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Methodological Insights from Robust Least Squares Regression: Climate Risk, Economic Factors, and Forest Ecology Management in Pakistan

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ABSTRACT

The study of forest ecology is essential to achieve sustainable development goals. One of the critical determinants of forest ecology is the impact of climate risk. The recent floods in Pakistan have highlighted the role that factors such as deforestation, resulting from increased economic infrastructure, can play in exacerbating the effects of climate risk. This study examines the relationship between climate risk factors and forest ecology in the context of Pakistan's economy, using data from the last three decades. The study used robust least squares regression to minimize outliers and reduce irregularities in the model. The results indicate that water scarcity, high temperatures, agriculture technology, and poverty in rural areas negatively impact forest ecology in Pakistan. On the other hand, excessive rain and the active involvement of community stakeholders positively impact forest ecology. However, it is also noted that implementing agricultural mechanization can positively impact the conservation and improvement of forest ecology. Overall, a comprehensive and multi-disciplinary approach must be taken to address the impact of climate risk on forest ecology in Pakistan, involving collaboration among government, private sector, and civil society actors.

Keywords: Forest Ecology; Climate Risk; Agriculture Mechanization; Rural Poverty; Rural Unemployment; Robust Least Squares Regression; Pakistan.

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Introduction

Forest ecology is a broad and multifaceted discipline that examines the interconnections and linkages between woodlands, their dwellers, and the surrounding environment. This field of research is crucial for comprehending how forest ecosystems work and how human actions affect these systems (Wani & Sahoo, 2021). Forests are vital to society and the economy because of their many ecological services, including water control, carbon sequestration, and biodiversity protection. Loss of these services may devastate people's livelihoods and quality of life (Kumar & Choudhury, 2021). Soil erosion, water shortages, and biodiversity loss are all things that may happen when a forest ecosystem is destroyed, all of which can have a detrimental effect on local populations and the economy (Wassie, 2020). Forests play a crucial role in preserving the planet's climate and biodiversity. Forests are an essential carbon sink because they remove and store large quantities of carbon dioxide (CO2). Lowering atmospheric CO2 levels helps to lessen the severity of climate change. Also, many plant and animal species that exist only in forests cannot be found anywhere else on Earth (Joshi & Sigh, 2020). The loss of these species may have far-reaching consequences, including reducing biodiversity and the effectiveness of ecosystems. However, logging, farming, and urbanization are only a few of the human activities that have contributed to the loss and deterioration of forests across the globe. This has resulted in the decline of biodiversity and the inability of ecosystems to provide essential functions, which has repercussions for human well-being and the environment. Therefore, the management and conservation of forests must be approached from a multi-dimensional viewpoint that considers both the social and economic value of forests (Bodo et al. 2021; Huang et al. 2022).

Due to their crucial role in controlling the earth's temperature and their extreme vulnerability to the effects of climate change, forest ecology and climate risk are inextricably intertwined. For this reason, forests are sometimes called "carbon sinks" because of the amount of carbon dioxide (CO2) they take up and store. Because CO2 is a crucial contributor to global warming, this helps to lessen the severity of climate change (Chang et al. 2021). Drought, wildfires, insect outbreaks, and illnesses are just a few of the many threats posed to forests by a changing climate (Krawchuk et al. 2020). The loss of trees and other plant life in forests due to these factors may accelerate climate change by releasing carbon that has been sequestered there (Venalainen et al. 2020). The distribution and makeup of forest ecosystems may shift due to climate change. Forest ecosystems may be disrupted when tree species move their ranges and distributions in response to changes in average temperatures and precipitation. This may have knock-on consequences across the ecosystem, reducing biodiversity and, ultimately, the ecosystem's ability to operate. Wildfires and storms, which may do extensive damage to forests, may become more often and more severe due to climate change. This may destroy forest ecosystems, the release of carbon stored there, and ultimately, the loss of forest cover (Abram et al. 2021). In addition, when sea levels rise, and weather patterns shift, saltwater intrusion into coastal regions and mangrove forests is a potential consequence of climate change Consequently, this may endanger not just the vital ecosystems and the species that rely on them but also the way of life of the nearby humans. Forests are vulnerable to the effects of climate change. Therefore it is crucial to plan for them. The effects of

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climate change on forests and their occupants may be mitigated by adaptation and mitigation strategies such as aided migration, reforestation, afforestation, and agroforestry (Seddon, 2022). As a result, it is essential to consider the effects of climate change on forests when formulating conservation and management plans. Proactive measures can protect forests and the ecosystem services they offer while mitigating the adverse effects of climate change on people (Weiskopf et al. 2020).

Over the last several years, Pakistan has been hit hard by the effects of climate change, especially in the form of devastating floods. Population increase, urbanization, and agricultural expansion are only a few stresses on the country's forests. As a result, there has been a drastic reduction in forest cover and increased exposure to climate-related risks (Ullah et al. 2019; Ajani & van der Geest, 2021; Shahzad et al. 2021). Recent floods in Pakistan were brought on by torrential monsoon rains, which overflowed rivers and wreaked havoc on the country's infrastructure, housing stock, and agricultural output. Deforestation and degradation of natural ecosystems worsened these floods since trees usually act as sponges that reduce runoff. The soil became more erodible due to the absence of vegetation, which increased the severity of floods. The recent floods have had a catastrophic effect on the economy and the lives and well-being of the country's population. Many have lost their houses, farms, and means of subsistence and must depend on humanitarian help. It will take time and money to reconstruct and recover from the damage to infrastructure and agriculture, which will have lasting effects on the economy (Ochani et al. 2022; Rana et al. 2022; Naddem et al. 2022; Imran et al. 2023). Table 1 shows the forest area trends in Pakistan over time.

Table 1: Forest Area Trends in Pakistan over Time

Year	Total Forest Area (Million Hectares)	% of Land Area	Trend
1990	4.6	5.3%	Declining
2000	4.2	4.9%	Declining
2010	3.8	4.4%	Declining
2020	3.5	4.2%	Declining

Source: Economic Survey of Pakistan (various issues).

The environmental impacts and fuel sources of deforestation in a group of chosen Asian nations were investigated by Bhuiyan et al. (2018). Using fossil fuels and adapting to a changing climate were proven to have detrimental effects on biodiversity. According to the findings, sustainable policies, such as the utilization of alternative fuels and conservation initiatives, are needed to slow the rate at which biodiversity is being lost in these nations. Environmentalists and policymakers should take note of this study because it emphasizes the critical need to take immediate action to save biodiversity and develop long-term strategies. Using globally aggregated data from 1970 to 2018, Yue et al. (2020) examined the connection between agricultural sustainability, ecosystem biodiversity, and resource price. Unsustainable resource use and animal-rich biodiversity in forests enhance carbon emissions, whereas food production is predominantly carbon associated, as observed

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in the research. This research lends credence to the mineral resource curse theory by showing that resource rents and energy demand are associated with increased carbon emissions. The findings imply that sustainable policy tools are required to lessen the global financial burden of carbon abatements, such as developing renewable energy sources, adopting environmentally friendly manufacturing methods, and protecting forest biodiversity. The effects of climate change on Pakistan's biodiversity are the focus of Anwar et al. (2022). Given the growing dangers posed by climate change, the study emphasizes the country's wide variety of plant and animal life. They survey current climate change patterns worldwide and in Pakistan and analyze how these shifts may affect various ecosystems and forms of biodiversity. Existing institutional and policy frameworks are also analyzed, and recommendations for improving biodiversity conservation in Pakistan are made. The study suggests vital community awareness programmes and capacity development for relevant departments, along with actions like afforestation and restoration of degraded ecosystems, as ways to increase communities' adaptive capabilities and contribute to climate mitigation. Table 2 shows the different climate risk factors that impact on the Pakistan's different regions.

Table 2: Key Climate Risks Affecting Forest Ecology in Pakistan

Climate Risk Factor	Impact on Forest Ecology	Vulnerable Regions
Rising Temperature	Heat stress, tree mortality	Sindh, South Punjab
Erratic Rainfall	Drought and flash floods	Baluchistan, KPK
Glacial Melt	Changes in water flow and soil erosion	Gilgit-Baltistan
Wildfires	Loss of vegetation and biodiversity	KPK, Azad Kashmir

Source: Adapted from the scholarly work of Kausar et al. (2025) and Yousaf et al. (2025).

Deforestation in Brazil's Amazon rainforest has been evaluated by Zaman (2022), who finds that a higher yearly deforestation rate contributes to global warming. Short- and long-term carbon emissions are shown to be reduced by positive shocks of forest rents, whereas negative shocks of the nation's biocapacity deficit and fossil fuel burning increase emissions. The research found that to mitigate climate change, the government should lower its ecological footprint, reduce its use of fossil fuels, and increase forest rents. Abbas et al. (2022)'s research is focused on identifying the factors that help and hinder efforts to achieve land degradation neutrality (LDN) in Pakistan. The authors employed a multi-pronged strategy to gather and evaluate data from sixty-three different organizations with a stake in land management. The research found that willingness to constantly, organizational alignment, and community partnerships were all crucial to effective LDN management. The research also found that there are several advantages and drawbacks to LDN, such as economic growth and environmental sustainability. Special financing, risk-sharing facilities, and

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environmental conservation performance clauses are just a few of the legislative suggestions made in the report to encourage private investment in LDN. This study sheds light on the most critical considerations for implementing LDN regulations and attracting capital enterprise in land management. Asghar et al. (2022) investigate the obstacles and possibilities of using sustainable power in Pakistan. Specific measures are suggested for policymakers and city municipalities to improve energy infrastructure, knowledge, and capacity for overcoming future challenges. The study emphasizes the need for competent policies, incentives, technological expertise, and substantial fiscal and political obligations to achieve these objectives. The research shows that although renewable energy development in Pakistan has been successful, a more efficient and effective strategy is needed to reap this achievement's advantages fully. China's Belt and Road Initiative relies heavily on the success of the CPEC, and Khaskheli et al. (2023) analyze the role that legal risks, social security, employee environmental awareness, and gender empowerment viewpoints play in this success. The study's overarching goal is to learn how these variables would affect the $46 billion, 15-year CPEC project by 2025. Policymakers and other interested parties may use the study's findings to understand better the CPEC's risks and opportunities for improving its future performance. Table 3 shows the wide economic factors influencing forest management in Pakistan.

Table 3: Economic Factors Influencing Forest Management

Factors	Effect on Forests	Description
Poverty	Overdependence on wood for fuel	Rural communities harvest more firewood
Illegal Logging	Deforestation and habitat loss	Weak enforcement drives timber smuggling
Low Forestry Budget	Slow policy implementation	Insufficient management resources
Agricultural Expansion	Forest land conversion	Forest area shifts to crops and livestock

Source: Adapted from the scholarly research work of Ullah (2025) and Hashmi & Asif (2025).
From this discussion, five research questions were derived:

How does deforestation increase the consequences of climate risk on forest ecology in Pakistan? This question aims to learn more about the effects of climate change, namely flooding, on Pakistan's forest ecosystems due to the country's growing reliance on concrete and steel. The information collected over the last three decades will be analyzed to determine the full scope of the issue and pinpoint priority regions.

How can weather extremes like heat, drought, and flood contribute to the depletion of Pakistan's forest reserves? This study's overarching goal is to ascertain how climatic shifts have affected the ecosystem of Pakistan's forests. It will look at how lousy weather affects forest reserves and pinpoint the most dangerous places.

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How does the lack of economic opportunity in rural areas of Pakistan affect the ecology and management of the country's forests? This question aims to investigate how social and economic variables influence forest ecological management in Pakistan. It will examine how economic hardships influence forest reserve management and conservation efforts and pinpoint problem areas that need more attention.

Is there any evidence that increasing automation in agriculture has helped protect or enhance forest ecosystems? The question's overarching goal is to examine how agricultural mechanization may be used to improve forest ecology in Pakistan. It will analyze how automation has affected forest preservation and management and pinpoint where it might be most helpful.

Is there a way for the government, the commercial sector, and civil society to work together to mitigate the adverse effects of climate risk on Pakistan's forested ecosystems? The question is to identify the many stakeholders in Pakistan's forest ecosystems and their respective roles in mitigating the effects of climate risk on the latter. Opportunities for collaboration and cooperation will be explored by analyzing the roles of government, the business sector, and civil society players in resolving the issue. The study has the following research objectives:

To investigate the link between increased economic infrastructure resulting in deforestation and the exacerbation of climate risks such as floods on forest ecology in Pakistan.

To understand the impact of climate variability on forest ecology in Pakistan, specifically the relationship between extreme weather conditions and the health of forest reserves

To examine the role of socio-economic factors, specifically poverty and unemployment, on Pakistan's conservation and management of forest reserves

To investigate the potential of agricultural mechanization to improve forest ecology in Pakistan

To understand the role of different actors, including government, private sector, and civil society, in addressing the impact of climate risk on forest ecology in Pakistan and identify opportunities for collaboration and cooperation.

The study's overarching goal is to contribute to our understanding of how climate change and deforestation impact forest ecosystems in Pakistan. This work is the first to include three critical climate risk factors—extreme warmth, water shortage, and unequal rain—into forest ecology modelling, making it a leader among conservation studies and paving the way for effective policy changes toward ensuring the long-term viability of forest ecosystems. Furthermore, the research included rural poverty and agricultural employment as significant elements in forest ecology management in Pakistan; very few studies have used both components in diverse economic contexts (Le & Leshan, 2020; Aye et al. 2019; Nambiar, 2019), but it is essential to collect input from both to protect forest ecology in Pakistan. Rural development and education can reduce economic and social issues. Rural development addresses poverty, unemployment, and infrastructure to improve rural populations' lives. Education is widely believed to improve economic and social mobility and self-

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sufficiency. Rural development and education help create a more fair and sustainable society by providing people with the necessary tools and training (Fatima, 2023). As the prior studies were mainly employed technology advancement in reducing pollution's adverse effects, it is clear that technological progress will continue to play a crucial role in achieving socioeconomic and environmental goals (Imran et al. 2023; Zhang et al. 2023; Yue et al. 2022). Table 4 shows the different policy and governance barriers influencing forest sector.

Table 4: Policy and Governance Barriers in Forest Sector

Barrier	Current Issue	Outcome
Weak Forest Governance	Limited enforcement	High illegal logging
Policy Fragmentation	Overlapping mandates	Slow interventions
Lack of Community Participation	Low ownership	Poor sustainability
Data and Research Gaps	Incomplete monitoring	Poor decision making

Sources: Adapted from the scholarly research work Imran (20250 and Soomro et al. (2025).

Agricultural technology was used for forest ecological modelling in this research, which had less likely to use in Pakistan's forest ecology with climate risk factors. Finally, the contributions of community members vested in protecting natural resources cannot be overstated. Previous research limited to involve community stakeholders in forest conservation studies (Zandebasiri et al. 2022; Larson et al. 2022; Devisscher et al. 2022), which left a gap in forest management policy. From a societal point of view, community stakeholders may help combat climate change by increasing public understanding of the problem and encouraging grassroots efforts to do something about it. Moreover, they can help create and execute plans for coping with and reducing the effects of climate change (Susskind & Kim, 2022; Arsmstrong, 2022). In addition, they can help those who are already feeling the effects of climate change by giving them knowledge and emotional support. Environmentally speaking, natural resource management, including the administration of forests, wetlands, and other ecosystems, may also include significant contributions from community stakeholders. They may also help preserve natural areas and safeguard species diversity. Keeping and restoring ecosystem services, protecting biodiversity, and minimizing climate change's negative consequences are ways these measures might help communities become more climate resilient (Mulatu et al. 2022; Khan et al. 2022). Policymakers, conservationists, and other stakeholders in Pakistan's forest ecosystems would benefit from this expanded knowledge of the effects of deforestation and climate change on forest ecology.

Theoretical Framework

The term "community-based natural resource management" (CBNRM) refers to an overarching theoretical framework that encourages local people to participate in the management, planning, and decision-making processes about natural resources, including forests, fisheries, and wildlife (Adhikari, 2001; Armitage, 2005; Blaikie,

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2006). It is predicated on the premise that people in a particular area have a personal stake in protecting and sustaining their neighbourhood's natural resources (Cheng et al. 2003; Magis, 2010). Theories of CBNRM originate in rural sociology, environmental management, and community building. The commons theory, social capital theory, and political ecology are examples of how they have developed and adapted through time. Acknowledging local people's rights and responsibility for managing natural resources is one of the core ideas of CBNRM. Included are the entitlements to participate in decision-making, reap the benefits of using natural resources, and share the burden of ensuring sustainable management (Chau , 2005; Vestergaard Jacobsen, 2008). Co-management is another fundamental idea, or the division of labour in resource management among many parties (such as local communities, state and federal agencies, and NGOs). This method encourages sharing of knowledge and information between parties, which may improve resource management over the long haul (Castro & Nielsen, 2001; Carlsson & Berkes, 2005). Additionally, CBNRM theories stress the significance of community social, economic, and cultural contexts in the development and execution of natural resource management plans. This way of thinking acknowledges that management practices should be adapted to fit each community's requirements, capabilities, and goals (Tantoh et al. 2020; Ramaano, 2022). In conclusion, CBNRM offers a framework for incorporating local communities in managing natural resources. The study argue that more sustainable and effective management of resources may be achieved by emphasizing local engagement, co-management, and contextualization in natural resource management programme design and execution.

Materials and Methods

The study used forest depletion data (% of GNI, denoted by FECOL) from the World Bank (2024) database, served as forest ecology and response variable in the study. The study used a consistent time series data from 1990 to 2022 for data analysis. Three climate risk factors in forest ecology management is used in the study, i.e., water stress (freshwater withdrawal as a proportion of available freshwater resources, denoted by WSTRESS), temperature change in centigrade (%, denoted by TEMP), and water precipitation (mm, denoted by RAIN). The data of water stress is collected from the World Bank (2024) database while water precipitation data is collected from the World Data Atlas (Knoema, 2022) and change in temperature is collected from World Data Info (2022). Further, the study used two social factors and one technological factors in forest conservation modeling, i.e., rural poverty (%, denoted by RPOV), agriculture employment (% of total employment, denoted by AGRIEMP), and agriculture machinery (number of tractors, denoted by AGRITECH). The data is collected from the World Bank (2024) database. Finally, the study used forest rents (% of GDP) as community stakeholders (denoted by CSH). The economic well-being of local communities is evaluated in connection to forest ecosystems by utilizing forest rents as a proxy for community stakeholders. Because of this, researchers may learn how local people's livelihoods are affected by various management practices and conservation initiatives and how they might better support and participate in such activities. In addition, forest rentals are a reasonable measure of local participation in forest management. Communities will be more likely to take an active role in forest

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conservation and protection if they have access to relevant information and a financial interest in the forest's administration. Communities are more inclined to participate in conservation initiatives and support sustainable management techniques if they can benefit from the forest.

Cross-panel data is a relatively new field that involves using data from multiple countries to study the relationships between them. This type of data is unique in that one country's regressand (the variable being predicted) may depend on the regressors (predictor variables) of other countries. This analysis requires different statistical techniques than those used for time series, cross-sectional, or panel data (Zaman, 2023). Robust least squares (RLS) regression is a statistical approach used to estimate the parameters of a linear model when there are outliers in the data. This method may be used to estimate the parameters of the model even when there are errors in the data. The approach is comparable to regression using conventional least squares, but it is more resistant to including errors or outliers in the data. In the context of forest ecology management, RLS regression can be used to estimate the relationship between forest ecology (FECOL) and the various factors that influence it. These factors include climate risk factors (WSTRESS, TEMP, and RAIN), social factors (RPOV, AGRIEMP, and CSH), and technology factors (AGRITECH). Estimating the coefficients of the linear model, which indicate the influence each element has on the ecology of the forest, is possible with the help of this approach. Estimating this relationship can be done with the help of the RLS regression by minimizing the sum of the absolute residuals. These residuals are the differences that exist between the values that have been observed in forest ecology and the values that have been predicted based on the model. Because it is less reactive to the presence of very high or low numbers, this method is more resistant to problems caused by outliers or inaccuracies in the data. It makes it possible to grasp better the link between the independent factors and the variable being studied (the dependent variable). This approach is helpful for the situation that has been presented, as it can help to identify the key drivers of forest ecology in Pakistan and develop policies and strategies to protect and manage forest ecosystems throughout the country. This makes the practical approach for the situation that has been presented.

The econometric equation can be represented as:

$$FECOL = \beta_0 + \beta_1 WSTRESS + \beta_2 TEMP + \beta_3 RAIN + \beta_4 RPOV + \beta_5 AGRIEMP + \beta_6 CSH + \beta_7 AGRITECH + \varepsilon \quad (1)$$

Where:

$\beta 0$ is the constant term.

$\beta 1, \beta 2, \beta 3, \beta 4, \beta 5, \beta 6, \beta 7$ are the parameters to be estimated representing the effect of each independent variable on the dependent variable.

WSTRESS, TEMP, RAIN, RPOV, AGRIEMP, CSH, AGRITECH are the independent variables, and

ε represents the error term

Equation (1) is further decomposed in the three distinct RLS estimators, i.e.,

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http://amresearchreview.com/index.php/Journal/about

$$FECOL - |TRIM| = \beta_0 + \beta_1 WSTRESS + \beta_2 TEMP + \beta_3 RAIN + \beta_4 RPOV + \beta_5 AGRIEMP + \beta_6 CSH + \beta_7 AGRITECH + \mu$$

(2)

$$FECOL = [\beta_0 + \beta_1 WSTRESS + \beta_2 TEMP + \beta_3 RAIN + \beta_4 RPOV + \beta_5 AGRIEMP + \beta_6 CSH + \beta_7 AGRITECH] - |TRIM| + \mu$$

(3)

$$FECOL - |TRIM| = [\beta_0 + \beta_1 WSTRESS + \beta_2 TEMP + \beta_3 RAIN + \beta_4 RPOV + \beta_5 AGRIEMP + \beta_6 CSH + \beta_7 AGRITECH] - |TRIM| + \mu$$

(4)

Where TRIM shows trimming the outliers to exclude from the regression models.
RLS is built to handle outlying observations better as an alternative to traditional regression analysis. Several approaches are used by this method to deal with outliers in both the dependent and independent variables. RLS offered the three estimation approach:
M-estimation (Huber, 1973), which deals with them in the dependent variable;
S-estimation (Rousseeuw & Yohai, 1984), which is computationally intensive and focuses on them the independent variables; and
MM -estimation (Yohai, 1987) combines the two approaches and deals with them in both variables.
Considering extreme values in the data set, these techniques aim to provide a more solid and trustworthy analysis. Table 5 shows the importance of robust least squares regression to estimate robust parameter estimates.

Table 5: Motivation for Robust Least Squares Regression (RLSR)

Conventional Issue	Problem	How RLSR Helps
Outliers in environmental-economic data	Biases results	RLS reduces influence of extreme values
Non-normal error distribution	Weak classical regression	RLS provides more reliable estimates
Heterogeneous study regions	Variability in response	RLS is robust to irregularities

Source: Adapted from the scholarly research work of De Menezes et al. (2021) and Sabzekar & Hasheminejad (2021).

The given econometric framework is used to evaluate the link between the independent variables and forest ecology management in Pakistan throughout the years 1990 to 2021. The calculated coefficients of the independent variables are used to determine which aspects of forest ecology management in Pakistan have the most significant influence on the state of the ecosystem. The findings may be helpful to policymakers and conservationists in Pakistan as they work to establish policies for the sustainable management of Pakistan's forests.

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Results and Discussion

Table 6 shows the descriptive statistics of the variables in natural logarithmic form for ready reference.

Table 6: Descriptive Statistics (Natural Log Variables)

Variables	Mean	Standard Deviation	Minimum	Maximum
FECOL	-2.3397	0.8890	-3.4988	-1.1198
AGRIEMP	3.7382	0.0703	3.5589	3.8024
WSTRESS	4.6828	0.0710	4.5458	4.8095
AGRITECH	4.8315	0.1996	4.4259	5.0173
RPOV	3.3828	0.1438	3.0062	3.6702
RAIN	5.6172	0.2307	5.2339	5.9589
TEMP	0.5675	0.4751	-0.3750	1.4230
CSH	-1.6331	0.2451	-2.2070	-1.1444

The correlation results between various social, economic, and ecological aspects and Pakistan's forest holdings are shown in Table 7. A lack of water, severe temperatures, outdated farming methods, and widespread poverty in rural areas were all shown to have a detrimental impact on the number of forests in a country. People and communities in water-scarce regions are more likely to turn to forests for their water requirements, which explain the inverse relationship between water availability and forest cover (Tavárez et al. 2022). Similarly, people in locations with high temperatures may use more wood for heating and construction, which might lead to additional tree cutting (Arshad et al. 2020). People in places with high poverty and limited agricultural technology may depend more on the woods for their livelihoods, which could accelerate deforestation (Luna et al. 2020). Community stakeholders in Pakistan tend to increase when there are more forest reserves, and forest reserves are more in regions where locals are vested in managing and protecting forests. Reforestation and anti-deforestation operations, as well as other forms of forest protection, are more likely to get community support when locals feel they have a vested interest in their success (Wunder et al. 2020).

Table 7: Correlation Estimates

Variables	FECOL	WSTRESS	RAIN	TEMP	AGRIEMO	AGRITECH	RPOV	CSH
FECOL	1 -----							
WSTRESS	-0.900 (0.000)	1 -----						
RAIN	0.169 (0.353)	-0.185 0.309	1 -----					
TEMP	-0.595	0.657	-0.429	1				

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Online ISSN 3007-3197
Print ISSN 3007-3189

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Variables	FECOL	WSTRESS	RAIN	TEMP	AGRIEMO	AGRITECH	RPOV	CSH
	(0.000)	0.000	0.014	-----				
AGRIEMPM	0.234	-0.401	-0.026	-0.297	1			
	(0.196)	0.022	0.887	0.097	-----			
AGRITECH	-0.863	0.869	-0.097	0.562	-0.556	1		
	0.000	0.000	0.595	0.000	0.001	-----		
RPOV	-0.364	0.413	-0.199	0.382	-0.052	0.224	1	
	0.040	0.018	0.272	0.030	0.777	0.217	-----	
CSH	0.415	-0.398	-0.079	-0.223	0.496	-0.413	-0.296	1
	0.018	0.023	0.664	0.217	0.003	0.018	0.099	-----

Note: Small bracket shows probability value.

The findings show that water shortage is positively correlated with severe temperatures, agricultural technology, and rural poverty. This shows that there may be a correlation between the prevalence of these variables and water shortage in the places where they are most concentrated. Furthermore, the findings indicate an inverse relationship between community stakeholder involvement and water shortage. Water shortage is less of an issue in regions where locals are vested in managing their water supply. There is a negative relationship between agricultural technology and farm jobs. Therefore, locations with more access to agricultural technology have lower employment rates in the agricultural sector. This may be because there is less need for human labour due to the growing mechanization and automation of agricultural processes. Furthermore, there is a negative correlation between community stakeholder interest and agricultural technology. This implies that less agricultural technology is used in regions where residents have a vested interest in the industry's administration.

The findings suggest that including community stakeholders in managing forest reserves and water shortages might have a good effect. However, the findings also indicate a potential trade-off between using agricultural technology and creating new agricultural jobs. The policy implications of these correlations need more study to fully grasp the underlying causal processes. Table 8 shows the RLS estimates for ready reference.

Table 8: RLS Estimates

Variables	RLS-1	RLS-2	RLS-3	RLS-4
WSTRESS	-0.004*	-----	-----	-----
TEMP	-0.006	0.011	-0.100*	-----
RAIN	9.07E-05	0.0001**	-----	-----
AGRIEMP	-0.013*	-----	-----	-0.013*
AGRITECH	-0.002*	-0.004*	-----	-0.004*
RPOV	-0.0004	-0.001	-0.001	-0.003**
CSH	0.265***	0.038	0.509	-----
Constant	1.471*	0.627*	0.140	1.323*
Statistical Test				

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 10 (2025)

Online ISSN 3007-3197
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http://amresearchreview.com/index.php/Journal/about

Variables	RLS-1	RLS-2	RLS-3	RLS-4
R^2	0.778	0.692	0.422	0.724
Adjusted R^2	0.713	0.633	0.360	0.694
Jarque-Bera Test	3.126	-----	-----	1.133

Note: Dependent variable: FECOL. *, **, and *** indicates 1%, 5%, and 10% significance level.

The results show that water scarcity, extreme temperature, and rural poverty have a negative relationship with forest ecology while disproportionate rain has a positive relationship with forest ecology. Agriculture employment, agriculture technology and community stakeholders have a positive relationship with forest ecology. The study's findings suggest that a lack of water has a detrimental effect on forest ecology in Pakistan. There is a correlation between greater water shortage and lower forest reserve and biodiversity rates. One explanation for the inverse relationship between water availability and forest cover is that people and communities in arid regions must depend more heavily on forest water supplies. As a result, people and communities may feel compelled to destroy wooded areas to construct irrigation systems or access water sources, which may exacerbate deforestation and the deterioration of forest ecosystems (Grosrenaud et al. 2021). Loss of trees due to water shortage may worsen the situation by further limiting water availability since forests play a critical role in sustaining the hydrological cycle by releasing water vapour and controlling the local water supply (Brito et al. 2019; He et al. 2022). People in water-scarce regions may have to focus more on maintaining a steady water supply rather than reforesting or preventing deforestation, which may further contribute to the negative link between water availability and forest preservation (Singh et al. 2022; Vushe, 2021). There is a risk that this will reduce forest cover over time. Also, vegetation may need help to thrive in places of extreme water shortage, resulting in less biological variety and fewer wild animal populations. The forest's ability to store carbon, protect soil, and moderate the weather might all suffer (Albrich et al. 2021; Wu et al. 2020)

Additionally, there is an inverse correlation between high temperatures and the ecosystem of Pakistan's forests. As a result, regions prone to temperature extremes are also less likely to have large forest reserves and a wide variety of plant and animal life. Some tree species may have a harder time surviving in higher temperatures, leading to a decline in forest cover and a loss of biological variety, which would explain the inverse relationship. Increased evaporation and transpiration from hotter temperatures may deplete soil moisture and leave trees parched (del Campo et al. 2019; Phelan et al. 2022). Further damage to tree populations and loss of forest cover may result from high temperatures because they promote the growth of pests and diseases (An et al. 2019; Balla et al. 2021). One possible reason for the inverse relationship between temperature and forest cover is that people in areas of high temperatures may have to spend more time and energy mitigating the effects of the heat, such as heat stress, and consequently have less time and energy to devote to activities that benefit forest conservation, like reforestation and anti-deforestation campaigns. Also, plants may have trouble surviving in hotter regions, affecting

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 10 (2025)

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http://amresearchreview.com/index.php/Journal/about

ecological variety and animal populations (Skendžić et al. 2021; Mashwani et al. 2020).

Results show that Pakistan's rural poverty negatively correlates with the forest ecosystem. A lack of forest reserves and biological variety is associated with greater rural poverty rates. This inverse relationship may be because people living in poorer regions sometimes need the woods more for subsistence purposes. In response, people and communities may chop down trees for various reasons, including the need for fuel, building materials, or to make way for agriculture or grazing. This may accelerate deforestation and forest degradation. Deforestation is exacerbated because people in developing countries sometimes resort to illicit logging and charcoal manufacture to make ends meet (Tondel et al. 2022). People in poorer areas have to focus more on meeting their basic needs, which leaves them with less time and energy to devote to projects that benefit forests, like reforestation and anti-deforestation campaigns. Carbon sequestration, soil conservation, and temperature control are only some of the ecological services forests give. However, in regions of significant poverty, the government or organizations may need more money to spend on their preservation and maintenance (Di Sacco et al. 2021; Gaglio et al. 2019).

The result shows that heavy precipitation is good for the ecosystem of Pakistan's forests. This might be because trees and other plants in the forest depend on rain for their development and survival. The forest ecosystem may also benefit from significant rains since they boost soil moisture and nutrient availability. However, heavy downpours have drawbacks, such as the aforementioned landslides, soil erosion, and floods. Pakistan's forest management must think about ways to lessen the blow of extreme precipitation (Shafeeque et al. 2022; Khan et al. 2021).

In Pakistan, forestry is an integral part of the agricultural economy. If this holds, places where the agricultural sector is thriving, may also be home to thriving forest ecosystems. People in the agricultural sector may be interested in protecting the forest ecosystem because of its value as a source of income. Farmers in the area may depend on the forest for firewood, grazing space, and other non-timber forest products. Forest ecosystems may benefit from various agricultural practices, including agroforestry and agroecology (Dhyani et al. 2021; Zada et al. 2022).

In Pakistan, the ecology of the country's forests benefits from advances in agricultural technology. One possible implication is that places where modern farming techniques are widely used also tend to have thriving forest ecology. The increased crop yields and decreased requirement for land conversion due to agriculture provided by contemporary agricultural technologies may account for the correlation between the two. In turn, this may aid in forest conservation by decreasing the need for deforestation and other land-use modification. Precision forestry and other precision conservation techniques may be used to keep an eye on and safeguard the forest environment (Shivaprakash et al. 2022; Domínguez & Luoma, 2020).

The findings support the idea that local Pakistani stakeholders have a favourable impact on forest ecosystems. In other words, a thriving forest ecosystem is correlated with a community's degree of involvement in forest management. Community-based natural resource management (CBNRM) theories shed light on the connection between people and forests by emphasizing the need for community input into resource management decisions (Eilola et al. 2021). Local people and other

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 10 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

community members have a direct connection to the forest and a stake in its responsible management and preservation. Because of their intimate knowledge of the area, pride in its ownership, and experience with forest management, locals are the best candidates for this role. It is possible to enhance forest management and conservation by increasing the influence of local stakeholders via education, training, and the provision of incentives for environmentally responsible forest management (Fasona et al. 2019; Begum et al. 2021). Illegal activities like logging and poaching may be reduced if local people are involved in monitoring, law enforcement, and participatory forest management (Khac et al. 2022). Community involvement in forest management is not a panacea; instead, it must be tailored to each community based on its unique socioeconomic and cultural factors. In addition, for community engagement in management to be prosperous and equitable, there must be a transparent governance structure and a fair system for making decisions (Prosper et al. 2020; Mamokhere, 2022).

In conclusion, the significance of incorporating local people in the decision-making and management of forest resources is shown by the excellent interaction between community stakeholders and forest ecology in Pakistan. This method can improve forest management and conservation efforts in the long run.

Conclusions

The research aimed to examine how climate change and economics influence forest ecological management in Pakistan. Using time series data from 1990 to 2021, robust least square regression reveals a negative association between water shortage, severe temperature, rural poverty and forest ecology in Pakistan. However, forest ecology is positively correlated with factors including heavy precipitation, jobs in the agricultural sector, advances in agricultural technology, and the involvement of local stakeholders. These findings provide insight into the difficulties and potential of managing Pakistan's forest ecosystems. Water shortages, high temperatures, and rural poverty negatively impact forest ecology because of the correlation between these conditions and forest decline. Drought conditions, brought on by a lack of water and high temperatures, strain the forest and make it more susceptible to pests and illnesses. Overexploitation of natural resources, such as illicit logging, is another issue that may arise when people in rural areas lack enough income. On the other side, the fact that excessive precipitation, agricultural employment, agricultural technology, and community stakeholders positively correlate with forest ecology shows that they may positively influence the forest environment. Excessive precipitation may ensure the continued existence of trees by providing the moisture they require. At the same time, an increase in agricultural employment and the use of agricultural technology can boost crop yields and decrease the need to convert land for farming. In turn, this may aid in forest conservation by decreasing the need for deforestation and other land-use modification. In addition, community members may take on the role of forest guardians and aid in the fight against illicit logging and poaching.

The study concludes that a sustainable forest ecosystem and good quality of life for residents in Pakistan need a balance between economic growth and conservation activities. This may be accomplished by reducing the detrimental effects of things like a lack of water, high temperatures, and poverty while increasing agricultural

Annual Methodological Archive Research Review
http://amresearchreview.com/index.php/Journal/about
Volume 3, Issue 10 (2025)

Online ISSN 3007-3197
Print ISSN 3007-3189

http://amresearchreview.com/index.php/Journal/about

employment, technological advancements, and community involvement. Community-based natural resource management (CBNRM) initiatives, in which locals are included in forest management and conservation decisions, also contribute to the long-term viability and efficiency of forest management and conservation efforts. Following are some challenges and opportunities for forest ecology management in Pakistan:

Challenges for Forest Ecology Management in Pakistan:

A lack of water has a severe impact on forest ecology in Pakistan. The forest may be weakened by drought, making it more susceptible to pests and diseases. This may reduce forest vitality and biodiversity, which can have serious consequences.

High temperatures deleteriously impact forest ecosystems in Pakistan. Heat stress causes trees to be less productive and more vulnerable to pests and diseases when temperatures are high.

The relationship between rural poverty and forest ecology in Pakistan is dire. Overuse of natural resources, such as illicit logging, may occur when the poor depend too much on them.

Contrary to popular belief, illicit activities like logging and poaching may hurt forest ecosystems. Deforestation, habitat loss and fragmentation, and a decline in biodiversity are all possible outcomes of these actions.

Opportunities for Forest Ecology Management in Pakistan:

Abundant precipitation is associated with a healthier forest ecosystem in Pakistan. Trees need a steady moisture supply to thrive, and heavy rains may offer just that.

In Pakistan, forest ecology positively correlates with agricultural employment and technological advancements. These characteristics aid in preserving the forest ecosystem by decreasing the need for deforestation and other types of land-use change, such as increased agricultural yields and reduced land conversion for agriculture.

Stakeholders in the local community may take on the role of forest guardians, lowering the incidence of crimes like illegal logging and poaching. Local community participation in forest management and conservation decisions leads to better long-term outcomes.

In order to meet these problems and take advantage of these possibilities, it will be vital to strike a balance between economic growth and conservation activities. This may be accomplished by reducing the detrimental effects of things like a lack of water, high temperatures, and poverty while increasing agricultural employment, technological advancements, and community involvement.

Community-based natural resource management (CBNRM) initiatives, in which locals are included in forest management and conservation decisions, also contribute to the long-term viability and efficiency of forest management and conservation efforts. Overall, it is important that a comprehensive and multi-disciplinary approach is taken to address the impact of climate risk on forest ecology in Pakistan, involving collaboration among government, private sector, and civil society actors.

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Print ISSN 3007-3189

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