CLIMATIC CHANGE AND ITS IMPACTS ON THE MEGA HYDROPOWER PROJECT; A CASE STUDY OF ATTOCK DISTRICT, PAKISTAN

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ABSTRACT: The study aims to analyze the climatic impact on the vegetation around the mega hydropower project and the Sustainable Development in the Attock. Forests, known for resilience, face peril from human activities, particularly deforestation and reduced carbon sink capacities. Urbanization emerges as a significant contributor to forest cover loss, triggering carbon emissions and environmental challenges. Land surface temperature alterations and widespread forest decay intensify the environmental crisis, releasing stored carbon and contributing to global warming. The accelerated phase of climate change, linked to anthropogenic carbon emissions, necessitates urgent action to address forest cover loss and improper land usage, impacting socio-economic aspects and hindering Sustainable Development Goals (SDGs) progress. A case study in Attock District, Pakistan, reveals climatic variations around the Mega Hydropower Project, impacting efficiency, energy generation, and local communities. NDVI and LST maps visually represent vegetative dynamics and thermal patterns, while demographic shifts, literacy rates, and infrastructure highlight evolving urbanization challenges. The study emphasizes the need for an integrated approach to climate adaptation and long-term planning to ensure sustainability and resilience.

Key words: Climate Impact, Hydrology, Precipitation , Socio- Economic Effects

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INTRODUCTION

The profound alterations in climatic patterns during the 21st century have emerged as a formidable threat to growth, development, and even the very survival of humanity. Forests, being versatile environmental entities, exhibit the resilience needed to adapt to ecosystem changes, offering sustainable benefits to the environment (Aljerf, 2017). However, a significant peril to forest cover and broader vegetative landscapes on land surfaces arises predominantly from human activities. The reported adverse impacts include erosion, drought, and biodiversity loss (Gao, Li, Gao, Zhou, & Zhang, 2017; Xie, He, & Xie, 2017). Human-induced actions, such as deforestation and the reduced capacity of forests to act as carbon sinks, remain primary contributors to forest cover loss (Zhang *et al*., 2015). Rapid urbanization stands out as a particularly severe factor behind the diminishing forest cover, triggering massive carbon release (Bhatt, 1990). Urbanization, a critical factor influencing forest cover, poses substantial challenges to both regional and global environments (Lin, Qiu, Yao, Hu, & Lin, 2019). Urban settlements, among other major threats, increasingly convert forested land and high-coverage grasslands into bare land and extensive physical infrastructure, diminishing overall grass and forest land coverage due to expanding human activities (Li, Cao, Long, Liu, & Li, 2017). Land use changes hurt terrestrial ecosystems and, as a result, carbon storage, which increases anthropogenic carbon emissions. This is particularly true when it comes to the conversion of forest land. Large-scale conversion of land and related carbon emissions result from changing land for high-rise urban structures (Chuai *et al*., 2015). This puts at risk the capacity of forests to absorb carbon dioxide from the atmosphere, preventing grasslands and forests from sequestering carbon, thus reducing global warming. The sudden shifts brought about by these variations in the surface temperature of the earth cause catastrophic events such as storms and floods, which also cause large socioeconomic losses. According to Song and Zeng (2017), this phenomenon also affects local and global climate change. Forest ecosystems are extremely susceptible due to the accelerated phase of climate change, which is thought to be caused by increasing tree mortality or forest degradation in response to rising temperatures (Allen *et al*., 2010). This alarming scenario is mostly caused by extensive changes to the terrain, such as the removal of wooded areas (Haque & Basak, 2017). According to Bachelet, Neilson, Lenihan, and Drapek (2001), the loss of vegetative cover, especially forest cover, reduces carbon sinks and releases absorbed carbon back into the atmosphere. A 2C increase in the global mean temperature is the result of this carbon release, which is closely associated with the rise in land surface temperature. It also impedes efforts to meet the carbon budget of 590–1240 $GtCO_2$. (Friedlingstein, 2016). This risky scenario gets worse as soil bacteria die off due to the warming impact, releasing more carbon that has been stored in the soil into the atmosphere. According to Schuur *et al*. (2015), this feedback process exacerbates the environmental catastrophe and has additional warming impacts. A notable rise in carbon emissions has resulted from changes in land use; in 2012, there were about 2.7 Gt CO2-eq emissions in the atmosphere, which represents a 12.5% increase from 1990 to 2010 as a result of human changes (FAO, 2012; Houghton *et al*., 2012). Variations in precipitation occurrences are a result of global warming, which is brought on by an increase in carbon emissions. For every 1C increase in temperature, there is a 7% loss in the air's ability to carry water (Trenberth, 2011). It is imperative to address the current levels of vegetation loss and inappropriate land usage to prevent future climate dependency, as confirmed by IPCC Assessment Report 5 (AR5), which attributes the rise in global mean temperature to past anthropogenic emissions rather than natural causes (Park, Yim, & Lee, 2017).

Although the global rate of decrease in vegetation cover is not well established, land-use expansion and the sharp decline in vegetative cover are seen as ubiquitous risks to biodiversity and the natural environment. According to reports, the shift in the forest cover has accelerated recently (Mangwale, Shackleton, & Sigwela, 2017). Micro-level effects are a consequence of global changes, significant increases in carbon emissions, and rising atmospheric temperatures (Kovalev, Liu, Urbanski, & Heilman, 2014). The UN Sustainable Development Goals (SDGs) are hampered by this phenomenon (Aljerf & Choukaife, 2016). According to Randhawa (2017) and Waseem & Khayyam (2019), Pakistan's forest area makes up around 1.9% of the country's total land area and is shrinking at a pace of 42,000 hectares each year. Large cities like Karachi and Islamabad, where fast changes in land cover are directly related to urbanization, are the focal points of this enormous loss. Due to rising population density, Karachi, which is located on the Arabian Sea, has become a center of high-rise structures and extensive urbanization, making it one of the most sensitive cities to environmental concerns. Significant risks to environmental quality are associated with land use and housing concerns (Qureshi, 2010). Green cover has suffered as a result of urbanization, which has led to the growth of the urban core and the outer spread into wooded regions. In recent decades, the city—once renowned for its abundant vegetation—has seen several urban alterations (Aerts & Honnay, 2011; Shaheen *et al*., 2015). Numerous research studies have thoroughly examined the effects of climate change on vegetation (Abbass *et al*., 2022; Al Mamun *et al*. The primary goal of the study is to examine how the mega hydropower project's surroundings are affected by the weather and to assess the surrounding infrastructure. The ambient temperature and vegetation conditions in the study region were analyzed using the LST and NDVI.

MATERIAL AND METHODOLOGY

Study Area: Attock District is one of the beautiful geographical and cultural areas of the north-western part of Pakistan. It covers a total geographical area of 6,857km² for the district and has a population of 1,883,556 in the year 2017. Attock District is an area that requires further research; it is located between the Indus River on the east side and the Khyber Pakhtunkhwa province with its mountains. Geographically, the district falls under the plain and foothill area which has led to a striking variation in the area of the district. The most extensive of these is the Indus River which covers a large part of the eastern part of the district and has a significant influence on the hydrological cycle of the region and also supports the agricultural sector through irrigation. The area is characterized by hills and mountains that give the area a beautiful view and the vegetation cover found on the hills and mountainous region are very vital in supporting bio-diversity. This culturally and ethnically diverse district consists of different ethnic groups and communities of the country with different cultures and practices in the region. The inhabitants of the population engage in different economic activities; however, the most common activity for most of them is farming. The area chosen for the study can be described as the urban and rural regions of the area, which are quite dissimilar to each other regarding infrastructure, living standards, and socio-economic processes, and therefore, are of great interest for social investigation.

Data Source: Multi-spectral data of Landsat 7 and 8 satellites for 2003, 2013, and 2023 was procured from the USGS website of the United States which is useful in providing temporal data on land-use and environmental analysis. At the same time, population data of the study area was obtained from the Survey of Pakistan website, providing demographic data necessary to assess the state of the region dynamics. Also, data on the establishments in the study area was obtained from the Punjab government's official website, which helps to conduct an analysis of infrastructure at the provincial level Growth and its factors on the population. This multidimensional data integration enables a more comprehensive understanding of spatiotemporal dynamics, which is a more comprehensive way of studying research and analysis.

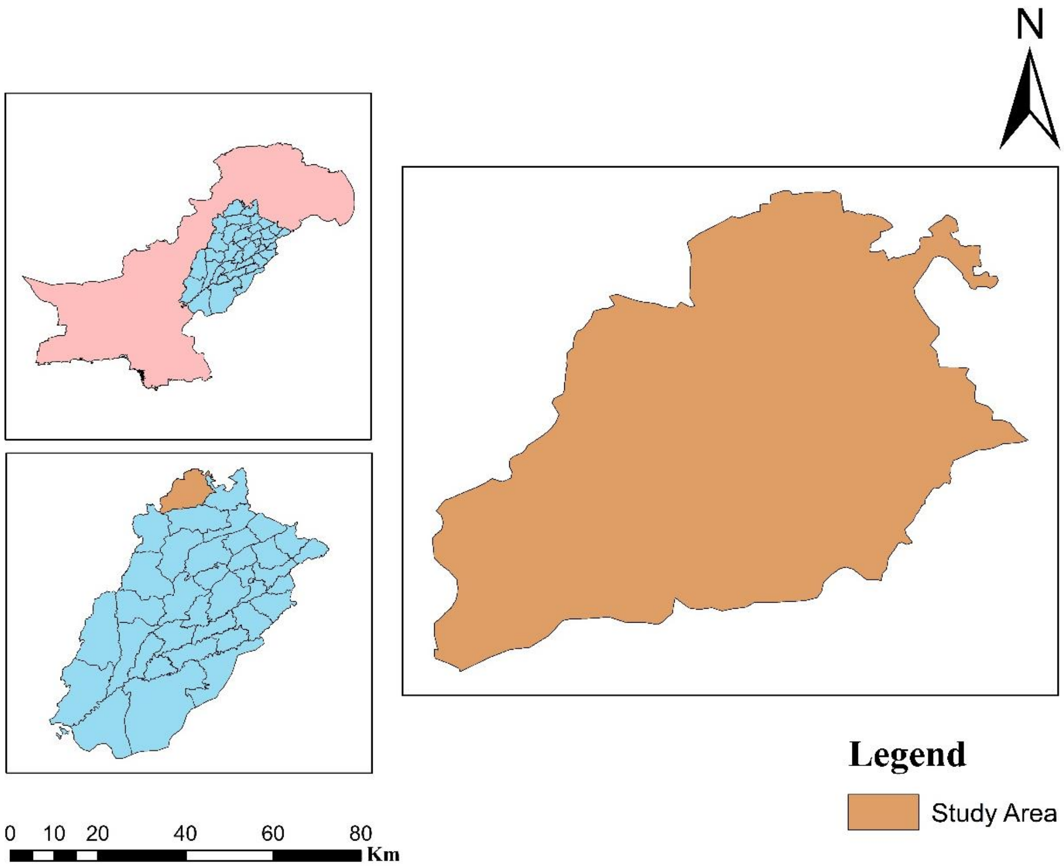

Figure 1: Study Area map of Attock, Pakistan. Source by Author, Software: ArcGIS

Data Analysis

Calculation of NDVI: The Normalized Difference Vegetation Index is also referred to as NDVI, it is a very significant factor in the RS domain as it allows evaluation of the health as well as density of vegetation present in a specific area. Landsat 7 utilizes Band 3 as the Red Band while Landsat 8 utilizes Band 4 as the Red Band both from Band 1 and Band 4 of satellite imagery (Abbas & Mayo, 2021; Abbass *et al*., 2022; Aerts & Honnay, 2011; Al Mamun *et al*., 2022). The calculate NDVI using this formula:

NDVI = (NIR–RED) / (NIR+RED) (1)

Calculation of LST: To estimate the LST, satellite data from Landsat 7 and Landsat 8 were used with the help of the ETM+ sensor and OLI/TIR sensor of the thermal bands. Abbas *et al*. (2021) have reported that the LST was obtained from Band 6 of the Landsat-7 ETM+ sensor and Band 10 of the Landsat-8 TIR sensor. The spectral radiance of the Landsat-8 thermal bands was converted from digital numbers (DN) as per the procedure followed by Abbas *et al*. (2021). The process began with computing the Top of Atmosphere (TOA) spectral radiance (Lλ) using Equation (2):

Lλ = (ML * Qcal) + AL – 0 5 \] **(2)**

where \(Lλ \) is the TOA spectral radiance, \(ML \) represents the radiance multiplier for Band 10, \(AL \) denotes the radiance addend for Band 10, \(Q_{Cal} \) signifies the quantized and calibrated digital numbers and the result is obtained by subtracting 0. 5 for calibration adjustments.

Next, the Brightness Temperature (BT) was calculated using Equation (3): Next, the Brightness Temperature (BT) was calculated using Equation (3):

BT = (K2)/(ln(K1/(Lλ+1)) – 273. 15 **(3)**

where, \(BT \) is the Brightness Temperature, (K2) is the calibration constant 2, (K1) is the calibration constant 1, \(Lλ \) is the TOA spectral radiance, (\ln \) represents the natural logarithm, and 273.15.

Additionally, the Normalized Difference Vegetation Index was calculated using Equation (4):

NDVI = {NIR - RED}{NIR + RED} **(4)**

The Plant Vigor (PV) was estimated using Equation (5): The Plant Vigor (PV) was estimated using Equation (5):

[PV = left(frac{NDVI - NDVI_{min}}{NDVI_{max}-NDVI_{min}}\right)^2] **(5)**

The Land Surface Emissivity (E) was determined using Equation (6): The Land Surface Emissivity (E) was determined using Equation (6):

[E = 0. It is up to 004 * PV + 0. 986] **(6)**

Finally, the Land Surface Temperature (LST) was computed using Equation (7): Finally, the Land Surface Temperature (LST) was computed using Equation (7):

[LST = frac{BT}{1 + (\lambda BT / ρ) \ln(E)}] (7)

RESULTS AND DISCUSSION

There are climatic changes that have been observed in and around the Mega Hydropower Project in Attock District, Pakistan, and deserve elaborate discourse. Effects of climate conditions especially the temperature and precipitation directly affect the feasibility and efficiency of the hydropower project in the recent past. Fluctuations in the river flow as a result of differences in precipitation affect the project's generation capability and planning for the long term. Climatic events such as floods or droughts, which are becoming more frequent and intense, create operational problems and need changes. Increased temperatures lead to glacial melt in the catchment area of the project hence water availability and the hydrological cycle are changed. These changes require constant review of the hydropower project layout and management methods to adapt to changing climatic conditions. Moreover, changes in precipitation will also have an impact on the sedimentation in the reservoir, which, in turn, will impact water quality and energy generation. Another important aspect, that is worth considering, is the socio-economic effects of climatic changes on the populations inhabiting the area of the hydropower project. Alterations in precipitation may affect crops and food security, which may result in shifts in the population's susceptibility. This paper underlines the importance of the multi-sectoral climate adaptation measures that would contribute to the project and serve communities' climate resilience. It underlines the need to integrate climate forecasts into strategic development planning and apply suitable actions for the minimization of possible impacts and the enhancement of the project's advantages in the context of climate change.

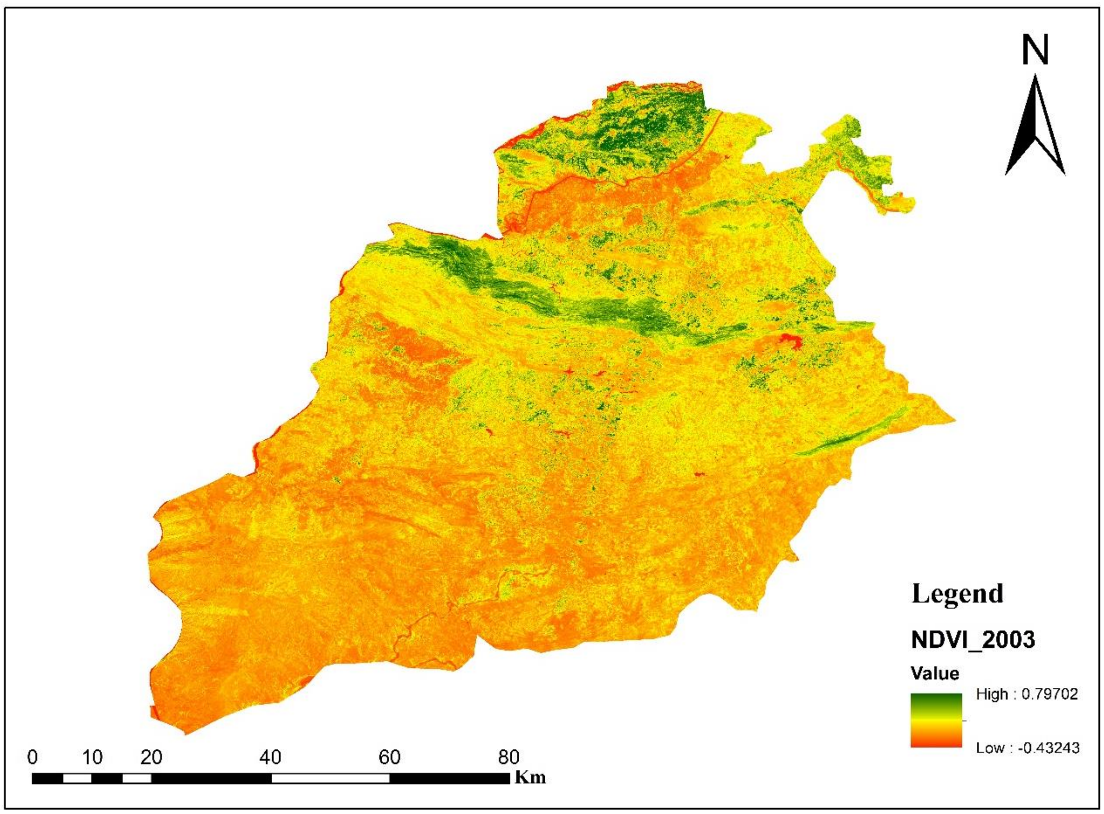

Figure 2: NDVI Map of Attock, Pakistan 2003

The normal Difference Vegetation Index is shown in figure 2 below where noticeable changes are described. Among all the years under consideration in the present work, the most significant NDVI index was identified in the year 2003 and it was equal to 0. 79702, which indicates that vegetation vigor and cover is quite high in the area. At the same time, the lowest value was recorded at – 0. 43243 pointing to the parts of the country that have few trees or that are relatively bare. These NDVI values are quite useful in depicting the vegetation characteristics of the study area, changes in the ecosystem, and its health within the given period.

The Normalized Difference Vegetation Index for the study area is depicted in Figure 3, which illustrates the vegetation cover changes. Specifically, the year 2013 has the maximum NDVI value of 0. 761646 which indicates healthy and dense vegetation cover in that period. On the other hand, the minimum NDVI registered in 2013 was -0. 642046, for the regions with low or very low vegetation density. These values proved to be important in determining the ecological status of the study area to analyze the changes in vegetative cover in the given period.

Figure 4 presents the Normalized Difference Vegetation Index (NDVI) map of the study area, which illustrates the variations in vegetation abundance. More to the point, the year 2013 has the highest peak NDVI value of 0. 66947, indicating good vegetation cover and density during that time of the year. On the other hand, the minimum NDVI value obtained in 2013 was -0. 77313, which represents the degree of fragmentation and loss of vegetation in the country. These values are very important in determining the condition of the environment of the study area and assist in the evaluation of vegetative changes within the stipulated period.

Figure 5 provides a representation of the thermal patterns of the study area based on the Land Surface Temperature (LST). The year 2003 shows the highest value of LST with 33. 66870C which corresponds to the regions of high surface temperature. On the other hand, the minimum LST value noted in 2003 was 12. 52980C, indicating areas with relatively low temperatures on the surface of the water. These values are important in the analysis of temperature changes in the study region, especially for the given period.

To complement the findings of the analysis, Figure 6 presents a visual representation of the study area's Land Surface Temperature (LST). The year 2013 demonstrates the highest value of the LST with 39. 60960C, the regions which show higher surface temperature. On the other hand, the minimum value of LST recorded in 2013 was 12. 57760C, implying the areas with relatively low surface temperatures. These values are quite useful in the analysis of temperature fluctuations within the study area, especially when the analysis is done over a given period.

As shown in Figure 7 below, the Land Surface Temperature (LST) of the study area shows thermal patterns of the area of interest. The year 2023 shows the highest value of the LST of 45. The 03090C values represent the areas of the surface with high temperatures. On the other hand, the minimum LST value recorded in the year 2023 is 15. 03520C meaning areas with relatively low surface temperature. These values help in the determination of the temperature changes in the study area during the stipulated period.

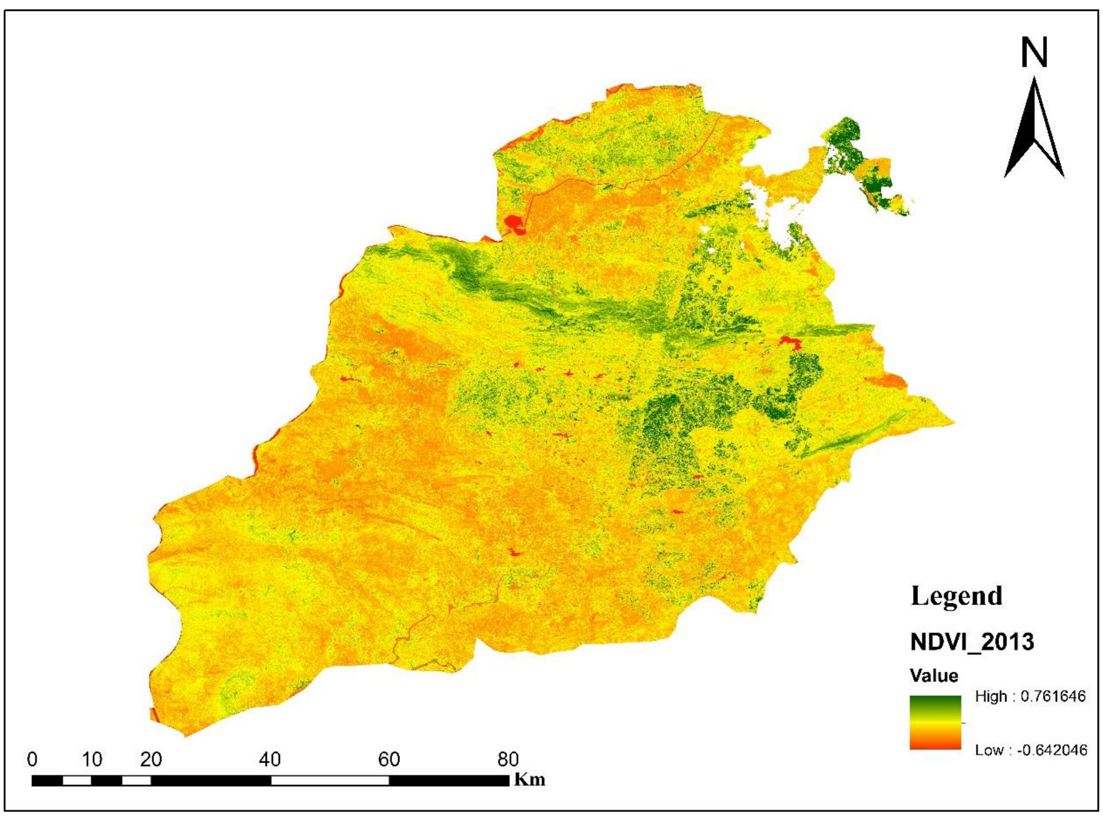

Figure 3: NDVI map of Attock, Pakistan 2013

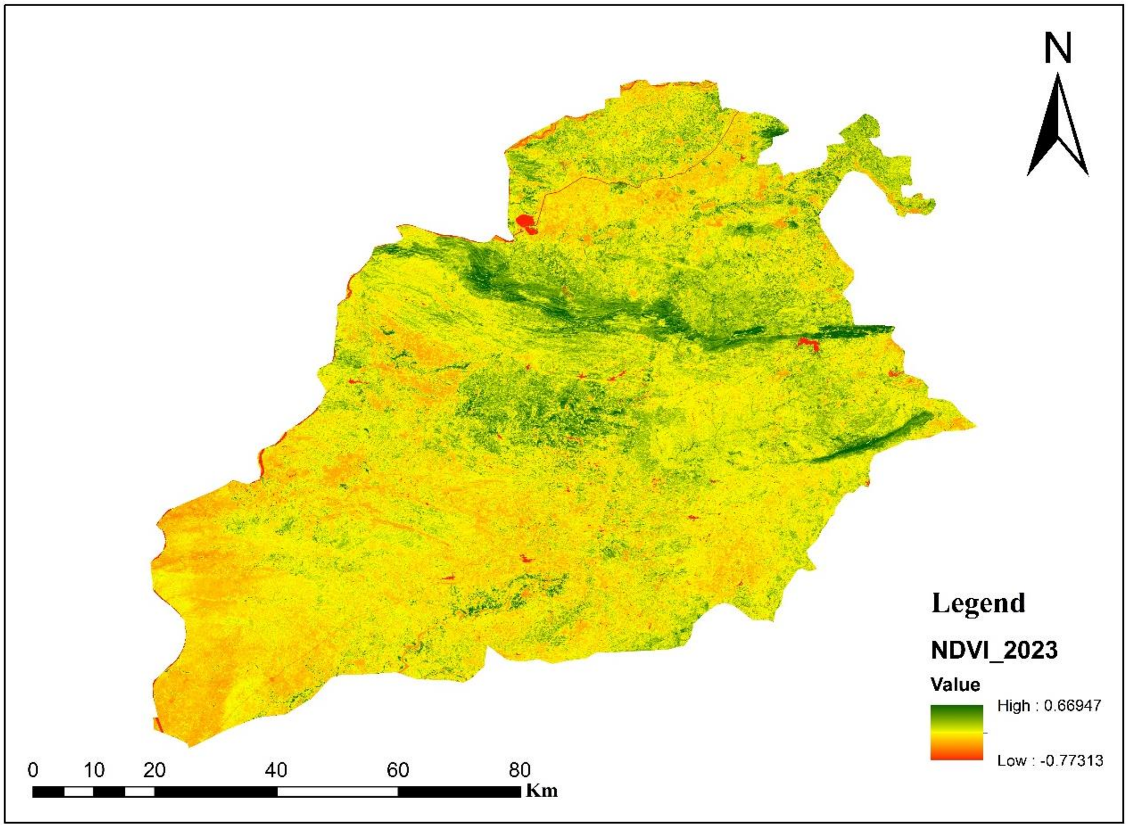

Figure 4: NDVI Map of Attock, Pakistan 2023

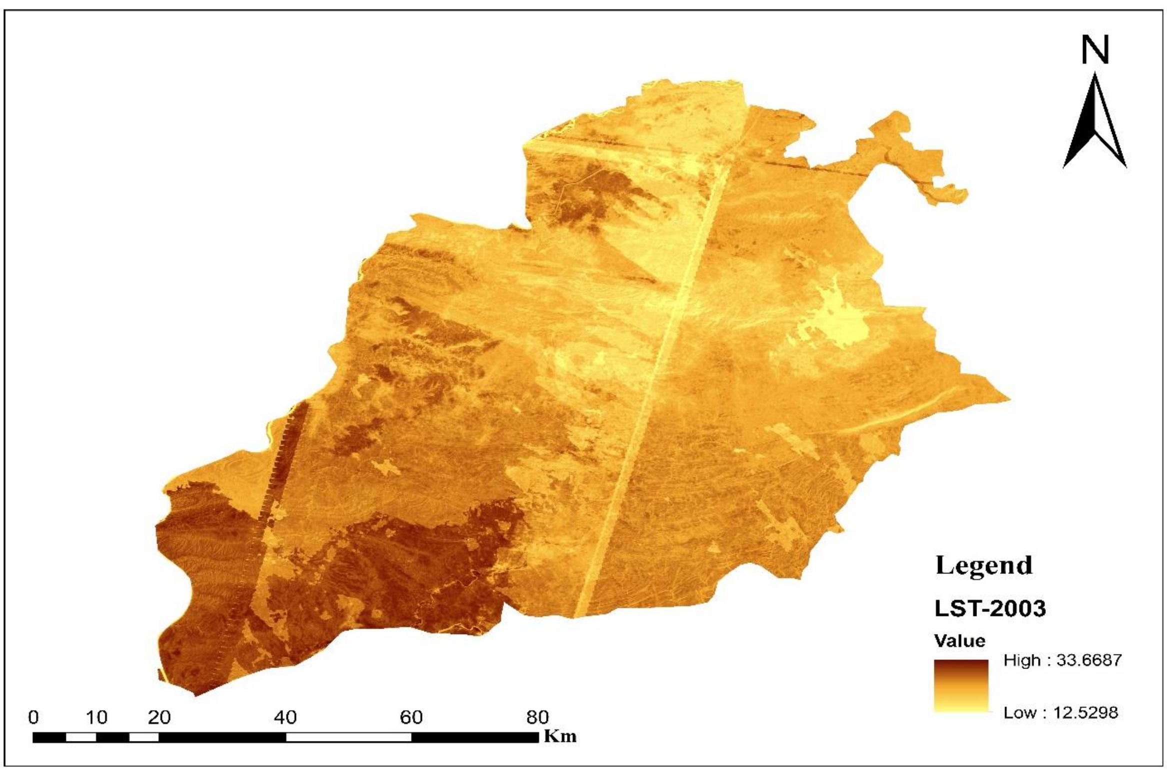

Figure 5: LST Map of Attock, Pakistan 2003.

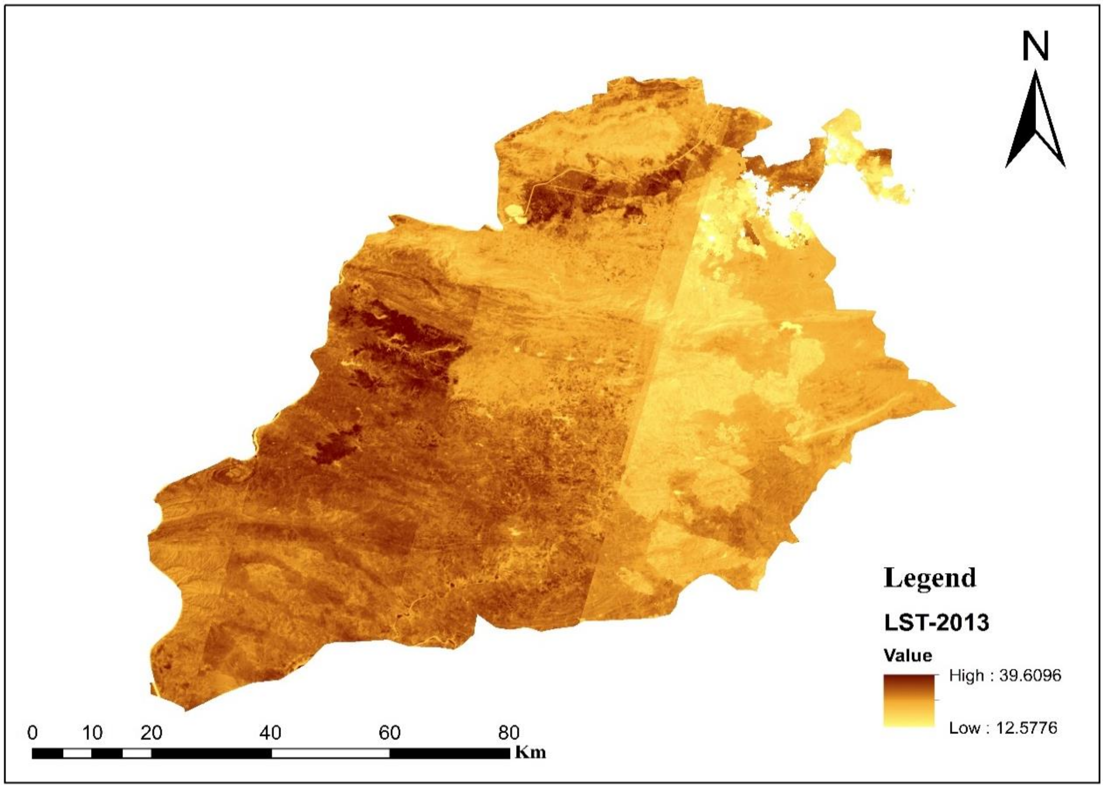

Figure 6: LST Map of Attock, Pakistan 2013

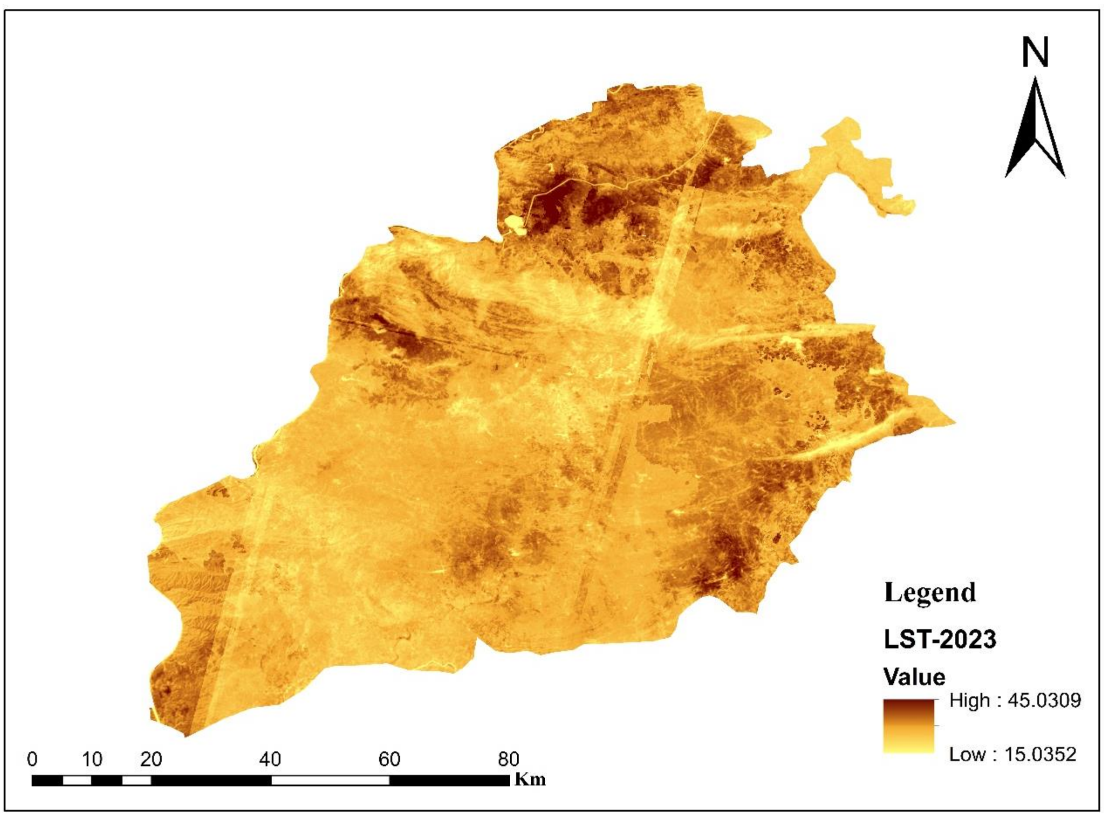

Figure 7: LST Map of Attock, Pakistan 2023

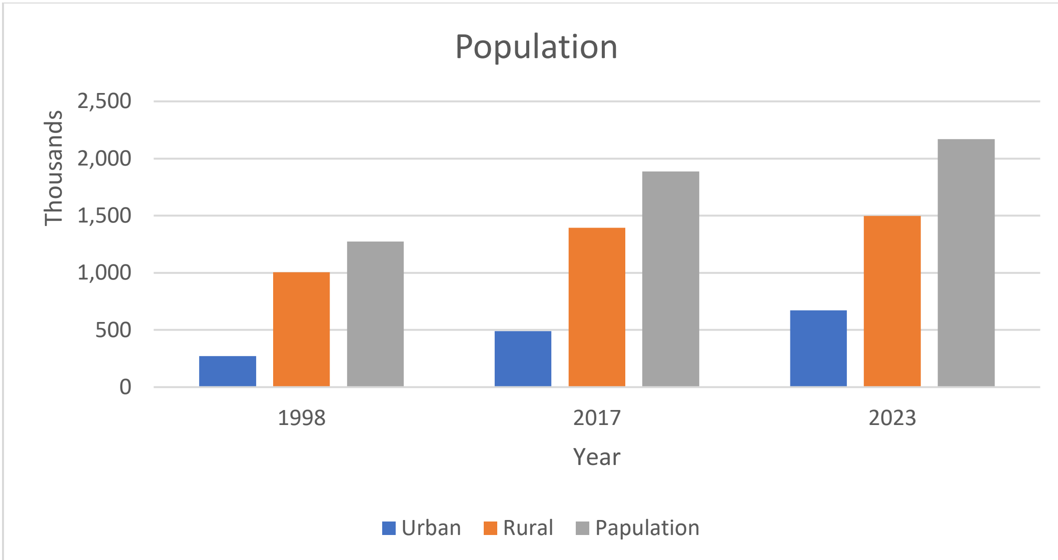

Figure 8: Population Bar Graph of Attock, Pakistan 1998-2023

In the years presented, there are apparent changes in the demographic figures as highlighted in the following analysis. The urban populace in 1998 was 271,092, which drastically rose to 490,908 in 2017 and is projected to be 672,875 in 2023. On the other hand, the rural areas presented a constant increase in the population that in 1998 was 1, 003,843, in 2017 it was 1, 395,470, and in 2023 it will be 1, 497,548. The general population of the area increased from 1,274,935 in the year 1998 to 1,886,378 in the year 2017 and further increased to 2,170,423 by the year 2023. These demographic changes give a picture of the changes in urbanization and population density within the specified period.

The literacy rate of Attock District shows a huge educational disparity with only 38% of the total population defined as educated. This figure means that the majority of them, 62%, are not educated or are illiterate. The findings call for intervention in the form of education campaigns and materials that will enhance literacy levels in the district. It will be important to understand and tackle the factors that have prevented learners from attaining their goals, by doing so a more empowered community in Attock will be developed. Measures aimed at narrowing this literacy gap can go a long way in the development of the region's socio-economy.

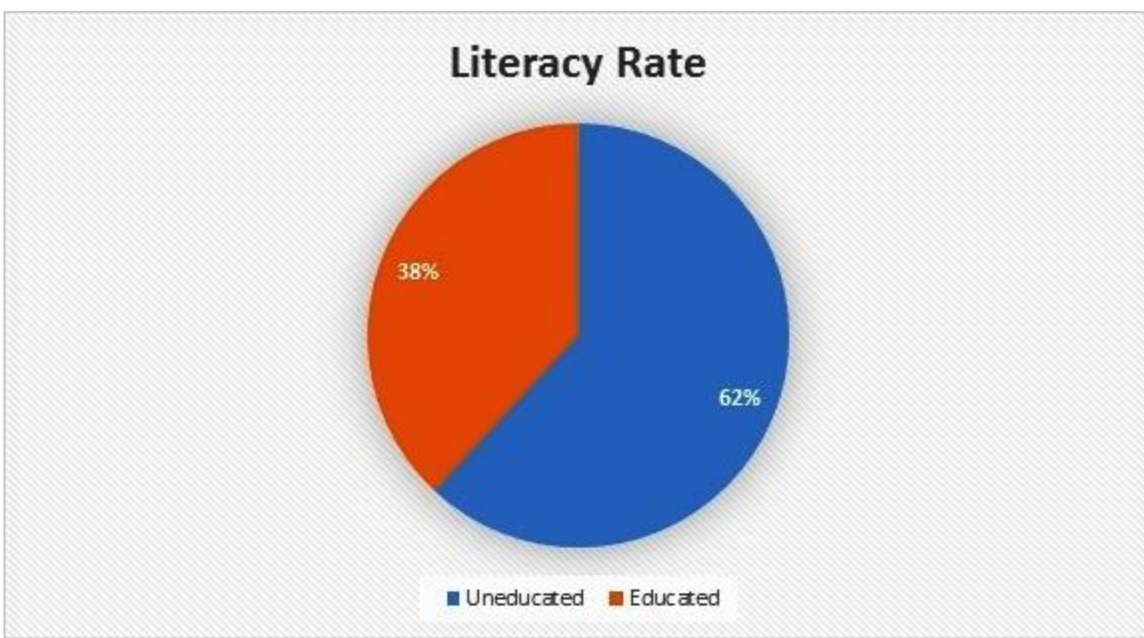

Figure 9: Literacy rate of Attock District, Pakistan

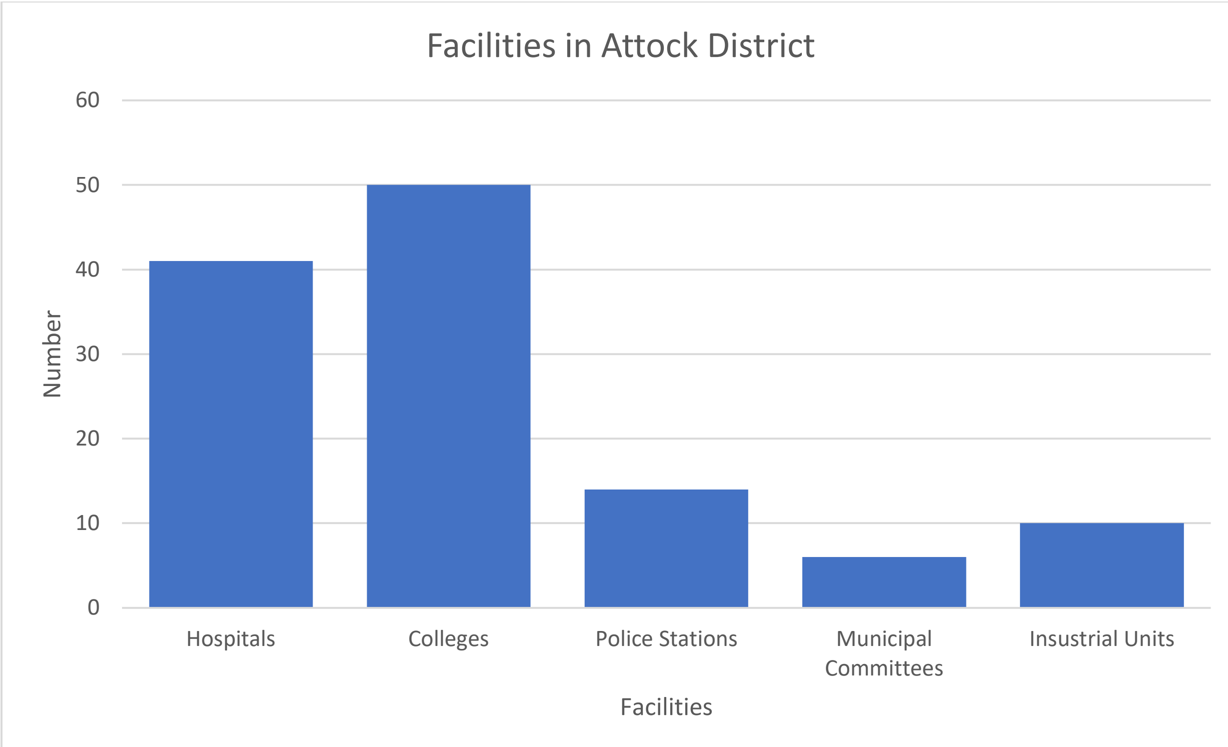

Figure 10: Bar Graph of Facilities in Attock District, Pakistan

From the data given, it is possible to state that the infrastructure of the given region is quite well-developed as it presents a relatively dense network of facilities. At the moment, there are 41 hospitals, thus providing healthcare availability. The educational facilities are well developed with fifty colleges indicating the focus on education. The issue of safety and security is well taken with 14 police stations located all over the area. Local administration is present with six Municipal Committees. Also, the industrial sector has 10 operating units and is involved in the growth of the economy of the region. This infrastructure snapshot paints a picture of a framework that will address various needs of the community.

Conclusion: In conclusion, climate change during the 21st century entails drastic changes that are capable of threatening the growth, development, and existence of human beings. Forests are versatile environmental structures that show some level of resistance but are very much at risk from mankind in the ways of deforestation and the diminishing ability to absorb carbon. Land-use change due to urbanization is a major factor that has an impact on forest cover and is a major source of carbon emissions and environmental issues. The Ghazi Barotha Dam Hydropower Project is a large-scale project of hydel power generation in Pakistan which is a very significant step towards the generation of renewable energy. This project involves taking water from the Indus River to produce electricity using hydroelectric power and is important in providing the energy needs of the region sustainably. During my study, I employed ArcGIS to develop various maps that would help in the explanation of different features of the project. These maps demonstrate the geographical location, water flow distribution, and hydropower facilities location and distribution. Using ArcGIS helped me to assess the environmental effects, determine the efficiency of water distribution systems, and identify the ways of the dam's successful incorporation into the territory. The GIS-based analysis proved advantageous in giving a clear picture of the situation and helped the decision-makers in the Hydropower Project of the Ghazi Barotha Dam. Changes in the LST and deterioration of forests aggravate the environmental problem by emitting stored carbon and thus causing global warming. The recent rate of climate change is associated with the increase in anthropogenic carbon emissions, which makes it important to solve the problem of deforestation and improper land management. The effects are not limited to environmental issues but also impact socio-economic issues and slow down the achievements of SDGs. The case of Attock District in Pakistan is quite informative in terms of understanding the regional nature of climate change. Thus, by analyzing the temperature and vegetation conditions in the Mega Hydropower Project's surroundings, it is possible to identify fluctuations in these factors year by year. These climatic changes affect the project's productivity, power output, and lifespan. Furthermore, the study focuses on the socio-economic effects in the context of local communities, which requires the consideration of climate change adaptation and long-term development strategies. The given NDVI and LST maps give an illustration of the vegetation changes and thermal conditions. The shifts in population demographics and literacy trends point to transformations in urbanization and learning processes. A brief look at the region's infrastructure shows a strategic framework of the health sector, education, security, and industrialization.

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