

Application of Time Series Analysis in Archaeology

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Abstract. Time series analysis is a statistical method widely used in archaeology to study changing patterns of ancient human activity. By analyzing these patterns, researchers can reveal how ancient civilizations interacted with their environment and developed and evolved. Radiocarbon dating, a classic application of time series analysis in archaeology, determines the age of ancient artifacts by measuring radiocarbon decay in samples. In addition, archaeologists have used time series analysis to study material and cultural changes in ancient societies, such as the evolution of pottery styles and the analysis of tree annual rings in environmental archaeology.

Keywords: Time Series Analysis; Archaeology; Cultural Evolution.

1. Introduction

Time series analysis is a kind of statistical method which is used to study patterns or changes over time and it is becoming more and more common in archaeology.

Archaeologists used it to understand how ancient human activities changed over time. By analyzing these patterns over time, researchers can uncover how ancient human civilizations developed and interacted with their environment. The time series analysis can not only help people know past civilizations, but also help people to learn subjects like geography, anthropology.

The classic application of time series analysis in archaeology is radiocarbon dating. This method helps scientists determine the age of ancient objects by measuring radiocarbon decay in a sample. Since the beginning of radiocarbon dating in the 1950s, radiocarbon dating has become an important tool in archaeology, especially for the dating of ancient remains. As technology has improved, the process has become more precise, allowing archaeologists to trace the path of ancient civilizations more precisely. For example, in Bayliss studies, several ancient sites in the United Kingdom were further dated by combining radiocarbon dating with advanced statistical models [1].

Time series analysis is also used to study the material and cultural changes in ancient societies. An important example is the analysis of the evolution of pottery styles. Archaeologists have analyzed changes in the shape, decoration, and production techniques of pottery at different levels of archaeology, revealing technological advances and cultural exchanges in ancient societies. For example, in a particular region, a change in the style of pottery may be associated with a social change, a trade change, or a process of cultural integration. This analysis is not only reveals how the material representation of culture has changed over time, but also provides evidence for understanding the economic, political, and cultural connections of ancient societies [2].

In addition, time series analysis also plays an important role in environmental archaeology. Time series data reveals the interaction between ancient human activities and the environment. One of the most important archaeological methods in this field is arborology. Study the annual rings of trees and record climate change, environmental disasters and human activities. By analyzing the width of the annual rings of trees, archaeologists can infer climate change in specific areas and help explain how ancient civilizations adapted and responded. Buck believes that the combination of tree chronology and plant chronology [3].

In conclusion, time series analysis in archaeology can not only help us to do better understanding in the temporal dynamics of ancient human activities, but also reveals their spatial distribution, evolution and spread. It transcends the limitations of traditional archaeology and deepens the understanding of ancient society through the integration of knowledge.

2. The overview of time series analysis

2.1. The definition of time series analysis

Time series analysis is a method of statistics it be used analysis the regular of the data which keep changing with time. According to Andrew F. Siegel, unlike cross-sectional data, time series analysis usually not focus on random sample from a population, the main intention of time series analysis is to predict the future, it based on created the model, it is an equation which can produce a several different artificial time-series datasets, but like other predict, the predict from series analysis also have inaccuracies, if model is correct for data, that the limited of correctly of predict from series analysis is 95% [1]. In the time series analysis, there also have the connect in the length of timeline. According to S. Sinharay, a time-series model generally have closer connect in the two observations which in the proximity time than two observations which in the further time [4].

2.2. The main method of time series analysis

According to Andrew F. Siegel, there are four basic parts of time series analysis on components of a monthly or quarterly: the long-term trend, the seasonal patterns, the cyclic variation, and the irregular component, and also using box–Jenkins ARIMA to create a model of modeling cyclic behavior [5].

The long-term trend representation the very long behavior of the time series analysis, it always posts the straight line or an exponential curve, the seasonal patterns representation impact of time of a year, each seasons in this year have its seasonal index, it will post this time is greater or shorter than other time, about the cyclic variation, in the cyclic variation, it contain the gradual ups and downs that do not repeat each year, so it is not be include in the seasonal component, cyclic variation are not random enough, cyclic variation are gradual, cyclic variation be thought important on business, because typical business cycle phenomena are considered part of the cyclic variation in economic performance, at last, the irregular component indicates the remaining changes that can't be explained, it the effect of those one-time occurrences which happened randomly and not regular, and the best way to deal with irregular component is to summary its range, for example use the standard deviation to determine whether it changes over time, and know that even in the best situation, the average predict can be no closer than typical size of the irregular variation [5].

2.3. The type and source of data

There are generally have two types of sources of data, the archeology data and the time series analysis data.

Archeology data:

The archeology data basic come from five parts: excavations of archaeological sites, excavated artifacts, the record of weather change, environment data and the record from ancient. The data from excavations of archaeological sites can be thought important, because can get the clear data from it, about the record from ancient, because there was no accurate equipment in the ancient to helped people to measure, so it had a lot of potential deviations. From ancient times to the present day, the environment was changed a lot, so the record of the weather changed, and the environment data can help to avoid some deviations from the time series analysis. The data of excavated artifacts can be considered a piece of evidence, according to compare the shape and possible ways to use of excavated artifacts with the result of time series analysis, the data of excavated artifacts can help to fix some deviations in the time series analysis [6].

Time series analysis data:

The time series analysis data basic come from three parts: Carbon-14 dating detection, the time of the discover the archeology sites and the number changed of the artifacts. About the Carbon-14 dating detection, the radiocarbon isotope carbon-14 are widely distributed on objects, and it can naturally decay, so according to measure the number of carbon-14, it can be easy to know the age of the artifacts, the data from this method are always accuracy. The data of the time of the discover the archeology sites are also important, archeologist are not always the first people to find the archeology sites, know the exactly time of the archeology sites can help to avoid some potential errors, because people's behaviors can also make something changed (Like environment or artifacts). The data of the number of the artifacts is the last typical source of time series analysis data. The number of artifacts have a large number of reasons to changed, for example, the ancient people perhaps moved to another place, or they were attacked by bandits, even can be stole by grave robber. So the data of the why number of artifacts changed can make overall analysis more precise and provide more evidence to support the model [7] [8].

3. time series analysis in archaeology

3.1. Insights from Historical Discoveries and Artifact Analysis

Archaeological sites preserve evidence of ancient human activities, providing a temporal sequence that chronicles the development of human civilization. The discovery and excavation of these sites provide a rich data set that can be subjected to analysis in order to gain insight into the patterns of archaeological activities and the changes in the number of artifacts unearthed.

The chronology of archaeological discoveries frequently commences with the initial identification of a site, which can be traced back to various historical periods and regions. By way of illustration, the discovery of the Terracotta Army in Xi'an, China, in 1974 constituted a seminal event in the history of archaeology. Subsequently, systematic excavations have been conducted, resulting in greater insight into the Qin Dynasty's burial practices and military organization.

The excavation process itself is conducted in a chronological order, with preliminary surveys to evaluate the site's potential followed by comprehensive excavations that may span years or even decades. The progression of these excavations is frequently non-linear, comprising periods of intensive work interspersed with phases of conservation and analysis. To illustrate, the ongoing excavations at Pompeii in Italy have been ongoing since the 18th century, with new areas being opened up and studied as technology and methodologies advance.

The analysis of temporal patterns in excavation activities can facilitate the identification of trends in archaeological practices. Following the identification of the Indus Valley civilization in the 1920s, there was a notable increase in the number of excavations conducted in the region. Subsequently, a period of consolidation ensues as researchers analyze the findings and publish their results.

The number of artifacts unearthed also exhibits a temporal sequence. Initially, there may be a surge in discoveries as the most accessible and visible items are found. Over time, the rate of discovery may decrease as excavations reach deeper levels or as the site is more thoroughly explored.

3.2. Time Series Analysis of Human Settlement Patterns Through History

The evolution of human settlement patterns is a fascinating journey that spans from the earliest nomadic tribes to the complex urban centres of ancient civilisations. The technique of time series analysis, which examines data points in chronological order, provides valuable insights into these changes.

In the earliest periods of human history, our ancestors were primarily nomadic, following the migratory patterns of animals and the seasonal availability of food sources. The initial notable transition towards a settled way of life commenced with the advent of agriculture. The Neolithic

Revolution, which occurred around 10,000 BCE, enabled humans to cultivate crops and domesticate animals, thereby facilitating the establishment of permanent settlements. A time series analysis of archaeological data from sites such as Çatalhöyük in modern-day Turkey demonstrates a gradual transition from small, dispersed communities to larger, more complex settlements.

As these early agricultural societies developed, so too did their need for social organisation and resource management. This resulted in the advent of the first cities. A time series analysis of urban cities such as Uruk in Mesopotamia and Mohenjo-daro in the Indus Valley demonstrates a pattern of growth and decline that is closely associated with environmental factors, technological advancements and geopolitical shifts. The growth of these urban settlements can be traced through an increase in architectural complexity, the development of writing systems, and the establishment of trade networks.

The decline of ancient cities is often marked by a combination of factors, including natural disasters, resource depletion, and military conquests. Time series analysis can assist in identifying the sequence of events leading to a city's fall. For example, the decline of the Maya civilization can be studied through a series of droughts, political instability, and warfare that occurred over several centuries.

3.3. Unraveling the Evolution of Ancient Networks Through Time Series Analysis

Trade and exchange networks have constituted a fundamental aspect of human civilization, facilitating not only the movement of goods but also the dissemination of ideas, technologies, and cultural practices. The evolution of these networks over time provides a comprehensive account of human interaction and cultural diffusion.

The ancient trade networks, including the Silk Road, the Inca Road System, and the Trans-Saharan Trade Routes, served not only as conduits for commercial activity but also as arteries for cultural exchange. A comparative analysis of the evolution of these networks over time reveals patterns of increased or decreased trade activity and communication frequency. To illustrate, during the height of the Roman Empire, trade along the Mediterranean was flourishing, with goods and ideas traversing the empire's extensive territories with ease. However, with the fall of the Roman Empire, these networks experienced a contraction, which resulted in a decline in trade and cultural exchange.

Time series analysis is an effective method for identifying patterns of cultural and technological diffusion. By examining the dissemination of particular cultural artefacts or technologies over time, it is possible to trace the movement of ideas and practices across regions and civilizations. The evolution of pottery styles can be observed as they disseminate from their points of origin to distant lands, thereby demonstrating the impact of trade on cultural development. Similarly, the dissemination of metallurgical techniques, such as the transition from bronze to iron, can be mapped across time and space, thereby elucidating the ancient societies.

The dissemination of the Phoenician alphabet is an exemplar of the capacity of a technological innovation to transform communication and trade. Originating in the Levant, the alphabet spread throughout the Mediterranean, facilitating trade and cultural exchange. The adoption of this writing system by various cultures, each adapting it to their own languages, is evidence of the power of trade networks in disseminating knowledge.

3.4. The Impact of Environmental Shifts on Ancient Civilizations and Activities

Environmental changes have constituted a significant driving force in the evolution of human activities throughout history. The analysis of ancient climates and archaeological data offers insights into the significant impact of climate change on the lives of our ancestors.

The termination of the last Ice Age, which occurred approximately 12,000 years ago, had a profound impact on human behaviour. As glaciers retreated and the climate warmed, humans underwent a significant transition from a nomadic hunter-gatherer lifestyle to a settled agricultural one. This transition was of great consequence, as it permitted the establishment of fixed settlements and the

genesis of early civilizations. Archaeological evidence, such as the remains of ancient irrigation systems in the Middle East and the domestication of crops like wheat and corn, demonstrates how early societies adapted to changing climatic conditions by cultivating the land.

The evolution of agricultural technology provides a clear illustration of how ancient societies adapted to changing climate conditions. In the Fertile Crescent, the world's inaugural agricultural revolution occurred in response to the necessity for food security in a region with a climate conducive to crop cultivation. However, in response to changing climates, agricultural practices also underwent modification. The development of terraced farming in mountainous regions and the construction of elaborate water management systems in arid climates are clear examples of human ingenuity in the face of environmental challenges.

Furthermore, climate change had an impact on trade and cultural exchange. The desiccation of the Sahara resulted in the decline of trans-Saharan trade routes, which in turn affected the dissemination of ideas and technologies. Similarly, the rise and fall of the Silk Road were closely tied to the climatic conditions that made travel and trade more or less feasible. Furthermore, ancient societies often developed sophisticated methods to cope with climatic variability. For instance, the ancient Maya in Mesoamerica developed a complex system of raised fields, canals, and reservoirs to adapt to seasonal fluctuation.

3.5. Long-Term Trends and Cyclical Changes in Archaeological Data

Archaeological data offers a treasure trove of information for understanding the long-term trends and cyclical changes in ancient human activities. By analyzing these patterns, we can uncover the underlying dynamics that have shaped human history.

Long-term trends in archaeological records often reflect significant shifts in human societies. One such trend is the development of agriculture, which marked a fundamental transition from hunter-gatherer lifestyles to settled farming communities. The long-term changes in agricultural practices can be traced through the domestication of plants and animals, the evolution of farming tools, and the expansion of agricultural frontiers. For instance, the shift from subsistence farming to agrarian civilizations in the Fertile Crescent is evident in the archaeological record through the presence of early irrigation systems, storage facilities, and the remains of cultivated crops like wheat and barley.

Technological innovations also exhibit long-term trends. The progression from the Stone Age to the Bronze Age and eventually to the Iron Age is marked by advancements in material technology. Archaeological evidence, such as the types of tools and weapons found at different sites, provides a timeline for these technological leaps. The spread of ironworking across the ancient world, for example, is indicative of a long-term trend that had profound implications for warfare, agriculture, and social structure.

Cyclical changes, on the other hand, refer to periodic fluctuations in human activities due to external factors. One notable example is the impact of flood cycles on ancient settlements. Archaeological studies of river valleys, such as the Nile in Egypt or the Indus in Pakistan, reveal a pattern of settlement expansion and contraction corresponding to periods of flooding and drought. Floods could enrich the soil, making it fertile for agriculture, but they also posed a threat to settlements, leading to their temporary abandonment or relocation.

The study of sediment layers and pollen grains in archaeological contexts can help reconstruct past environmental conditions and their impact on human activities. For example, periods of increased aridity may correspond to declines in agricultural productivity and shifts in settlement patterns. Conversely, times of climatic stability and abundant rainfall could correspond to periods of population growth and cultural florescence.

4. Summary

This study examines the application of time series analysis in archaeology, demonstrating its importance in revealing patterns of change in ancient human activities. Time series analysis not only provides an in-depth understanding of the development of ancient civilizations, but also promotes the understanding of the interaction between human societies and their environment. Through time series analysis of archaeological finds, pottery evolution, ancient settlement patterns and trade networks, we are able to understand more clearly the dynamic changes of ancient societies. Meanwhile, the far-reaching effects of climate change on human activities are also elucidated in the study. These findings emphasize the importance of time series analysis as a research tool to help us understand human history and its development process more comprehensively.

Authors Contribution

All the authors contributed equally and their names were listed in alphabetical order.

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