Impact of Land Use Dynamics on Groundwater Table in Abbottabad city, Khyber Pakhtunkhwa (2008-2018)

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Abstract

Abbottabad is one of the rapidly expanding cities in Pakistan. Urban growth and the built environment have expanded during the past ten years, leading to an increase in impervious surface area and surface sealing, which has had a negative impact groundwater table (GWT). The purpose of the study is to assess the influence of expanding built-up environment on GWT in Abbottabad city. Satellite images of SPOT 5 for the year 2008, with a 5-m resolution were acquired from the Space & Upper Atmosphere Research Commission, Peshawar, while 2018 images were downloaded using the SAS planet platform. ArcGIS's maximum likelihood classifier method was used to classify these images into several LULCC. After calculating the area under various LULCC for both 2008 and 2018, the growth in the built-up was estimated. The GWT data for 67 tube wells, hand pumps, and dug wells for the years 2008 and 2018 was acquired from Public Health Engineering Department. The image analysis reveals that the built-up area of Abbottabad city expanded from 1575.1ha in 2008 to 1897.5ha in 2018. The study suggests that in various parts of the city the GWT is depleting at the rate of 0.17 to 4.00 feet per year. For a selected area of 219.26 acres, the computed runoff in 2008 was 0.583 cubic feet per second (cfs), while in 2019 it was 0.689 cfs. An expansion in the built-up area in 2019 is blamed for the rise in runoff because this trend speeds up runoff and reduces soil's ability to absorb water.

Keywords: Urban Expansion, Surface sealing, Rational Model, Surface runoff, Groundwater Table

Introduction

Urbanization is regarded as the most significant and irrevocable influence of scientific and technological advancement and is a predicted trend in the development of human life. The need for infrastructure, accessibility, and development leads to changes in demography around the globe. From the steam period to the current information and technological age, human lifestyles have transformed. Industrial economics eventually replaces small-scale rural economy, stimulating

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economic expansion (Liang et al., 2019). Urban economic development in emerging economies is more pronounced than rural economic development. Consequently, there was significant urbanization as a result of the rural people moving to urban areas. Urbanization refers to the movement of people from rural to urban areas as well as the switch from agriculture to non-agro base industries as the dominant economic activity (Liang et al., 2019; Lucas, 2004). Numerous issues, including food security, LULCCs, urban flooding, and environmental degradation, were brought on by rapid urbanization in recent decades (Li et al., 2017; Wille et al., 2017). The dynamics of LULCC from open spaces and farmland to built-up area is one of the most permanent shifts brought on by urbanization. The main causes of the rapid urban expansion are migration from rural areas and the transformation of rural administrative units into urban entities. All these driving forces can be traced through economic development (Liang et al., 2019).

Although the trend of urbanization is anticipated to continue throughout the world, developing nations are primarily responsible for the increase in the urban population. In 2008, cities and metropolitan areas were home to 50% of the world's population (Zho et al., 2019). According to estimates, there will be about 6400 million urban residents worldwide by 2020. (Borelli et al., 2018; Sun et al., 2011). This will increase the demand for housing and may result in the loss of prime agricultural land as well as changes to the hydrological cycle (Putra and Baier, 2012). With the current trend of urban population expansion, the consequences of urbanization on groundwater resources are a pressing concern (Mohr et al., 2012; Utto et al., 2000).

Accelerated infrastructure growth and urbanization led to more surface sealing, which in turn will increase runoff and reduce GW recharge (McDonald et al., 2011; Wakode et al., 2016). The built environment and surface sealing accounted for 0.6 million Km2 of the worldwide surface area in 2000, and by 2050, that number is anticipated to rise to 2 million Km2 (Angel et al., 2011). With only 100 liters of available GW per capita per day, 150 million urban residents live in cities that are experiencing a water shortage. It is anticipated that by 2050, the urban population is expected to increase by 1 billion, which means the freshwater supply for an additional 1 billion urban inhabitants (Putra et al., 2010; Gleeson et al., 2010; Niemela et al., 2010). Surface sealing of a sizable portion of the earth's surface and increasing groundwater usage are typical effects of urbanization, which have an impact on infiltration and GW recharge capacity (Chen et al., 2010; Sun et al., 2010; Carlson et al., 2011; Srinivasan et al., 2013). Urban water supply is a global concern, and the present climate change scenario is expected to further deplete the already scarce groundwater resources. Due to the green revolution, industrialization, and rapid population growth, groundwater extraction and consumption have increased by up to 2%/year in several nations since the middle of the 20th century (Kraft et al., 2012; Van Weert and Van der Gun, 2012; Chaudhuri and Ale, 2014; Costa wt al., 2016). Studies have shown that the urban population grew by more than 10 times throughout the 20th century, and that this substantial population increase negatively impacted GW quality and quantity due to changing LULC patterns and recharge rates (Yeh et al., 2009; Sheikhy et al., 2013; Kanagaksmi and Nagan, 2013).

The study area is located in the Abbottabad district, which is well-known among tourists for its nice weather, tranquility, and security. In addition, it is also known for its top-notch educational institutions. In the past fifteen years, Abbottabad has seen at least three large-scale migrations from different parts of the country. The first wave of immigrants came from the Balakot and Mansehra regions of Azad Kashmir as a result of the terrible earthquake that struck the region in 2005. The second and third waves of migration were triggered by the military operations Rahi-e-Nijat, Rah-e-Rast, and Rahi-e-Haq, which were carried out in Swat and South Waziristan district, respectively, in 2009–2010. In the beginning, TDP were housed in camps, but soon the wealthy among the displaced handled their own life in the city; either in rented apartments or, in some cases, built their own dwellings. As a result, there was a rise in the demand for housing, which led to an expansion of the built-up area. Additionally, the research indicates that since 1960, the average annual rainfall has decreased by more than 40% (IUCN. 2004).

The studies suggest that if the present trend of climate change continues, which is predicted to continue, it would lead to a water shortage and probably put a lot of pressure on groundwater resources. Therefore, the purpose of this research is to evaluate how urbanization and population growth affect GWT in the Abbottabad city.

Material and Methods

Study Area

Abbottabad city is the 6th largest city in the Khyber Pakhtunkhwa province, and the 40th largest city in Pakistan. The city is situated km to the east of Peshawar and 120 km north of Islamabad, the country's capital. After Major James Abbott, the city is established and given his name in January 1953. Geographically the city is situated between 34°-06′-30″ to 34°-13′-45″ north latitude and 73°-11′-30″ to 73°-16′-45″ east longitude, encircled by the Sarban hills. The study area is part of the intense monsoon region located at a height of 1256 meters above sea level in the foothills of the Himalayan range. A cool, temperate climate prevails in Abbottabad. The average yearly minimum and maximum temperatures measured are 11.41 °C and 22.76 °C, respectively, while the mean annual rainfall is 1366.18mm. Wintertime temperatures drop below 0 °C, and the surrounding mountains are frequently blanketed in snow (GoP. 2000).

With an average annual growth rate of 3.75%, the district's population increased from 319,00 in 1950 to 880,666 in 1998, outpacing the 2.6% average annual growth rate of Pakistan (GoP. 2000). The district's population climbed to 1,332,912 people, as per the 2017 census. Between 1998 and 2017, there was a growth rate of 2.20%. According to demographic and household data from the Pakistan Bureau of Statistics (GoP. 2018), the Abbottabad district has 293137 urban residents, (22% of the total population), and 1039775 rural residents, representing 78% of the total population (GoP, 2018). The serious issue in Abbottabad City is the population density in comparison to the population increase. In 1951, there were 162 people/km^2; which increase to 447 in 1998, and by 2017, the density of the population increased to 660 people / km^2 (GoP, 2018).

The district's overall geographic area is 179653.5ha out of which 20.3% of the land is covered by forests, 48.2% is farmland, and 31.5% is rangeland and built-up area (Kreditanstalt, 2000). out of total agricultural land, 10.7% is uncultivated, while the remaining 89.3% is cultivated. Despite the district's high rainfall, just 0.39% of its entire land is irrigated. Although the district has high cropping intensity (88.82%), the lack of irrigation water limits double-cropping (Kreditanstalt, 2000). The district's two principal rivers are the Kunhar and Jhelum rivers (IUCN. 2004). The location map of Abbottabad is depicted in Figure 1.

Data Collection and Analysis

The SPOT-5 image of 2008 with a 5-m resolution was acquired from the Space and Upper Atmosphere Commission, Peshawar, while the 2018 image with a 5-m resolution is acquired from the SAS Planet network. These images were categorized into several LULCC with the help of the Maximum Likelihood classifier method using the ArcMap 10.5. The classification accuracy was then calculated for both 2008 and 2018, and then the area was calculated for each LULC class. LULCCs were then computed from 2008 to 2018.

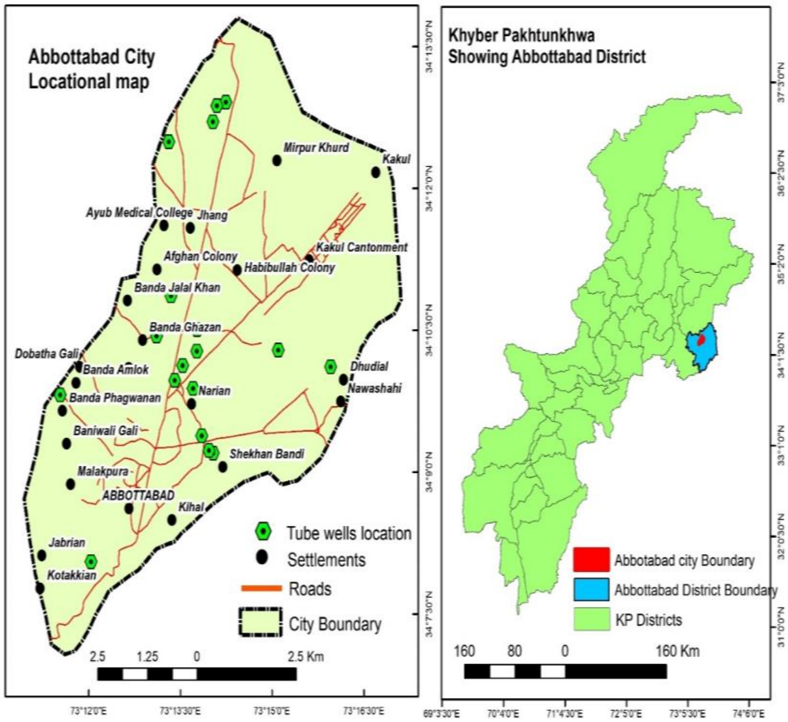

Fig 1: Displaying the location of the city of Abbottabad (Study Area)

The first step of the adopted procedure is to train the software system to recognize patterns in the data. In ArcMap 10.5 a feature class known as a training sample was specifically created for this purpose. Polygons corresponding to homogenous pixels for each type of LULC were digitized and labeled in feature class. At least 50 training samples for each LULC class were chosen. The training sample from the feature class is then used as the input to create signatures class. Numerous factors can have an impact on the training signatures of the LULC classes. Variations in soil type, soil moisture, and vegetation health are a few examples of environmental factors that can impact the signature and the accuracy of the final classification.

Data on the GWT of 2008 and 2018 were acquired from the Public Health Engineering Department (PHED) Abbottabad. The information was utilized to ascertain how urbanization affected groundwater levels. Data has been retrieved and saved in ArcMap 10.5. The continuous surface was produced using an interpolation algorithm. The change in the GWT for the given time period was calculated by subtracting the interpolated surface of 2008 from 2018.

The Rational method for the estimation of surface runoff was used to reinforce the effect of urbanization on the groundwater table and verify the results of the study. From the 2008 and 2018 classified images, a sample area (219 acres) was selected for this reason. Data on rainfall was collected from the Regional Meteorology Office, Peshawar. For 2008 and 2018, surface runoff was determined by rational equation 1:

$$Q=Ci\,A \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The Q indicates the discharge and is usually stated in cubic meter/second (m^3/s) or cubic foot/second (f^3/s). C= runoff-coefficient of the rational method (acquired from available literature, i.e. Chin et al., 2010, The percentage range within each class was calculated based on land use/land cover analysis). i = rate of rainfall, inch/hour, and A = area of drainage in acres.

The variance in discharges functioned as a proxy for the influence of LUCs on runoff and, as a result, the ability of groundwater aquifers to recharge. A specific runoff was measured with the help of equation 2.

$$\begin{aligned} Q= (&\text{Drainage area}*\%\ \text{BP area}*\text{BP coefficient}+ \\ &\text{Drainage area}*\%\ \text{BL area}*\text{BL coefficient}+ \\ &\text{Drainage area}*\%\ \text{Ag area}*\text{Ag coefficient})\ *i \end{aligned} \quad \ldots\ldots (2)$$

Where BP is a built-up area, BL is a barren land and Ag is an agricultural area. The adopted technique is shown in Figure 2.

Results and Discussion

Land Use Land Cover 2008-2018

Table 1 displays the outcome of image classification and area covered by several LULCC. The analysis suggests that the LULC in Abbottabad city has altered over the past ten years. The built-up area in Abbottabad city however records a substantial growth from 1575.10ha (26.40% of the total urban area) in 2008 to 1897.50ha (31.81% of the total urban area) in 2018, at a rate of 31.15ha per year. The net growth reported in the last 10 years is 322.39ha. Figure 3 shows the built-up area of 2008 and 2018 in the study area. Due to the fast rate of urbanization in Abbottabad city, the farmland, vegetative surfaces, and open spaces have been converted into housing colonies, hotels, and shopping malls. Urbanization has consistently expanded the impervious surfaces, lowering GW aquifer replenishment potential. The population, on the other hand, is growing, placing extreme pressure on groundwater supplies, so the groundwater table is descending.

Table 1
Area under various LULCC Abbottabad City, 2008-2018

S.No.	**LULCC 2008**		**LULCC 2018**		**Change in Area (ha)**
	Area in ha	% age of Total	Area in ha	% age of Total	
Built-up Area	1575.10	26.40	1897.50	31.81	322.40
Agriculture Area	1547.50	25.94	1377.80	23.10	-169.70
Vegetation	1278.70	21.44	1266.00	21.22	-12.70
Barren Land	1564.10	26.22	1423.80	23.87	-140.30
Total	5965.30	100.00	5965.10	100.00	

Source: Data Analysis in ArcMap10.5

Groundwater Table 2008

To determine the effect of the built-up area on the GWT the acquired data is displayed in ArcMap 10.5. The data were interpolated and the continuous raster surface was created from the wells' GPS points. Furthermore, the interpolated surface was classified into different groundwater table zones (GWTZs). Table 2 shows the area and percentage under various GWTZs (2008). The analysis of table 2 and figure 4A reveals that a 12.20-21.33m deep GWTZs covers an area of 2413.52ha (40.17 percent of the total area). The area having the deepest GWT (>30.48m) accounts for 13.18% of the total area.

Table 2
Area and Percentage under different GWT Zones 2008

S. No.	**GWT in meter**	**Area in Hectare**	**%age of Total area**
1	6.40-12.19	1396.71	23.24
2	12.20-21.33	2413.53	40.17
3	21.34-30.48	1406.7	23.41
4	>30.48	791.73	13.18
Total		6008.67	100

Source: PHED Abbottabad, data analysis in ArcMap 10.5

Groundwater Table 2018

Table 3 displays the area and proportion of the study area covered by various GWTZs for the year 2018. The results suggest that the GWT in the majority of the study area is between 12.20 and 21.33 meters deep and occupies 2146.40ha or 35.72% of the study area. Similarly, the GWT >30.48m covers an area of 1691.37ha

(28.15% of the study area). Figure 4B depicts the area under various GWTZs in 2018.

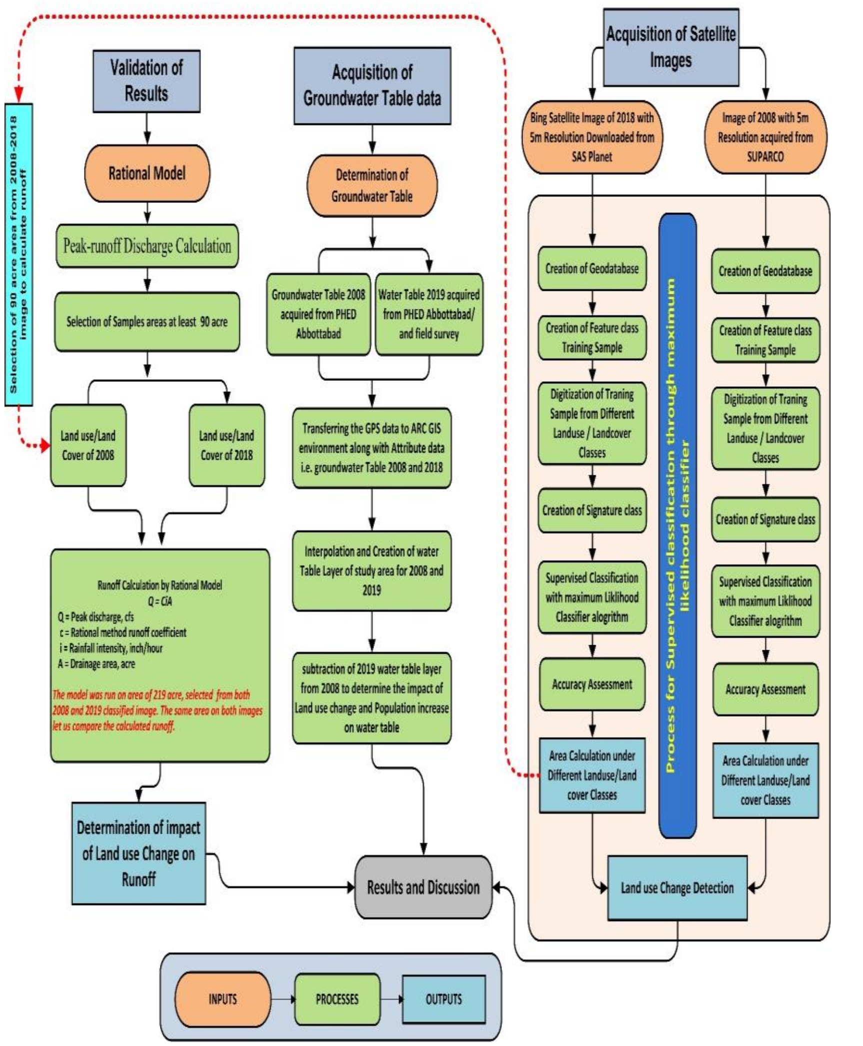

Fig. 2. Showing the methodology adopted to achieve the research objectives

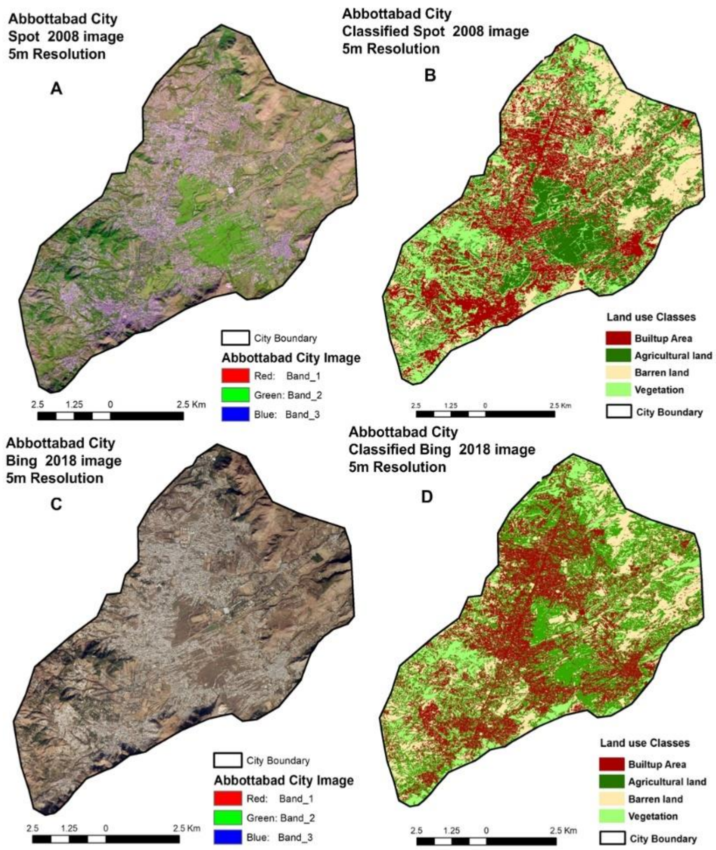

Fig 3: Abbottabad city *A*. Satellite Image 2008, *B*. Classified 2008 Image showing LULC, *C.* Satellite Image 2018, *D.* Classified 2019 Image showing LULC

Table 3

Abbottabad city Area and %age under various GWTZs 2018

S. No.	GWT in meter	Area in ha	%age of Total area
1	6.40-12.19	528.39	8.79
2	12.20-21.33	2146.41	35.72
3	21.34-30.48	1642.50	27.34
4	>30.48	1691.37	28.15

Source: PHED Abbottabad, data analysis in ArcMap 10.5

Change in Water Table 2008-2018

Table 4 shows the change in area and percentage of various GWTZs from 2008 to 2018, while figure 3 displays the same data graphically. The analysis reveals that in an area of 791.72ha the GWT was >30.48m in 2008, and the area of the same GWT rose to 1691.36ha in 2018 (13.18 percent of the total city area to 28.15 percent of the total city area respectively). This indicates that the GWT has fallen more than 30.48m over the last 10 years in an area of 899.85ha. Figure 4 shows the area under different GWTZs 2008-2018. Figure 5A is illustrating the GWT of 2008, 5B. GWT 2018 and 5C GWT, 2008-2018. The study results suggest that in the Abbottabad city, the rate of GWT decline varies from 0.03m per year to more than 1.2m per year.

The analysis shows that the decrease in GWT in the northwestern part of the city is more rapid. The maximum decrease was reported in tube well No.1 (Saeen Baba Chowk Jhangi Syadan). In this tube well the GWT descends from 8.0m in 2008 to 34.39m in 2018. From 2008 to 2018 the rate of GWT decline computed is 0.94m per year. The study reveals that in congested built-up areas, the decrease in the GWT is more rapid compared to the non-built-up area. This shows how the GWT has been impacted by the expansion of the impervious surfaces. In the congested built-up area, the rate of GWT decline per year is more pronounced.

Table 4
Abbottabad City: Area and %age under various GWTZs 2008 and 2018

Depth of GWT	**GWT 2008**		**GWT 2018**		**Change in GWT 2008-18**	
	Area in ha	%age of the total area	Area in ha	%age of the total area	Area in ha	%age change
6.40-12.19	1396.74	23.24	528.40	8.79	-868.34	-14.45
12.20-21.33	2413.58	40.17	2146.45	35.72	-267.12	-4.45
21.34-30.48	1406.73	23.41	1642.53	27.34	235.80	3.93
>30.48	791.74	13.18	1691.40	28.15	899.66	14.97

Source: Data analysis in ArcMap 10.5

Validation of Results

Runoff is the outcome of the interaction between LULC and climate change within the basin (Huntington, (2006; Wang et al., 2014). Several factors are responsible for runoff generation including LULC, stream network, physiography, and topography of the basin (Xu and Zhao, 2006). However, LULC changes can directly affect the generation of runoff and flow processes (Li et al., 2009; Birkinshaw et al., 2017).

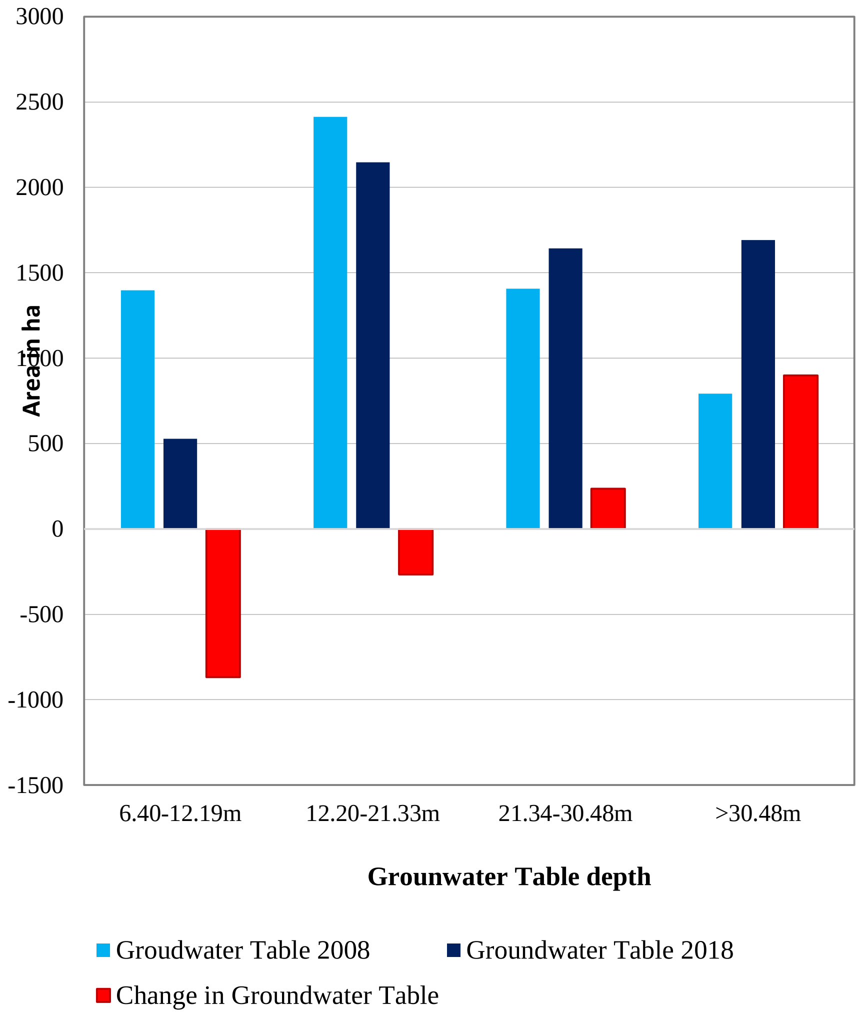

Fig 4: Showing the Area under different GWTZs 2008-2018 and change in GWT 2008-2019

Nevertheless, LULC changes indicate the impact of anthropogenic activities on groundwater resources. To calculate the surface runoff, the present study used the Rational model. The Rational model is widely used to estimate surface runoff for small urban catchment areas (Needhidasan and Nallanathel, 2013; Mehr and Akdegirmen 2021). The study area is larger than the capability on which the rational model can perform to assess the surface runoff therefore; the model is applied to a smaller area of 219.26 acres extracted from the classified images of 2008 and 2018. The rational model assumes that (Needhidasan and Nallanathel, 2013; Erena and Worku, 2019):

- The whole catchment area contributes to the runoff generation.
- The precipitation is distributed consistently throughout the catchment area.
- The runoff coefficient (C) incorporates all the losses from the catchments.

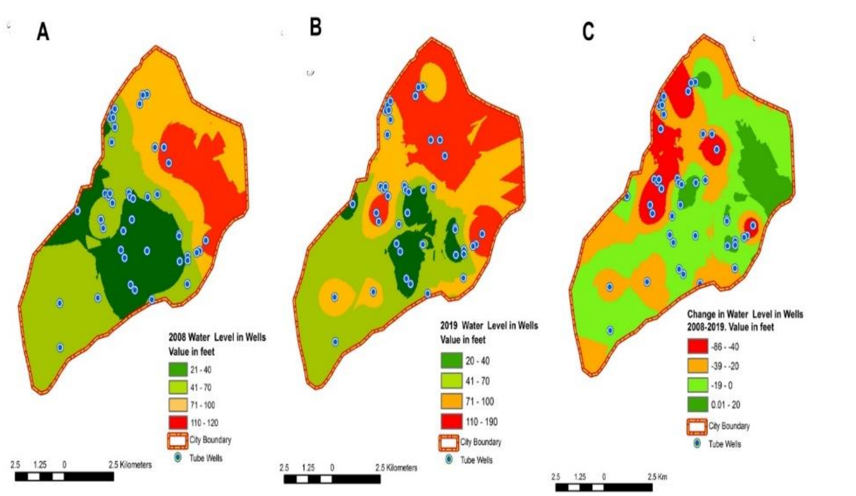

Fig 5: *A.* Showing Groundwater Table 2008, *B.* Groundwater table 2019 and *D.* Change in Groundwater 2008-2019.

For the present study the runoff was estimated through the following equation for both 2008 and 2018 (Needhidasan and Nallanathel, 2013):

$$Q = CiA \dots\dots\dots\dots\dots\dots\dots\dots..(3)$$

An area of 219.26 acres was extracted from booth 2008 and 2018 classified images followed by a calculation of the area under various LULC classes within the extracted area of 219.26 acres (88.73 ha). Using the above equation, the total runoff was computed. Due to the unavailability of the rainfall intensity per hour data the maximum average daily rainfall was divided by 24 to get the required data for runoff calculation. The runoff coefficient for various land use land cover classes was acquired from Chin (2000). Tables 5 and 6 summarize the results of the analysis, showing the comparative statistics of runoff estimation by the Rational model for the years 2008 and 2018. Figure 6A shows the change in groundwater table 2008-18 vs built-up area 2008-18. Figure 6B depicts the satellite image of Abbottabad city 2018 vs the change in GWT 2008-18. The analysis of Figures 6 A and B reveals that in the built-up area the groundwater table depletion is more prominent compared to vegetative areas.

Table 5

Parameters for Runoff Calculation for an area of 219.26 acres from the 2008 classified image of Abbottabad city

LULC Categories	Area in acre (A)	Rational Runoff Coefficient (B)	Average runoff Coefficient (C)	Area x Coefficient (D) (AXC)	Rainfall calculated from average daily rainfall (GOP, 2017) (E)	Runoff cf/second (D X E)
Agriculture	94.39	0.08-0.041	0.285	26.90		
Vegetation	24.64	0.05-0.025	0.175	4.311		
Built-up	55.00	0.3-0.75	0.675	37.12	0.0067	0.58251
Barren Land	45.23	0.1-0.62	0.41	18.60		
	219.26			86.94		

Source: Data analysis in ArcMap 10.5

Table 6

Parameters for Runoff Calculation for an area of 219.26 acres from the 2018 classified image of Abbottabad city

LULC Categories	Area in acre (A)	Rational Runoff Coefficient (B)	Average runoff Coefficient (C)	Area x Coefficient (D) (AXC)	Rainfall calculated from average daily rainfall (GOP, 2017) (E)	Runoff cf/second (D X E)
Agriculture	70.65	0.08-0.041	0.285	20.13		
Vegetation	6.92	0.05-0.025	0.175	1.21		
Built-up	88.71	0.3-0.75	0.675	59.87	0.0067	0.6897
Barren Land	52.98	0.1-0.62	0.41	21.72		
	219.26			102.94		

Source: Data analysis in ArcMap 10.5

The difference in runoff calculated for 2008 and 2018 is 0.108 cubic feet /second. This means that during the course of ten years, the runoff created from the same 219.26-acre area rose owing to an increase in the built-up area, from 55.00 acres in 2008 to 88.71 acres in 2018. The built-up area's runoff coefficient is 0.3 to 0.75, which is greater than for other LULC classes, resulting in higher runoff and less infiltration, which can decrease aquifer recharge capacity.

Figure 7 is showing the comparison of estimated runoff for the 219.26-acre area of Abbottabad city vs built-up for both 2008 and 2018. The analysis reveals that the runoff of 2018 increased due to the increase of impervious surface as a result of the built-up area which results in accelerated runoff and decreases percolation. This is also a major cause of urban flooding in Abbottabad city which is more frequent in the last couple of years. This is also revealed by the fact that Abbottabad city is often inundated after heavy rainstorms specifically in summer.

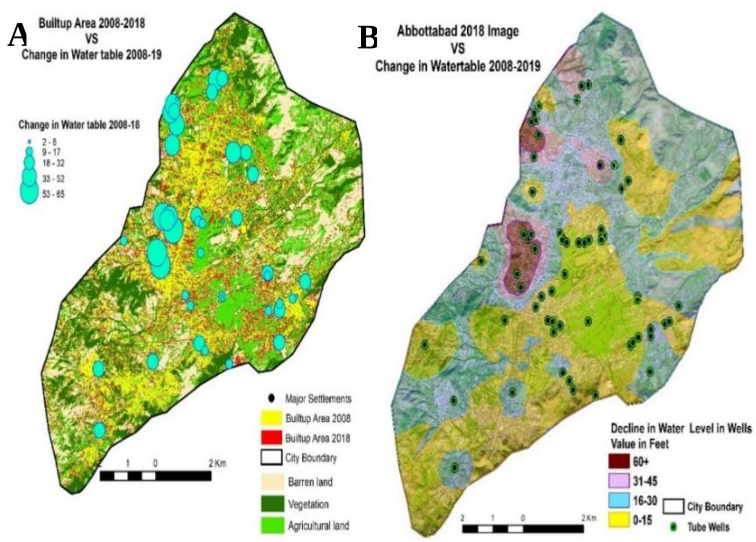

Fig 6: A Showing change in Groundwater table 2008-18 vs Built-up area 2008-18, B Satellite image of Abbottabad city vs change in Groundwater table 2008-2018

Conclusion

Urbanization refers to the physical growth of the city, which takes place as people migrate from the surrounding rural areas to cities. It triggers LULCC which affects hydrology in many ways. For instance, degrading water quality, causing urban flash floods, and change in the recharge potential of the aquifers. Urbanization is consuming quality agricultural land, eating away open spaces, barren land, and vegetation cover. Urbanization results in infrastructure development i.e. construction of roads, airports, public buildings, etc. progressively, the surface is covered with asphalt, referred to as surface sealing which causes greater runoff and decreases the infiltration capacity of the soil. Thus urbanization, on one hand, decreases the recharge capacity of groundwater aquifers while on the other hand, the population increase overexploits the already scarce water resources causing the groundwater table to decline.

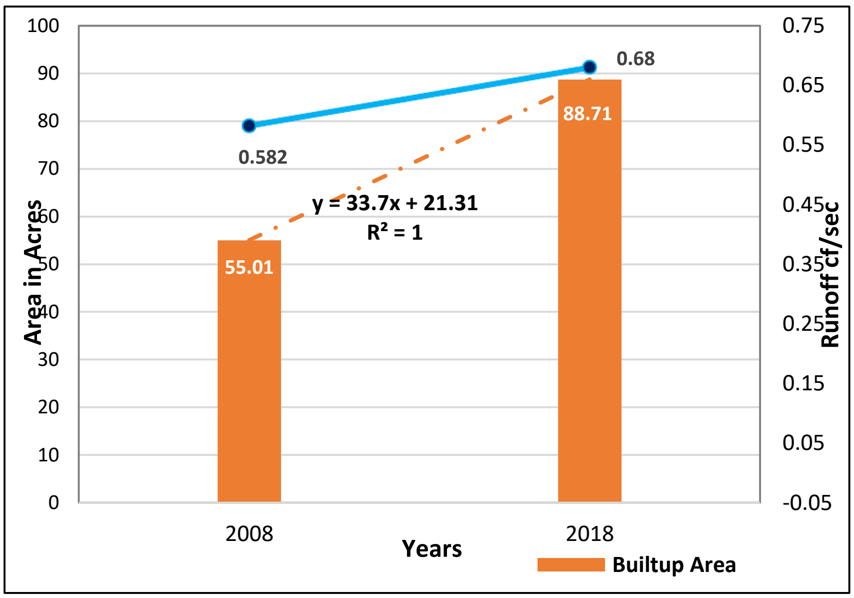

Fig 7: Showing the built-up area and runoff estimated through rational model for 2008 and 2018 for 219.26 acre area of Abbottabad city.

From 2008 to 2018, the built-up area of Abbottabad City grew by 322.39ha at a rate of 31.15ha per year. The rate of GWT decline ranges from 0.05m per year to more than 1.21m per year. In the heavily populated northwest corner of the city, the decline is particularly pronounced. The average annual decline in the water table in Abbottabad City is 0.70m. Studies suggest that the temperature of urban areas is likely to increase while the precipitation will decrease resulting in water scarcity and can put intense pressure on already challenged groundwater resources. According to IUCN in 2004, a total of 75 tube wells ceased to function in Abbottabad due to groundwater depletion. In 2012 the water demand in Abbottabad city was 26826 cubic meters/day for 200249 inhabitants of the city, as per population growth of 3.3% the population of the city almost double in 2020 with an increased water demand of 53,652 cubic meters/day (Faiza, 2012).

The field survey and discussion with the official of PHED Abbottabad reveal that a total of 06 tube wells ceased their function due to the lowering of groundwater depth. The lowering of the groundwater table is directly associated with LULCCs and the rapid growth of the urban population. To ensure long-term environmental protection and sustainable development, the study recommends ongoing monitoring of LULCC dynamics and assessment of the quantity and quality of GW resources.

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