Journal of Himalayan Earth Sciences Volume 52, No. 1, 2019 pp. 86-105

Impact of Built environment on groundwater depletion in Peshawar, Pakistan

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Submitted: 2/12/2019 Accepted: 3/13/2019 Published online: 29/03/2019

Abstract

This paper attempts to explore the impact of built environment on the potential of groundwater infiltration in district Peshawar, Pakistan. In the study area, rapid increase in population together with inevitable urban expansion over the fertile agricultural land has been recorded, since 1980. During past four decades, major land use land cover changes have been recorded in infrastructural and housing sectors. In this study, state of the art tools and techniques of Remote Sensing (RS) and Geographical Information System (GIS) have been used to spatio-temporally analyze the changes in built-up environment and its possible impacts on infiltration and groundwater recharge. In Peshawar, groundwater is the sole source of water supply with more than 1,400 public tube wells having a total discharge of 8 million gallons/hour ($8.41 m^3/sec$). Besides these, private tube wells, hand pumps and dug wells are also supplying fresh water to fulfil the citizen's requirements. During 1981 to 2017, the population growth has augmented the demand and requirements of fresh water, which multiple times increased from 56 million liters/day to over 213 million liters/day. During the same period, the area under the built-up environment has also increased from 3.70 % of the total geographical area to 16.27 % and reduced the infiltration rate by 4 %. Such consistent increase in impermeable surfaces have depleted groundwater recharging rate from 108.75 millimeter/year (mm/y) in 1981 to 91.35 mm/y in 2014. In 2014, the abstraction of fresh water from ground sources was 105 mm/y, indicating high extraction and low recharging rate of groundwater from precipitation, resulting the depletion of groundwater sources and fluctuating the water table. The analysis at union council level revealed that falling of water table and drying up of tube wells have been observed and situation is quite alarming in the old city area. In some areas, the water table has been dropped down by more than 16 meters. Such consistent increase in the built-up environment and the resultant groundwater depletion need to be properly monitored so that its adverse impacts could be minimized.

Keywords: Built environment, ISC, LULC, GIS, RS, Groundwater.

1. Introduction

Globally, population is increasing at a rapid pace and there is a consistent change in the land use land cover (LULC) specifically the natural surfaces have been gradually replaced by artificial Impervious Surface Covers (ISC; Rahman et al. 2019). These interventions can be seen at most of the places, however, urban areas are commonly favored. Impermeable surfaces and Contiguous built-up areas are among the common characteristics of cities which are responsible for the development of built environment and surface cover changes (Turok and Mykhnenko 2007; Wessolek 2008; Prokop et al. 2011). In cities, buildings and pavements are the major physical developments combine with socio-economic and infrastructural improvements contribute to the soil sealing (Montanarella 2007; Breuste 2011). Its adverse impacts on human health and urban environs are observed as rise in surface and air temperature, accelerating surface runoff which often intensify risk of flash flood and reducing the recharge rate of groundwater by reducing or halting the infiltration (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). Similarly, the built environment consume fertile agricultural land and produce serious threats to ecology and urban food security (Burghardt 2006; Samiullah 2013).

Worldwide, in different regions groundwater plays an essential role regarding the ecological values (Alley et al. 1999; Griggs and Noguer 2002) which may also be considered as a key factor in the management of urban hydrology. Land Use Land Cover (LULC) changes has great impacts on groundwater system which are mainly associated with built-up environment. Previously, focused area for researches was anthropogenic practices in connection with the utilization of groundwater and often ignored changing pattern of LULC. However, urban expansion has great impacts on groundwater at local as well as regional scales (Hibbs and Sharp 2012). Anthropogenic activities are frequently changing quantity and quality of fresh water sources. Growing population and the resultant economic developments, infrastructural improvements and irrigated forming always stress the potential of fresh water. LULC changing pattern is one of the important human induced factor affecting groundwater system. Surface water sources mostly fulfill fresh water requirements, however, variability in regional climatic conditions and other relevant dynamics are increasing dependency on groundwater (Wada et al. 2010; Döll et al. 2012). Pakistan is a water stress country and is among the hot spots of Asia, facing the threats of increased water utilization, deteriorating water quality, depleting groundwater sources and the risk of climate change. In 1951 the per capita water availability of the country was about 5,000 cubic meters (m^3) which has dropped to 1,100 m^3 in 2006 (Martin et al. 2006). If the same trend continued, the per capita availability of water will be 700 m^3 by 2025 with a drastic depletion in water table and acute shortage of fresh water availability. Globally, Pakistan ranks 4th in terms of groundwater abstraction with total groundwater extraction of 64 Km^3/year which is used for domestic, agricultural and industrial purposes (Margat 2008).

This study investigates the depletion of groundwater due to increased built environment in the northwestern city of Pakistan. For this purpose, the promising techniques and tools of Geographical Information System (GIS) and Remote Sensing (RS) were utilized to monitor and detect the impacts of built environ on the rate of infiltration.

2. The study area

This study has been carried out in the rapidly growing northwestern district of Peshawar in the province of Khyber Pakhtunkhwa (KP). Latitudinal extent of the study area is from 33° 44′ N to 34° 15′ N, whereas the longitudinal extent is from 71° 22′ E to 71° 42′ E (GoP 1999; Figure 1). Having a total area of 1,257 square km, Peshawar is a historical city with socio-economic and geostrategic significance. In the district of Peshawar the identified factors of land take and surface sealing are urban expansion, rapid population growth, socio-economic, infrastructural and physical developments. The rapidly expanding built environment has sealed the soil by impervious materials. These modifications have accelerated surface runoff which often cause flash flood and reduced infiltration, seepage and percolation to the aquifers (Rahman et al. 2016; 2019). The falling of water table and drying up of tube wells in the district have already been observed. Similarly, the rapid increase in population of district Peshawar has multiplied fresh water extraction from ground sources. Low infiltration rate and increased rate of abstraction from groundwater sources have always threatened the potential of fresh water sources of the district.

In the study area River Kabul and Bara are the major sources regarding the groundwater recharge, however, irrigation canals, streams and precipitation also augment the process (GoNWFP 2009). Average elevation of the district is about 358 meters (GoP 1999). Flow of the surface water follow the sloping pattern of the district which is from southwest towards the northeast. Although major irrigation canals flow from northwest towards the southeast, yet their flow follow the slope of nearly the same or gentle gradient (Figure 2). In such circumstances precipitation play an important role in the groundwater recharging process. Average annual rainfall recorded at Peshawar Met Station and Agriculture Research Institute (ARI) Tarnab is over 400 millimeter (Figure 3 & 4).

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 clay and sand and favorable for cultivating a number of crops. Soil of the district has been classified into alluvial, flood plain, piedmont and loess plains (Figure 5).

3. Materials and methods

Data were collected from both Primary and Secondary sources. In different parts {Union Councils (UCs)} of the study area field survey was conducted. Global Positioning System (GPS) was used for locating the groundwater sources. To know about the daily average and peak demand and requirements of fresh water of the citizens in district Peshawar, household survey was carried out in the sample UCs by random means. Structural interviews and Focused Group Discussions (FGD) with the concerned stockholders were also conducted.

Soil data for this study was acquired from the Soil Survey of Pakistan (SSP). Climate data was collected from Regional Meteorological Department Peshawar and Agriculture Research Institute (ARI) Tarnab. Population data and information about the study area were compiled from the published Census Reports of the district (GoP 1952; 1962; 1973; 1983; 1999; 2017). However, estimated and projected population of the district were calculated, using the formula (GoKP 2013; Eq. 1)

$$P = Po\ (1 + r/100)\ n \ \ldots\ldots\ldots\ldots\ldots\ldots \text{Eq.1}$$

Where P is the estimated/projected population, Po is the population of base census which is used for calculation, r is the growth rate and n is the interval/period of time/years, to calculate population between two censuses. Data regarding urban expansion was extracted from the temporal LANDSAT (1981; 1991) and SPOT (2009; 2014) images. Maximum likelihood classification method was used for the analysis of satellite images. Signature were created to identify and classify LULC of the study area. From the analysis of the satellite images urban growth and expansion leading to soil sealing was clearly observed and identified in district Peshawar. It was analyzed that sealed surfaces have rapidly increased from 1981 to 2014. LULC maps were also acquired from the published sources. Similarly, Digital Elevation Model (DEM) of the district was extracted from Shuttle Radar Topographic Mission (SRTM) of USGS database.

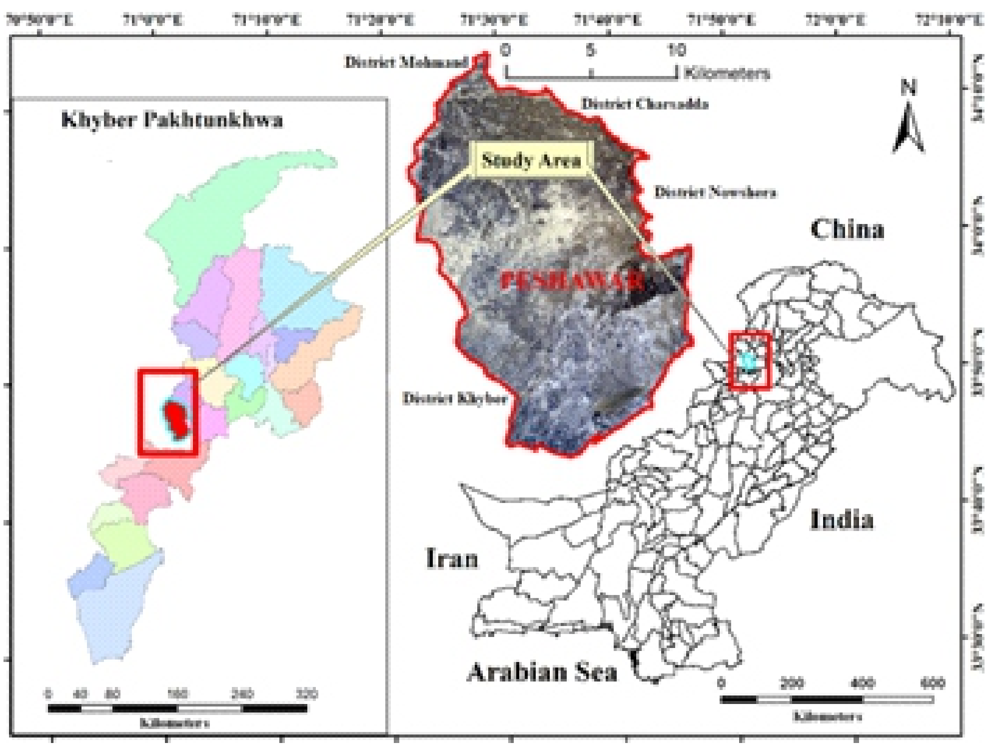

Fig. 1. Location of District Peshawar.

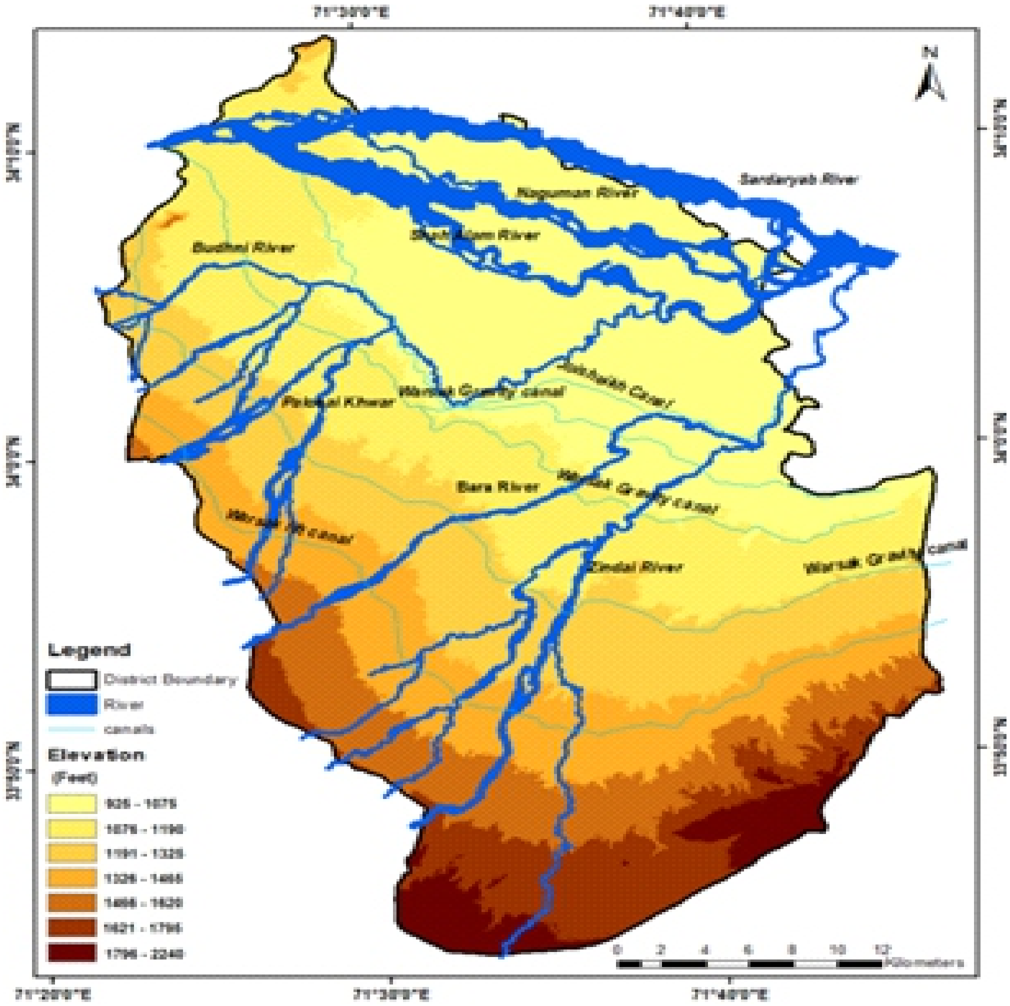

Fig. 2. Surface terrain and Hydrology of Peshawar.

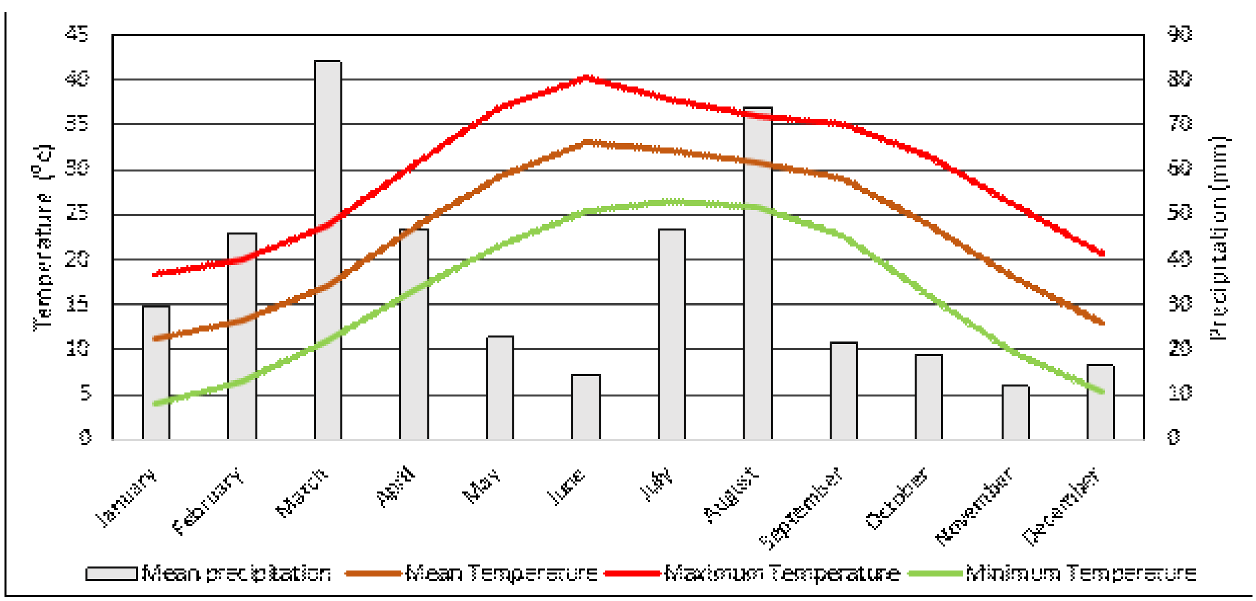

Fig. 3. Peshawar, Mean Monthly Temperature and Precipitation.
Source: Pakistan Meteorological Department (Average for 30 years 1985-2015)

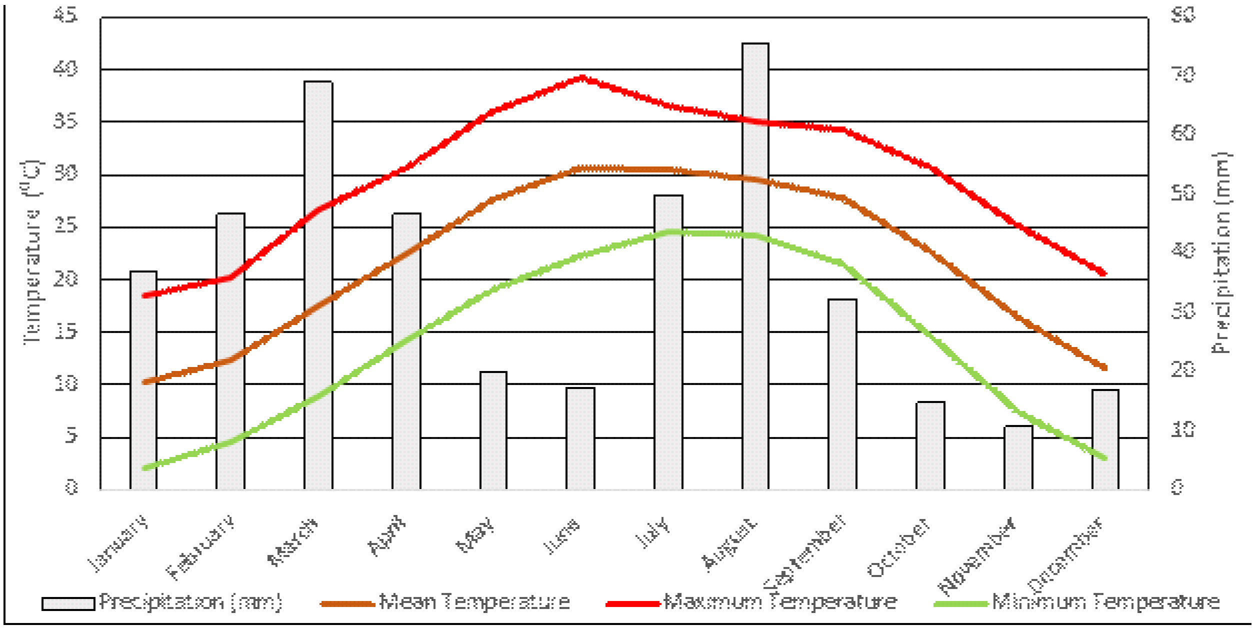

Fig. 4. Tarnab, Mean Monthly Temperature and Precipitation.
Source: ARI Tarnab (Average for 30 years 1985-2015)

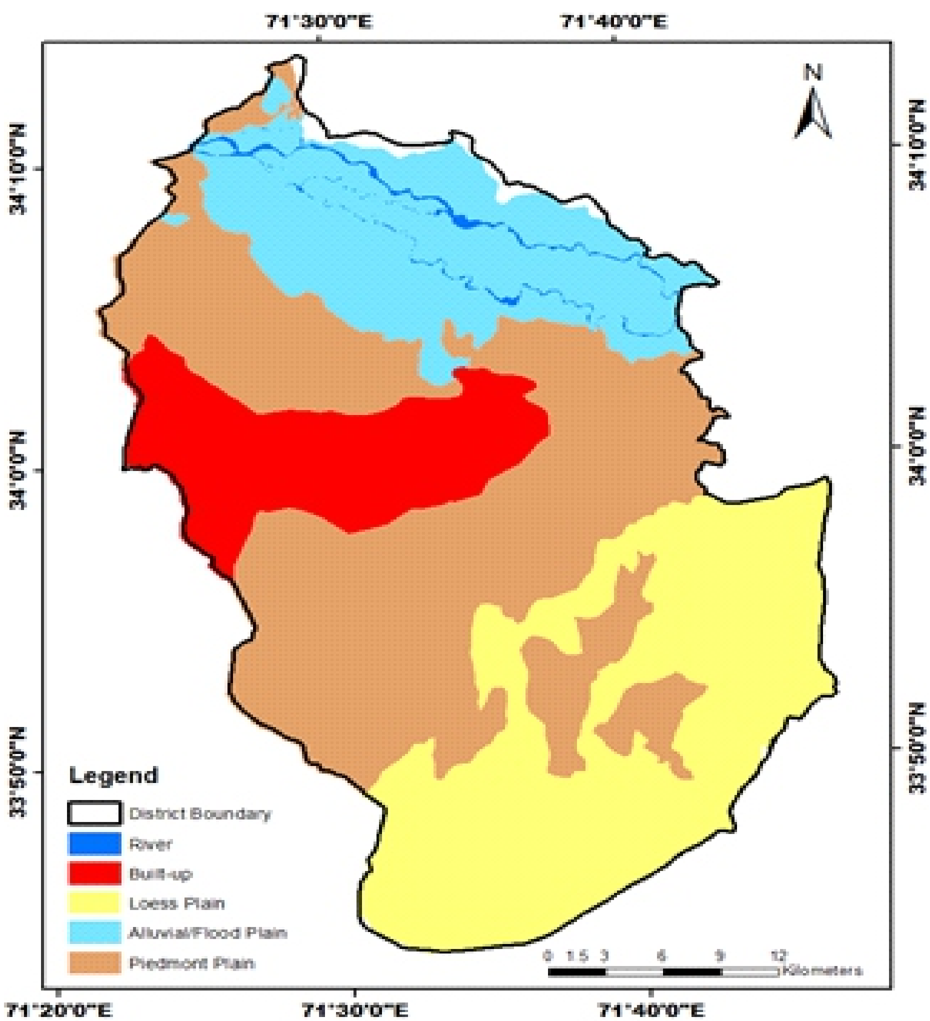

Fig. 5. Major Soil groups of Peshawar.

Data regarding the groundwater sources of the study area have been acquired from Water and Sanitation Services Peshawar (WSSP), Public Health Engineering Department (PHED) and irrigation department. In the entire district 140 tube wells were selected as sample tube wells. The groundwater data collected from WSSP, PHED, irrigation department and field survey was interpolated through Kriging in ArcGIS to create water table map of the study area. SRTM, DEM was analyzed to extract the elevation of tube wells. Water table depth was subtracted from the elevation of groundwater sources to generate a Raster surface for depth of the groundwater. Further analysis on the generated Raster surface was carried out to create maps of the recharging zones for groundwater on the basis of elevation. Watersheds delineation of the major rivers and streams was also analyzed from SRTM, DEM. Watersheds and groundwater recharging zones were overlapped to know about the recharging pattern from surface water sources.

Discharge of groundwater sources which was given in million gallons/hour were summed up and were converted into million liters per day (ml/d) and millimeters per year (mm/y). Fluctuation in water infiltration with Impervious Surface Cover (ISC) was followed from the guidelines of the United States Environmental Protection Agency (Table 1; USEPA 1993). The difference between discharge from groundwater sources and recharge from average annual rainfall was quantitatively calculated.

4. Results and discussion

Analysis of the data has determined that spatio-temporally the district of Peshawar has been experiencing rapid urban expansion, population growth, socio-economic, infrastructural and physical developments (GoP 1999; Khan 2001; Samiullah 2013; Rahman et al. 2016; 2019). The rapidly increasing population has augmented the extraction from ground sources, while urban expansion has consumed the fertile agriculture land. Similarly, infrastructural and physical improvements and developments are consistently replacing natural ground by artificial ISC and fluctuating the rate of infiltration. The increasing trend of groundwater abstraction and reducing infiltration rates have increased pressure on fresh water sources and threatened the potential of groundwater. Dropping down of the water table and drying up of the tube wells have already been observed.

4.1. The Spatio-temporal growth of district Peshawar

The rapidly growing district of Peshawar has shown Spatio-temporal growth in term of population, urbanization and the increasing trend in built environment. Which has resulted land take and increase in the ISC has caused soil sealing. These alterations of natural ground cover by impervious materials have accelerated surface runoff and reduced infiltration into the ground from precipitation.

4.1.1. Rapid population growth

The district of Peshawar has witnessed rapid increase in population in different periods. Population of the district according to 1998 census was 2.1 million and further increased to 4.269 million (2017). However, the estimated population for 2030 is about 6.2 million. Since the first national census in 1951, the district of Peshawar has shown rapid increase in term of population which increased from 0.391 million (1951) to 4.269 million (2017). During this period the overall increase was more than 10 times. Population of district Peshawar has shown fluctuations in different census years, however, rapid growth was recorded during the intercensal period of 1981-1998. During this period the increase in population was more than 80 % and average growth rate was 3.56 per annum. The rapidly growing population will demand more fresh water supply, resulting the increase in its abstraction. This changing trend will increase pressure on groundwater sources. In this study groundwater abstraction has been correlated with the Population growth. The United Nations international standard of fresh water usage is 20 to 50 liters per individual per day (Water 2006). However, this amount varies seasonally in different regions and countries of the world. Socio-economic condition of a society also affect the per capita consumption of fresh water. During the household survey, it was predicted that the average daily water requirements of the citizens was about 13 gallon per capita per day (50 liters per individual per day) however, the daily peak requirements of the citizens was about 1.5 times greater than their daily demand.

4.1.2. Urban growth

The district of Peshawar has also experienced rapid pace of urbanization. Upto the census of 1961, urban population was increasing with a slow pace when it was only 0.218 million. Rapid increase in urban population was recorded during the intercensal period of 1972-1981 and urban population has increased from 0.27 million to 0.57 million. Similarly, urban population of Peshawar according to 1998 census was 0.98 million and has further grown to 2.299 million in 2017. From 1972 to 2017, density of urban population has also increased about 7 times in a period of 45 years from 218 persons per square Km to about 1566 persons per square Km. On the basis of rapidly growing population Peshawar has been declared as overcrowded city. Since 1961, Peshawar has occupied top position in terms of urban population share in the province (Figure 6).

Major cause of the rapid urbanization of district Peshawar is rural-urban migration. People of rural areas are of the opinion that the provincial capital will provide them facilities of healthcare, education along with other needs and services. During the last decade in the province of KP, 63 % of people have migrated from rural areas, out of which more than 50 % have resided in Peshawar city (UN 2013). Besides, migration from rural areas, natural increase in urban population is another factor contributing to the rapid urbanization process (Arif and Hamid 2009; Mehmood et al. 2016). Similarly, engulfing of the surrounding rural areas into the city also augment the process (Kugelman 2013; Raziq et al. 2016). These interventions are mainly contributing to land take and increase the ISC in district Peshawar, as a consequence water infiltration into the ground has been reduced.

Table 1. Guidelines of USEPA, 1993.

Type of Surface Cover	*Runoff (%)*	*Evapotranspiration (%)*	*Shallow Infiltration (%)*	*Deep Infiltration (%)*
Undisturbed Surface	10	40	25	25
Impervious upto 20 %	20	38	21	21
35-50 % Impervious	30	35	20	15
75-100 % Impervious	55	30	10	5

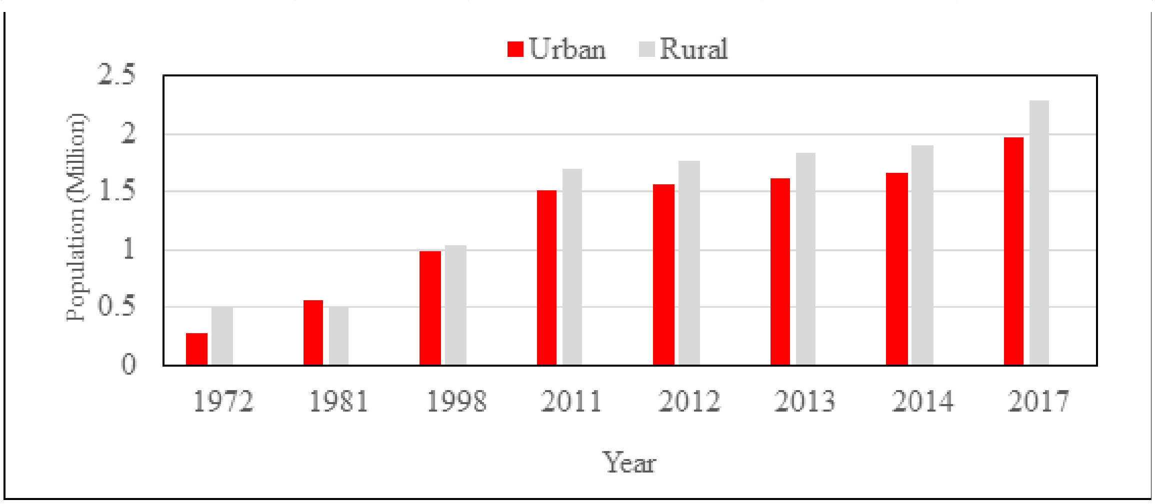

Fig. 6. District Peshawar, share of urban and rural population (1972-2017).

4.1.3. Spatio-temporal expansion of built environment

The built-up environment in Peshawar has been rapidly increased, since 1981. In 1981 the built-up environment of the district was about 4,635 hectares (ha; 3.70 %) and in 1991 it has been enlarged to 7,182 ha (5.7 %) and further increased to 16,986 ha (13.5 %) in 2009. While LULC analysis of satellite images for the years 1981, 1991, 2009 and 2014 (Figure 7, 8, 9 & 10) has indicated further increase in sealed surfaces which has accounted as 20,451 ha (16.27 %). With the same pace the estimated figure for the year 2030 will be 22 %. The residential sector is one of the major consumer of agriculture land and used up about 8,748 ha farmland from 1991-2009 (Samiullah 2013).

4.2. Groundwater sources in district Peshawar

Groundwater in district Peshawar is a major source of potable water, however it is also used for industrial and irrigational purposes. In the study area, groundwater is the sole source of fresh water supply with 1,400 public tube wells operated by the government agencies. However, a number of community/private tube wells, hand pumps and dug wells also supply fresh water to the citizens. Besides recharging from the major rivers and irrigation canals, precipitation is an important contributor to the process. In the study area depth of water table varies from 1.5 meters (5 feet) in the north upto more than 76 meters (250 feet) in the southwest (Figure 11 & 12). Similarly, groundwater depth (Aquifer's depth) in the district varies from 210 meters (690 feet) upto 515 meters (1690 feet; Figure 13). The groundwater recharging zones generated in GIS environment, confirm the fact of the recharging process from rain water and sloping pattern of the study area.

4.3. Groundwater recharging zones

Recharging of aquifers are not confined to the administrative limits. However, surface terrain and altitude of an area have obvious effects on the recharging process. It was attempted to demarcate the recharging zones of groundwater within the district boundary (Figure 14). The factors which were given due consideration were depth to groundwater (aquifer's depth), elevation of groundwater sources, surface water flow and water table depth. Consequently, three recharging zones of groundwater were demarcated, including one major and two other minor zones (Figure 14d). These zones have certain characteristics and variations regarding landforms, hydrology, elevation and development of built-up environment.

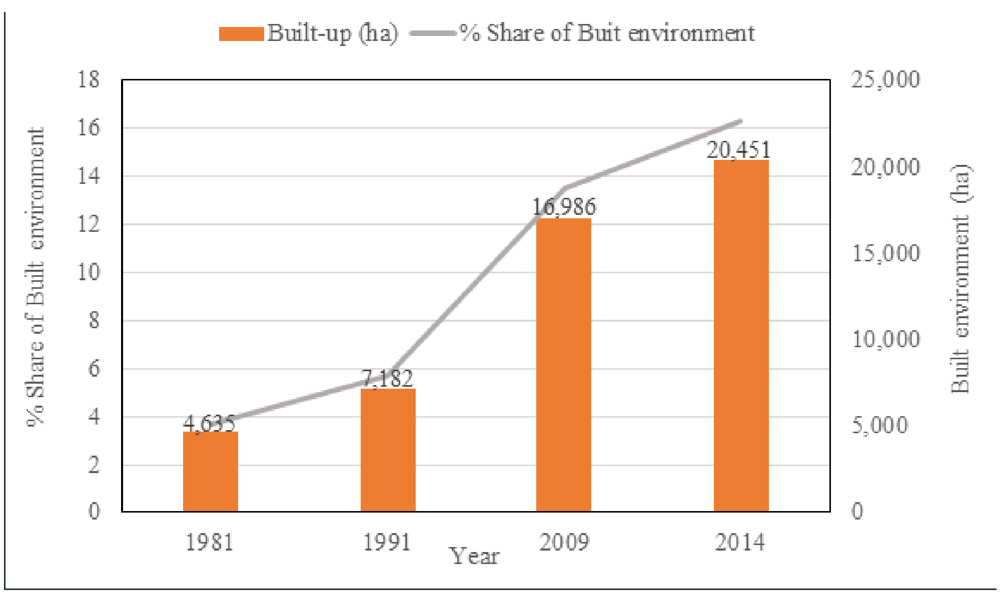

Fig. 7. District Peshawar, temporal growth of built environment (1981-2014).

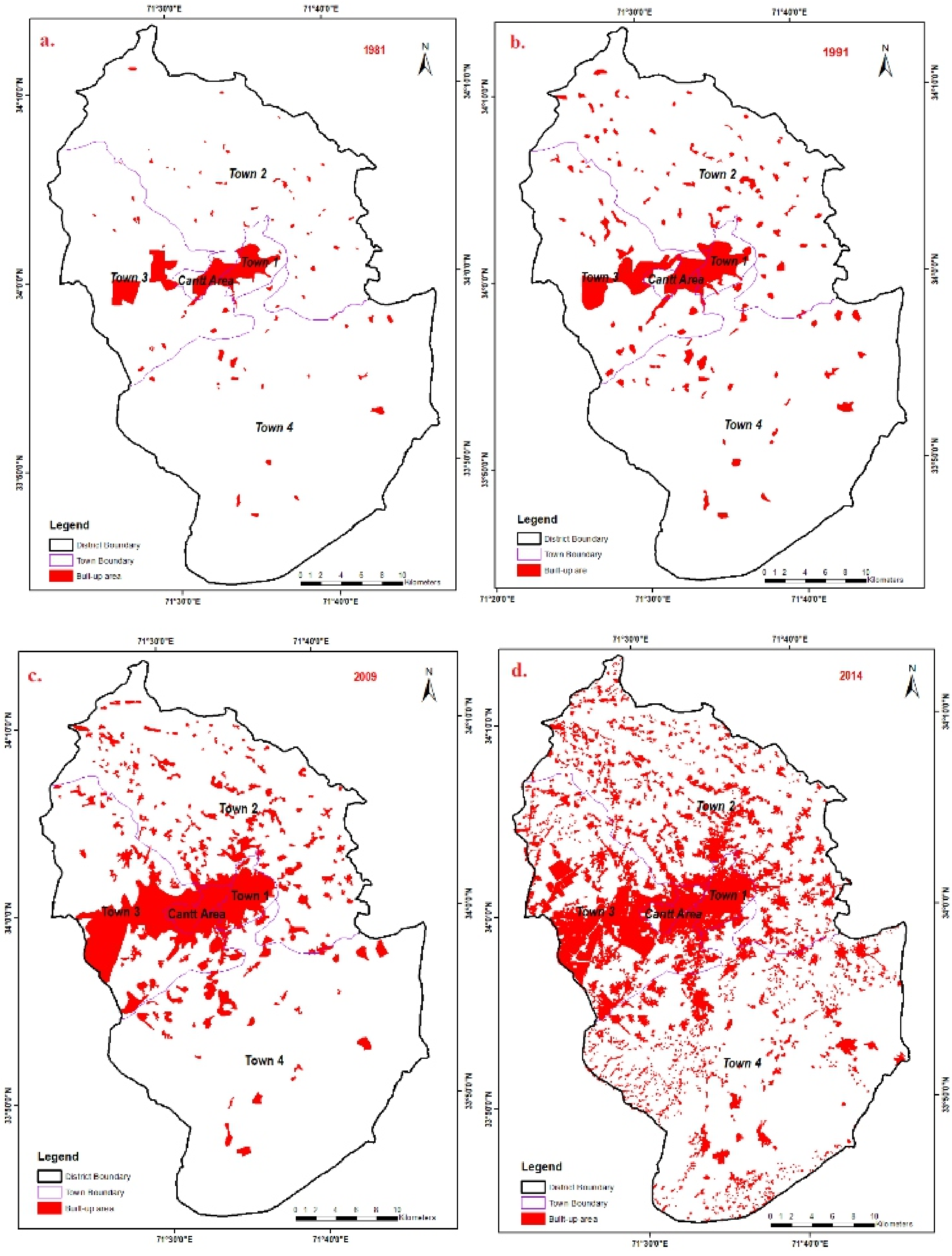

Fig. 8. District Peshawar Spatio-temporal growth of Built-up areas.
a.1981, b. 1991, c. 2009, d. 2014.

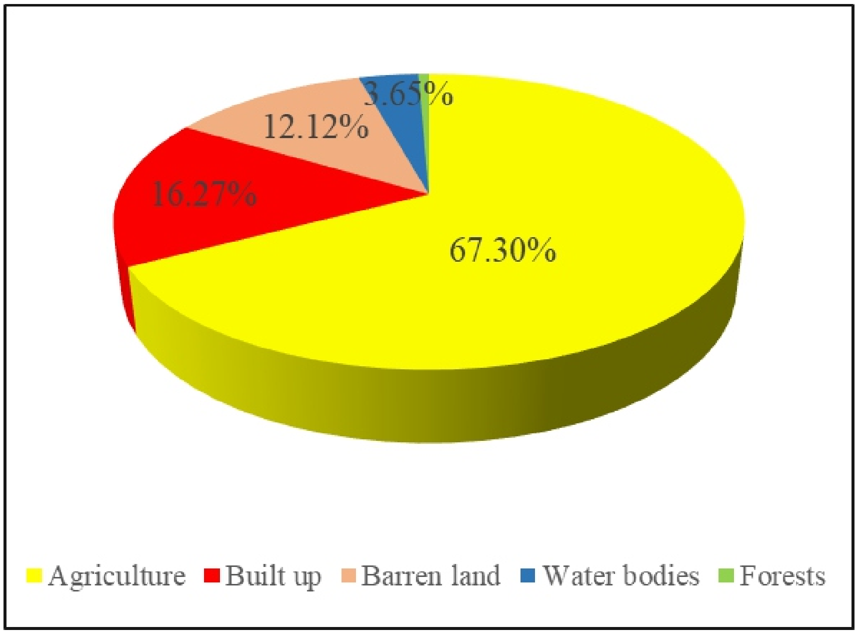

Fig. 9. District Peshawar, Land utilization 2014.

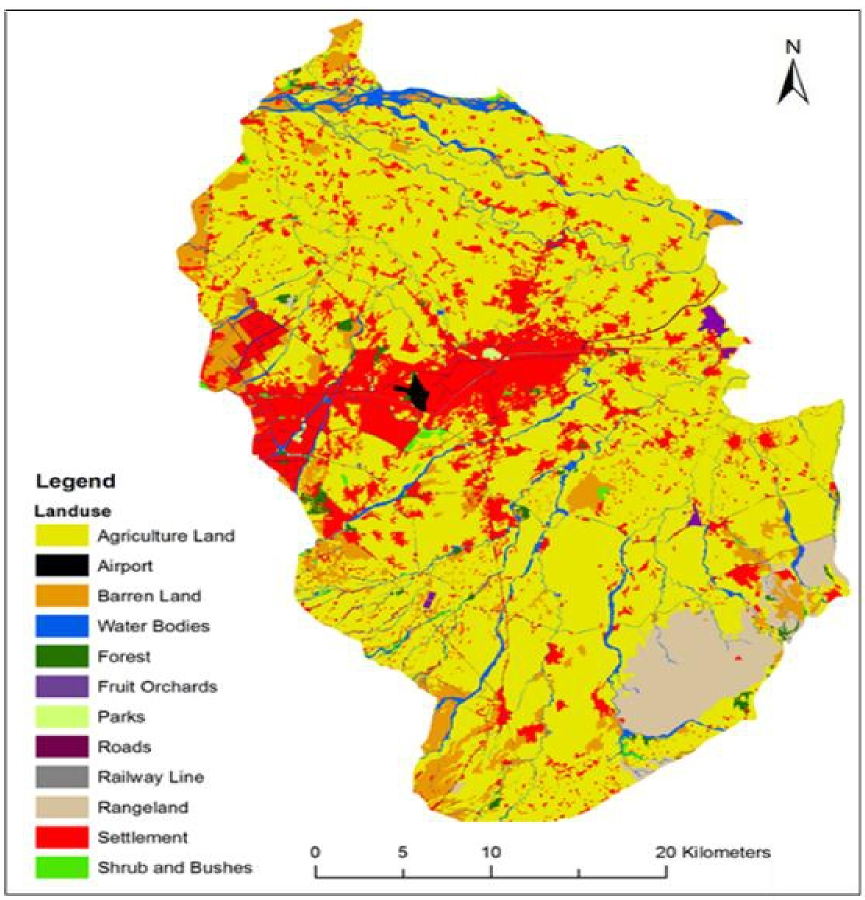

Fig. 10. Land use Land cover of District Peshawar. Source: SPOT image 2014

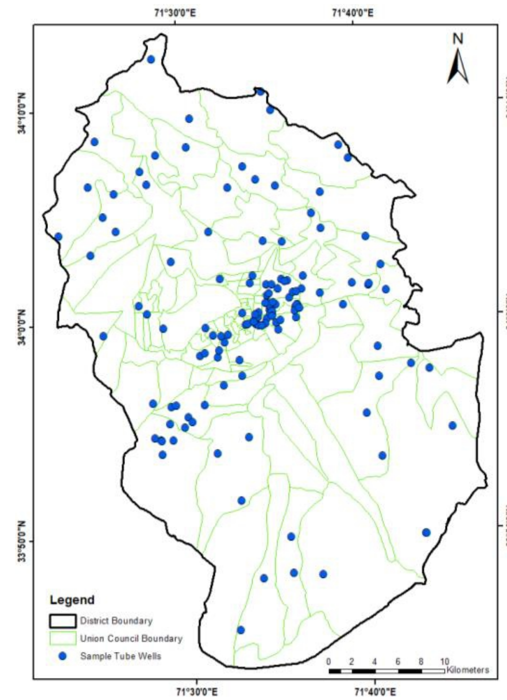

Fig.11. Sample Tube wells

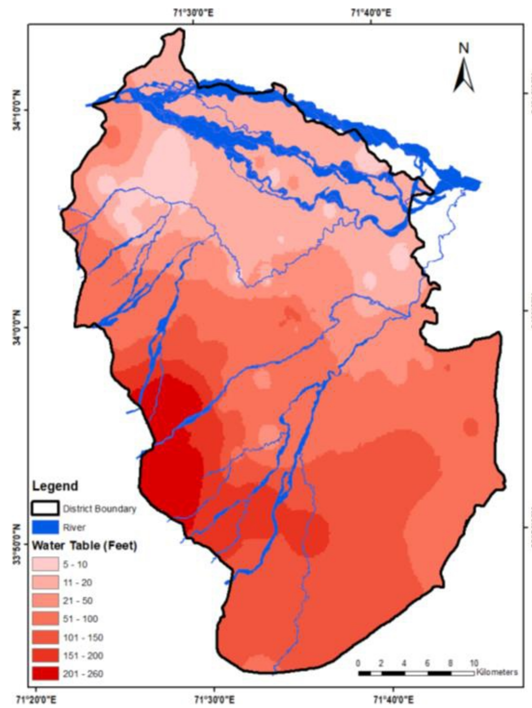

Fig.12. District Peshawar, Water Table Depth.

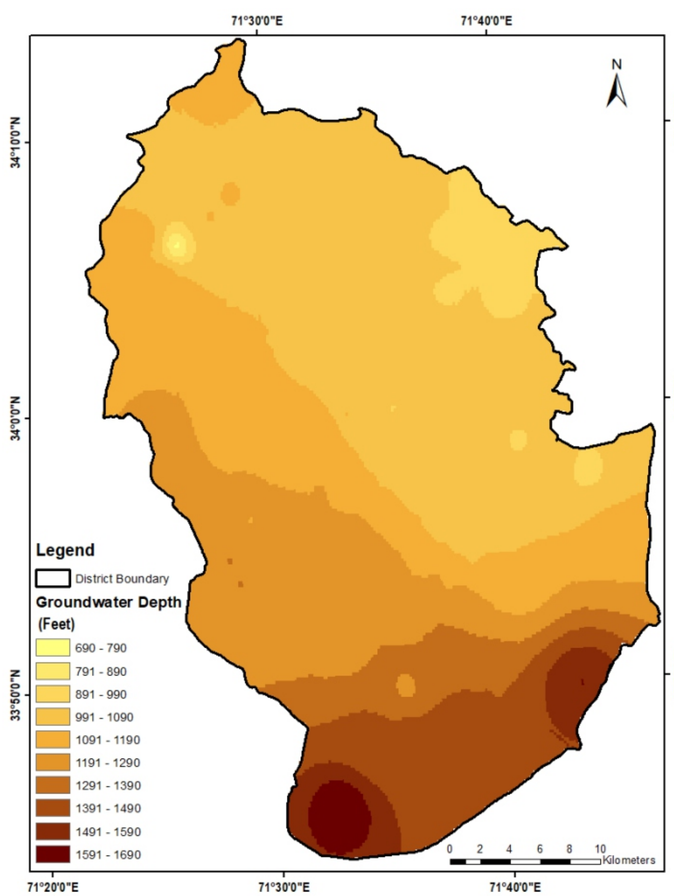

Fig. 13. District Peshawar, Groundwater Depth (Aquifer Depth).

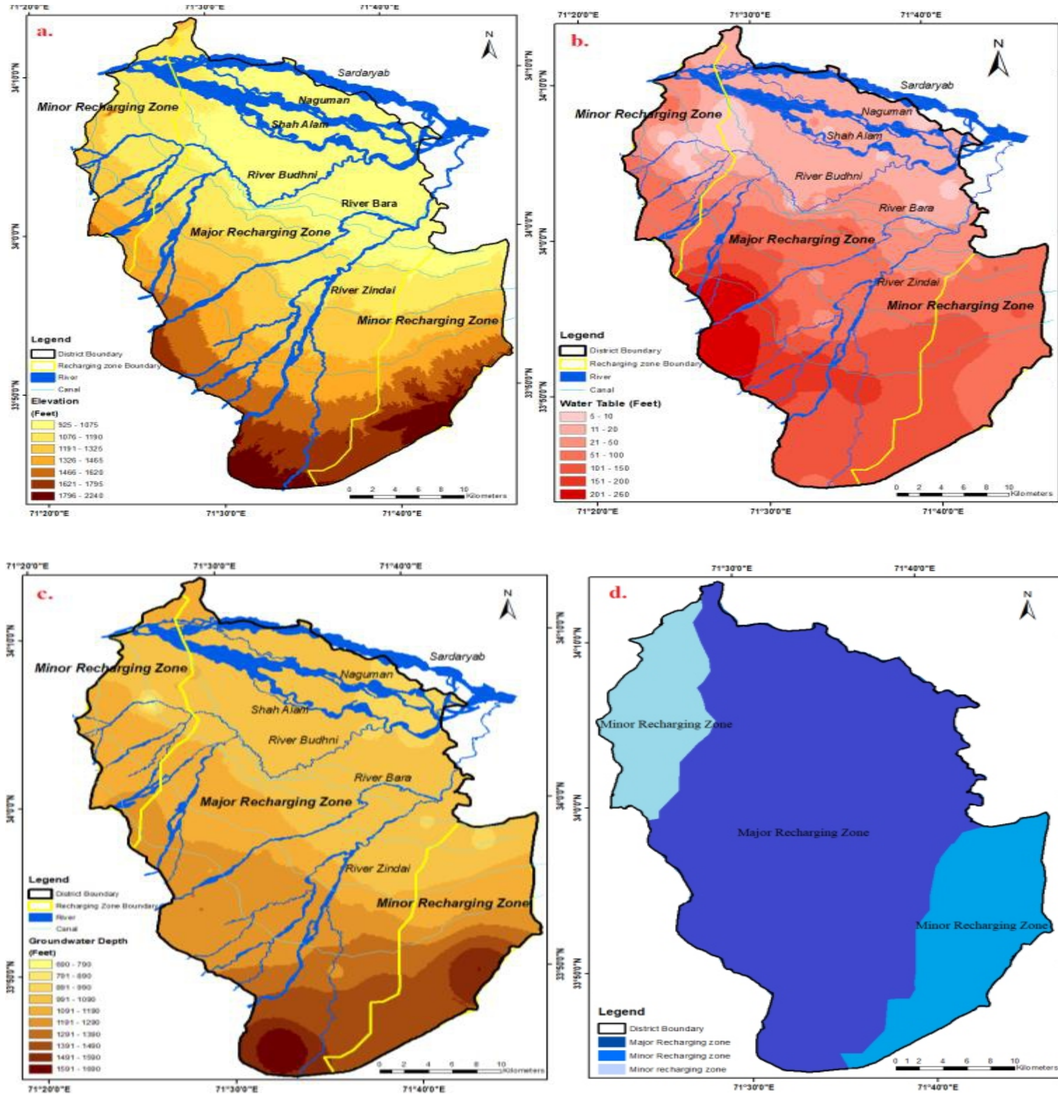

Fig. 14. District Peshawar, Groundwater Recharging Zones.

a. Elevation, b. Water Table Depth, c. Aquifer Depth, d. Recharge Zones

4.3.1. Major recharging zone

Total area of the major groundwater recharging zone is 900 sq.km and it covers 72 % of the geographical area of Peshawar. The major zone has variety regarding numerous features such as surface water flow, soil, water table depth, elevation, urban watersheds of streams and rivers and aquifer's depth. However, the peculiar characteristic of this zone is the rapid expansion and development in impervious surfaces. Almost all the soil groups of the study area (piedmont, loess plains and River alluvium/Flood plain) exist in the major zone. Its altitude ranges from 282 meters (925 feet) upto 682 meters (2,240 feet). Similarly water table depth of the zone ranges from (1.5 meters (5 feet) upto 76 meters (250 feet). Depth to aquifer of the zone varies from 213 meters (700 feet) upto 518 meters (1700 feet). Major rivers, canals and streams of the study area flow through this zone. Urban watershed of River Budhni in this zone shares 245 square km (67 %; Figure 15). Similarly, drainage basin of Bara river, Kala and Garhi streams are entirely (100 %) in this zone. Urban drainage basin of Zindai river in this zone is 360 sq.km (69 %). In the study area the recharging process of aquifers within this zone has the maximum share. Built-up areas within this zone has considerably increased from 1981 to 2014. In 1981 built-up environment was 3,427.51 ha (3.81 %) which increased to 16,435.28 ha (18.26 %) in 2014 (Figure 16 & 17). This subsequent replacement of natural ground cover by ISC has always reduced water infiltration into the ground.

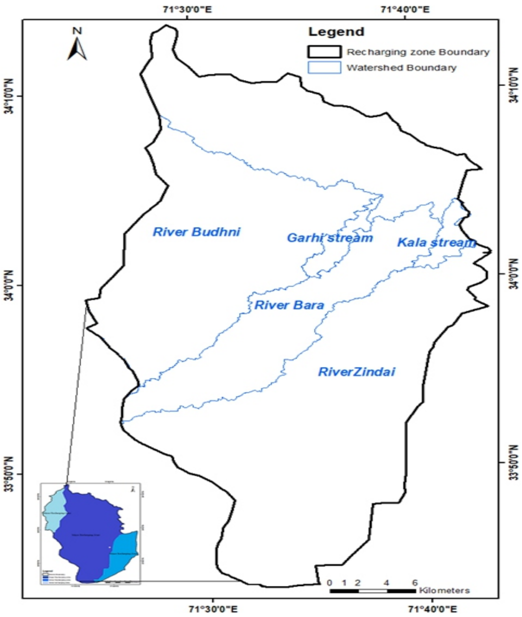

Fig. 15. Urban watersheds of major River and Streams in Major Groundwater Recharging Zone.

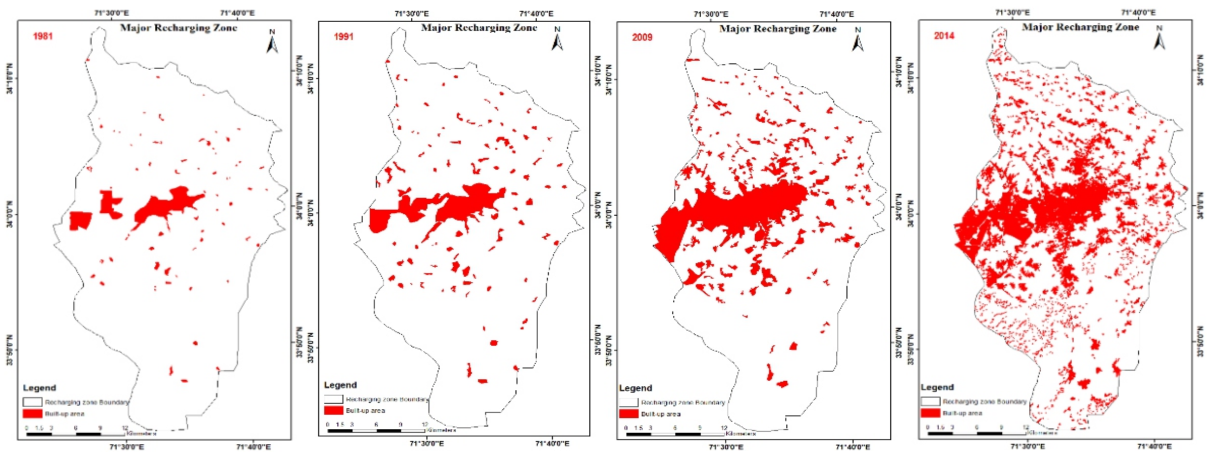

Fig. 16. Spatio-temporal growth of Built environment within Major Recharging Zone.

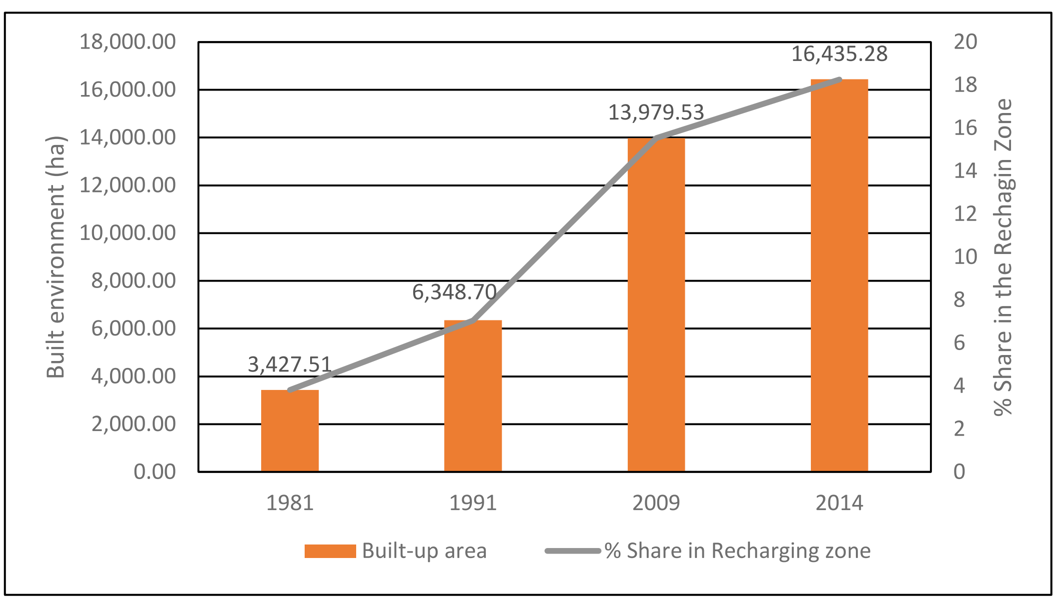

Fig. 17. Built environment and its % Share in the Major Groundwater Recharging Zone.

4.3.2. Minor recharging zones

In district Peshawar two smaller recharging zones of groundwater were find out one in southeast and other in northwest. These minor zones cover about 28 % by area of the study area and their contribution to the recharging process is also less. However, in connection with the recharging process, these are also important.

In the northwest of the study area a minor recharging zone exist and covers an area of about 144 square km which is 12 % of the total geographical area. Landforms of the zone are flood plains, loess and piedmont plains. The Built-up environment in this zone is not too much as compare to the major zone. Variation in elevation of this zone is also less. Due to its location near the streams and major rivers water table is not too deep and mostly water logged conditions are found in this minor zone. This minor recharging zone has experienced rapid expansion in terms of sealed surfaces. In 1981 built-up environment in the zone was less than 20 ha, which further increased to about 278 ha in 1991; 927 ha in 2009 and 2,354.90 ha in 2014 (Figure 18 & 19).

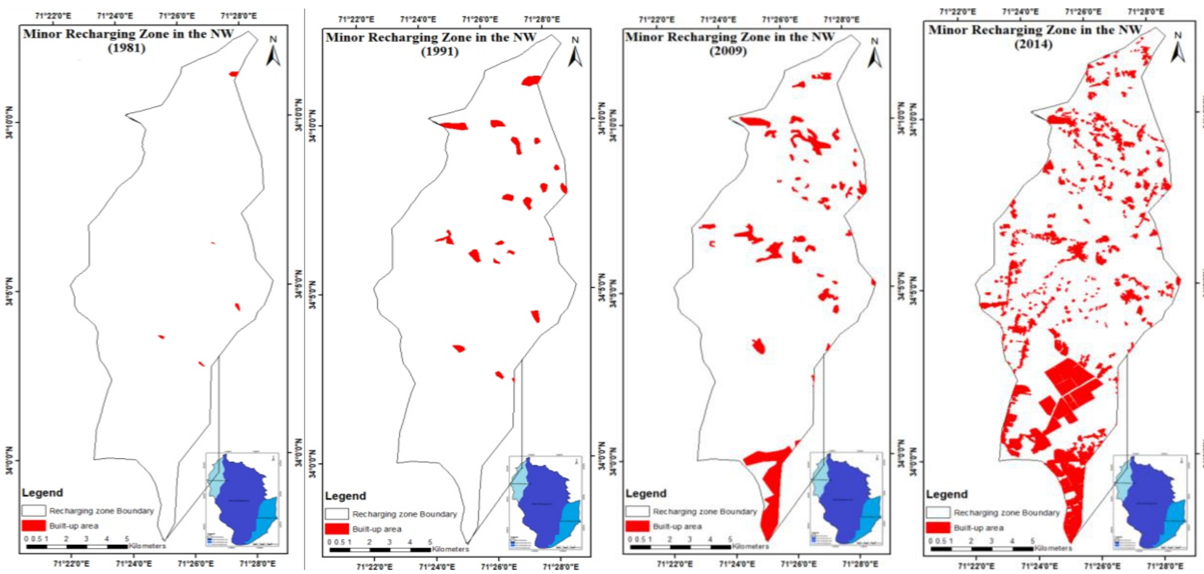

Fig. 18. Spatio-temporal growth of Built environment within Minor Recharging Zone of Northwest.

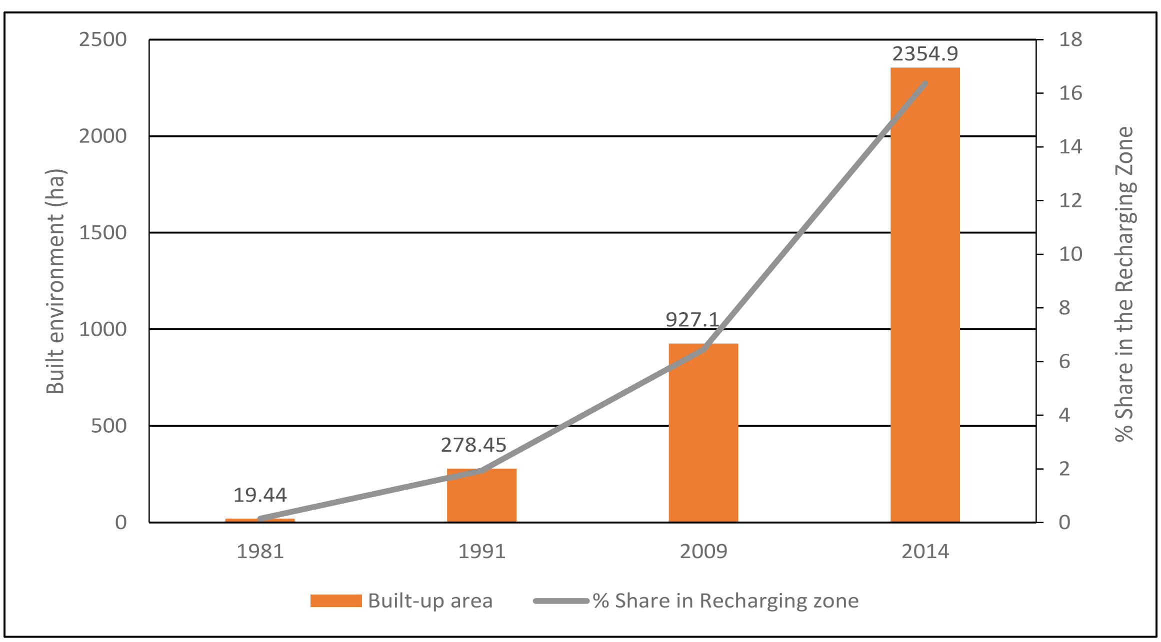

Fig. 19. Built environment and its % Share in the Minor Recharging Zone of Northwest.

Another minor groundwater recharging zone was identified in the southeast of district Peshawar and covers an area of about 214 square km which is about 17 % of the district. Piedmont and Loess plains prevail in most parts of this minor recharging zone. Its elevation ranges from 300 meters (1,000 feet) upto 671 meters (2,200 feet). Similarly, water table depth of this zone ranges from 30 meters (100 feet) upto 60 meters (200 feet), however aquifer's depth is maximum and ranges from 300 meters (1,000 feet) to about 518 meters (1,700 feet). This zone does not have any perennial river or stream. Built-up environment have not experienced too much expansion as compare to the other recharging zones. In 1981, impervious surfaces within this minor zone were 116.16 ha which increased to 302.48 ha in 1991, 316.02 ha in 2009 (negligible), while rapid growth of built-up area was recorded after 2009 with 1,010.52 ha in 2014 (Figure 20 & 21).

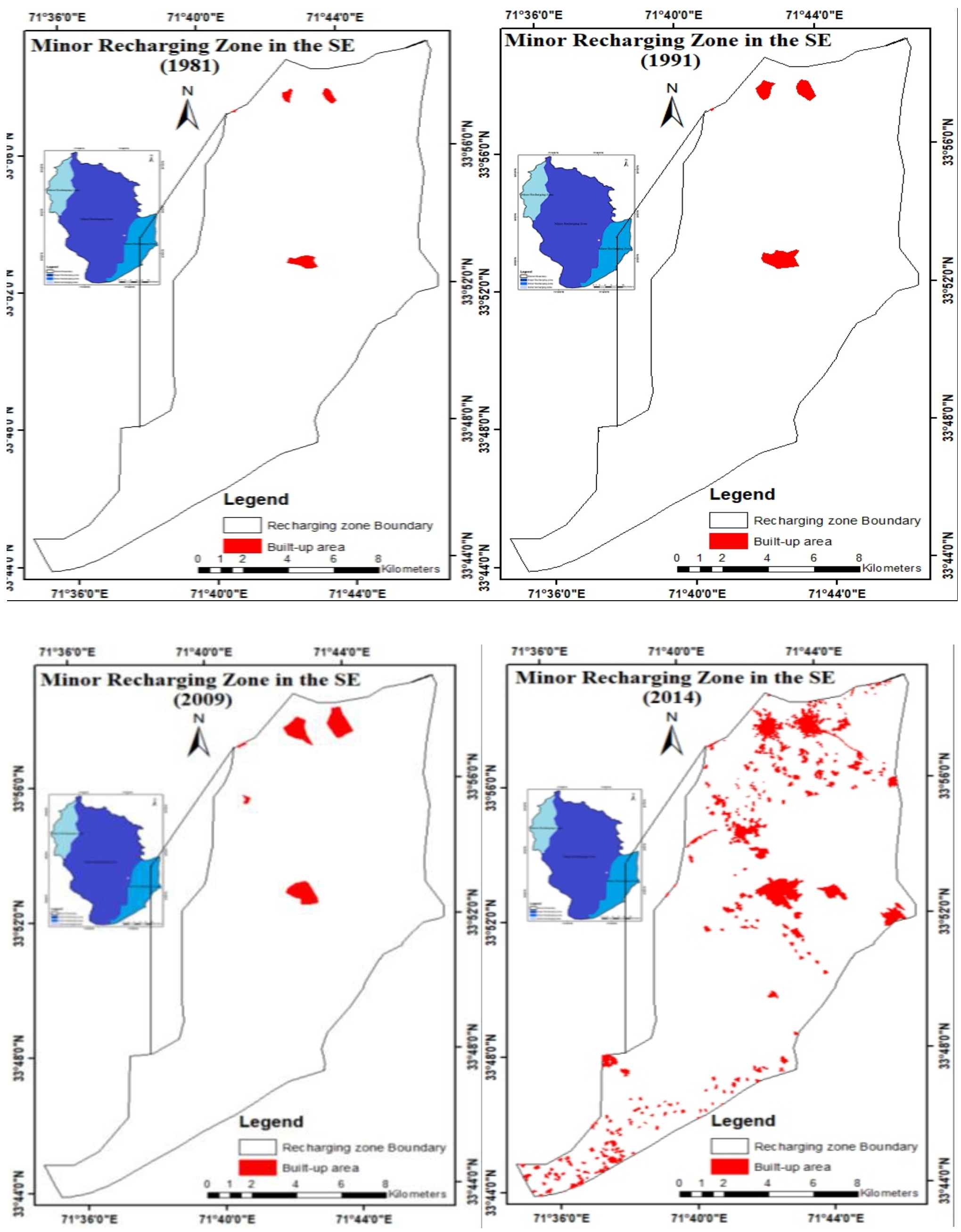

Fig. 20. Built environment and its % Share in the Minor Recharging Zone of Northwest.

4.4. Population growth and groundwater abstraction

The rapidly growing population of the study area has resulted to increase extraction of fresh water from ground and consistently threatened the potential of groundwater. From the household survey in the sample UCs, it was determined that average daily requirements of citizens was about 13 gallons per capita per day (50 liters per individual per day), however, daily peak demand was even greater than average daily demand. Similarly, the average daily requirements of the citizens have also augmented from 56 ml/day (1981) to 210 ml/d (2017) and may further increase to be about 310 ml/d by the end 2030 (Table 2; Figure 22).

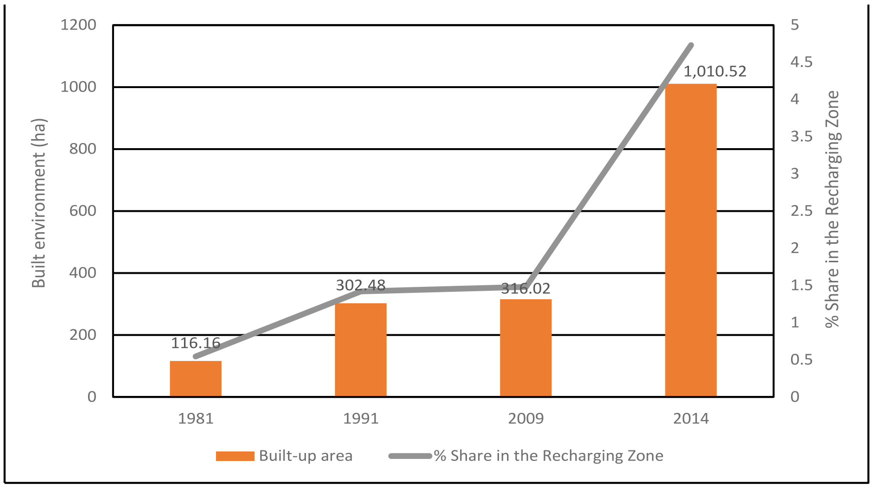

Fig. 21. Built environment and its % Share in the Minor Recharging Zone of the Southeast.

Table 2. Peshawar, average Daily and peak demand of fresh water of the citizens

*million liters per day, ** Average daily demand x 1.5 Source: Field Survey 2017

Year	Population (Million)	Average daily demand of fresh water (ml/d*)	Peak daily demand** (ml/d)
1981	1.113	56	84
1998	2.019	101	152
2014	3.6	180	270
2017	4.269	213	320
2030	6.20	310	465

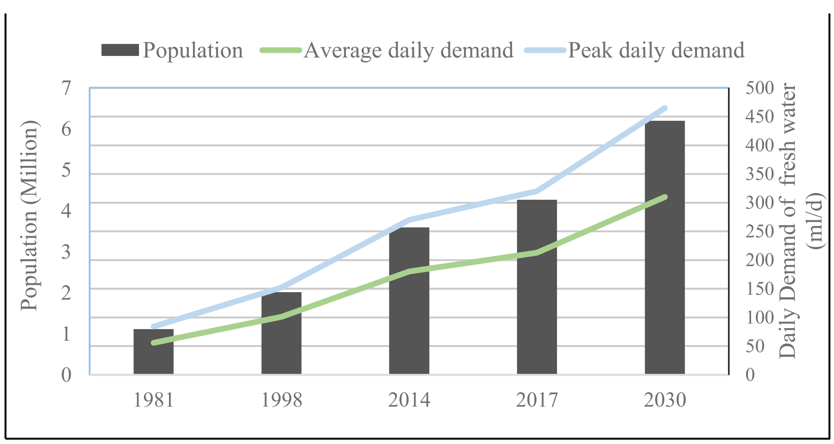

Fig. 22. District Peshawar, Daily demand of fresh water of the citizens.

4.5. Built environment and groundwater depletion

When artificial Impervious Surface Cover (ISC) replaces the natural ground cover, it undergoes modification, which disturbs surface runoff and the infiltration of water into the ground. This study reveals that the ISC in the study area has increased to 16.27 % in 2014 from 3.7 % in 1981, the overall change in the built environment was 12.57 %. When 10 - 20 % surface cover of an area is converted into impermeable surfaces, runoff is augmented by two folds, whereas both shallow and deep infiltrations are decrease by 4 %. Shallow infiltration is not too much contributor to the recharging process, however deep infiltration is important for the recharging process of aquifers. In areas of low water table, groundwater is often polluted from shallow infiltration which deteriorate the quality of groundwater.

In the study area discharge of groundwater is about 30 million liters per hour (8 million gallons per hour; 105 mm/year). As average annual precipitation of Peshawar is 435 mm/year and built-up area is 16.27 %, consequently infiltration will be 21 %. The average annual discharge of groundwater sources is 105 mm/annum, while recharge from precipitation was 91.35 mm/annum in 2014. Which indicates much higher discharge rate than recharge. Similarly, the infiltration rate has also decreased from 1981 (108.75 mm/year) to 2014 (91.35 mm/year). The decrease in infiltration (1981 – 2014) was 17.4 with an average rate of 0.51 mm/year. The estimated reduction of infiltration for 2030 will be 8 mm. The estimated population of the study area by 2030 will be more than 6 million, the rapidly increasing population will require more water, whereas the decrease in infiltration will further deteriorate the status of groundwater.

4.6. Depletion of water table

In the study area a field survey was conducted in the months of October and November (2017). During this survey 50 sites have been sampled to determine the water table and position of groundwater. It was found from the analysis that in 10 % of the tube wells water level has dropped down and about 20 % of the tube wells have dried up. In Peshawar some of the tube wells which were artesian type in past from which water was extracted without any power source. But due to dropping down of water table in these particular sites now power sources are needed for their operation. Similarly, the analysis of the data, it was also determined that deep digging has been practiced as compare to 30 years back. It was also observed that water table has dropped down by more than 15 meters (50 feet). In the study area dropping down of water table and depletion of groundwater sources is a serious threat to the potential of groundwater sources.

5. Conclusion

This paper has analyzed the spatio-temporal growth of district Peshawar by LULC change detection through LANDSAT (1981 and 1991) and SPOT images (2009 and 2014). The rapid physical, socio-economic and infrastructural improvements and developments of the district has consumed the prime agricultural land and the subsequent increase in the built environment has resulted to seal the soil and replaced the natural ground by ISC. The increasing trend of ISC has the capacity to reduce the infiltration of rain water into the ground. As a consequence the recharging rate from precipitation has been reduced. Similarly, rapid population growth has also been increasing the extraction of fresh water from ground sources. The discharge rate from groundwater sources is more than its recharge from precipitation, thus threatening the potential of fresh water sources, which has resulted depletion and lowering down of water table.

Population of the study area has increased to 4.269 million in 2017 from 1.113 million in 1981, whereas the projected number will be 6.2 million by the end of 2030. The growing population has also increased the requirements and demand of fresh water supply from 56 ml/day in 1981 to 213 ml/day in 2017, however the peak daily demand is even higher than the average daily demand. The projected demand of fresh water of the citizens in 2030 will rise to 310 ml/d. The existing water supply system of Peshawar is entirely fulfilled from ground sources with more than 1,400 public tube wells. To fulfill the requirements of the citizens, the abstraction from ground sources has been continuously increasing and threatening their potential.

Built-up areas in the study area has also recorded rapid growth and expansion and increased to 20,451.39 ha (16.27 %) in 2014 from 4,635 ha (3.7 %) in 1981, marking an overall growth of 1,5816.39 ha (340 %). With the same trend the projected increase in ISC for the year 2030 might be 22 %. The conversion of natural ground cover into impermeable surfaces has reduced the infiltration rate by 4 % and increased the surface runoff by more than two folds. The recharging rate from precipitation has reduced to 91.35 mm/year in 2014 from 108.75 mm/year in 1981. Total discharge from the groundwater sources is 105 mm/year, indicating a high discharge from ground sources and low recharging rate from rain water. Fluctuations in water table and depletion in groundwater sources have already been observed in the form of drying up of tube wells. Deep digging has been practiced for the extraction of fresh water from ground sources. Government is also working on certain projects for the alternate supply of fresh water from the major rivers in order to reduce pressure on scarce groundwater sources, however, these plans are still needed to be implemented. To properly manage water resources of the study area the unprecedented process of soil sealing has to be checked in order to control over the depletion of groundwater and to ensure the sustainable availability of fresh water supply in future.

Acknowledgement

This manuscript is part of the Ph. D Dissertation of the Principal author.

Authors Contribution

Attaullah Khan conceived the idea. Atta-ur-Rahman carried out the analysis. Samiullah equally contributed in the preparation of the manuscript. Muhammad Ali did the data gathering and writing of the manuscript.

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