong and Adler 2008).

Fig. 2 Distric Peshawar: Spatial Distribution of Surface Deposits

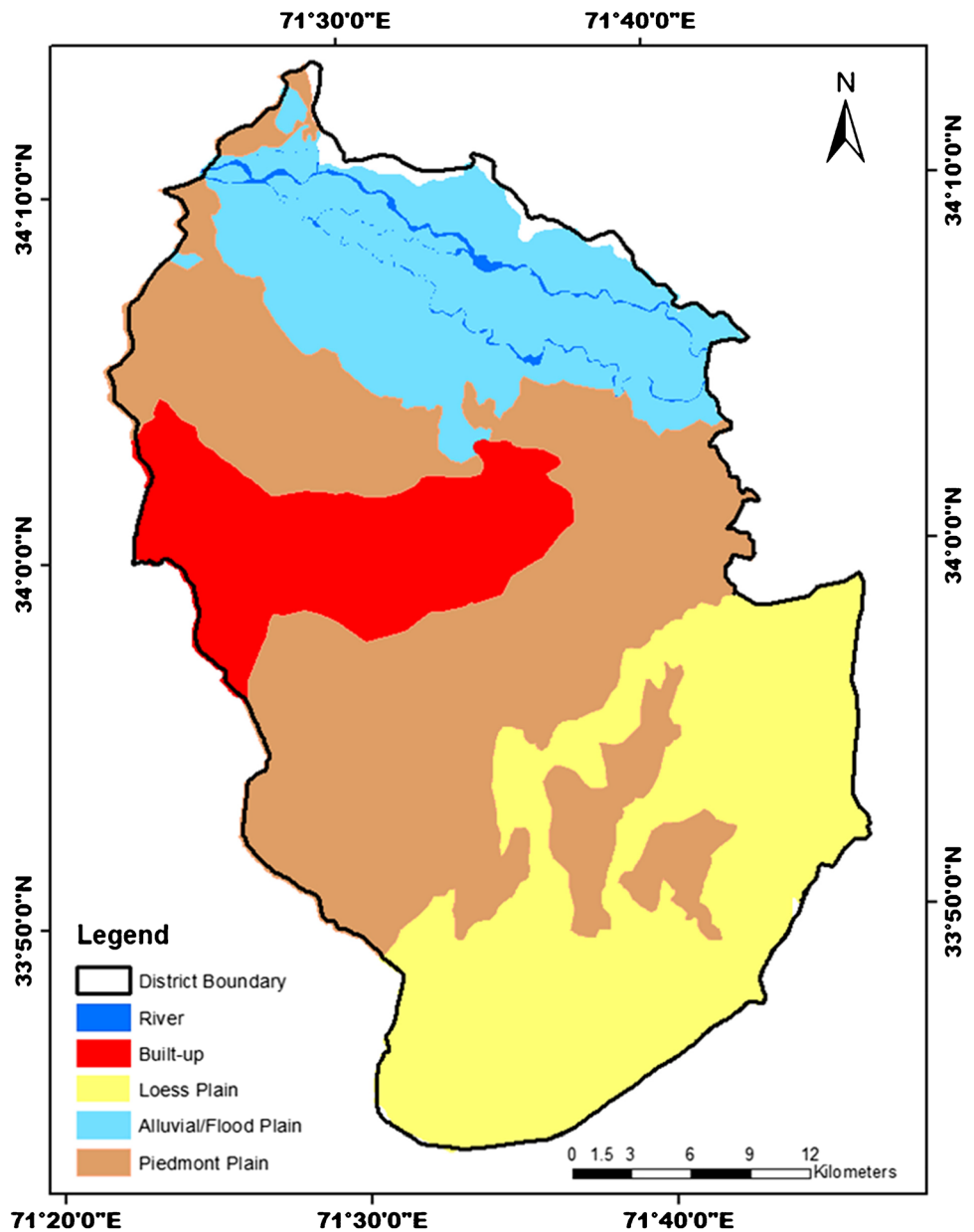
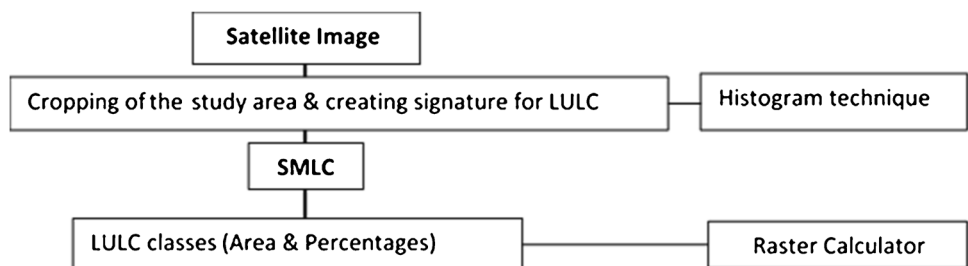


Fig. 3 Extraction of LULC from satellite images



In Peshawar valley, the soil has been formed by different geomorphic agents in various periods and followed the international standard. It is helpful for surface runoff calculation

on the basis of the curve number (CN) method. The replacement of natural ground cover by impervious surface cover (ISC) disturbs the soil profile, and thereafter, it requires

Fig. 4 Methodology for watershed delineation

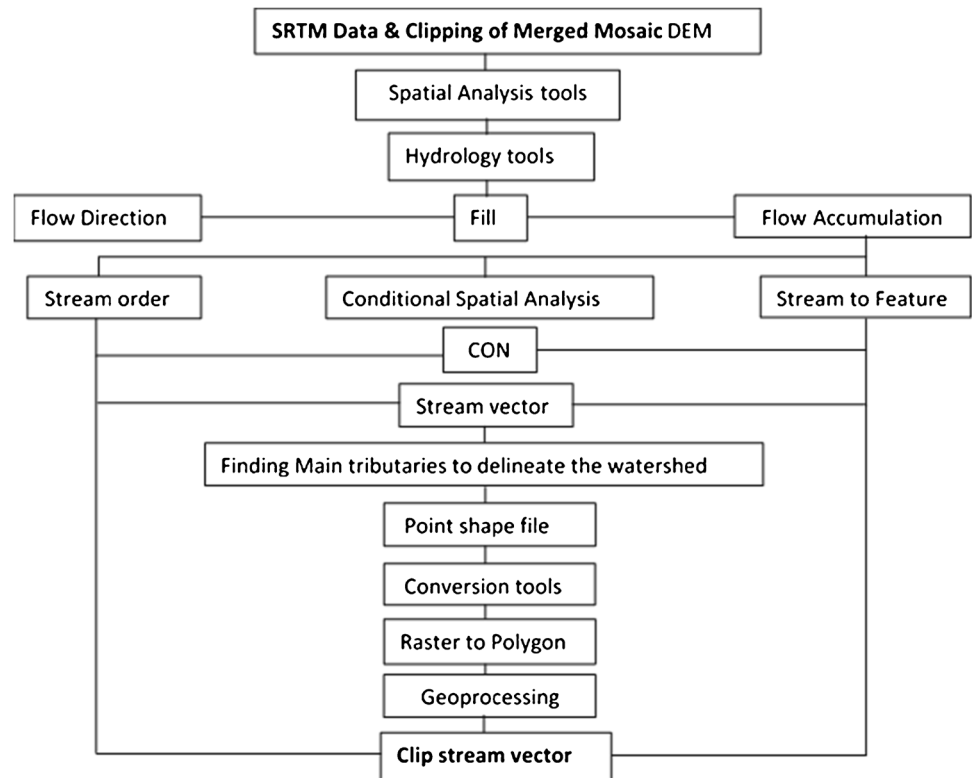


Table 1 Land cover and hydrological soil groups

Land cover	CN of hydrological soil group			
	A	B	C	D
Water bodies	-	-	-	-
Evergreen (needles)	34	60	73	79
Evergreen (broad leaf)	30	58	71	77
Deciduous (needle leaf)	40	64	77	83
Deciduous (broad leaf)	42	66	79	85
Mixed forests	38	62	75	81
Closed shrub lands	45	65	75	80
Open shrub lands	49	69	79	84
Woody savannas	61	71	81	89
Savannas	82	80	87	93
Grasslands	49	69	79	84
Permanent wetlands	30	51	71	78
Crop land	67	78	85	89
Urban and built-up areas	80	85	90	95
Cropland/natural vegetation	52	69	79	84
Permanent snow and ice	-	-	-	-
Barren/sparsely vegetated	72	82	83	87

Modified after USDA (1986), NEH-4 (1997), and Hong and Adler (2008)

new CN values for different surface covers, keeping in view the guidelines of NRCS. On the basis of LULC and soil types, CN values were assigned and the CN grid map of the

Peshawar district was prepared in GIS. CN grid map was a base for the calculation of surface runoff.

In this study, the volume of surface runoff was calculated using the curve number (CN) method (Eq. 1). It is one of the most widely used models for runoff estimation and prediction, which is still opted over the other models (Hawkins 1993; Ponce and Hawkins 1996; King et al. 1999; Mishra et al. 2003; Schneiderman et al. 2007; McGinley et al. 2013; Troolin and Clancy 2016; Vannasy and Nakagoshi 2016; Acosta-Coll et al. 2018; Khan 2019).

$$Q = (P - I_a)^2 / (P + S - I_a) = (P - 0.2S)^2 / (P + 0.8S) \quad (1)$$

where Q is runoff volume, P is precipitation, storage index (S) = $(1000/CN) - 10$, and I_a is initial abstraction.

Results and discussion

In Peshawar, rapid population growth and urban expansion have been increasing physical and infrastructural developments (GoP 1999; Khan 2001; Samiullah 2013; Rahman et al. 2016; Khan 2019; Khan et al. 2019; Rahman et al. 2019; Samiullah et al. 2019). Consequently, such anthropogenic activities have consumed fertile farmland in and around the city. In the past, Peshawar was considered as a food basket and a city of flowers, but unfortunately, the situation has been aggravated by the

Table 2 District Peshawar temporal change in built-up areas (1981–2014)

S. no	Year	Built-up area (ha)	Percentage	% Increase in built-up area
1	1981	4635	3.70	-
2	1991	7182	5.70	2.0
3	2009	16,986	13.50	7.8
4	2014	20,451	16.27	2.77

Extracted from LANDSAT (1981;1991) and (2009; 2014) images

Table 3 District Peshawar, land use land cover in 2014 “modified and extracted from SPOT images 2014”

S. no	LULC type	Area (ha)	Percentage (%)
1	Agriculture	84,596.1	67.30
2	Built-up	20,451.39	16.27
3	Barren land	15,234.84	12.12
4	Water bodies	4588.05	3.65
5	Forests	829.62	0.66
Total		125,700	100

rapid urban growth and physical expansion of the city. Likewise, infrastructural and physical developments have substituted natural permeable ground with artificial impermeable surfaces. These impervious surface covers have generated problems for the city dwellers by escalating surface runoff and intensifying fluvial, pluvial, and urban flash floods. The city always presents a scene of a pond of water after a slight rainfall.

Spatio-temporal expansion of built-up environment

During the study period (1981–2014), the built-up area in the district has increased from 3.7 to 16.27%. In 1981, the sealed surfaces in Peshawar were 4635 hectares (ha) which enlarged to 7182 ha (5.7%) in 1991 (Table 2). Built environment further increased to 16,986 ha (13.5%) in 2009. While LULC analysis of SPOT image 2014 (Table 3; Figs. 5 and 6) has indicated further expansion in impervious surfaces and accounted it for 20,451 ha (16.27%). At the same pace, sealed surfaces of the study area are predicted to be increased 22% by the year 2030. The built-up environment is continuously encroaching over the fertile agricultural land. The residential sector is one of the major consumers of farmland and used up to 8748 ha of fertile land during the period of 1991–2009 (Samiullah 2013; Rahman et al. 2016, 2019; Khan 2019; Khan et al. 2019; Samiullah et al. 2019).

District Peshawar: the drainage system

The drainage system of Peshawar flows toward the east and finally confluences with River Kabul and is considered as a central spine drainage basin (Fig. 7). In the study area, a total of six sub-drainage basins of streams and rivers were delineated, including the watersheds of Budhni, Bara, and Zindai rivers and the streams of Mera, Garhi, and Kala as well as their perennial and seasonal tributaries (Fig. 8). The watersheds of these rivers and streams within the study area are considered as part of urban drainage basins (Fig. 9). In this study, the focus has been made on the urban watersheds and the impact of built-up environment on the surface water resources of the study area.

Surface runoff

Surface runoff volume generation from the impervious as well as pervious surfaces within the urban watersheds of rivers and streams in district Peshawar has been calculated by using weighted average volume and weighted average curve number (CN) techniques. The input data for these methods are rainfall, area of the surface covers, and CN of various surfaces. The same amount of rainfall events of 33 mm (mm) of 31st May 1981, 15th August 1991, 6th April 2009, and 11th March 2014 were selected. The spatio-temporal growth of sealed surfaces within the urban watersheds of rivers and streams has already been analyzed in Arc GIS 10.2. Curve numbers of different surfaces for the whole district were also calculated in Arc GIS 10.2, and a detailed CN map was prepared which was based on the soil and land use land cover (LULC) data of 2014 (Fig. 10a). CN map of the study area has revealed that built-up areas have shown the highest CN value of 98 as compared to other surface covers where it was less than 70 (Fig. 10b). However, the maximum CN value within the urban watershed of 100 was also observed for water bodies which were excluded in the calculation. According to the international standards, CN values are not applicable to water bodies. Having maximum CN values, the built environment also generates the highest surface runoff as compared to the natural ground cover and unsealed surfaces (Fig. 11). Fig. 11 District Peshawar, spatial distribution of surface runoff

Surface runoff within urban drainage basins

Spatio-temporally urban drainage basins of the two major rivers, Budhni and Bara, have shown remarkable growth and expansion of the built environment. Although a large catchment area of these rivers lies outside the district boundary in the adjoining Khyber district, however, due to the availability of climate data and rapid growth of built-up areas within the district, surface runoff was calculated for the

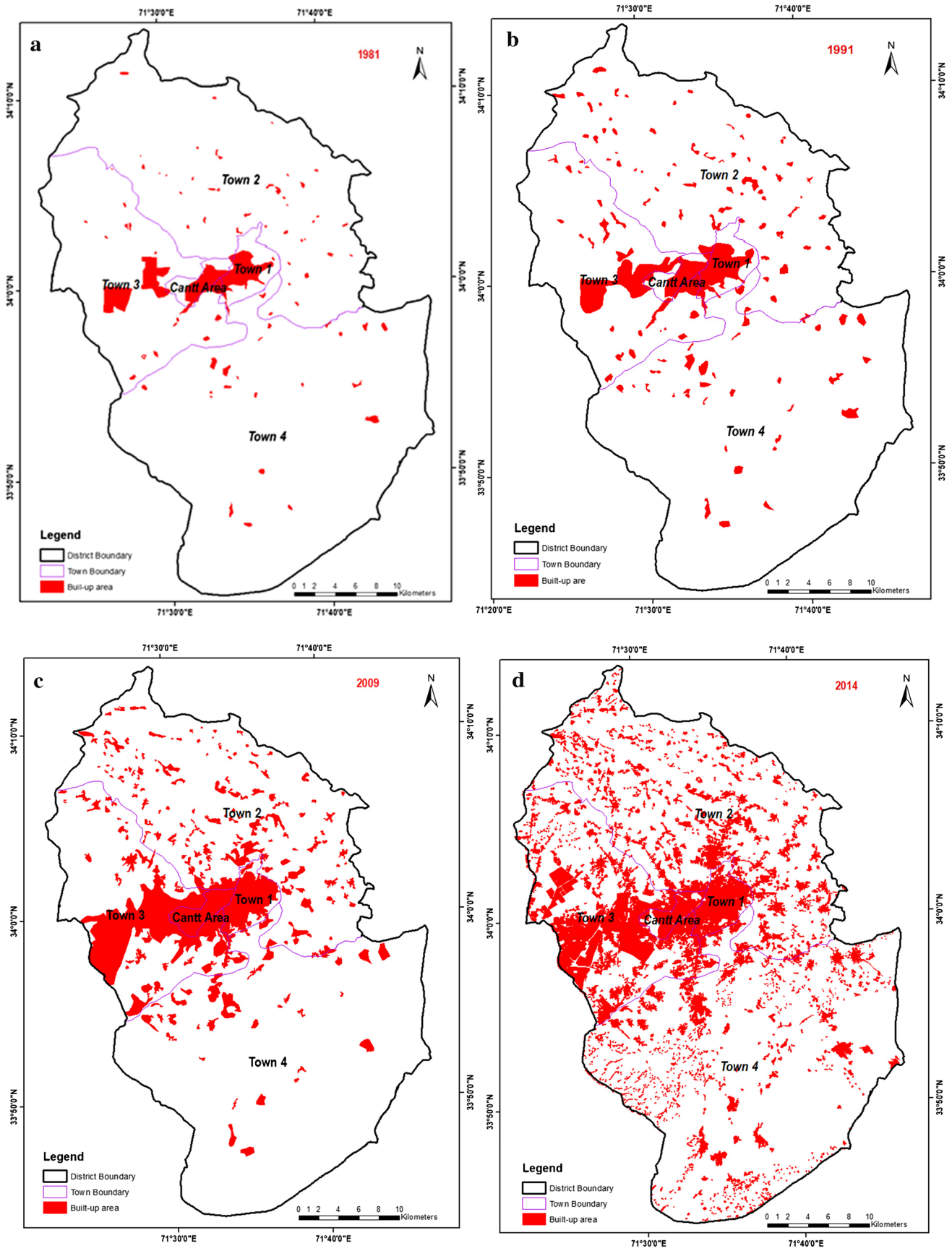
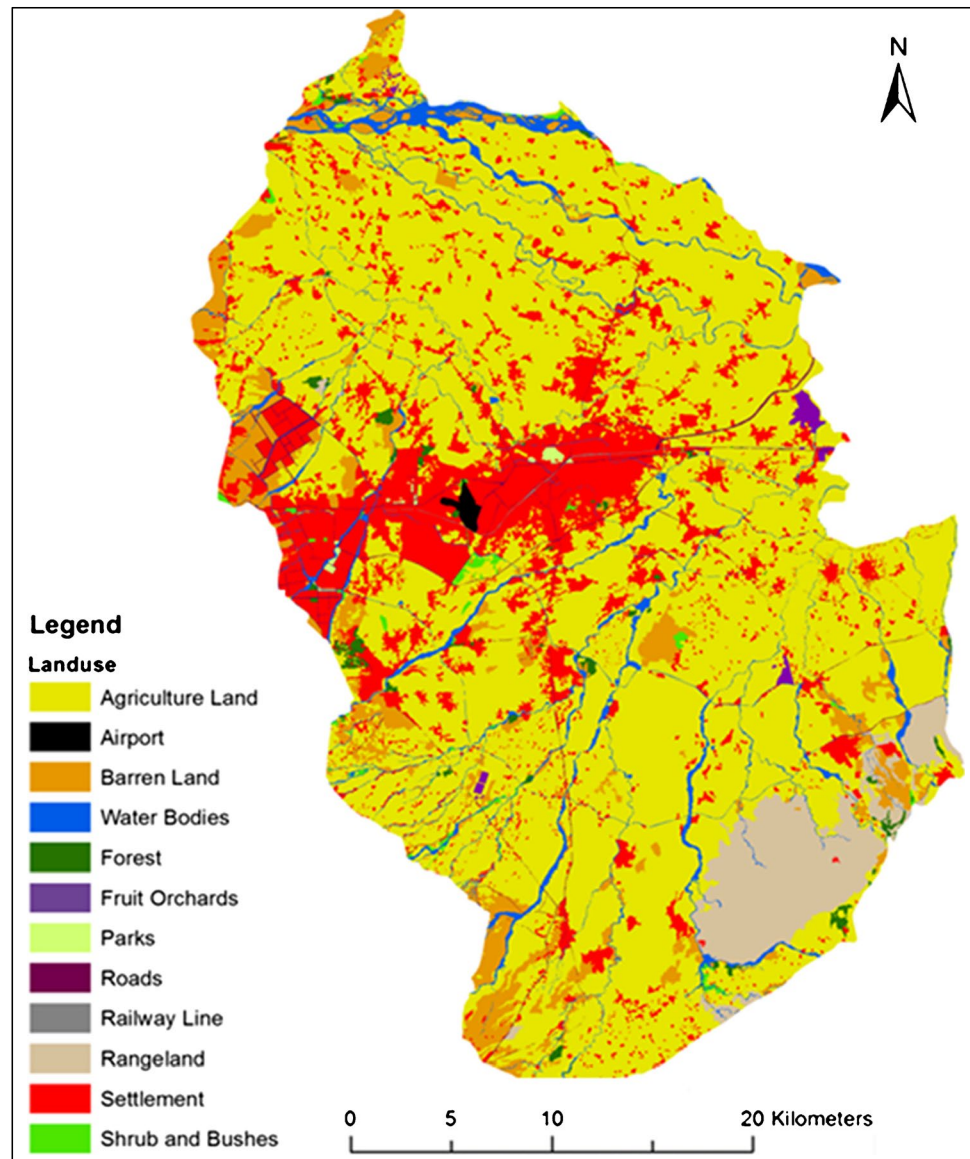


Fig. 5 District Peshawar: Spatial Distribution of Built-Up area (1981-2014)

Fig. 6 Peshawar: Spatial distribution of LULC

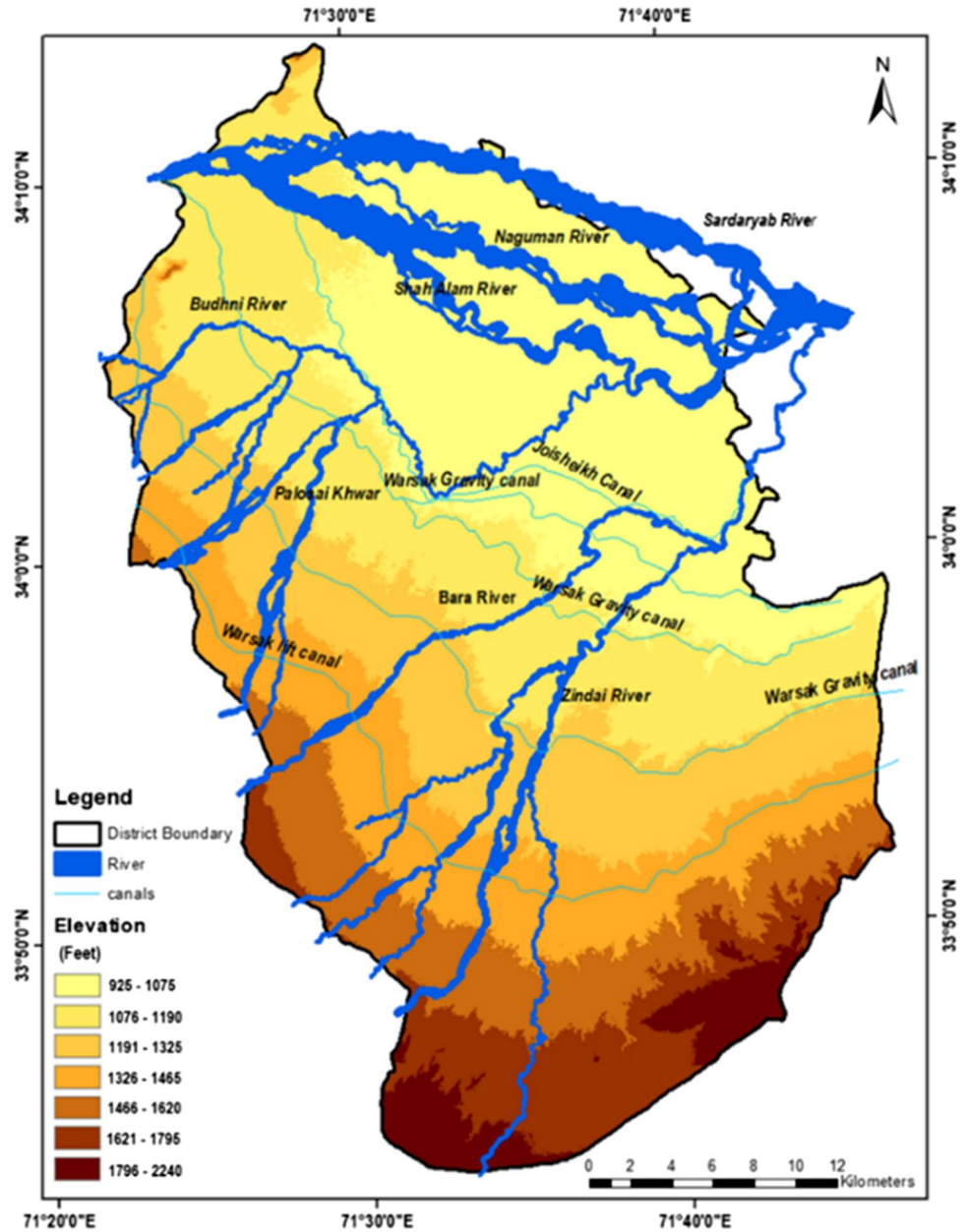


urban drainage basins of these rivers. Similarly, the spatio-temporal increase of surface runoff for River Zindai, Mera, Kala, and Garhi streams has also been calculated. It has been determined that having maximum built-up areas, the urban watershed of River Budhni has also generated a greater volume of surface runoff followed by the urban catchments of Zindai and Bara rivers. Streams within the district boundary have a lesser share of impervious surfaces and have generated a small amount of runoff volume within their urban drainage basins. The increase in [surface runoff](#) has always been escalated and triggered flooding events within the district.

The built environment within the urban drainage basin of River Budhni has been shown remarkable growth and expansion from 2648.45 ha (7.22%) in 1981 to 11,032.63 ha (30.06%) in 2014. As a consequence, runoff volume generation has also been escalated, especially

from the impervious surfaces (Fig. 12). In 1981, the built-up areas within the urban watershed of River Budhni were 7.22%, from which runoff volume generation was 9 Cumecs while it was 39 Cumecs (81%) from the impermeable surfaces. The runoff volume generation from impervious surfaces on 31st May 1981 was about 19% of the total runoff. However, on 15th August 1991, for the same amount of rainfall (33 mm), the runoff volume from the sealed surfaces has been escalated to 15 Cumecs (29%) when the built environment within the urban drainage basin was 12.27%. Runoff volume from the pervious surfaces has been reduced from 39 Cumecs in 1981 to 37 Cumecs (71%) in 1991. On 14th April 2009, the runoff volume generation from the impermeable surfaces further increased to 33 Cumecs (51.6%), as the built-up areas within the urban drainage basin were 26.68% and runoff volume from the unsealed surfaces has been reduced to 31

Fig. 7 Peshawar: Surface Hydrology and River System



Cumecs (48.4%). Similarly, on 11th March 2014, the runoff volume generation from the sealed surfaces (30.06%) has further been augmented to 38 Cumecs (55.9%) and runoff from the permeable surfaces has been reduced to 30 Cumecs (44.1%). Total runoff volume in the urban watershed of River Budhni has been increased from 48 Cumecs (1991) to 68 Cumecs (2014), experiencing an overall increase of 20 Cumecs (41.67%). However, an increase in the runoff volume has only been experienced by the impermeable surfaces (322.22%), and runoff from the permeable surfaces has shown a reduction of about 30%.

As compared to the urban watersheds of other rivers and streams in district Peshawar, built-up areas account more in the urban drainage basin of River Budhni; consequently,

runoff volume generation from the impervious surfaces is also maximum which will further increase over time. Another important fact about the urban drainage basin of River Budhni is that not only surface runoff volume generation is maximum but also the flow of the drains and Kathas of the main city are toward this river. Similarly, a number of perennial and seasonal streams which pass through the planned, developed areas of Regi Lalma and Hayatabad townships as well as other areas of the district also join this river. Due to this, fluvial as well as pluvial and flash floods are often experienced in its urban watershed during the rainy seasons. Likewise, pluvial and flash floods have regularly been observed after a slight amount of rainfall.

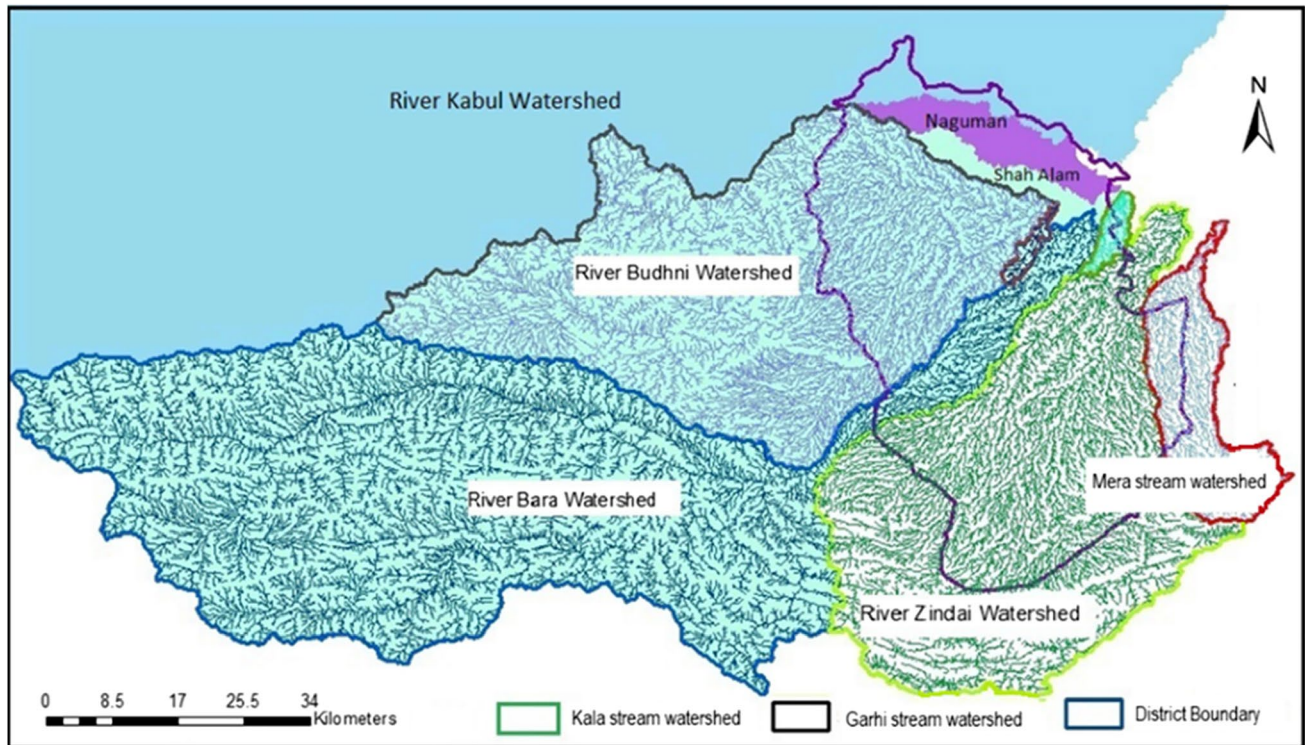


Fig. 8 Peshawar: Watersheds of Rivers and Streams

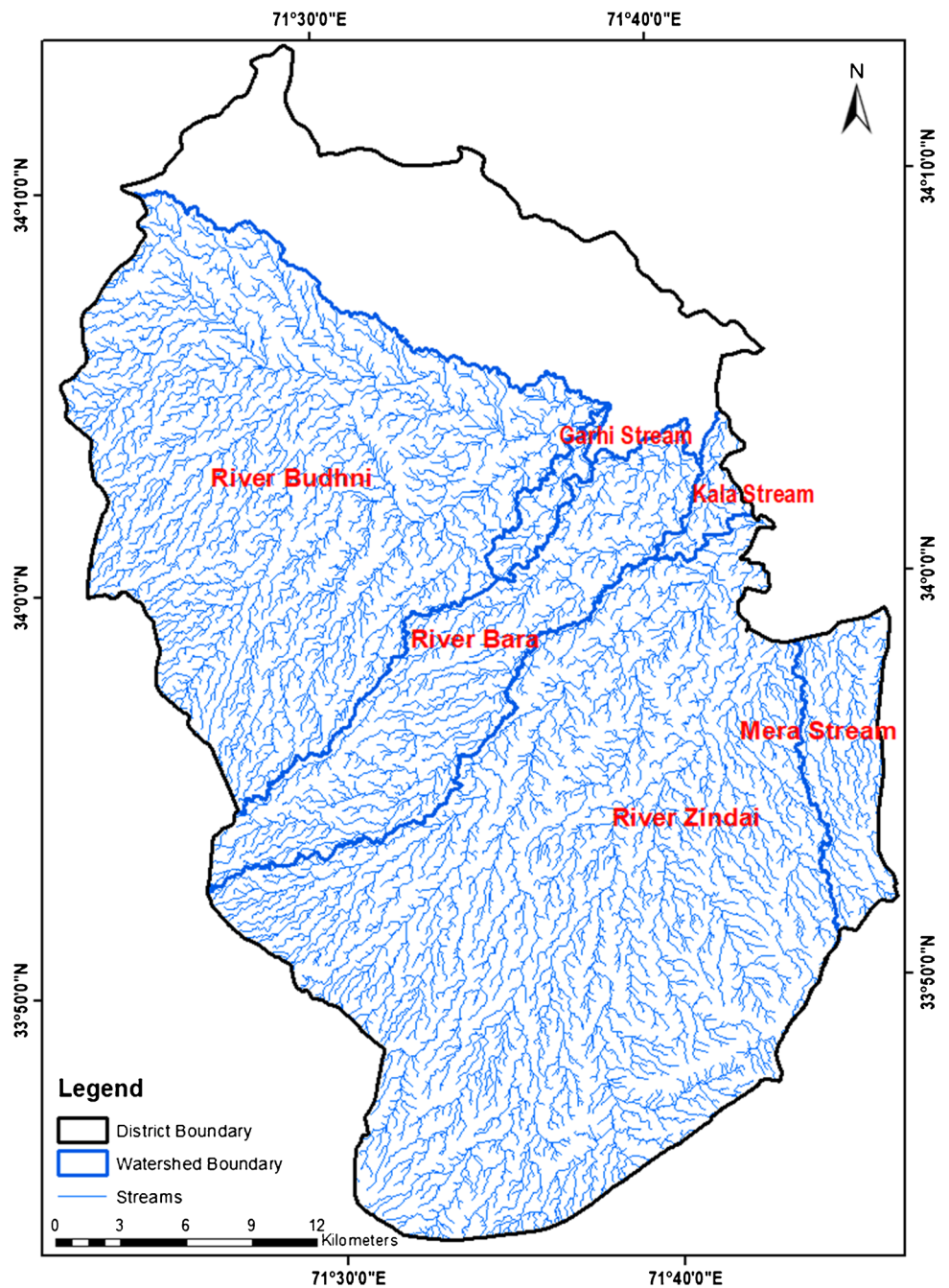
The urban watershed of River Bara has also shown an escalation in runoff volume from ISC, i.e., 1 Cumec in 1981 to 10 Cumecs in 2014. The urban drainage basin of River Bara receives runoff water from the southeast of the main city. However, more than 93% of its total drainage basin lies outside the district boundary in the adjoining Khyber district, and sometimes, flood is also experienced in the surrounding of the city when it rains in the upper catchment areas which confirm the famous Pashto proverb that it has been raining over Tirah (a locality in Khyber district) and washed away horses and donkeys in Khalisa (a locality in the northeast of Peshawar). Another important fact about the urban drainage basin of River Bara is that it receives drainage from the built-up areas in the south of the city along Kohat road, some areas along the Grand Trunk (GT) Road, ring road, and other adjacent areas. These areas are also flooded during the rainy seasons.

Analysis of runoff volume generation from the impervious as well as pervious surfaces within the urban watershed of River Zindai indicated that it has been augmented from the built-up areas while from the natural ground covers, it has shown reduction. Total runoff volume from 1981 to 2014 has been escalated from 53 to 60 Cumecs. However, this increase has only been experienced from the built environment, which has been augmented from 1 to 11.3 Cumecs. Natural ground and permeable surfaces have

shown a reduction in runoff volume from 52 Cumecs in 1981 to 48.7 Cumecs in 2014. River Zindai receives drainage from a number of streams coming through the district of Khyber and entering into the study area from the southwest. Combine water of these streams that have developed an urban drainage basin within the district boundary. Surface runoff volume generation from the sealed surfaces within the urban watershed of River Zindai was lesser than Budhni and more than Bara. However, flooding during the rainy season is often experienced due to not only the localized rain but also in the adjacent district Khyber where most of the tributaries of River Zindai have their sources. Combine water then flow into River Bara, where the situation becomes more aggravated during the rainy season.

Built environment within the urban drainage basins of streams in district Peshawar has small area due to which runoff volume generation is also lesser as compared to the major rivers. However, from the analysis of the spatio-temporal growth of built environment within the urban watersheds of these streams, it has been revealed that Garhi stream has totally urban watershed; the built-up areas are also more as a result of runoff volume generation which is maximum followed by Mera stream. In the urban watershed of Kala stream, the built-up areas are less due to which runoff volume generation from the sealed surfaces is also minimum.

Fig. 9 District Peshawar, drainage basins of major rivers and streams extracted from SRTM image



Land use regulations and urban policies

Peshawar is rapidly expanding on the expanse of fertile farmland to check the haphazard urban growth, and the expansion government has formulated certain land use regulations and urban policies (Samiullah 2013; Rahman et al. 2016, 2019; Khan 2019; Samiullah et al. 2019). The master plan for the city was developed in 1965 to control the unplanned physical expansion of Peshawar. The approval of the urban planning act of 1971 was another

step in this regard to direct the urban growth and expansion in an orderly manner. Similarly, the status of the Municipal Committee was changed to Municipal Corporation in 1981. Likewise, the structural plan for Peshawar was constituted in 1986 for the implementation of which Peshawar Development Authority (PDA) was established in 1987. To prevent the unplanned expansion of Peshawar, PDA has developed two townships of Hayatabad and Regi Lalma in the west and northwest of the city. The urban policy unit was instituted in 2013; the main theme

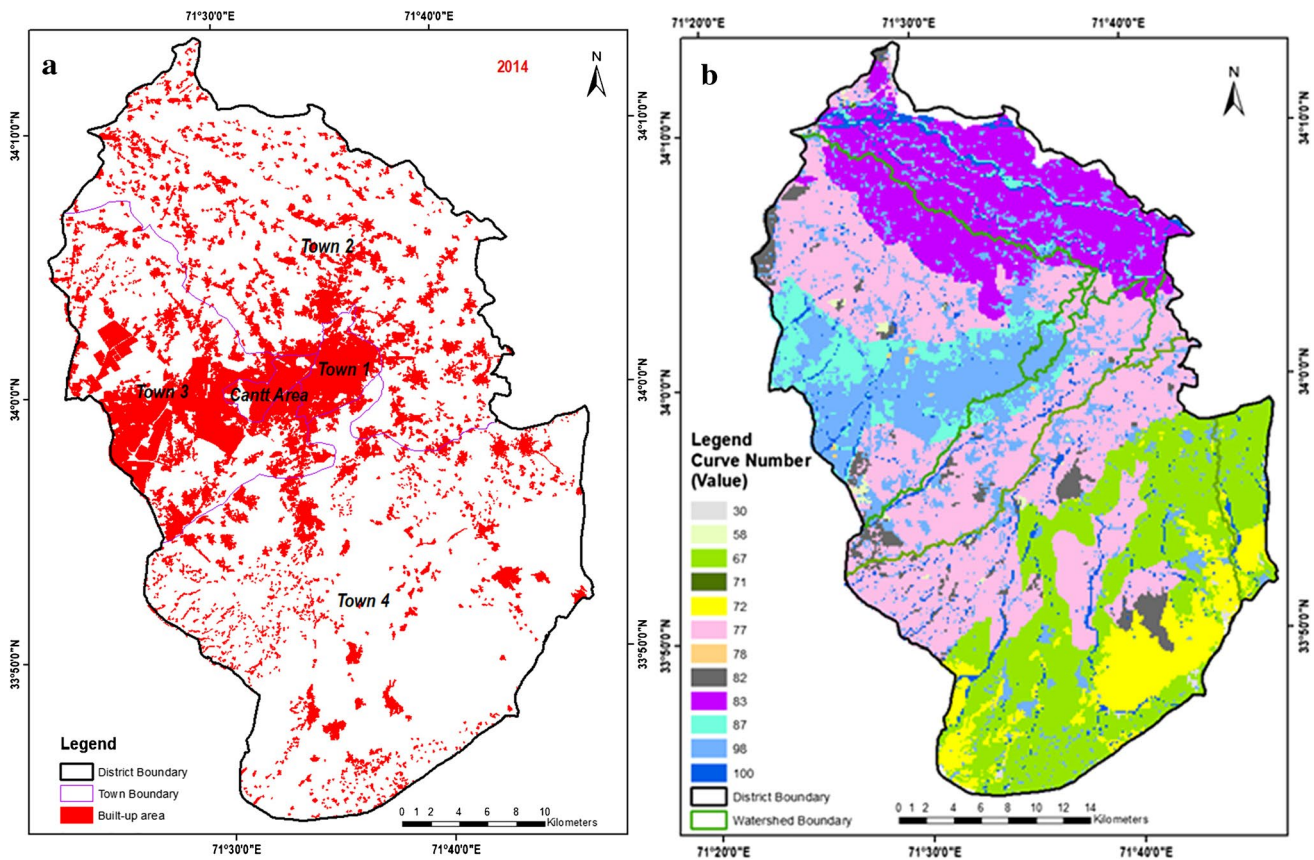


Fig. 10 a Peshawar: Spatial distribution of Sealed Surfaces. b CN map of District Peshawar

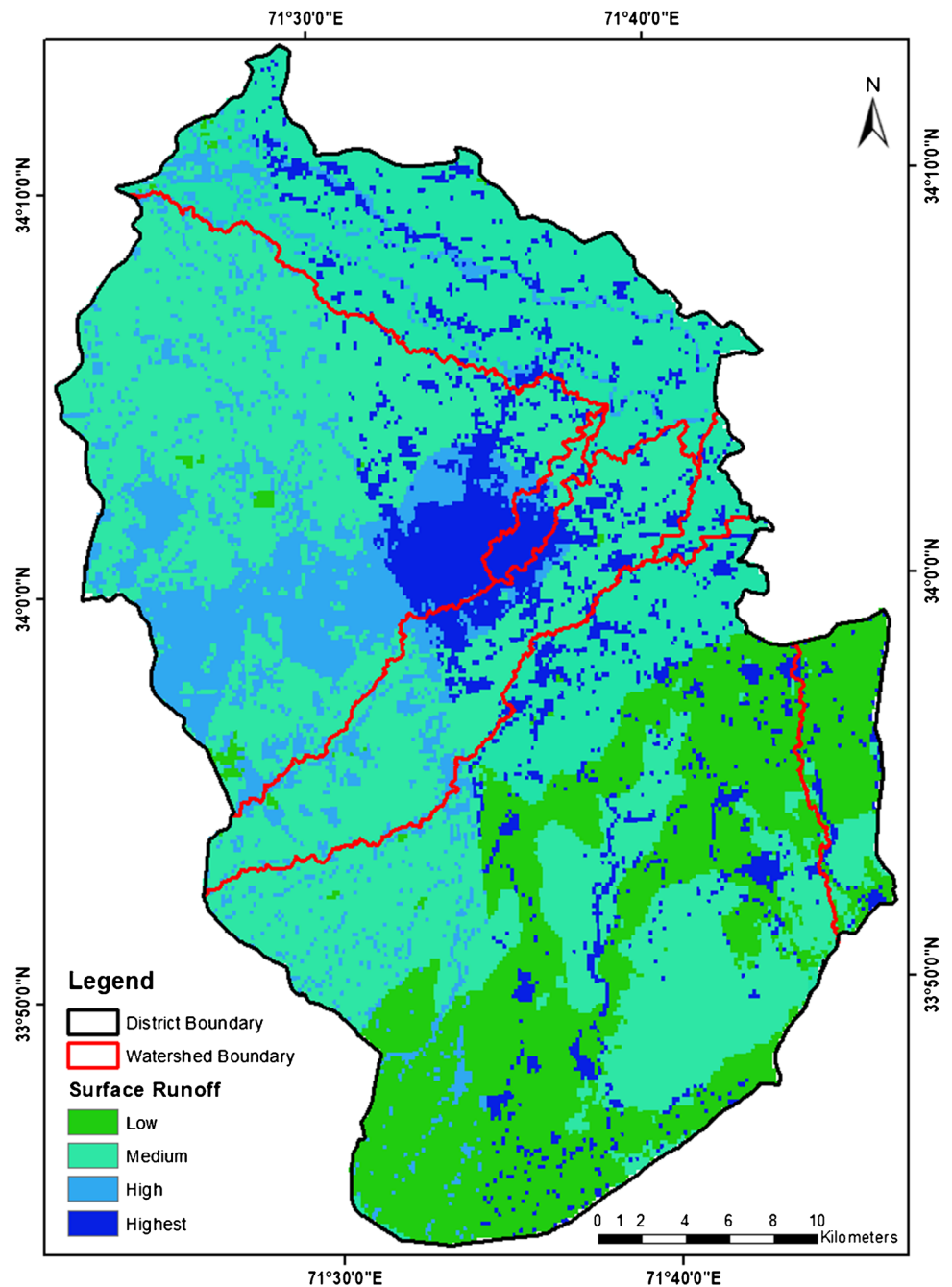
of which was to frame urban strategic policy, institutional, and legal management for Peshawar. Housing and settlement policies and the provision of five-year plans are other important initiatives which have been taken to prevent the fertile farmland and to direct the unplanned growth of the city in an orderly manner. However, such policies could not be implanted due to the existence of multiple agencies and the non-existence of coordination among them. As a consequence, encroachment over the fertile agricultural land still continues which generates problems to the environment and water resources of the city. To prevent the prime farmland and reduce the adverse impacts on water resources, urban land use regulations and policies need to be fully implemented.

Conclusion

Peshawar is not only the provincial capital of Khyber Pakhtunkhwa but also the largest urban center of the province. Being an economic hub, the city has been expanding and growing in terms of population size and physical and infrastructural developments. These anthropogenic developments have been increasing the built-up areas and subsequently replacing the natural permeable ground with

artificial impermeable surfaces. ISC has the capacity of water flowing over it rather than seeping and percolating to recharge the aquifers, thus escalating surface runoff and generating fluvial, pluvial, and flash floods. The increasing trend of sealed surfaces within urban drainage basins of major rivers and streams has been generating problems to the water resources of the study area. Surface water is affected by the accelerated surface runoff volume due to the fact that water moves faster over the sealed surfaces rather than infiltrating through them. Spatio-temporally, the urban watersheds have been experiencing rapid growth and expansion in terms of built-up areas. As a consequence, the runoff volume generation has always been escalated over time, resulting in flash, pluvial, as well as fluvial floods. During the study period (1981 to 2014), the maximum increase in runoff volume has been observed in the urban drainage basin of River Budhni, followed by River Zindai, River Bara, and Garhi, Kala, and Mera streams. River Budhni receives water from the main built-up areas of the district where the increase in impervious surfaces is also greater; as a result, fluvial and pluvial floods have been observed in its basin. In its urban drainage basin, runoff volume from the impervious surfaces has been increased from 9 Cumecs (1981) to 38 Cumecs (2014). Similarly, River Bara also receives rain

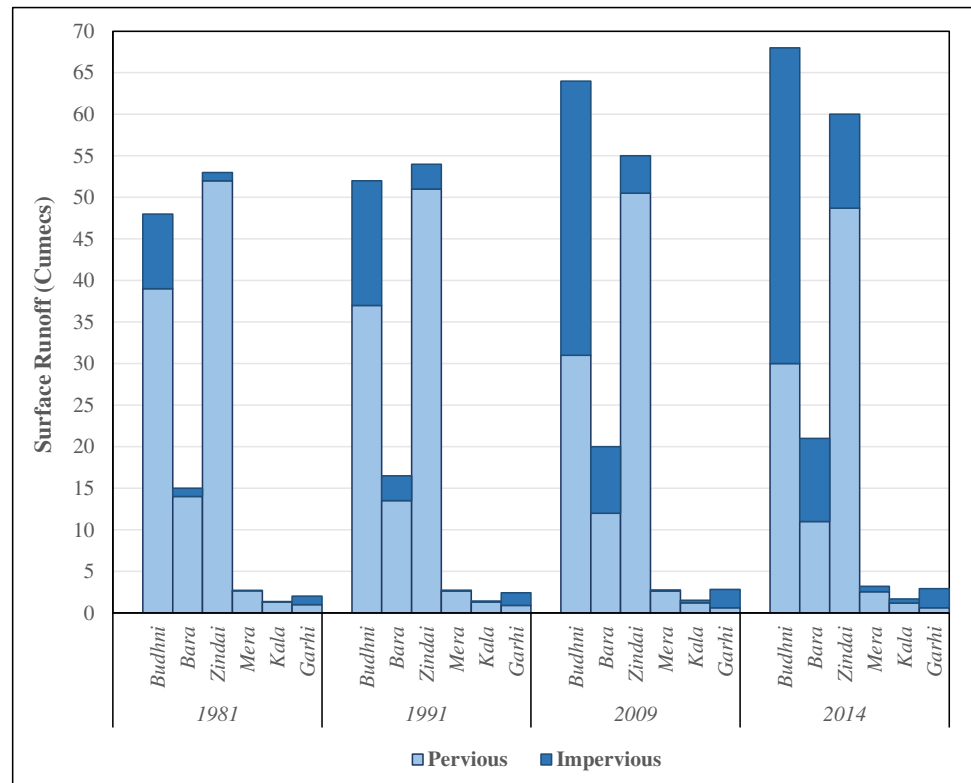
Fig. 11 District Peshawar, spatial distribution of surface runoff



and drainage water from some parts of the city. River Bara is joined by River Zindai which has itself developed a watershed from a number of streams coming through the district of Khyber. During the study period, urban parts of the watersheds of these rivers have also been recorded escalation. In the watershed of River Zindai, runoff volume from the impermeable surfaces has been escalated from 1 to 11.5 Cumecs. Similarly, during the same period, the runoff volume generated by the sealed surfaces in the urban drainage basin of River Bara has also been augmented from 1 to 10 Cumecs.

A number of streams which have developed independent drainage and are considered as part of the major rivers have also been recorded escalation in the runoff volume generation. Garhi stream having a total urban watershed has shown the maximum increase in runoff volume from 1 Cumec in 1981 to 2.3 Cumecs in 2014. However, having the lesser expansion of built environment within the urban parts of the two other streams, Mera and Kala have also observed minimum surface runoff from the built-up areas. A large part of the major rivers and their tributaries has catchment areas outside the district boundary, and non-localized rainfall in their

Fig. 12 Temporal increase in surface runoff within the urban drainage basin of rivers and streams



upper catchments also contributes to pluvial and urban flash floods within the district. The existing land use regulations need to be fully implemented in order to check and reduce the menace of unprecedented increase of built environment and its bad impacts on the water resources of the study area.

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Author contribution All authors have contributed right from the inception of the idea to the final write-up. Attaullah Khan put forth the main idea of the “Impact of Soil sealing on the genesis of pluvial flood in Peshawar, Pakistan.” Atta-ur-Rahman further elaborated and helped Attaullah Khan to work on the various stages in which the research was to be carried out. Attaullah Khan was also responsible for the data acquisition and final write-up. Samiullah mainly carried out the analysis part which included remote sensing and GIS application. Mohammad Ayub assisted Attaullah Khan in field work and the final write-up.

Declarations

Conflict of interest The authors declare that they have no competing interests.

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