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Research Article

Understanding Past and Predicting Future Climate Changing Scenarios through Tree Rings in Oak Forest Region of Khyber Pakhtunkhwa, Pakistan

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ABSTRACT

The Earth's climate system exhibits variability in temperature and rainfall, among other factors. However, existing weather station and satellite observations are too short or sparse to capture this variability fully. To address this limitation, we used tree rings to archive information about past environmental conditions. Tree rings are formed based on various physical, biochemical, and environmental conditions present during the year they were formed, making them a valuable tool for understanding long-term climate variability. They provide a detailed record of environmental conditions, such as temperature, precipitation, and drought, over the lifetime of the tree. This information can be used to reconstruct historical climate patterns and understand how they have changed over time. Tree rings are formed when a tree grows a new layer of wood each year. Various environmental factors, such as temperature, precipitation, drought, and sunlight, can influence the width and characteristics of these rings. The study focused on understanding past and predicting future climate-changing scenarios in the mountainous by using the most common and straightforward measurement of the width of the annual ring, which reflects variability in the factors responsible for annual growth. The rainfall pattern and temperature fluctuations in the region have been found to exhibit a complex relationship. The rainfall pattern has shown variations, and the temperature has experienced increases during specific periods. We observed an increase in the frequency of droughts and flooding events in the study area. Tree rings from Malam Jabba showed the highest rainfall decline in the late 1990s, while an increase was observed in Miandam, Kalam, and its upper mountains. Similarly, we noted moderate to extreme droughts in the years 1918 to 1935, and then in the years 1960 to 1965, 1987, and then with some intervals, i.e., 2014 to 2018, both in lower and upper Swat regions. The analysis of tree rings has revealed a significant positive trend in the magnitude of maximum annual and seasonal temperatures in both the upper and lower regions of Swat, particularly during the late winter and early summer periods. This trend was observed to be most pronounced during the 1950s and 1960s.

Keywords: Tree Rings; Annual Summer Temperature; Climate Change; Swat; Pakistan

INTRODUCTION

Climate can be defined as the “average weather conditions” or in the statistical description in terms of the mean and variability of relevant weather components of an area over prolonged periods called climate (Wilks, 1992; Qasim et al. 2014; Masood, et al. 2023). Classically, a minimum period of thirty years is kept as standard. Thus, climate change refers to any significant change in the measures of climate lasting for an extended period of time (Wadanambi et al., 2018). Similarly, according to UNFCCC (1992), climate change means "a change of climate, attributed directly to human activities, that alerts the composition of the global atmosphere, and which is in addition to natural climate variability observed over comparable periods”.

There are many natural and anthropogenic causes of greenhouse gas emissions and other driving forces responsible for climate change. Natural levels of greenhouse gases in the atmosphere are essential for life on Earth. The primary drivers of modern climate change are the increased human-caused emissions of greenhouse gases, especially carbon dioxide from burning fossil fuels and deforestation, which are amplifying the natural greenhouse effect and leading to global warming (Wadanambi, et al. 2020; Khan, 2013). The industrial revolution has been a significant factor in the increase of greenhouse gas emissions over the last two centuries. The use of machines and mechanization of processes, rapid urbanization, and the development of industries that rely on fossil fuels have all contributed to this increase (Wadanambi, et al, 2020; Khan, 2013).

Deforestation, which is another important driving force of climate change, is responsible for 25% of the world's total greenhouse gas production (Khan, Z.A, 2013; Bennett, 2017). Furthermore, forests around the world store more than double the amount of carbon dioxide that is found in the atmosphere. This means that when areas are deforested, the carbon dioxide stored in those trees is released into the atmosphere, contributing to greenhouse gases and climate change. Similarly, agricultural practices, especially using pesticides, ploughing, and biomass burning, are also very important in terms of climate change (Bennett, 2017). vegetation plays a vital role in the global carbon cycle, acting as a natural carbon sink and storage system as burning occurs, it can release hundreds of years' worth of stored carbon dioxide into the atmosphere in a matter of hours. It has been estimated that the total amount of biomass burned by humans makes up a whopping 90% of the total number, whereas natural fires are only around 10%. According to NASA, "Since fires produce carbon dioxide, a major greenhouse gas, biomass burning emissions significantly influence the Earth's atmosphere and climate. Above mentioned causes are just a few, and there are many more discussed in the following paragraphs.

For authentic documentation of climate changes, researchers have used various approaches and methodologies, including monitoring GHG emissions, urbanization, deforestation, and various spatiotemporal data analysis via GIS and RS from a regional to global scale. Similarly, paleoclimatology is another emerging field of understanding past, present, and future climatic changes and global warming (Waltman et al., 2022).

The retrospective nature of paleoclimatology and dendroclimatology offers valuable insights into the past, but their long-term perspective also provides crucial context for understanding present climate variability and change. This is particularly significant in the context of tree-ring data and the climate reconstructions that can be generated from them. Paleoclimate reconstruction of past global and hemisphere-scale temperatures allows us to analyze temperature trends in the full context of the last millennium, identify the magnitude and spatial patterns associated with changes due to radiative forcing anomalies from volcanic eruptions, solar variability, and greenhouse gas emissions, and characterize patterns of internal climate system variability at timescales from decadal to centennial (Fyfe, et.al, 2013, Schmidt et.al, 2018).

Considering the authenticity, novelty, and highly scientific approach described above, this research was designed to study climate change through tree rings in the mountainous region of Khyber Pakhtunkhwa. The goal was to construct a pattern of changes in rainfall and droughts in high mountainous regions of Swat for about a hundred years through tree rings.

MATERIALS AND METHODS

Location and importance of study area

This study was conducted in District Swat, a mountainous region in the Khyber Pakhtunkhwa Province of Pakistan (Figure 1). This area is characterized by the following features of topographic and ecological zones;

- District Swat consists of many valleys with scrub and/or coniferous forests on the upper slopes.
- The upper ridges of the mountains are covered in alpine pastures.
- The region has three distinct topographic and ecological zones, which provides a good basis for comparative analysis.

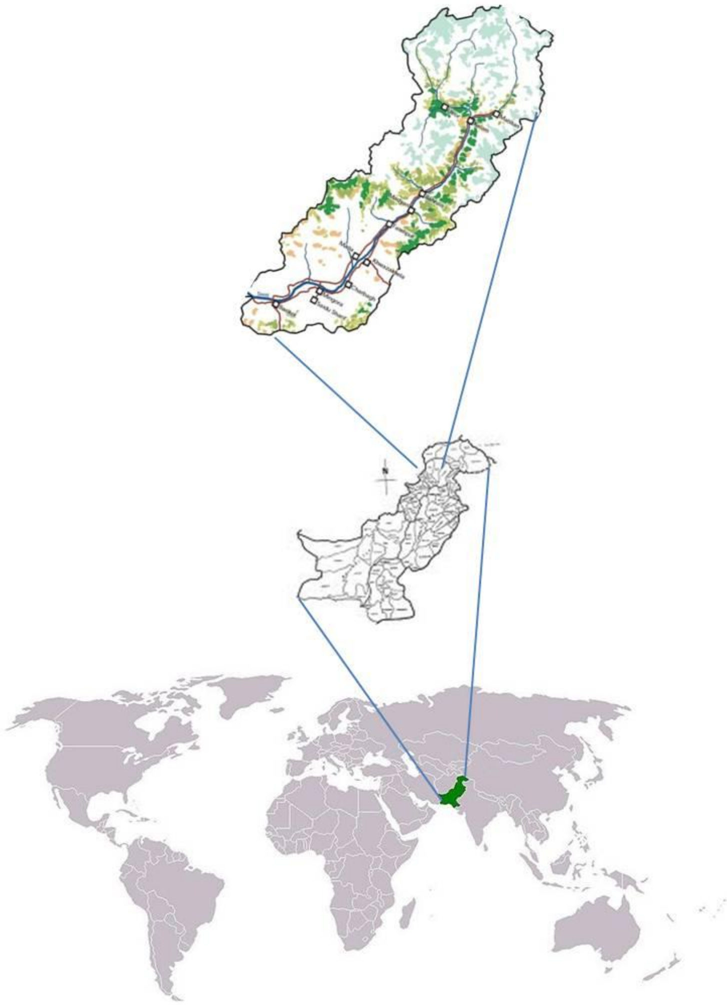

Figure 1: Location of the study area (District Swat) on World Map

The area of district Swat is 5037 km^2, and the total population is 2.3 million (GoP, 1999). The average population density is $248/km^2$. The Swat district in Pakistan can be divided into three distinct regions based on the dominant land cover types:

1. Kalam region (the forest zone): This northern region of Swat is dominated by coniferous forests and alpine pastures. The elevation can reach up to 6,500 meters above sea level. Compared to the mid- and lower regions of Swat, this region has a lower population density and less developed infrastructure.
2. Malam Jabba region (the agro-forest zone): This middle area of Swat has a mix of agricultural land and pine forests as the main vegetation cover. Agriculture is more dominant than forests, and the area has a few larger settlements but is less densely

populated than the southern region. The elevation in this zone ranges between 1,000 and 2,000 meters above sea level.

3. Southern region: The southern part of Swat district has a higher population density and more developed infrastructure compared to the northern and middle regions. The land cover in this area is likely more urbanized and developed.

Figure 2: Getting trained for TRW data

The climate of most of the district Swat is temperate to sub-tropical, characterized by pleasant weather throughout the year. Winter, which lasts for 4 to 5 months, is mild but can be harsh at times. In contrast, summers are mildly torrid. The upper areas of Swat often receive significant snowfall. There are two main rainy seasons: the winter rains during the Rabi season from November to May and the summer monsoon during the Kharif season. These rainy seasons provide the necessary water for the respective crops [1].

Data Collection and Analysis

There are multiple methods that are appropriate and reliable for monitoring various drivers of climate change.

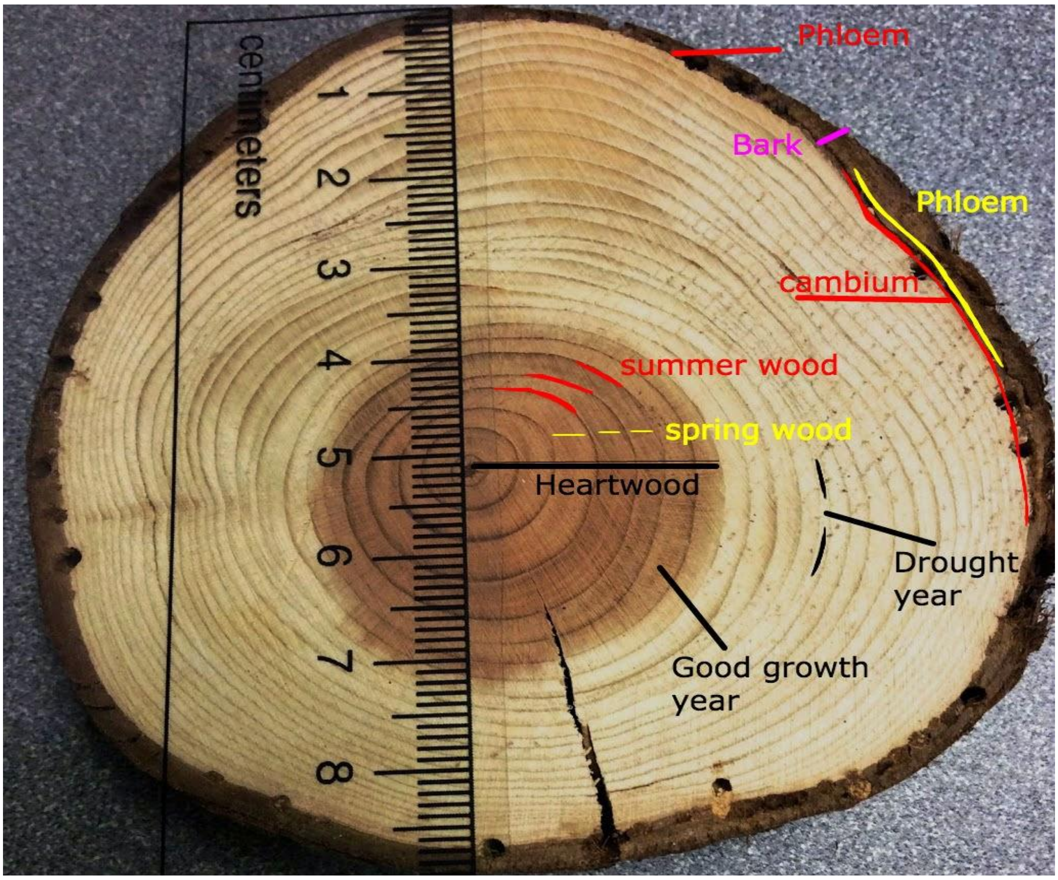

Figure 3: Sample of tree rings showing good growth and dry / wet periods (Source: Internet / google)

But in most cases the existing observations of the climate system from weather stations and satellites are too short or too sparse to completely characterize this variability, particularly at decadal, multi-decadal, and centennial time scales. And yet these modes of variability are critical for short- and medium-term natural resources management, climate policy, and economic planning. Paleoclimatology is the study of past climates, which is crucial for understanding the Earth's climate system and predicting future changes. One of the primary challenges in paleoclimatology is that direct instrumental records of climate data are limited to the past few centuries. To overcome this limitation, researchers use proxy data, which are indirect indicators of past climate conditions. Tree rings are a significant source of proxy data, providing valuable insights into the climate of the past several thousand years.

The most common and straightforward measurement is the width of the annual ring, which reflects variability in the most limiting factor for annual growth. Subannual measurements of the ring may resolve seasonal climate variations (Meko and Baisan 2001). Therefore, in this project, we also followed the same methodology of counting, measuring, and analyzing the tree rings from the study area (as shown in Figure 2 above). Trees were selected based on type, elevation, and age within the study area.

Authenticity of the data

There are several proxies that can be used to quantitatively reconstruct past temperature and hydro-climate variability before the advent of modern instrumental, historical, and satellite measurements of climate and weather. These proxies provide valuable insights into the Earth's climate history, allowing us to better understand long-term trends, patterns, and variability. Tree rings have had several advantages as proxies over the last few thousand years: they are widespread over the mid-latitudes, particularly across the Northern Hemisphere. They are precisely dated to their year of formation, which allows not only exact chronological determinations of past climate anomalies but also statistical comparison and calibration with corresponding instrumental records of climate where both overlap. This precise dating is crucial for understanding past climate fluctuations and making accurate predictions about future climate trends.

RESULTS

Table 1 below details the collected samples, their number, location, and the age of the tree calculated from the number of tree rings.

Table 1. Number and age of samples from various sites

Site	Total samples	*Quercus robur*	*Cedrus deodara*	*Populus nigra*	Highest age	Lowest age
Kalam and Gabral areas	10	6	3	3	180	45
Miandam and nearby areas	10	8	2	0	165	50
Malam Jabba area	10	6	2	2	130	70

We clearly got the oldest sample from Gabral, where the oak tree noted was 180 years old. In the Miandam area, from the same site, we also had a sample of a populus tree, which was 45 years old only. Here, it may be noted that, apparently, the tree trunk (sample) in diameter was big enough.

Table 2. Topographic and Edaphic Variables of Sampling Sites

Location	pH	EC	TDS	OM	Elevation	Slope	Aspect
Kalam	6.07	1249	61.8	11.2	2898	35	NE
Miandam	5.75	1495	68.3	10.7	2700	30	NW
Malam Jabba	5.95	1364	68.2	11.1	2461	33	NE

EC electrical conductivity: TDS total dissolve solids: OM organic matter: Aspects (East, West, North, South)

Annual Rainfall and its Changing Patterns:

As clear from Figures 5 and 6, the annual rainfall in each ecological zone was assessed from the tree rings based on its thickness and other associated growth patterns. In Swat, there is great altitudinal variation therefore; large variability in rainfall has been recorded. The highest average annual rainfall was recorded at Malam Jabba, followed by Miandam and its surrounding areas. Lesser or minimum rainfall was noted in Malam Jabba region in the decades from early 1980s to 1990s, and this was a drought years in the whole study area.

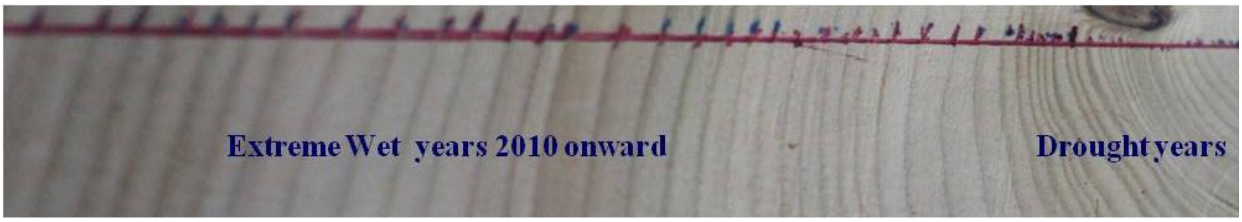

Figure 4. TWR showing drought and wet periods

Similarly, an increase in summer rainfall in the Miandam and Kalam region was observed from the tree rings of the year 1957 to 1960, which could have been flood years in river Swat. Another of the highest precipitation levels was observed in 1988 in Madyan and the surrounding areas. The minimum rainfall was observed in 1971 and 2001, respectively, in lower and mid-Swat. From young tree samples, we observed the highest rainfall in 2010 and 2022, which is a record and confirmed by other sources.

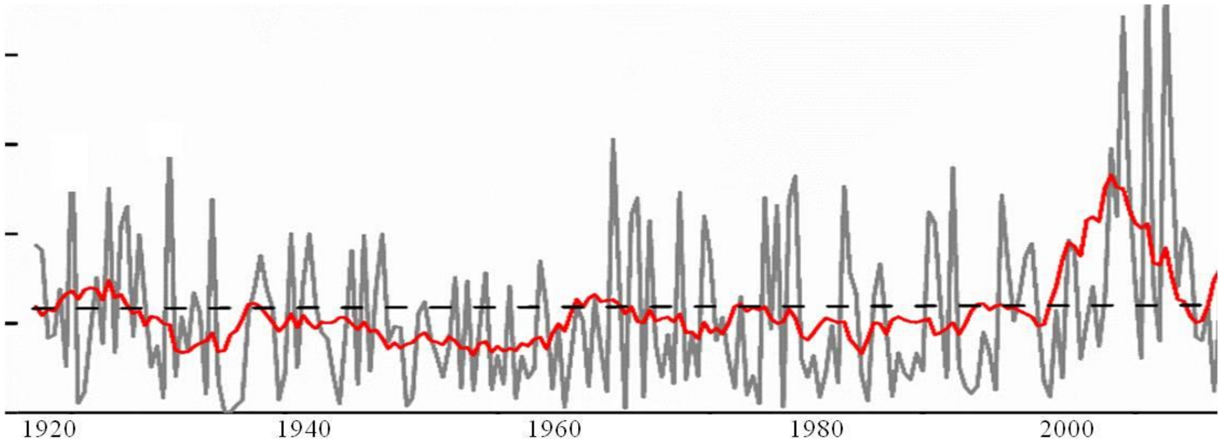

Figure 5: Average of all TRW samples for showing the rain and drought trend

Statistical Analysis of Tree Rings Data

Three standard chronologies were developed using Oak trees from Kalam, Miandam, and Malam Jabba Valleys (Table 3). The Kalam represented the oldest chronology, 180 years. The mean TRW (Tree-Ring Width) of the Miandam chronology was 0.98, with a standard deviation (SD) of ± 0.23 around the mean value. Additionally, the Malam Jabba chronology represented a growing record of 130 years and had a threshold value greater than 0.85.

Table 3: Statistical Analysis of Tree Rings Width and Site Description

Site	**Kalam**	**Miandam**	**Malam Jabba**
Species	*Quercus robur*	*Quercus robur*	*Quercus robur*
Latitude (N)	35° 49′	35° 04′	34° 79′
Longitude (E)	72° 59′	72° 56′	72° 57′
Elevation range (m)	2001-3074	2020-3060	2252 - 3349
Chronology span	1842-2022	1857-2022	1892- 2022
Series-inter correlation	0.65	0.65	0.61
Mean R_{BAR}	0.54	0.60	0.48
R_{BAR} within a tree	0.84	0.90	0.68
R_{BAR} between trees	0.50	0.57	0.44
Standard deviation	0.24	0.25	0.26
Mean sensitivity	0.24	0.30	0.20
EPS > 0.85 since	1560 (0.97)	1490 (0.95)	1740 (0.97)
Missing rings (%)	08	11	09

All chronologies (Table 3) showed an overall positive growth tendency as the TRWs, in majority, were consistently near to or > 1. This positive growth tendency suggests that the data is generally increasing and expanding over time, which can be an important indicator of various economic and financial trends. TRWs, that were less than 1 in each chronology and did not consistently show a decline in growth trends over at least 9 consecutive years with an average of less than 0.7 cannot be considered reliable indicators of a decline in growth trends. (Li & Zhang, 2017). A significant and strong association was found between all site's chronologies for the periods 1980 to 2000. The correlations grew stronger for progressively younger chronologies, particularly between 2000-2022 for Miandam and Malam Jabba.

Climate-tree growth assessment

The reliable mean sensitivity, which is the year-to-year ring width variability to climate parameters, and higher EPS values > 0.85 for our study sites indicated a coherent stand level. Consequently, we examined the influence of climatic parameters on tree growth, and correlation analysis was performed between the climate data and individual tree ring widths to understand the relationship between climate and tree growth patterns.

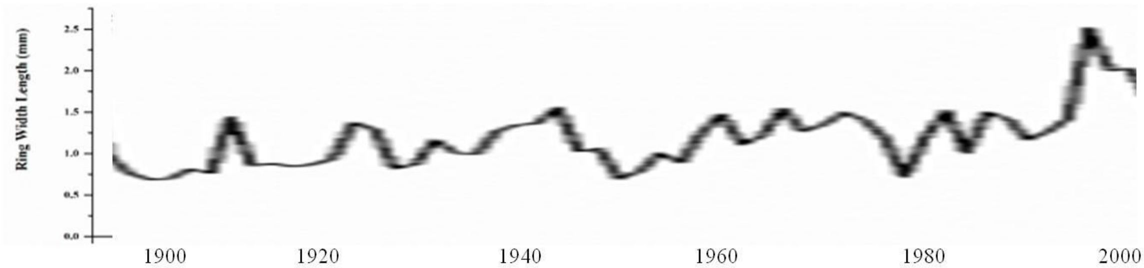

Figure 6: TRW data of various samples from Kalam and nearby areas

Changes in Annual and Seasonal Temperature Patterns

It is obvious from the analysis that the rainfall pattern varied a bit in a complex manner, and the temperature also increased during various periods. We observed an increase in the frequency of droughts as well as flooding events in the study area. Tree rings from Malam Jabba showed the highest decline in the amount of rainfall in the late 1990s, while an increase was observed in Miandam, Kalam, and its upper mountains. Similarly, we noted moderate to extreme droughts in the years 1918 to 1935, and then in the years 1960 to 1965, 1987, and then with some intervals, i.e., 2014 to 2018, both in lower and upper Swat regions.

Figure 6: TRW data of various samples from Miandam and nearby areas

It was found from the analysis that the mean annual temperature has a rising trend in late winter and early summer, especially during the 1950s to 1960s. The results derived from rings revealed a notable positive trend in the magnitude of maximum yearly as well as seasonal.

DISCUSSION AND CONCLUSION

Spatial Distribution of Seasonal Rainfall Trend

In Khyber Pakhtunkhwa, rainfall mostly occurs from summer monsoon and western disturbances in distinct time periods. Almost 60% of the annual average rainfall occurs from monsoon winds during the summer season in the months of July to September. As the monsoon enters the province from the east, the eastern parts, especially the mountains, i.e., the lesser Himalayas and some parts of the Hindu Kush ranges, receive ample amounts of rainfall from the monsoon. The winter and spring seasons receive rainfall from western disturbances. These winds originate from the Mediterranean Ocean and enter Khyber Pakhtunkhwa from its west through Afghanistan; thus, the meteorological stations located in the western part receive comparatively more rainfall during winter and spring. Thus, most of the areas in District Swat receive the highest rainfall from western disturbances. As we observed from samples of Malam Jabba, the area receives a high amount of rainfall almost in all seasons, but a comparatively higher amount of rain is received in monsoon. The seasonal rainfall analysis shows a significant negative trend in winter at Kalam, while a significant positive trend was found at Malam Jabba and Miandam Valley.

Discussion on Environmental variables

As we know trees rely on various environmental factors such as soil characteristics, topography, and climatic conditions for their growth and development. Soil characteristics, including the presence of organic matter, play a crucial role in supporting tree growth. However, arid zone soils often have low amounts of organic matter, which can limit the growth and survival of trees in these regions. (Aubert 1960). The pH of the forests in this study ranged from 5.4 to 6.7, which is consistent with previous findings. Malik et al. (1973) recommended a pH range of 6.0–6.5 as ideal for the growth and development of pines. According to Siddiqui (2011), pH values from 5.2 to 7.0 were recorded from different pine forests of Pakistan's moist temperate areas of the Himalayan and Hindukush ranges. This range indicates that the pH levels in these forests are generally neutral to slightly alkaline. The study by Siddiqui (2011) focused on the community structure and dynamics of coniferous forests in these regions, highlighting the variations in edaphic variables across different climatic zones. Specifically, Malam Jabba in the Swat District of Pakistan, which is a moist temperate area, showed some variations in edaphic variables compared to other climatic regions. These variations are likely influenced by factors such as soil composition, altitude, and local environmental conditions. Tree-ring studies have made significant contributions to understanding environmental changes and forest stand dynamics (Pederson et al. 2007). Environmental factors often restrict further expansion of the population on the limit of distribution of a tree species, e.g., a timberline on a mountain (Block and Treter 2001).

Recommendations

This study was carried out in various parts of District Swat to understand the past and predict future climate-changing scenarios through tree rings in the oak forest region of Khyber Pakhtunkhwa, Pakistan. The study revealed that considerable changes in rainfall and temperature have taken place since nineteen hundred onward. This study is on the basis of the variation in tree rings width associated with the temperature and rainfall. According to the findings of this study, there is a decreasing trend in rain while having some very high rain events as well. The flow of water changed in the downstream rivers during such high rainfall events. The increase in temperature and the flow of water has negative impacts like the availability of fresh water for household use and the availability of water for irrigation purposes. To tackle these issues following are some recommendations;

Institutional capacity in the country should be enhanced to face different environmental challenges on local and global scales. The efficiency of current environmental institutions should be enhanced to work properly on the current environmental issues. For food security, trans, boundary study/research regarding climate change and its effects, like the melting of glaciers, through the use of new technology and scientific manner, should be maintained/encouraged. Climate change adaptation efforts should be/enhanced, especially in rural communities where they typically depend on agriculture production. The water flow in the downstream rivers should be monitored with an advanced flood warning system. Policies should be made and implemented regarding the sustainable utilization of freshwater resources for different purposes like household and agriculture use.

Data Availability Statement

All relevant data are within the paper and its Supporting Information files.

Conflict of interest/ Competing interests

The authors declare that they have no conflict of interest. The authors have no relevant financial or non-financial interests to disclose. The authors have no competing interests to declare that are relevant to the content of this article.

Consent for publication

A written informed consent was taken from all the participant of the study and all shows willingness for publication of their data.

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