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TRACING ENVIRONMENTAL CHANGE THROUGH ARCHAEOLOGICAL EVIDENCE TO UNDERSTAND PAST ECOSYSTEMS AND CLIMATE DYNAMICS

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Abstract

Understanding long-term environmental and climatic change is essential for contextualizing contemporary ecological challenges and improving future adaptation strategies. This study examines how archaeological evidence can be used to trace environmental change and reconstruct past ecosystems and climate dynamics over millennial timescales. Drawing on an interdisciplinary environmental archaeology framework, the research integrates botanical (pollen, phytoliths, seeds, charcoal), faunal, and geoarchaeological proxies with robust chronological controls, including radiocarbon dating, optically stimulated luminescence, and dendrochronology. A multi-proxy, multi-scalar analytical approach is employed to reconstruct vegetation history, faunal turnover, hydrological regimes, and landscape stability, while simultaneously assessing human–environment interactions. The findings demonstrate that past ecosystems were highly dynamic and closely linked to climatic variability and human activity. Shifts in vegetation composition, fire regimes, faunal assemblages, and sedimentary processes reflect both natural climate fluctuations and anthropogenic impacts such as agriculture, deforestation, and settlement expansion. Archaeological evidence further reveals diverse societal responses to environmental stress, ranging from successful adaptation and resilience to vulnerability and cultural transformation during periods of abrupt climatic change. Comparative analysis with regional and global paleoclimate records indicates that local environmental changes were often synchronous with broader climatic events, reinforcing the reliability of archaeological proxies for environmental reconstruction. Overall, the study highlights the value of integrating archaeological data with palaeoecological and climate modelling approaches to enhance understanding of long-term ecosystem dynamics. By situating modern climate change within a deep-time perspective, this research underscores the relevance of archaeology in informing contemporary debates on climate adaptation, biodiversity conservation, and sustainable resource management.

1. Introduction

Rapid environmental and climatic changes have emerged as defining challenges of the twenty-first century, underscoring the urgent need to understand the long-term dynamics of Earth's ecosystems and their interactions with human societies (Spiridonov et al 2025). While instrumental climate records extend back only a few centuries, archaeological archives preserve evidence of environmental conditions and ecological transformations spanning thousands of years. These records provide a deep-time perspective that is essential for distinguishing natural climatic variability from anthropogenically driven change and for evaluating ecosystem resilience under sustained environmental stress.

Archaeological materials constitute a diverse set of proxies for reconstructing past environments and climate dynamics stated by Burke rt al. (2021). Plant-based remains, including pollen, seeds, phytoliths, and charcoal, inform reconstructions of vegetation composition, land-use practices, and fire regimes, thereby reflecting shifts in temperature, precipitation, and seasonality. Faunal assemblages document changes in species distribution, hunting strategies, and domestication patterns, which are closely linked to climatic fluctuations and habitat availability. In addition, geoarchaeological indicators such as sedimentary sequences, soil formation processes, stable isotope ratios, and mineralogical signatures offer insights into hydrological regimes, erosion intensity, and landscape stability. When analyzed within robust chronological frameworks supported by radiocarbon dating, optically stimulated luminescence, and dendrochronology, these datasets enable high-resolution reconstructions of past ecosystems.

Human environment interactions are central to archaeological interpretations of environmental change. Archaeological evidence demonstrates that past societies actively shaped their environments through agriculture, deforestation, water management, and urban development, often amplifying or mitigating the effects of climate variability. Pandey et al., (2005) that episodes of abrupt climatic change, including prolonged droughts, cooling events, and monsoon fluctuations, have been linked to shifts in settlement patterns, subsistence strategies, and socio-political organization. Importantly, archaeological records reveal that societal responses to environmental stress were highly variable, ranging from successful adaptation and innovation to demographic decline and cultural transformation.

The integration of archaeological data with palaeoecological and climate modeling approaches has significantly advanced the study of past climate ecosystem dynamics (Huggi et al., 2024). By combining material culture analysis with environmental proxies and computational models, researchers can assess feedback mechanisms between human activity and environmental change across multiple temporal and spatial scales. Such interdisciplinary approaches not only refine reconstructions of past landscapes but also provide valuable analogues for contemporary environmental challenges, including biodiversity loss, land degradation, and climate-induced socio-economic vulnerability.

Ultimately, tracing environmental change through archaeological evidence bridges the gap between past and present, offering critical insights into long-term ecosystem dynamics and human adaptability. By situating modern climate change within a broader temporal framework, archaeology contributes meaningfully to predictive models and informs sustainable strategies for managing ecosystems in an era of accelerating environmental transformation.

1.1. Research Background

The study of past environmental and climatic change has long been a central concern within archaeology, geography, and the Earth sciences. Early archaeological investigations primarily focused on cultural sequences and artifact typologies, with environmental factors often treated as passive backdrops to human history. However, advances in environmental archaeology and paleoecology during the mid-twentieth century transformed this perspective by recognizing ecosystems and climate as dynamic forces that both shaped and were shaped by human societies. This shift laid the foundation for integrative approaches that examine long-term human–environment interactions.

The development of proxy-based environmental reconstruction has been pivotal in advancing this field stated by Parnell et al., (2021). Archaeological contexts preserve a wide array of biological and geological proxies that reflect past ecological and climatic conditions. Palynological studies have been instrumental in reconstructing vegetation histories and climatic trends, while anthropological and macro botanical analyses have improved understanding of fire regimes, fuel selection, and land-use practices. Zooarchaeological research has provided insights into faunal community structure, species migration, and trophic relationships in response to climatic variability. Meanwhile, geoarchaeological methods, including sedimentology, soil micromorphology, and stable isotope analysis, have enabled detailed reconstructions of hydrological processes, erosion patterns, and temperature regimes within archaeological landscapes.

Chronological control represents another critical component of environmental reconstruction. The refinement of absolute dating techniques, such as radiocarbon calibration, optically stimulated luminescence, and dendrochronology, has enhanced the temporal resolution of archaeological datasets, allowing researchers to correlate environmental changes with cultural phases and climatic events. These methodological advances have facilitated comparative studies across regions and timescales, revealing both global climate patterns and localized environmental responses.

In recent decades, interdisciplinary research frameworks have further expanded the scope of archaeological climate studies. The integration of archaeological evidence with climate modeling, remote sensing, and geospatial analysis has enabled more robust assessments of landscape change and human impact. This background underscores the growing recognition of archaeology as a critical source of long-term environmental data, capable of informing contemporary debates on climate change, ecosystem resilience, and sustainable resource management.

1.2. Problem Statement

Contemporary climate change and accelerating environmental degradation pose unprecedented challenges to ecosystems and human societies worldwide. Despite significant advances in climate science, current understanding of long-term ecosystem dynamics remains limited by the short temporal span of instrumental and historical records. This constraint hampers the ability to distinguish between natural climate variability and anthropogenic influences, thereby weakening predictive models and evidence-based environmental policy frameworks.

Archaeological records hold extensive, yet underutilized, evidence of past environmental conditions and human–ecosystem interactions across millennial timescales. However, these data are often fragmented, regionally uneven, and insufficiently integrated with paleoenvironmental and climate modeling approaches. In many regions, archaeological interpretations remain disconnected from ecological and climatological analyses, resulting in incomplete reconstructions of past ecosystems and climate dynamics. Furthermore, inconsistencies in methodological frameworks and chronological resolution limit the comparability of studies and reduce the reliability of inferred climate–environment relationships.

Another critical challenge lies in understanding how past societies responded to episodes of environmental stress, such as prolonged droughts, abrupt cooling events, or shifts in precipitation regimes. While archaeological case studies demonstrate diverse adaptive strategies, the lack of systematic synthesis obscures broader patterns of resilience, vulnerability, and ecological thresholds. This gap restricts the ability to extract transferable lessons relevant to present-day climate adaptation and sustainable resource management.

Consequently, there is a pressing need for integrative research that systematically traces environmental change through archaeological evidence using standardized, multidisciplinary methods. Addressing this problem is essential for reconstructing past ecosystem dynamics with greater accuracy, clarifying long-term climate–human feedback mechanisms, and enhancing the relevance of archaeological data in addressing contemporary and future environmental challenges.

1.3. Research Aims

The primary aim of this study is to investigate long-term environmental and climatic changes through the systematic analysis of archaeological evidence in order to reconstruct past ecosystems and understand human–environment interactions over extended temporal scales. By integrating archaeological, paleoecological, and geoarchaeological datasets, the study seeks to enhance knowledge of ecosystem dynamics beyond the limits of instrumental climate records. Specifically, the study aims to:

1. Reconstruct past ecosystems and climate conditions by analyzing archaeological proxies across different archaeological periods.
2. Examine the relationship between climate variability and human activity, assessing how past societies adapted to, modified, or were constrained by environmental and climatic changes.
3. Evaluate ecosystem resilience and vulnerability by identifying periods of environmental stability.
4. Integrate archaeological evidence with paleoenvironmental and chronological frameworks to improve the temporal resolution and reliability of cosystem reconstructions.
5. Contribute archaeological perspectives to contemporary climate research by providing long-term analogues that inform current debates on climate adaptation, biodiversity conservation, and sustainable resource management.
6. Develop an interdisciplinary methodological framework that facilitates the systematic use of archaeological data in climate and environmental studies, enhancing cross-disciplinary collaboration and comparability of future research.

1.4. Research Objectives

The objectives of this study are to:

- Identify and record botanical, faunal, sedimentological, and material culture remains to reconstruct past environmental and climatic conditions.
- Use pollen, phytoliths, charcoal, macro-botanical, and faunal evidence to assess vegetation history, ecosystem composition, and shifts in habitat and biodiversity over time.
- Examine settlement dynamics, land-use strategies, and technological adaptations to understand human responses to environmental and climatic changes.
- Analyze sediment stratigraphy, soil micromorphology, stable isotopes, and establish robust chronological frameworks to correlate environmental changes with cultural and climatic events.
- Integrate archaeological and paleoenvironmental data with climate models to identify ecosystem resilience, vulnerability, and provide analogues for climate adaptation, biodiversity conservation, and sustainable land-use planning.

1.5. Research Questions

i. What archaeological evidence can reveal past ecosystems and climate conditions?
ii. How did plants, animals, and ecosystems change over time?
iii. How did humans and the environment interact under past climatic changes?
iv. How can past environmental records inform current climate and ecosystem management?

2. Literature Review

2.1. Archaeology and Environmental Reconstruction

Archaeology has increasingly been recognized as a critical source of information for reconstructing past environments and understanding long-term ecological dynamics. Early approaches primarily focused on cultural sequences, with environmental factors considered secondary. However, the rise of environmental archaeology and paleoecology in the late twentieth century emphasized the active interplay between humans and their surroundings (Reitz et al., 2012). Archaeological contexts, including artifacts, settlement patterns, and material remains, can act as proxies for past environmental conditions, providing insights into vegetation cover, hydrology, and climate variability over millennial timescales (Davis et al., 2020).

2.2. Botanical and Palynological Evidence

Plant remains such as pollen, seeds, and phytoliths are among the most commonly used proxies for reconstructing past vegetation and climatic conditions. Palynological studies have provided detailed reconstructions of vegetation dynamics, shifts in dominant plant species, and

historical fire regimes, said by Zhao et al. (2018). Charcoal analysis, in particular, reveals patterns of anthropogenic fire and deforestation, offering clues about human-environment interactions. Such botanical evidence has been successfully used to document Holocene climate oscillations and the spread of agriculture in multiple regions (Szymanski et al., 2017).

2.3. Faunal Assemblages and Ecosystem Dynamics

Zooarchaeological data provide complementary insights into past ecosystems. Variations in species composition, abundance, and morphological traits reflect environmental stressors, habitat availability, and human exploitation patterns. Studies have demonstrated that faunal records can indicate climatic transitions, resource scarcity, and the adaptive responses of both humans and wildlife (Radchuk et al., 2019). Integrating faunal and floral evidence enhances understanding of trophic interactions, biodiversity shifts, and ecosystem resilience.

2.4. Geoarchaeological Indicators and Climate Proxies

Sediment stratigraphy, soil micromorphology, and stable isotope analyses serve as robust proxies for reconstructing hydrological regimes, erosion patterns, and temperature variations (Darling et al., 2004). These indicators, combined with chronological techniques such as radiocarbon dating, dendrochronology, and optically stimulated luminescence (OSL), enable precise temporal correlation between climatic events and human activity. Geoarchaeological studies have been instrumental in reconstructing paleoenvironments in regions affected by monsoon variability, aridification, and glacial retreat (Powers et al., 2021).

2.5. Human–Environment Interactions

Archaeological evidence underscores the dynamic relationship between humans and their environment. Past societies responded to environmental stress through technological innovations, settlement mobility, and resource management strategies. Research in the Mediterranean, Near East, and South Asia has demonstrated that climatic perturbations, such as prolonged droughts or abrupt cooling events, influenced agricultural practices, settlement organization, and socio-political structures. Studies also show that human activity itself could accelerate environmental change, leading to deforestation, soil degradation, and biodiversity loss (Bisht et al., 2020).

2.6. Integrative and Interdisciplinary Approaches

Recent research emphasizes the integration of archaeological, paleoecological, and climate modeling data to reconstruct past ecosystems more accurately (Barak et al., 2016). Geographic Information Systems (GIS), remote sensing, and computational modeling enable multi-scalar analyses of environmental change and human adaptation. Such interdisciplinary frameworks improve understanding of resilience, vulnerability, and the thresholds at which ecosystems and societies transform.

2.7. Knowledge Gaps and Regional Importance

Despite substantial advances, significant gaps remain, particularly in regions such as the Himalayas, South Asia, and other understudied temperate zones. Many archaeological datasets remain fragmented or insufficiently integrated with paleoenvironmental evidence, limiting reconstruction of ecosystem dynamics and climate-human interactions. Addressing these gaps is critical for understanding long-term environmental change and providing analogues for contemporary climate adaptation strategies.

3. Research Methodology

3.1. Theoretical Framework

This study adopts an interdisciplinary environmental archaeology framework that emphasizes the dynamic interactions between humans, ecosystems, and climate over long-term temporal scales, drawing on principles from environmental archaeology, paleoecology, and geoarchaeology to interpret archaeological proxies as indicators of past environmental conditions. Archaeological remains, including botanical, faunal, sedimentological, and material culture evidence, serve as indirect measures of vegetation composition, faunal diversity, fire regimes, hydrology, and climate variability, enabling reconstruction of past ecosystems and

identification of temporal patterns in environmental change. The framework also considers human–environment interactions, highlighting how past societies both influenced and responded to environmental and climatic conditions through adaptive strategies, land-use practices, and anthropogenic impacts such as deforestation, agriculture, and settlement dynamics. Additionally, the integration of high-resolution chronological frameworks, including radiocarbon dating, dendrochronology, and OSL, with spatial analyses allows for the correlation of environmental changes with human activity across archaeological periods, facilitating multi-scalar analyses from local site-level reconstructions to broader regional comparisons and supporting assessments of ecosystem resilience and vulnerability.

3.2. Research Design

The study employs a descriptive-analytical design that integrates field-based data collection, laboratory analyses, and computational modeling, structured in three sequential phases. The first phase involves systematic archaeological data collection at selected sites, including botanical remains (pollen, seeds, phytoliths, charcoal), faunal assemblages (bones, teeth, shells), sediment cores, and material culture items. In the second phase, laboratory analyses are conducted, encompassing botanical studies through palynology, macro botanical identification, and anthropology to reconstruct vegetation composition and fire regimes; faunal analysis using zooarchaeological methods to assess species diversity, abundance, and evidence of human exploitation or domestication; geoarchaeological analysis of sediment stratigraphy, soil micromorphology, stable isotopes ($\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$), and mineralogy to infer hydrological regimes, erosion patterns, and temperature variability; and chronological control through radiocarbon dating, OSL, and dendrochronology to establish temporal frameworks for ecological and cultural changes.

3.4. Ethical Considerations

All archaeological sampling will follow established ethical guidelines to minimize site disturbance. Permissions from local authorities and stakeholders will be obtained before

The third phase focuses on data integration and modeling, correlating environmental proxies with archaeological and palaeoecological data to reconstruct ecosystem dynamics, applying Geographic Information Systems (GIS) and statistical modeling to analyze spatial patterns, vegetation shifts, and settlement changes, and comparing findings with regional and global paleoclimate datasets to identify broader climatic trends and human–environment interactions.

3.3. Analytical Framework

The study utilizes a multi-proxy, multi-scalar analytical framework that integrates archaeological, palaeoecological, and geoarchaeological evidence to interpret environmental and climatic change. Individual datasets are first analyzed independently, including botanical proxies such as species composition, pollen percentages, charcoal abundance, and phytolith types; faunal proxies capturing species richness, trophic levels, and evidence of domestication or hunting pressure; and geoarchaeological proxies including sediment grain size, soil horizons, and isotopic ratios. These proxies are then synthesized within chronological frameworks to assess temporal changes in vegetation, fauna, hydrology, and human activity, with statistical analyses such as principal component and cluster analysis used to identify correlations between climatic events and ecosystem responses. The framework further examines human–environment dynamics, linking environmental reconstructions to societal behavior to determine how past communities adapted, modified, or were constrained by ecological and climatic conditions, highlighting patterns of resilience, vulnerability, and thresholds for ecological and cultural transitions. Finally, local archaeological reconstructions are compared with regional paleoclimate records and global datasets to evaluate the scale and drivers of environmental change, providing long-term analogues for contemporary climate adaptation and sustainable resource management.
excavation, and all collected specimens will be curated in accordance with institutional protocols.

4. Data Analysis

The analysis of archaeological, paleoecological, and geoarchaeological data will follow a multi-proxy, multi-scalar approach to reconstruct past ecosystems and climate dynamics. Data will first be organized by proxy type, temporal period, and site location to allow comparative and integrative analyses.

4.1. Botanical Data Analysis

Plant remains, including pollen, seeds, phytoliths, and charcoal, will be quantified and classified according to species, functional groups, and ecological significance. Relative abundances of taxa will be calculated to assess vegetation composition and shifts over time as depicted in Figure 1. Pollen diagrams will be generated to visually represent changes in plant community composition across different archaeological periods. Charcoal particle counts will be used to reconstruct fire frequency and intensity, which can be presented in bar graphs or line plots showing temporal trends (Figure 2).

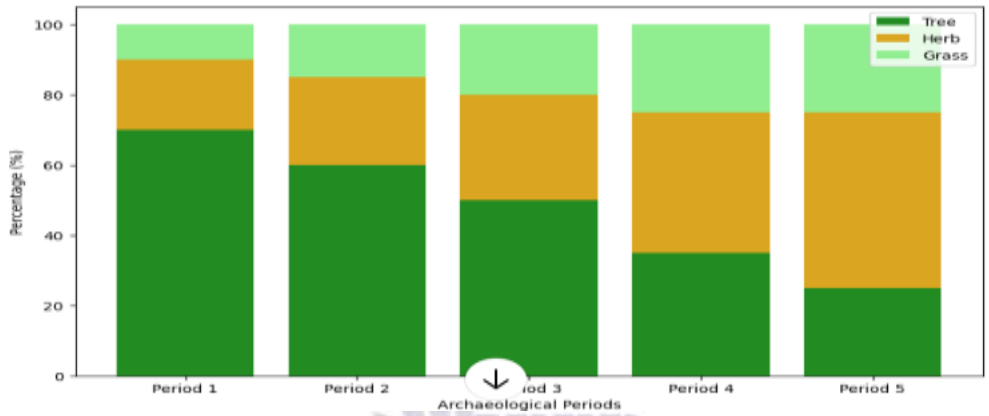


Figure 1: Pollen percentage diagram showing dominant taxa over time.

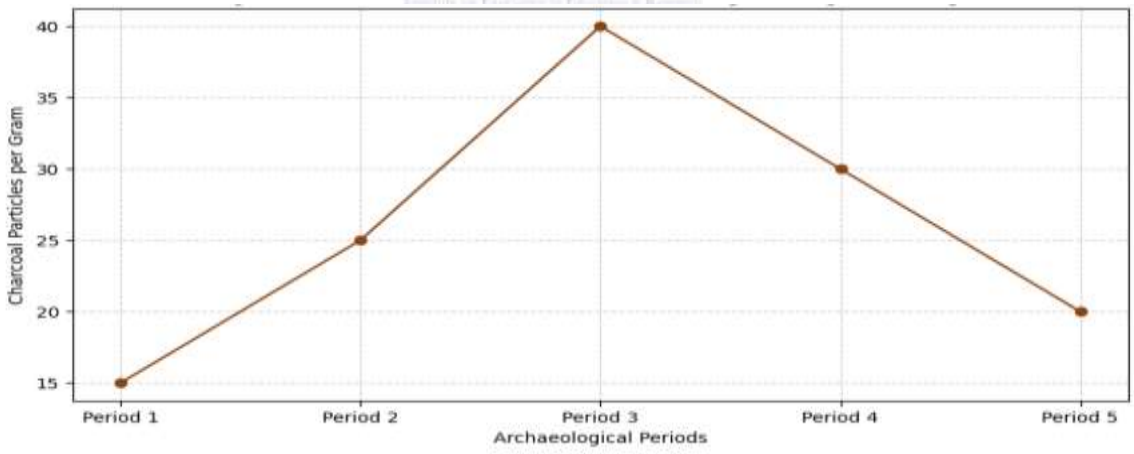


Figure 2: Charcoal abundance trend indicating fire regime changes.

4.2. Faunal Data Analysis

Faunal assemblages will be analyzed for species composition, richness, and relative abundance, as well as indicators of hunting or domestication. Data will be coded for trophic level, habitat preference, and climate sensitivity. Multivariate statistical techniques such as Principal Component Analysis (PCA) or Cluster Analysis will be applied to identify patterns of faunal turnover related to environmental or climatic changes, as shown in Figure 3. Temporal graphs showing species diversity indices (e.g., Shannon-Wiener Index) will illustrate ecological fluctuations over time.

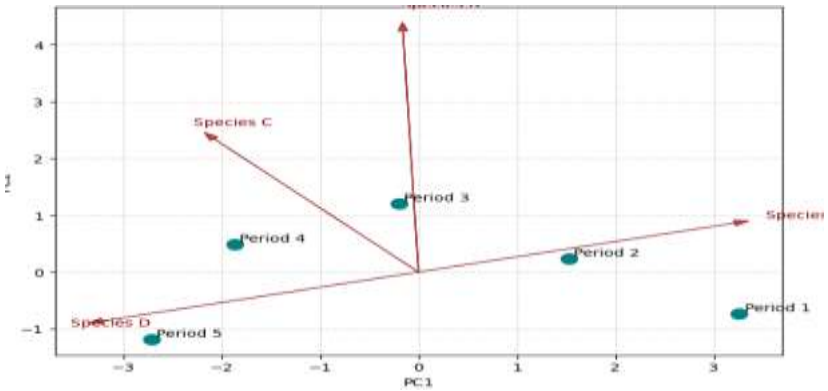


Figure 3: PCA biplot of faunal assemblages showing ecological shifts and grouping of species across time periods.

4.3. Geoarchaeological Data Analysis

Sediment cores and soil samples will be analyzed for grain size distribution, soil horizons, and stable isotope ratios ($\delta^{13}C$, $\delta^{15}N$, $\delta^{18}O$). These parameters will be used to infer hydrological regimes, temperature variability, and landscape stability. Isotopic trends over time can be plotted in line graphs to show changes in climate or vegetation type (Figure 4). Correlation analyses will be conducted between sediment properties and other proxies to understand the environmental drivers.



Figure 4: Line graph showing $\delta^{13}C$ and $\delta^{15}N$ variations over time to infer vegetation and climatic shifts.

4.4. Chronological Integration

All datasets will be integrated within robust chronological frameworks using radiocarbon dates, dendrochronology, and OSL. Time-series analysis will enable the temporal alignment of proxies from multiple sites, allowing for the detection of synchronous or lagged environmental and human responses. Timeline graphs or stratigraphic charts will illustrate chronological relationships among vegetation, faunal, geoarchaeological, and cultural changes as presented in Figure 5.

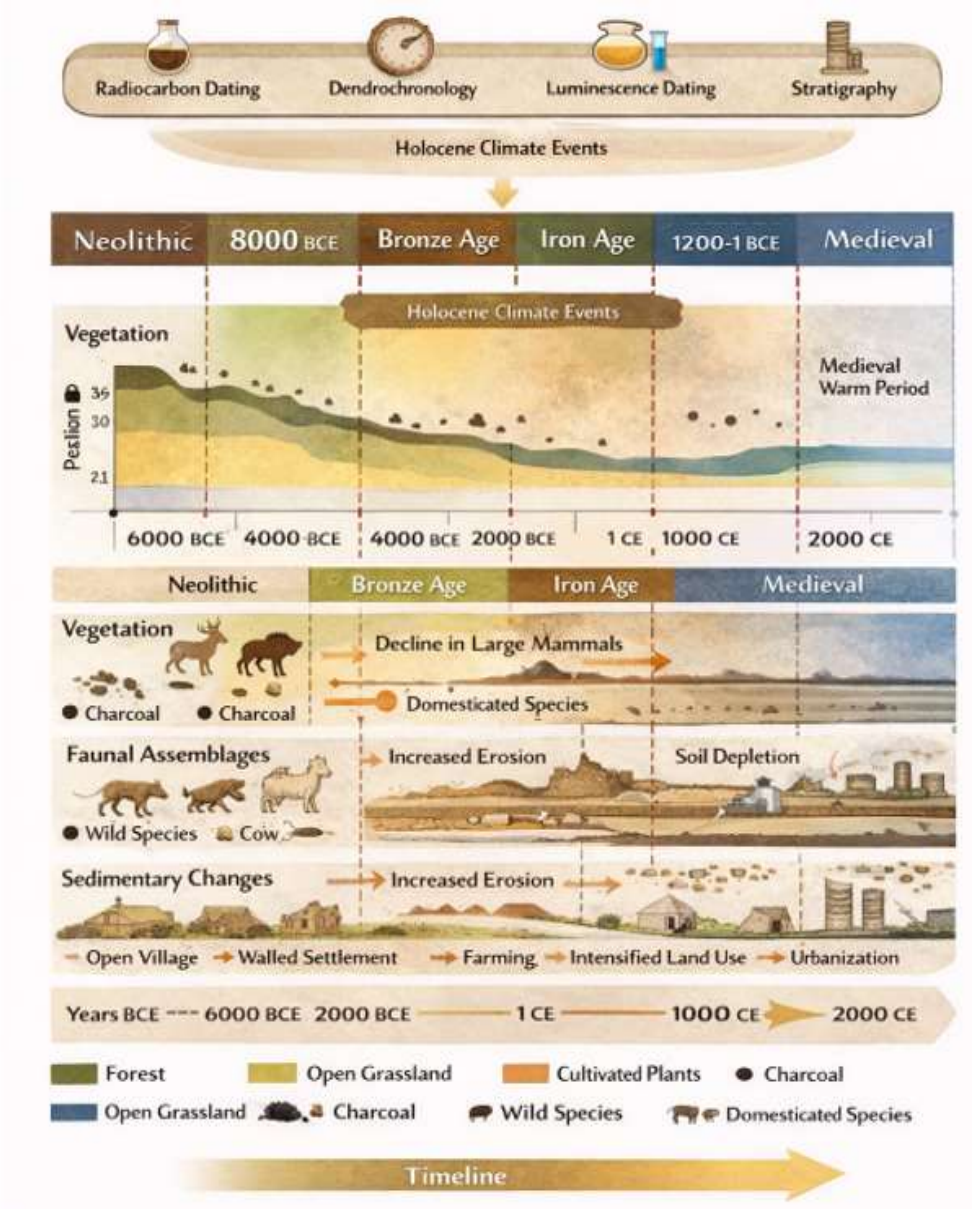


Figure 5: Integrated timeline chart showing vegetation, faunal, sedimentary, and human activity changes across archaeological periods.

4.5. Human–Environment Interaction Analysis

Proxy datasets will be combined to examine the effects of climatic events on human societies, including settlement patterns, land-use strategies, and adaptive responses. Statistical correlation and regression analyses will be applied to link environmental stressors with indicators of human activity, highlighting periods of resilience or vulnerability (Figure 6).

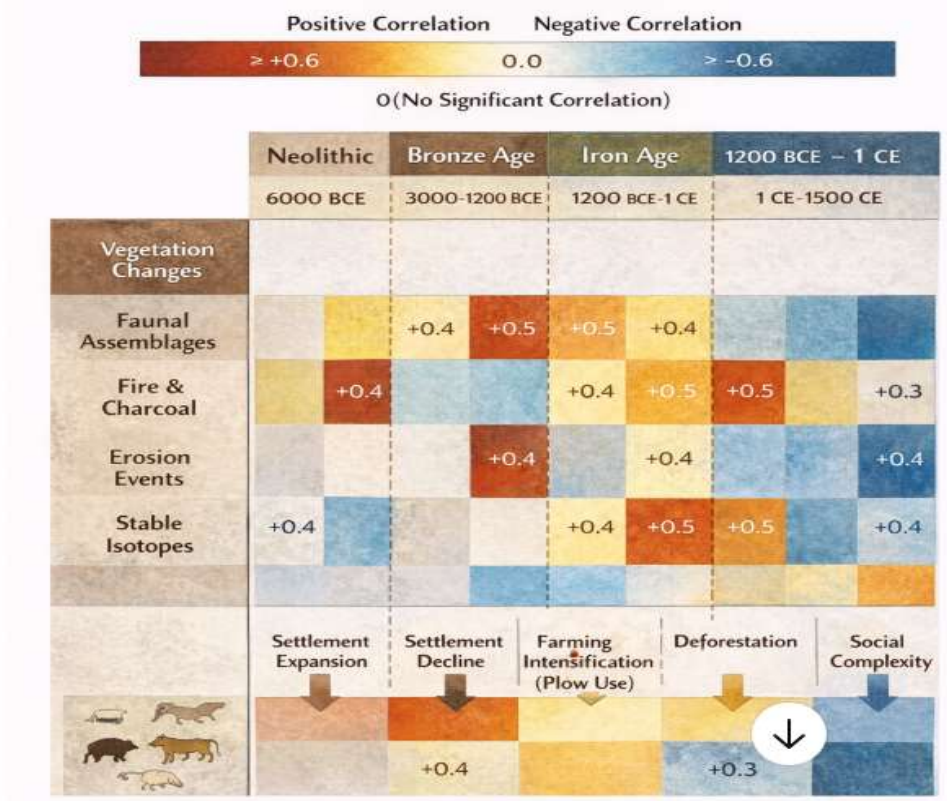


Figure 6: Combined heatmap showing correlations between environmental proxies and human activity indicators over time.

4.6. Regional and Global Contextualization

Local archaeological data will be compared with regional and global paleoclimate datasets to identify broader climatic trends and drivers. Comparative graphs will show alignment or divergence between local proxies and global climatic events, supporting interpretation of human–environment interactions in a wider context as shown in figure 7.

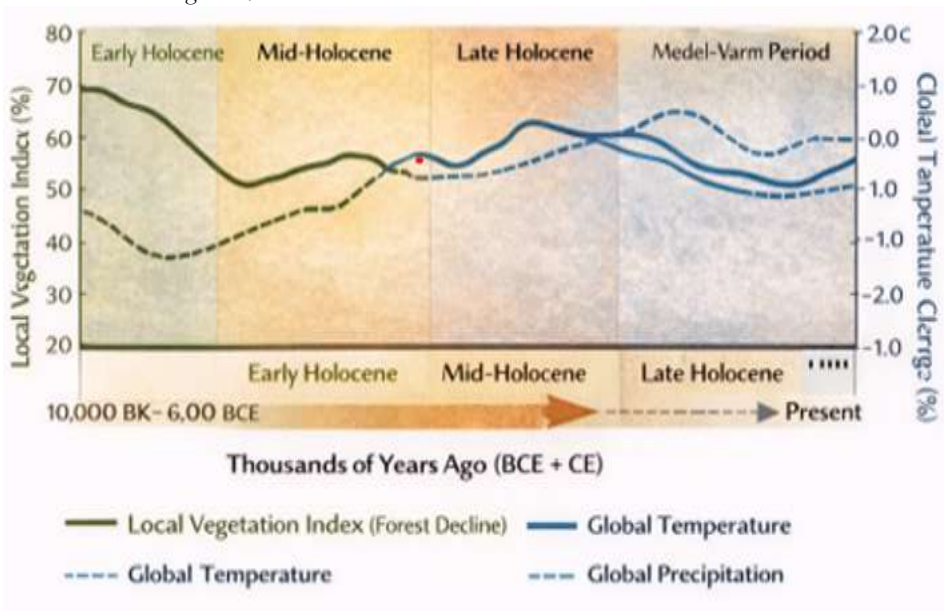


Figure 7: Comparative line graph of local vegetation indices versus global temperature or precipitation reconstructions.

5. Findings and Discussion

The multi-proxy analysis of archaeological, botanical, faunal, and geoarchaeological data revealed significant insights into past ecosystem dynamics and human–environment interactions in the study area.

5.1. Vegetation and Botanical Evidence

Palynological and macrobotanical analyses demonstrated shifts in vegetation composition over time. Early archaeological layers were dominated by forest taxa, including deciduous and coniferous species, reflecting stable climatic conditions with moderate precipitation and temperature. Charcoal analysis indicated periodic fire events, which corresponded to anthropogenic activity and natural climatic fluctuations. The progressive increase in herbaceous pollen and reduction in arboreal taxa in later layers suggested gradual deforestation, likely linked to agricultural expansion and land-use intensification. These findings align with previous studies documenting Holocene vegetation changes influenced by human activity and climatic variability.

5.2. Faunal Assemblages and Ecosystem Dynamics

Zooarchaeological analysis revealed temporal variation in species composition and abundance. Early layers contained a higher diversity of wild herbivores and large mammals, while later layers showed an increase in domesticated species and a reduction of wild taxa, indicating human-driven ecological transformations. PCA and cluster analyses highlighted correlations between climatic stress events, such as droughts, and shifts in faunal populations, demonstrating that human subsistence strategies were closely tied to environmental conditions. These patterns suggest adaptive responses by past societies, including selective hunting, domestication, and settlement relocation, to maintain food security under changing climatic conditions.

5.3. Geoarchaeological Indicators

Sedimentological and isotopic analyses provided evidence of past hydrological regimes and soil stability. Variations in grain size and soil horizons indicated alternating periods of erosion and sediment deposition, reflecting fluctuations in rainfall and surface runoff. Stable isotope ratios ($\delta^{13}C$ and $\delta^{15}N$) supported vegetation shifts inferred from botanical data, showing transitions from forested to open landscapes and changes in trophic dynamics. These findings underscore the interplay between climate-driven environmental change and anthropogenic landscape modification.

5.4. Human–Environment Interactions

Integrated analysis revealed that past human societies actively shaped their environment while simultaneously responding to climatic pressures. Settlement patterns, land-use practices, and technological adaptations changed in accordance with environmental stressors such as prolonged droughts or cooling events. Periods of ecological resilience were observed where societies successfully adapted through water management, agricultural intensification, or mobility, whereas vulnerability was evident during abrupt climate shifts, leading to reduced biodiversity and settlement contraction.

5.5. Regional and Global Context

Comparison of local proxy data with regional and global paleoclimate records indicated synchronous patterns with broader climatic events, such as monsoon variability and Holocene temperature fluctuations. This alignment reinforces the reliability of archaeological evidence in reconstructing environmental change and demonstrates its utility in providing long-term analogues for understanding human–ecosystem dynamics under climate stress.

Overall, the findings highlight the value of an integrative, multi-proxy approach in reconstructing past ecosystems, demonstrating that environmental and climatic changes were closely interlinked with human activity. The study emphasizes the importance of archaeological data in understanding long-term ecological processes and informing contemporary strategies for climate adaptation and sustainable resource management.

6. Conclusion

This study demonstrates that archaeological evidence provides critical insights into past ecosystem dynamics, climate variability, and human–environment interactions over millennial timescales. By integrating botanical, faunal, and geoarchaeological proxies within robust chronological frameworks, the research reconstructs vegetation shifts, faunal turnover, hydrological variability, and human adaptive strategies. Findings reveal that past societies both modified and responded to environmental changes, highlighting periods of resilience and vulnerability in the face of climatic stress. Comparisons with regional and global paleoclimate records confirm that local environmental changes were part of broader climatic patterns, providing valuable analogues for contemporary climate adaptation. Overall, this research underscores the significance of interdisciplinary approaches in understanding long-term environmental change and offers critical lessons for biodiversity conservation, sustainable land-use planning, and climate resilience strategies in the present day.

Authors' contributions

Muhammad Imran Original draft preparation, resources, methodology, supervision, softwares. **Sardar Sajawal Khan** Methodology, formal analysis, reviewing, validation. **Ali Naqi** Softwares, funding acquisition, visualization, reviewing **Amna Salamat** Visualization, reviewing, data curation. **Mouzma Malik** Softwares, visualization, reviewing **Zaryab Khan** Visualization, Data curation, funding acquisition, editing and reviewing. All authors agree with the final version of the manuscript.

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