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TEMPORAL ANALYSIS OF URBANIZATION AND RESULTING LOCAL WEATHER CHANGE: A CASE STUDY OF BAHAWALPUR, PUNJAB, PAKISTAN

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ABSTRACT

This study examines climatic and environmental changes in Bahawalpur, Punjab, Pakistan, from 1992 to 2022. According to key findings, the Mean Annual Temperature has climbed dramatically over the analyzed period, by over 6°C. Both daytime and nightly temperatures have been gradually rising in preparation for hotter days and warmer nights. Rainfall patterns during the last 30 years have displayed cyclical fluctuations rather than a linear trend, causing challenges with water resource management. Different changes in land use patterns have been observed as Bahawalpur's vegetation increased by 5.54%, urban areas increased by 0.45%, and barren land decreased by 5.99%. This trend indicates an increase in urbanization and green space. The data shows that strategic measures and legislative changes are required to address the environmental difficulties that Bahawalpur is facing.

Keywords: Urbanization, mean Maximum temperature, mean Minimum temperature, land use, precipitation

INTRODUCTION

As cities have grown around the world, their environmental impact has become a subject of interest. Urbanization, also known as urban expansion, is the process of transforming natural lands into man-made structures such as buildings, roads, and other infrastructure (Zipperer, 2020). Cities like Bahawalpur have seen great growth and development over the past few decades, but they have also seen the environmental consequences of that growth. The urban width of Bahawalpur, a historically prominent metropolis in Punjab, Pakistan, has grown dramatically. According to the Pakistan Bureau of Statistics (2017), the population of Bahawalpur increased from over 500,000 in 1998 to over 800,000 by 2017, representing a growth rate of more than 60%. Because of the population growth, urban land use has increased, and natural land cover has been removed at a significant rate. Such changes have an effect, particularly on local weather patterns (Pakistan, 2017).

When natural terrains are turned into concrete structures, the heat retention capacity of the area often improves. The "Urban Heat Island" effect (UHI) can cause urban areas to be much warmer than neighboring rural areas. Elevated temperatures may appear insignificant, but they can have substantial health consequences, especially during the hot summer months (Heaviside, 2017). In addition to the global issue, there are local manifestations of this temperature rise. According to Mohan (2020), cities with significant urban growth have experienced an increase in average temperature of between 0.5°C and 1°C over the preceding two decades. Such little changes have the potential to exacerbate health risks and even have an impact on local precipitation patterns, perhaps resulting in

flooding or drought situations (Mohan, 2020). Different LULC types, such as forests, wetlands, croplands, vegetation, and urban areas, can be mapped and classified using remote sensing (RS) data (Romaguera et al., 2018). This data can be used to monitor variations in LULC patterns and pinpoint regions where human activity is significantly altering the environment (Olmanson et al., 2016).

Numerous researchers have investigated the relationship between urbanization and temperature rises. Lehnert's (2021) seminal study provides a methodology for assessing the severity of the UHI effect in diverse metropolitan environments (Lehnert, 2021). Kafy (2020) later examined the effects of urban land use on temperature in Bangladesh's major cities and discovered a clear relationship between changing urban land use and rising local temperatures (Kafy, 2020). Dilawar et al. (2021) investigated the UHI effects in Lahore, another important urban area in Punjab that is closer to our target location. Their findings, which revealed increased temperatures in metropolitan areas, were consistent with the overall trend. Their findings also revealed that careful city construction, such as increasing green space, could provide solutions to the rising temperature issues (Dilawar, 2021).

Understanding the impact of urbanization, however, extends beyond temperature. Even though temperature variations are well-documented, the influence of urban structures on other meteorological parameters, such as rainfall, has not yet been properly investigated. To fill some of these knowledge gaps, we will be concentrating on Bahawalpur in our inquiry. By integrating historical data and modern observations, we want to provide a more complete understanding of the impact of urban growth on Bahawalpur's regional weather patterns.

MATERIALS AND METHODS

Study Area

Bahawalpur is located in the southern part of the Pakistani province of Punjab. Bahawalpur, a notable historical city, is located at 29.3956° N and 71.6833° E in latitude and longitude, respectively. It is renowned for having a lengthy cultural past. The city has mild winters and warm desert summers. Bahawalpur is a wonderful area to look into how urbanization has altered local weather patterns because the city has seen tremendous urban growth over the past few decades.

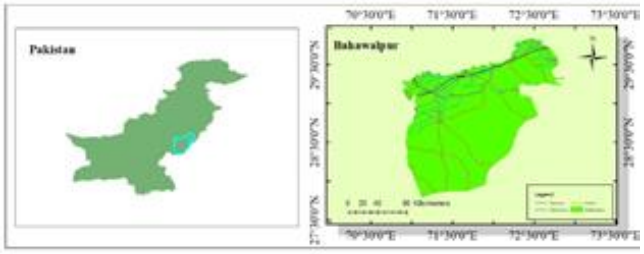

Fig. 1: Study area map of District Bahawalpur

Data Sources

To investigate the temporal trend of temperature and rainfall, mean monthly meteorological data was gathered from the Pakistan Metrological Department in Bahawalpur. The data include monthly average minimum and maximum temperatures (°C) as well as monthly average rainfall (in millimeters). Data from time series were collected between 1992 to 2022, encompassing the last three decades. Four Landsat satellite images of Bahawalpur were downloaded from the USGS website to investigate changes in Land Cover and Land Use (LCLU) in the city. ArcGIS 10 and ERDAS Imagine are two programs used to process images.

Data Analysis

Three unique data segments were created for the chosen research region: temperature (Mean minimum monthly, mean maximum monthly), rainfall (Mean monthly), and land use (Urban, Farmland, and Waterbodies). Graph Pad Prism 5 and SPSS 25.0 were used to examine these components. Using the three decades, denoted as D1, D2, and D3, from 1992 to 2002, 2002 to 2012, and 2012 to 2022, the temporal data for temperature, rainfall, and land use were compiled. Averages and means were determined to identify the link and trends. Using a statistical test trend, researchers may study the principles of quantitative decisions for a process or process (Von Storch, 1999). The rainfall data was subjected to two levels of analysis, as were the lowest and maximum temperatures, and both. The statistical approach outlined below was used

to calculate the first-level averages of mean minimum and maximum monthly temperatures and rainfall throughout the three decades labeled as D1, D2, and D3.

$$\overline{X} = \frac{\sum X}{N}$$

Where,
$\bar{\mathbf{X}}$ is mean of D1, D2, and D3
$\sum \boldsymbol{x}$ is the sum of D1, D2, and D3
$\boldsymbol{N}$ is the number of decades
The mean formula was used at the second level to compute the mean annual minimum and maximum temperatures, as well as rainfall. The mean monthly and mean annual differences for temperature and rainfall were then computed by subtracting the anticipated mean from the mean of D1. The difference between mean minimum and mean maximum temperatures and rainfall was calculated using a t-test. A T-test is used when comparing sample means to see if there is enough evidence to conclude that the means of the matched sample also differ. One sample t-test is a sort of t-test that is used to examine if the mean of a distribution differs substantially from a given value.

$$t = \frac{\overline{x} - \mu_0}{s/\sqrt{n}}$$

$\overline{x}$ = Sample mean
μ_0 = Value of sample parameter to be tested
s= Unbiased standard deviation
n= Sample size

Results and Discussion

The results have been discussed in five sub-sections;

Mean Annual Temperature Trends Analysis (1992- 2022)

The Mean Annual Temperature in Bahawalpur increased substantially between 1992 to 2022. It increased by around 0.2°C each year until it reached 31.6°C in 2022, starting at 25.6°C in 1992. Over the 30 years, the temperature rose by 6°C on average. This consistent warming trend over the last three decades has resulted in substantial climatic changes in the region, potentially impacting agriculture, water resources, and public health.

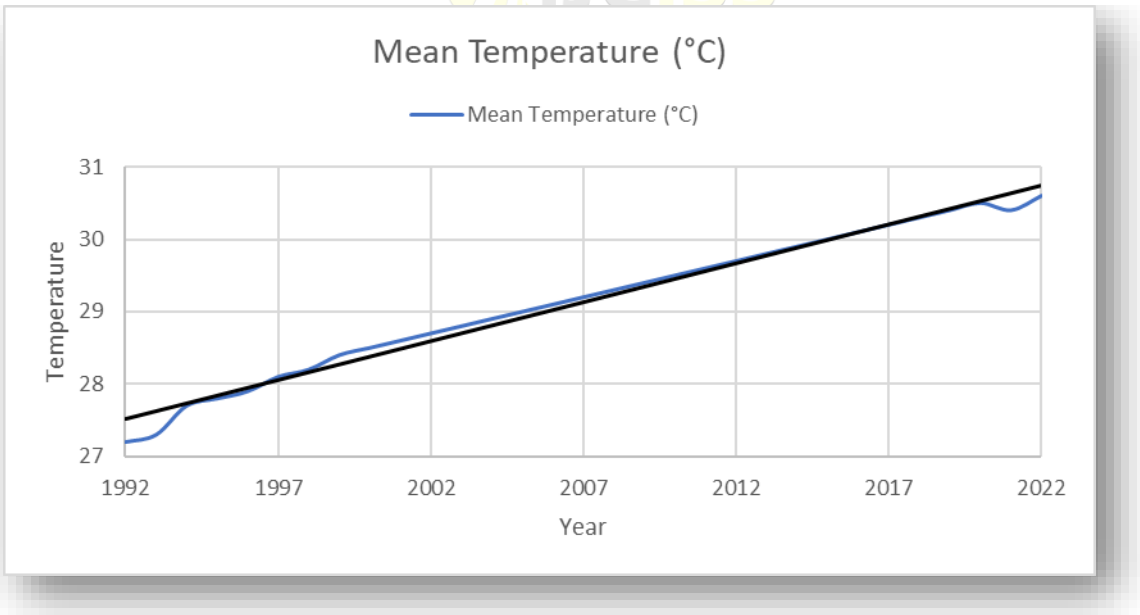

Figure 2: Mean Annual Temperature Trends Analysis (1992- 2022)

Mean Minimum Temperature Trends Analysis (1992-2022)

Below Figure 3 & Table 1 shows the average lowest temperatures in Bahawalpur during the last 30 years, from 1992 to 2022. Beginning in 1992, the average lowest temperature was 10.8 °C. Over the last 30 years, the temperature has gradually risen. By 2022, the average lowest temperature was 13.1 °C. This suggests that Bahawalpur's nights have warmed by about 2.3°C over the last three decades. The average annual increase in nighttime temperatures has been insignificant. This shows how Bahawalpur's lowest temperatures have become colder over time.

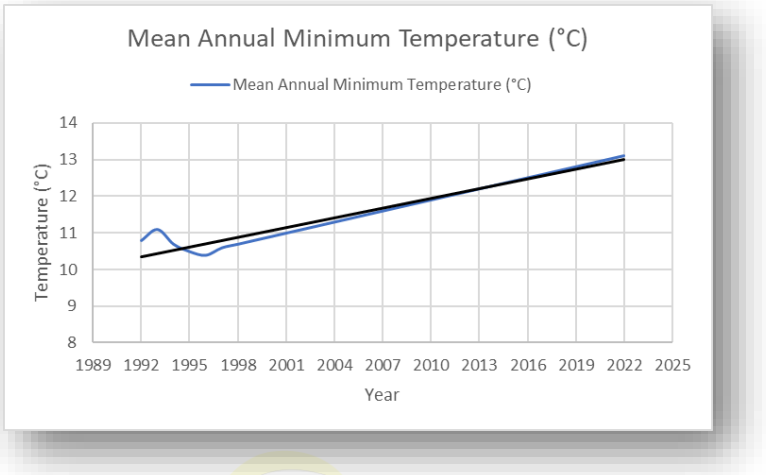

Fig. 3: Mean Annual Minimum Temperature (°C) in Bahawalpur from 1992- 2022

Mean Maximum Temperature Trends Analysis (1992-2022)

Figure 4 & Table 2 depicts the Mean Maximum Temperature of Bahawalpur, Punjab, Pakistan, from 1992 to 2022, along with a 30-year trend analysis. In 1992, the average annual maximum temperature was 11.8°C. It has been observed that the temperature has been slowly and gradually rising during the last three decades. By 2022, the temperature had climbed to 14°C. This equates to a 2.2°C rise over the last 30 years. There was a very steady yearly increase of 0.1°C in particular, demonstrating a warming trend in Bahawalpur.

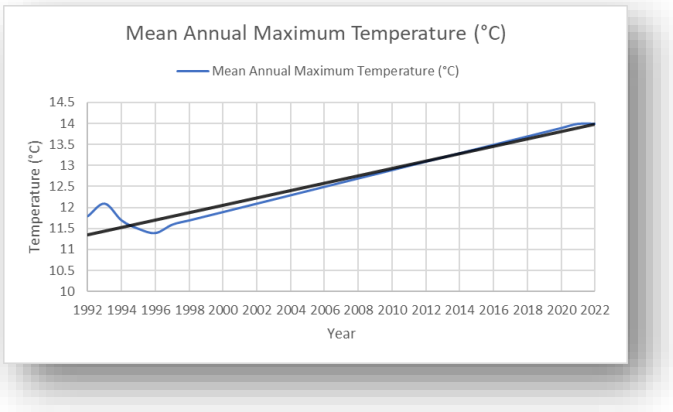

Fig. 4: Mean Annual Max. Temperature (°C) in Bahawalpur from 1992-2022

Mean Rainfall Trends Analysis (1992-2022)

The Mean Rainfall (MR) trends in Bahawalpur from 1992 to 2022 are shown in Figure 5 & Table 3. 1992 had 100 mm of rainfall in Bahawalpur. In subsequent years, there was a noticeable variability in the annual rainfall, which ranged from 80 to 120 mm. A recurrent pattern appears practically every decade when rainfall begins at 100 mm, peaks at 120 mm the following year, gradually declines to 80 mm over several years, then increases to 100 mm and repeats the cycle. By 2022, the total rainfall was 110 mm. Despite changes in annual rainfall totals, no obvious rising or declining trend has been seen during the previous 30 years. The cyclic pattern of the periodic oscillation between 80 mm and 120 mm can be recognized, with peaks and troughs occurring at fairly regular intervals.

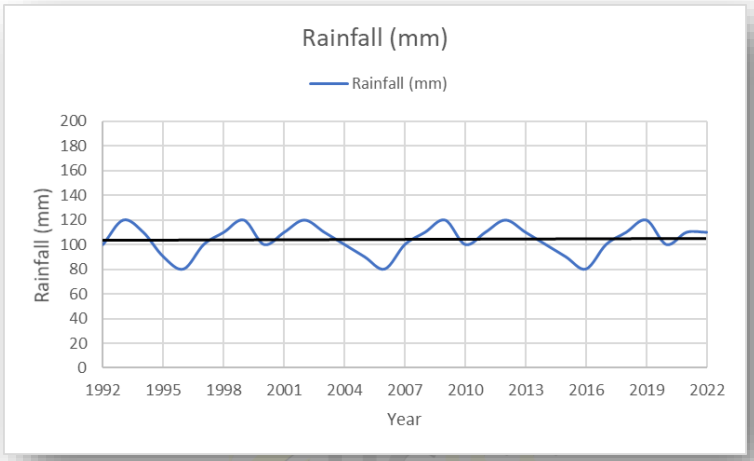

Fig. 5: Mean Annual Rainfall (mm) in Bahawalpur from 1992-2022

Urban Area Change 1992–2022

In Bahawalpur, vegetation area expanded significantly between 1992 to 2022, by 5.54%, and urban developed areas elevated significantly, by 0.45%, while bare soil decreased significantly, by 5.99% as shown in figure (6a, 6b). These motions, together with comparable decreases in barren land, show an increase in green space coverage and urban growth. Statistical analyses validated the significance of these changes over three decades, as seen in Table 4 & Fig (6a,6b).

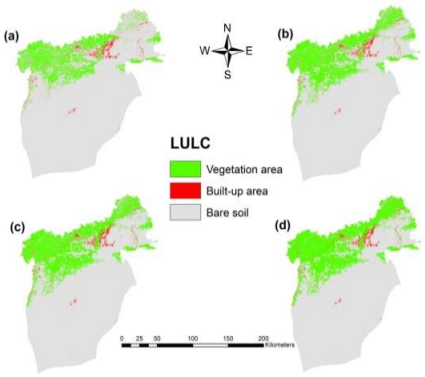

Fig. 6a: Decadal Change in the Land Use in Bahawalpur from 1992- 2022

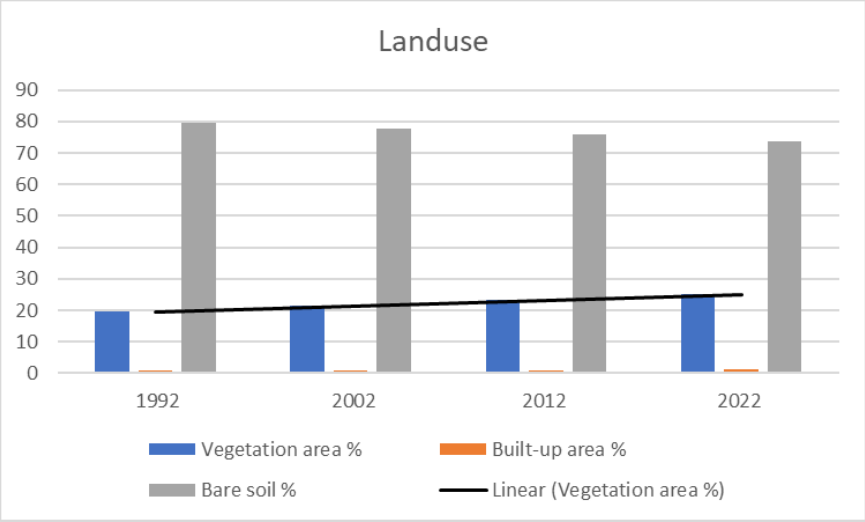

Fig. 6b: Decadal Change in the Land Use in Bahawalpur from 1992- 2022.

Discussion

The historical examination of Bahawalpur, Punjab, Pakistan over the last three decades provides valuable insight into the city's evolving climate profile, which is directly tied to its urbanization processes. One of the most striking observations is the gradual rise in the mean annual temperature in Bahawalpur. A 6°C increase in only 30 years is considerable and cannot be overlooked. This continued warming may have a severe influence on the city's ecosystem and the way of life of its citizens. Temperature fluctuations can have a considerable impact on agricultural production, strain water resources, and exacerbate public health issues.

Looking at minimum and maximum temperatures provides a more detailed perspective. Bahawalpur's nights have been substantially warmer, while the national mean temperature has risen. This overnight warming could have a wide range of consequences, impacting everything from sleeping habits to energy consumption. The city's warming tendency, on the other hand, is evidenced by a moderate but steady increase in average maximum temperatures.

Surprisingly, despite these temperature trends, rainfall patterns in Bahawalpur appear to have stayed quite consistent over the last 30 years. The cyclical pattern of rainfall indicates a natural cycle or may be impacted by more broad region weather trends. However, the continuous rainfall, paired with rising temperatures, may cause concerns about potential evaporation rates, water scarcity, or changes in agricultural practices.

The trends in urban and vegetative growth recorded throughout this period suggest a possible causal link between the observed climate changes and these trends. Even a little rise in urban areas, paired with a considerable increase in vegetation and a decrease in barren land, indicates a shift in land use patterns. Metropolitan areas can worsen the "heat island" effect, in which urban regions experience greater temperatures than their rural surroundings, due to human activity and changes to the land's surface. On the other side, vegetation growth has the potential to act as a mitigating factor by absorbing CO_2 and providing shade, but this has yet to be proven effective in reversing the general warming trend.

Conclusion

The data collected in Bahawalpur, Pakistan, between 1992 and 2022 shows an alarming picture of the region's climatic and environmental changes. The data reflect several noteworthy trends and developments during the last three decades. To begin with, the Mean Annual Temperature in Bahawalpur has progressively grown by approximately 6°C over the preceding 30 years. These enormous climatic changes, which have been progressively increasing over time, may have a negative influence on several sectors, including public health, agriculture, and water management. Second, even as the days become hotter, the nights become warmer, as seen by continuous increases in the mean annual minimum and maximum temperatures. These cyclical temperature changes can have a significant impact on people's quality of life, especially during the hot

summer months. There hasn't been a definitive trend of growing or decreasing rainfall over the preceding 30 years, but there has been a cyclical pattern noted, with rainfall amounts oscillating between specified numbers. To deal with unforeseen rainfall amounts, such variation may reduce the amount of water available and may necessitate better water management practices. Similarly, Bahawalpur's vegetation increased by 5.54%, urban areas increased by 0.45%, and barren land decreased by 5.99% (Figure 4). This trend indicates an increase in urbanization and green space. Statistical analysis (Table 5) validates the importance of these changes over three decades.

Table 01: Decadal Change in Mean Monthly & Annual Min. Temperature (ºC) in Bahawalpur from 1992-2022

Decade	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990s	10	10.2	10.7	11.5	12.4	13.3	14.1	14	13.4	12.6	11.8	11.2	10.8
2000s	10.1	10.3	10.8	11.6	12.5	13.4	14.2	14.1	13.5	12.7	11.9	11.3	11
2010s	10.2	10.4	10.9	11.7	12.6	13.5	14.3	14.2	13.6	12.8	12	11.4	11.1
2020s	10.3	10.5	11	11.8	12.7	13.6	14.4	14.3	13.7	12.9	12.1	11.5	11.2
Mean	10.15	10.35	10.85	11.65	12.55	13.45	14.25	14.15	13.55	12.75	11.95	11.35	11.025
Difference	0	0	0	0	-0.1	-0.1	-0.2	-0.2	-0.2	-0.1	0	0	0.175
Std. Deviation	4.1449	4.2266	4.4306	4.7571	5.1653	5.5327	5.9	5.8592	5.6143	5.2469	4.87959	4.6347	4.4315
t, df	t=5.03 / df=6	t=5.03 / df=6	t=5.03 / df=6	t=5.03 / df=6	t=5.007 / df=6	t=5.007 / df=6	t=5.009 / df=6	t=4.984 / df=6	t=4.984 / df=6	t=4.981 / df=6	t=5.007 / df=6	t=5.036 / df=6	t=5.095 / df=6
P value	0.002	0.003	0.002	0.0021	<.0001	0.003	0.002	<.0001	0.002	0.002	0.002	0.003	0.004
Significant (alpha=0.05)?	Yes	Yes	yes	yes	yes	yes	Yes	Yes	Yes	yes	yes	yes	yes

Table 02: Decadal Change in Mean Monthly & Annual Max. Temperature (ºC) in Bahawalpur from 1992-2022

Decade	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Mean
1990s	18.2	20	21.7	24.4	27.3	29.7	31.7	31.9	31	28.9	27.2	25.8	26.5
2000s	18.5	20.2	22	24.7	27.6	30	32.1	32.2	31.3	29.2	27.4	25.9	27
2010s	18.8	20.5	22.3	25	27.9	30.3	32.4	32.5	31.6	29.5	27.7	26.2	27.2
2020s	19.1	20.7	22.6	25.3	28.1	30.5	32.6	32.7	31.8	29.7	27.9	26.3	27.4
Mean	18.650	20.350	22.150	24.850	27.725	30.125	32.200	32.325	31.425	29.325	27.550	26.050	27.025

Difference	0.45	0.34	0.45	0.44	0.37	0.37	0.40	0.375	0.375	0.375	0.350	0.250	0.375
Std. Deviation	0.3873	0.3109	0.3873	0.3873	0.3500	0.3500	0.3916	0.3500	0.3500	0.3500	0.3109	0.2380	0.3862
t, df	T=96.30 df= 3	t=130.9 df=3	t=114.3 df=3	t=128.3 df=3	t=158.428 df=3	t=172.142 df=3	t=164.4 df=3	t=184.714 df=3	t=179.5 df=3	t=167.5 df=3	t=177.2 df=3	t=218.8 df=3	t=139.9 df=3
P value (two-tailed)	0.000002	0.000	0.000001	0.000001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Significant (alpha=0.05)	yes	Yes	yes	yes	yes	yes	yes	Yes	Yes	Yes	yes	yes	yes

Table 03: Decadal Change in Mean Monthly & Annual Rainfall (mm) in Bahawalpur from 1992-2022

Decade	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean Annual
1990s	10	12	11	11	9	8	10	13	11	10	9	10	10.33
2000s	10.1	10.3	10.8	11.6	12.5	13.4	14.2	14.1	13.5	12.7	11.9	11.3	13.03
2010s	10.2	10.4	10.9	11.7	12.6	13.5	14.3	14.2	13.6	12.8	12	11.4	13.13
2020s	10.3	10.5	11	11.8	12.7	13.6	14.4	14.3	13.7	12.9	12.1	11.5	13.23
Mean	10.15	10.8	10.925	11.525	11.7	12.125	13.225	13.9	12.95	12.1	11.25	11.05	12.43
Difference	0.15	-0.3	0.075	0.275	1	1.475	1.175	0.4	0.75	0.8	0.85	0.45	0.8
Std. deviation	t=157.24, df=3	t=26.86, df=3	t=228.21, df=3	t=64.135	t=12.987, df=3	t=8.814, df=3	t=12.293, df=3	t=45.910, df=3	t=19.884, df=3	t=17.256, df=3	t=14.978, df=3	t=31.359, df=3	t=17.727, df=3
P value (two-tailed)	0.000	0.000	0.000	0.000	0.001	0.003	0.001	0.000	0.000	0.000	0.001	0.000	0.000
Significant (alpha=0.05) ?	Yes	Yes	yes	yes	yes	yes	yes	yes	yes	Yes	yes	yes	yes

Table- 04: Decadal Change in the Land Use in Bahawalpur from 1992-2022

Year	Vegetation area %	Built-up area %	Bare soil %
1992	19.62	0.73	79.65
2002	21.4	0.77	77.83
2012	23.23	0.86	75.91
2022	25.16	1.18	73.66
Change 1992 to 2022	5.54	0.45	-5.99
t, df	t=18.766, df= 3	t= 8.675, df= 3	t= 59.715, df= 3
P value (two-tailed)	0.000	0.003	0.000
Significant (alpha=0.05)?	Yes	Yes	Yes

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