# Exploring the Relationships between Ancient Chinese Gardens and Climate Change: A Multidisciplinary Approach

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# Declaration

This work has not been submitted previously for examination to any tertiary institution

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Abstract

This study investigates the relationships between ancient Chinese gardens and climate change in China from 221 B.C. to 1911 A.D., providing insights into historical climate change adaptation and human-environment interactions. Using a multidisciplinary approach, the research addresses current gaps and limitations in the literature by examining the connections between climate change, population growth, social crises, and the development of royal and private gardens. The study employs Spearman's Correlation Analysis, Principal Component Analysis, and spatial analysis techniques to assess the impacts of climate factors, social factors, and gardens on a nationwide scale.

The research reveals that climate change, particularly the decrease in temperature, can lead to social crises and migrations, which subsequently affect housing demands and contribute to the increase in the number of Chinese gardens. Population growth and economic development were found to significantly influence the spatial distribution of ancient Chinese gardens, with private gardens being more directly affected by these factors, while royal gardens exhibited greater resilience to climate fluctuations due to their sociocultural attributes.

The insights gained from this study can inform modern urban planning, landscape design, and climate resilience strategies by drawing on the lessons learned from ancient Chinese gardens as physical and cultural spaces for refuge and spiritual freedom.Furthermore, this research highlights the importance of considering social

factors and the interplay between nature and human society when examining the impacts of climate change on housing and the built environment. Future research could further explore the role of different social classes and political systems in shaping garden development and design, as well as investigate the potential consequences of increased housing demands on less affluent populations.

# Exploring the Relationships between Ancient Chinese Gardens and Climate Change: A Multidisciplinary Approach

## Introduction:

The increasing severity of climate change impacts on settlements, where the majority of the global population resides and economic activities take place, has become a pressing concern (Hürlimann et al., 2022). In this context, housing, as one of the fundamental human needs, plays a critical role in protecting individuals from natural disasters caused by extreme weather conditions (Li et al., 2021; Rañeses et al., 2021). Ancient Chinese gardens, which have been a crucial component of China's rich cultural heritage for centuries, represent well-designed landscapes that harmoniously balance natural and man-made elements. They also embody artistic, social, and philosophical ideals from different historical periods (Fu & Tang, 2019; Poulsen et al., 2020; Zhou, 2008). Studying architecture plays a crucial role in understanding the impacts of climate change and society's response to it (Li et al., 2021). However, research in this area is limited and often lacks consideration of social factors, particularly when examining larger temporal and spatial scales (Li et al., 2020; Li et al., 2021). In light of this, the present study aims to examine the relationships between ancient Chinese gardens and climate change in China, spanning from 221 B.C. to 1911 A.D.

**Literature review:**

- Characteristics of Ancient Chinese Gardens: Types & A Reflection of Nature and Society

It is essential to discuss the classifications of ancient Chinese gardens, as they exhibit distinct characteristics based on ownership, function, and scale (Su et al., 2019). These gardens can be categorized into three main types: imperial, private, and temple gardens (Su et al., 2019; Wang, 2006; Zhou, 2008). Private gardens were typically owned by scholars and literati, serving as spaces for daily activities and intellectual pursuits. In contrast, imperial gardens were used for both political and ceremonial purposes, as well as providing a setting for the daily lives of the royal family (Zhou, 2008). Temple gardens are a more ambiguous category, as their funding and maintenance often came from various sources, including the royal family and commoners (Ning, 2019; Zhou, 2008). This study primarily focuses on imperial and private gardens to ensure a more representative analysis. It is important to note that the different types of gardens may exhibit varying capacities for climate adaptation due to their origins in social classes with diverse levels of economic status and social capital (Carmen et al., 2022; Lo et al., 2016).

The relationship between ancient Chinese gardens and nature is a key aspect of understanding the historical context of climate-responsive design in traditional housing. Over centuries of experience and observation of climate and nature, traditional built forms of housing evolved to be climate-responsive, adapting to local natural environments (Arif,

2021). This adaptation involved using natural materials and adjusting spatial layout and building form based on natural conditions (Sha et al., 1999; Tao et al., 2018; Zhao et al., 2013). Ancient Chinese gardens not only encompassed the characteristics of traditional residential houses but also displayed unique features as gardens.

In ancient China, traditional gardens integrated natural elements into their designs, advocating and pursuing harmony with nature (Su et al., 2019; Zhou, 2008). These gardens created a natural environment that promoted harmonious coexistence between humans and nature through the combination of mountains, water, vegetation, and architecture (Dong & Zhou, 2013; Zhou, 2008). By integrating climate-responsive design principles and embracing nature, ancient Chinese gardens serve as an excellent research subject for understanding historical climate change information. Studying these gardens will provide valuable insights into how past societies adapted to and mitigated the effects of climate change through thoughtful design and a deep connection with the natural environment.

However, Chinese classical gardens are rooted in nature yet transcend it, representing a unity of natural and cultural landscapes (Yi & Wang, 2017). In other words, they also reflect the society and culture of their time (Wang, 2022). Some scholars, from a Taoist perspective, have pointed out that the exploration of "Dao" and "Li" in the potential natural world is the reason for the Chinese classical gardens' reverence for and pursuit of nature (Huang, 2017). The Chinese classical garden is a microcosm of Chinese culture, embodying the essence of various aspects, including philosophy, ethics, religion, painting,

calligraphy, craft, literature, architecture, and horticulture (Han, 2012). In contemporary times, Chinese classical gardens serve as a symbol of national identity, representing Chinese culture in the context of globalization (Ding et al., 2021).

Changes in social class can affect the development of ancient Chinese gardens. The rise of the literati class, with its strong personal style, propelled the development of the artistic style of Chinese classical garden rockeries, giving birth to a representative landscape aesthetic style, and under the influence of the literati, affected the aesthetic preferences of other social classes regarding rockeries (Cheng, 2022). The spirit of advocating natural, free and unfettered emptiness, adaptation, simplicity, non-action, and indifference to freedom, romantic and elegant, is reflected in the garden art theme of the garden.

Population is also one of the social factors that needs to be considered. Although the current literature does not mention the relationship between population and ancient Chinese gardens, traditional Chinese gardens have basic residential attributes, providing shelter to meet human physiological needs and avoid harsh surrounding environments (Maslow, 1943; Sinouvassane & Charumathi, 2017). Research on modern housing suggests that there is a connection between population and housing demand, with population growth being the primary driver of housing demand (Krakover, 1999). This may imply that there could be a relationship between population and ancient Chinese gardens that warrants further exploration. In the field of climate change, housing plays a crucial role in climate adaptation efforts. Climate change leads to extreme weather events, such as storms, floods, and cyclones, which can cause significant damage to housing and

infrastructure (Qin & Stewart, 2020). The impact of climate change mitigation and adaptation strategies related to housing on public health is an important consideration (Jaakkola & Amegah, 2014). Studying Chinese gardens as an alternative form of housing can deepen our understanding of the complex interactions between climate change and human society.

In summary, ancient Chinese gardens, classified into imperial, private, and temple gardens, exhibit distinct characteristics based on ownership, function, and scale. These gardens provide insights into historical climate change adaptation as they demonstrate the integration of natural elements and climate-responsive design principles. Reflecting both the natural and cultural landscape of their time, they serve as a microcosm of Chinese culture and a symbol of national identity. Social class changes, such as the rise of the literati, influenced the development and aesthetic preferences of these gardens. Additionally, the relationship between population growth and ancient Chinese gardens warrants further exploration, as housing is one of basic human needs and plays a crucial role in climate adaptation efforts. Studying Chinese gardens as a form of housing can deepen our understanding of the complex interactions between climate change and human society.

- The impact of Climate change on ancient China: fatal synergies

Climate change is defined as a long-term shift in global or regional climate patterns, characterized by changes in temperature, precipitation, and other meteorological

variables spanning several decades or more. It results from both natural factors, such as volcanic eruptions and solar radiation, and human activities, including burning fossil fuels, deforestation, and land-use changes (Fisher, 2000; Ransom, 2020). In recent literature, the topic of the fatal synergies of climate change has emerged as a critical area of study. These synergies are defined as the compounding and cascading effects of climate change on various human-environment systems, including cooling or drying, harvest failures, food shortages, epidemic outbreaks, and violence within or between polities (DeGroot et al., 2021, p. 547). The potential impacts of these fatal synergies are significant, as they can exacerbate existing problems and create new ones, leading to a range of adverse impacts and implications (Lawrence et al., 2020).

Agriculture has long been the cornerstone of ancient China's economy, with its development and prosperity being highly sensitive to climate change and variability (Cai, 1997). The main impacts of these environmental shifts included changes in agricultural geographic boundaries, alterations in crop yields, and effects on agricultural systems as a whole. Moreover, climate change-induced impacts have been shown to create fatal synergies (Su et al., 2015), as evidenced by the conflicts between nomadic and farming groups that arose due to changes in regional agricultural and animal husbandry productivity. Cooling phases and climate change have had significant consequences on China's agricultural landscape (Pei & Zhang, 2014; Zhang et al., 2007), resulting in the substantial shrinkage of agricultural production. Coupled with population pressure and China's unique historical and geographic setting, these climate-related challenges have contributed to high frequencies of warfare over the last millennium.

Research has also found that climate change was a significant factor in the migration of nomadic populations in historical China, particularly over long-term and large spatial scales (Pei & Zhang, 2014). In China's history, precipitation had a greater impact on the migration of nomadic populations than temperature (Pei & Zhang, 2014). Migration is considered an effective way to enhance people's climate resilience and adapt to climate change (Draper, 2022). However, migration and housing are closely related, as housing costs and availability can influence migration decisions (Laurinavičius et al., 2021; Hämäläinen & Böckerman, 2004; Stawarz et al., 2021). Previous research has overlooked the impact of housing in the context of climate change. To address this gap, this study will use ancient Chinese gardens as a case to examine the impact of climate change on housing, aiming to improve our understanding of the complex interactions between climate change and human society, and ultimately provide a more comprehensive perspective on climate change-induced fatal synergies.

Understanding the mechanisms behind these fatal synergies is crucial for addressing the contemporary climate crisis. By conducting comprehensive and in-depth research on the ways in which climate change interacts with human-environment systems, policymakers and stakeholders can develop more effective strategies to mitigate the worst effects of climate change and build resilience in vulnerable communities.

- Current research gaps

Ancient Chinese traditional gardens, which possess residential attributes, provide a

valuable context for understanding the current research trends in the area of climate change and housing. The focus of these studies primarily emphasizes strategies and solutions to mitigate negative impacts and promote sustainable, resilient housing systems. Examples of such research include studies by Roders et al. (2013), Darko et al. (2018), Hearne (2020), Rañeses (2021), and Gupta et al. (2013), which cover a range of topics. These studies explore the feasibility of climate change adaptation measures for social housing stock, identify green technologies for sustainable housing development, argue for the need for a Green New Deal for Housing (focusing on affordable and sustainable homes), examine the identification and classification of existing climate-adaptive measures for housing, and assess the potential of green building technologies to mitigate climate change impacts on buildings and their inhabitants. By connecting ancient Chinese garden characteristics to contemporary research, this paper argues that these efforts will collectively contribute to our understanding of the interplay between climate change and housing, providing a foundation for future work in this critical area.

Recent research on the impact of climate change on housing has provided valuable insights, although much of the existing literature is limited to smaller scales of time and space. Sussman et al. (2014) examined the effect of climate change on housing prices, demonstrating that it acts as a disamenity, particularly in central-to-southeastern states. Additionally, studies have explored the implications of housing-related climate change mitigation and adaptation strategies on public health, such as the association between climate change, housing dampness, mold problems, and respiratory health (Jaakkola et al., 2014). Bezgrebelna et al. (2021) highlighted the vulnerability of homeless and

precariously-housed populations, who are disproportionately exposed to climatic events and face adverse physical and mental health outcomes as a result. Despite these advances, it is worth noting that a substantial amount of research in this area has focused on short-term consequences and specific regions, rather than taking a broader, long-term perspective on the impacts of climate change on housing.

A recent study by Li et al. (2021) provides a rare example of research on the effects of climate change on buildings over a large time scale, specifically examining the adaptation of traditional Chinese architecture to climate change over a millennium in response to extreme snowfall events. This study demonstrates human adaptation to the impact of climate change on daily life. However, there are some limitations to Li et al. (2021)'s study. The research focuses on traditional architecture in central and eastern China, meaning that the results may not be applicable to other regions. Additionally, the study does not consider social or cultural factors that could influence architectural design over time, such as population changes, economic conditions, or political systems.

Since the impact of global climate change on human beings will be comprehensive, multi-scale, and multi-layered (Shi, 2018), research on the impact of climate change on human society at different scales can help further reveal the complex interactions between nature and human society (Rautman, 1994). This paper plans to study traditional Chinese gardens from 221 BC to 1911 AD across China, to address the deficiency of research on large temporal and spatial scales. Additionally, we will also consider the characteristics of gardens, including the influence of natural and social factors.

**Research questions:**

Based on the aforementioned literature review and research gaps, the research questions for this paper are:

- What is the relationship between gardens and climate change on a nationwide scale in China from 221 BC to 1911 AD?
- What are the roles of social and cultural factors in these relationships?
- What are the differences in response to climate change between private gardens and royal gardens?

**Data and Methods:**

- Data

In accordance with the research questions and data availability, this paper selects garden data, temperature data, precipitation data, and population data. Gardens are our primary research subjects, and the dataset includes both the annual total number of gardens (sum of royal gardens, private gardens, and temple gardens) and the number of royal and private gardens. We use temperature and precipitation data to reflect climate change over the years and population data to represent social factors. The following sections will detail the sources and processing methods of the data.

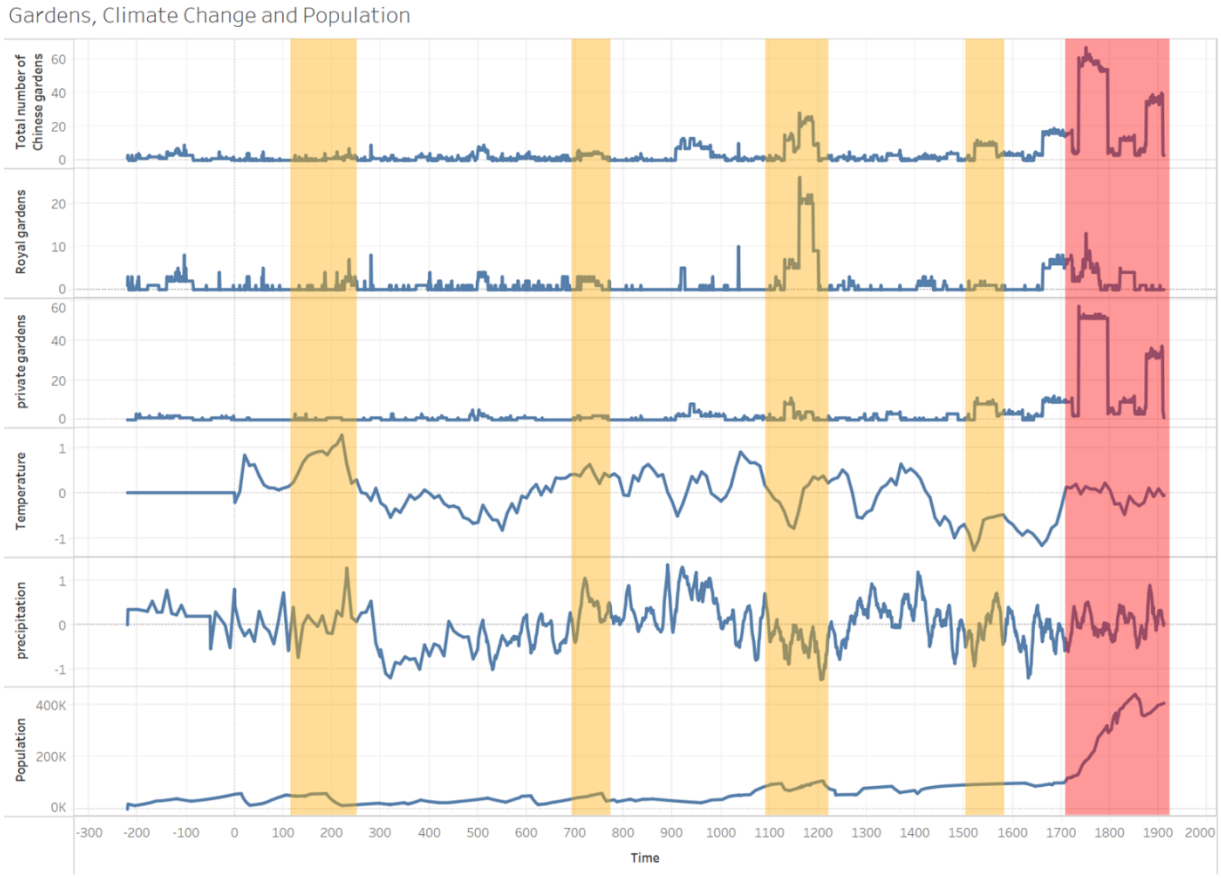
Previous studies on the relationship between climate change and housing have rarely incorporated data from classical Chinese gardens on long time scales and large spatial scales. As one of the oldest civilizations in the world, Chinese civilization boasts a rich, continuous, diverse, and detailed collection of historical events (Jiang et al., 2015; Fang et al., 2017; Han & Yang, 2021). This abundance of historical records provides an ample source of data for research, particularly when examining the interplay between climate change and housing.Professor Ning Jing (2019) compiled important works in the field of Chinese classical garden research, writing the *Chronology of Chinese Garden History* to sort out the historical events of China's garden development in chronological order, striving to cover garden activities and recorded gardens in various historical periods, providing an essential data source for this research. Based on this, we further organized and summarized the data in Excel according to research needs and unified standards. The organized data information covers time (year), the number of gardens, garden names, ancient locations, current locations (province or city), builders (royal, private, or others), and historical changes (construction, renovation, destruction, etc.). The specific data processing methods are as follows:

1. Both construction and renovation are considered garden-building activities. However, garden destruction events are not included in this study.
2. If a garden is continuously built for a long time, the number of gardens increases by 1 for each year during that period. For example, "Lou Garden in Macau was built from 1904 to 1925," the number of gardens increases by 1 for each year during this period.
3. The ancient locations in contemporary names are determined using the

*Comparison of Ancient and Modern Place Names in China* by Xue Guoping (2010).

4. The type of the garden is determined based on the builder. For example, if the builder is the royal family, it is a royal garden; if the builder is an individual (merchant, scholar, etc.), it is a private garden.
5. Due to incomplete records, years with missing garden data are considered NoData instead of 0.

For temperature, precipitation, and population data, this paper uses the same dataset as Pei (2017), Pei et al. (2018a), and Pei & Zhang (2014). The temperature, precipitation, and population data required for this paper have been generously supported and authorized by Dr. Pei. The advantage of these datasets is that they cover the entire territory of China during the research period and have been adopted by several international journals, with their quality recognized by the international scientific community (Damette et al., 2020).




(Figure 1: The data used is presented in a time series format)

Figure 1 presents the data in a timeline format, from which we can observe some general trends. For example, the trend of garden changes appears to roughly correspond with the trend of population changes (highlighted in red), while the trend of garden changes is opposite to the trend of temperature changes (highlighted in yellow). However, the specific relationships between these factors require further investigation.

- Methods

Based on the title and research questions of my thesis, the following elaboration of the research methods is provided:

Spearman's Correlation Analysis: This non-parametric method is used to measure the strength and direction of associations between variables (e.g., temperature, precipitation, population, gardens)(Barbour & Cost, 1993; Nagai, 2022). It is particularly useful in our study as it can identify monotonic relationships between variables, even when the relationship is not linear. By calculating the Spearman's rank correlation coefficient, we can assess the degree to which the variables are related, providing valuable insights into the associations between climate factors, social factors, and garden distribution.

Principal Component Analysis (PCA): This multivariate statistical technique is employed to identify key components or patterns in the data, simplifying the analysis and interpretation(Sharafi, 2022). By transforming the original variables into a new set of uncorrelated variables (principal components), PCA reduces the dimensionality of the data while retaining most of the variance. This enables us to identify the most significant factors driving the relationships between climate, population, and gardens, facilitating a more focused and efficient analysis of the data.

ArcGIS Standard Deviation Ellipse Analysis & Kernel Density: These spatial analysis techniques are used to visualize and analyze spatial patterns and trends in the distribution of gardens, as well as their relationships with climate and population factors. Standard Deviation Ellipse Analysis calculates the direction and dispersion of garden distribution across different regions and time periods (Zhang et al., 2020), while Kernel Density estimates the density of gardens at each location. By combining these methods, we can

better understand how gardens are spatially distributed in relation to climate change and population dynamics, and identify potential underlying factors that may have influenced these patterns. This comprehensive spatial analysis provides a more nuanced understanding of the geographical dimensions of garden distribution and its relationship with climatic and social factors.

**Result**

| | | | Precipitation | Temperature | Population |
|---|---|---|---|---|---|
| Spearman's rho | Total_number_of_Chinese_gardens | Correlation Coefficient | .097** | -.185** | .503** |
| | | Sig. (2-tailed) | <.001 | <.001 | <.001 |
| | | N | 1426 | 1257 | 1426 |
| | Royal_gardens | Correlation Coefficient | -.083* | -.034 | .337** |
| | | Sig. (2-tailed) | .025 | .388 | <.001 |
| | | N | 726 | 636 | 726 |
| | Private_gardens | Correlation Coefficient | -.010 | -.296** | .673** |
| | | Sig. (2-tailed) | .724 | <.001 | <.001 |
| | | N | 1139 | 975 | 1139 |

Correlation is significant at the 0.01 level (2-tailed).**

Correlation is significant at the 0.05 level (2-tailed).*

(Table 1: Results of Spearman's Correlation Analysis)

In summary, the results of the Spearman's Nonparametric Correlation Analysis reveal the following key findings:

The total number of Chinese gardens has a weak positive correlation with precipitation and a weak negative correlation with temperature. This indicates that as precipitation increases, the number of gardens slightly increases, and as temperature increases, the number of gardens slightly decreases. Additionally, a moderate positive correlation was observed between the total number of Chinese gardens and population, suggesting that as the population increases, the number of gardens also increases.

For royal gardens, a weak negative correlation was found with precipitation, while no significant correlation was observed with temperature. This suggests that the number of royal gardens may decrease slightly as precipitation increases, but no clear relationship is found with temperature. A moderate positive correlation was identified between the number of royal gardens and population, implying that the number of royal gardens increases as the population grows.

Private gardens exhibited no significant correlation with precipitation but had a moderate negative correlation with temperature, meaning that as temperature increases, the number of private gardens decreases. A strong positive correlation was found between the number of private gardens and population, indicating a substantial increase in private gardens as the population increases.

Overall, the results suggest that climate variables, such as precipitation and temperature, have varying degrees of association with the total number of Chinese gardens, royal gardens, and private gardens. Population appears to be an influential factor in the

development of both royal and private gardens. Further analysis using Principal Component Analysis will be conducted to identify the key factors in this relationship.

| Total Variance Explained | | | | | | |
|---|---|---|---|---|---|---|
| | Initial Eigenvalues | | | Extraction Sums of Squared Loadings | | |
| Component | Total | % of Variance | Cumulative % | Total | % of Variance | Cumulative % |
| 1 | 1.271 | 42.375 | 42.375 | 1.271 | 42.375 | 42.375 |
| 2 | 1.040 | 34.682 | 77.057 | 1.040 | 34.682 | 77.057 |
| 3 | .688 | 22.943 | 100.000 | | | |
| Extraction Method: Principal Component Analysis. | | | | | | |

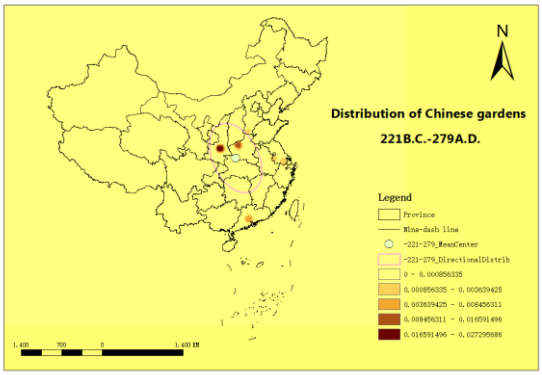
| Component Matrix[a] | | |
|---|---|---|
| | Component | |
| | 1 | 2 |
| Precipitation | .691 | .523 |
| Temperature | .822 | -.075 |
| Population | -.344 | .872 |
| Extraction Method: Principal Component Analysis. | | |
| a. 2 components extracted. | | |

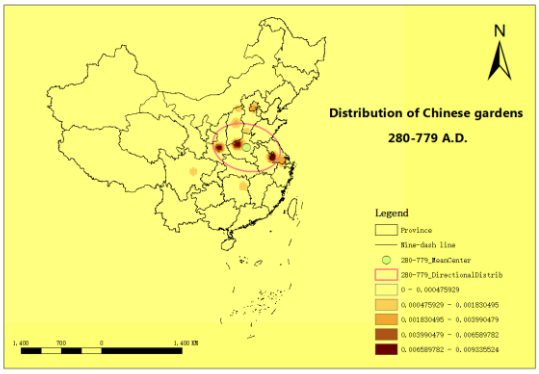
(Table 2: Results of Principal Component Analysis)

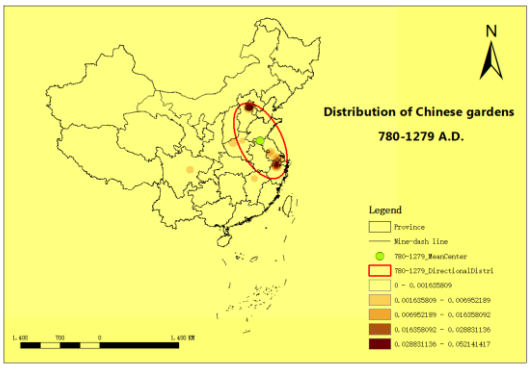
The results of the PCA analysis identified two distinct components. Component 1 has a strong positive loading (0.822) for temperature and a negative loading (-0.344) for population, whereas Component 2 has a strong positive loading (0.872) for population and a weak negative loading (-0.075) for temperature. These loadings demonstrate that temperature and population have unique influences on the two components.

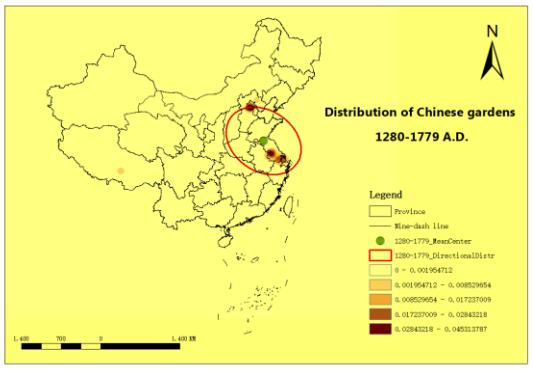
These PCA findings may indicate different aspects of the relationship between climate change and garden distribution in ancient China. The distinct loadings for temperature

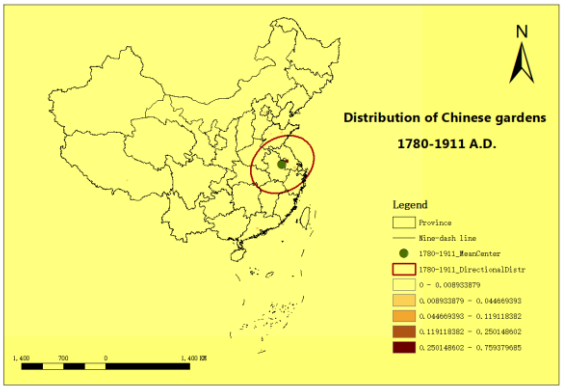
and population in the two components suggest that these factors might have played varying roles in shaping the distribution and development of gardens throughout Chinese history. Further investigation into these components could help to better understand the complex interplay between climate change, population dynamics, and the spatial distribution of ancient Chinese gardens.

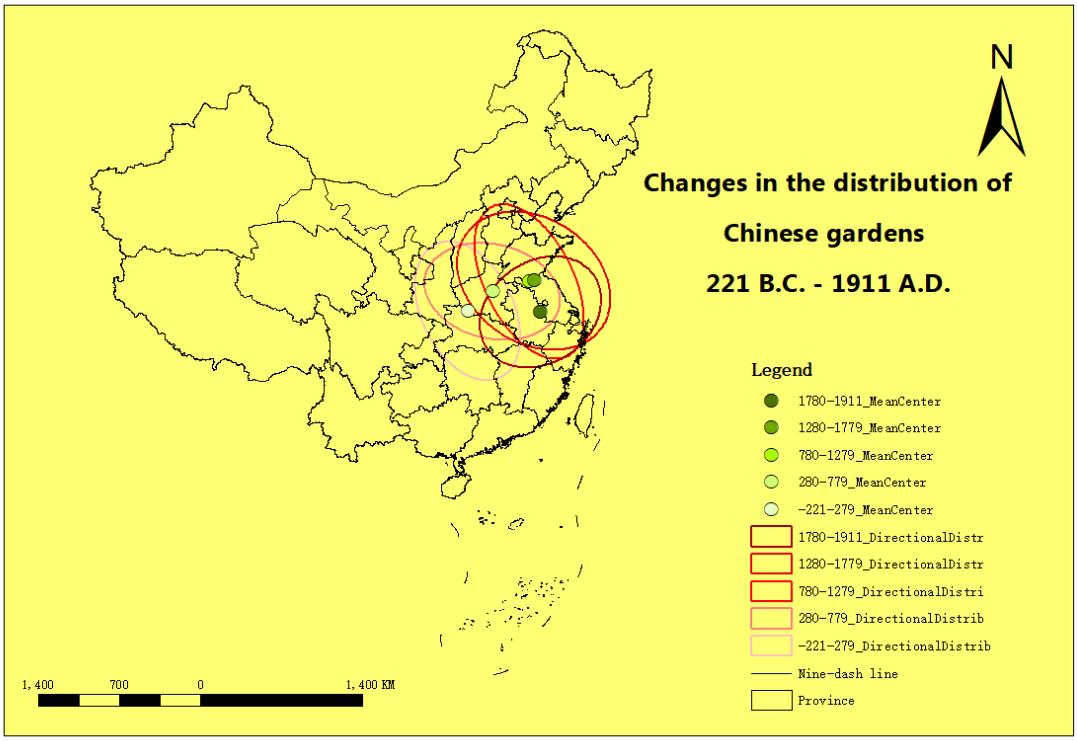





(Image set 1: Changes in the distribution of Chinese gardens 221 BC - 1911 AD)

The spatial analysis results, including standard deviation ellipse and kernel density analysis, reveal distinct spatial patterns in the distribution of ancient Chinese gardens. Over time, the center of distribution for these gardens shifted from the north, specifically the Yellow River Basin, to the south in the Yangtze River Basin. This shift indicates a changing preference in garden location throughout different historical periods.

Moreover, the distribution of gardens predominantly followed a north-south orientation during most periods. Kernel density analysis further identified the main centers of garden distribution as being in southern Shaanxi, northern Henan, Beijing, and the middle and lower reaches of the Yangtze River.While the distribution pattern of ancient Chinese gardens evolved over time, the analysis shows that they were primarily concentrated in

China's traditional agricultural areas. This concentration highlights the close relationship between gardens and agricultural practices, which played a vital role in shaping the spatial distribution of these cultural landscapes in ancient China.

**Discussion:**

Based on the analysis results, this study finds that the relationship between climate change and ancient Chinese gardens is complex, influenced by both natural factors and social and cultural factors. This section will interpret and discuss the results in the context of the research questions and existing literature.

The research questions mentioned earlier are as follows:

- What is the relationship between gardens and climate change on a nationwide scale in China from 221 BC to 1911 AD?
- What are the roles of social and cultural factors in these relationships?
- What are the differences in response to climate change between private gardens and royal gardens?

Gardens and Population:

According to the results of the Spearman correlation analysis and principal component analysis, this study finds a strong positive correlation between ancient Chinese gardens

and population, indicating that as the population increases, the number of gardens also increases. Research shows that population growth leads to an increase in housing demand (Omowa et al., 2023), as housing is one of the basic human needs (Maslow, 1943), and residential properties are one of the basic attributes of ancient Chinese gardens. Chen (2022) highlights that during the Qing Dynasty (1644-1912), there was a remarkable increase in population growth, making it one of the fastest-growing populations in the pre-modern world. The total population surged from over 100 million at the end of the 17th century to 430 million by the mid-19th century. This substantial population growth resulted from Chinese families taking advantage of new and improved economic opportunities, particularly the rejuvenation and expansion of agriculture, as well as enhancements in food production and living standards. Figure 1 illustrates the evident trends of population and garden growth during the Qing Dynasty. Related research also suggests that the advent of agriculture enabled a fivefold escalation in population growth compared to earlier expansions of hunter-gatherer societies (Gignoux et al., 2011). This evidence underscores the crucial role agricultural development played in the majority of cases involving the growth of China's ancient population.

However, population growth includes both natural growth and population migration. Combining the analysis of standard deviation ellipses, it is found that in almost every period, the highest garden distribution density is in the economic and political centers of that time. For example, southern Shaanxi and northern Henan were the political and economic centers of the Qin, Han, Tang, and Northern Song dynasties; Beijing was the political center of the Yuan, Ming, and Qing dynasties; the middle and lower reaches of

the Yangtze River (including Nanjing, Suzhou, Yangzhou, etc.) were important political and economic centers with developed agriculture, handicrafts, and commerce during the Ming and Qing dynasties (Lü, 2013). Studies have shown that politically stable and economically prosperous places attract more immigrants (Alesina et al., 2016). Immigrants often have more economic opportunities and stable lives in these places (Borjas & Chiswick, 2019). Research shows that well-educated young people have a stronger desire to migrate (Wu, 2010), and relatively wealthy people have a greater likelihood of migration because migration costs are high (Dustmann & Okatenko, 2014). One of our research subjects, the builders of private gardens, are often landowners, literati, and merchants with high education levels and strong migration abilities (Wang, 2010). This, to some extent, explains the high concentration of garden distribution in some areas in Image Set 1.

Furthermore, the development of transportation infrastructure, such as the Grand Canal, has promoted the flow of people and goods, boosting commercial prosperity and population growth (Wu et al., 2016). For example, the core areas of various dynasties are located in the eastern plains of China, and the Grand Canal runs from south to north, connecting China's north and south (Lee et al., 2022). The Grand Canal was initially constructed during the Sui Dynasty, expanded during the Six Dynasties, and has been a regional infrastructure that promotes social, economic, and political development throughout Chinese history (Dezhang, 2006). This, to some extent, explains the phenomenon in Image Set 1 where the garden distribution in some areas is primarily oriented along a north-south axis.

In summary, this section explains why there is a strong positive correlation between ancient Chinese gardens and population growth. The foundation of our argument is that housing is one of the basic human needs, and as the population increases, the number of gardens with residential attributes also increases. However, there were two main ways in which the population increased in ancient China: one was through the development of agricultural productivity, which promoted natural population growth, and the other was through political and economic centers attracting more immigrants. Additionally, the improvement of infrastructure (such as the Grand Canal) facilitated communication and exchange. Private gardens were often built by landowners, literati, and merchants with high education levels and strong migration abilities. This further explains the spatial patterns of garden distribution, as they tend to be concentrated in the political and economic centers of various dynasties. These findings provide valuable insights into the complex interplay between population growth, economic development, and garden distribution in ancient China, revealing historical human-environment interactions and their potential implications for contemporary urban planning and sustainable development.

Gardens, climate change and social crisis:

As mentioned in the previous section, the number of gardens is closely related to the migration of affluent and highly educated populations, which can be classified as active migration. However, there are more passive migrations related to climate-induced social

crises throughout Chinese history, particularly when viewed from long-term temporal and spatial scales (Pei et al., 2018b). This study can further explore and refine the fatal synergies of climate changes mentioned earlier.

Climate change can have an indirect impact on farmers' migration by promoting social crises (Pei et al., 2018b), and population migration further stimulates the generation of new housing demands. Related studies show that, on long temporal and spatial scales, the impact of temperature on migration in Chinese agricultural areas is greater than that of precipitation (Pei & Zhang, 2014; Pei et al., 2017). As shown in Image set 1, ancient Chinese gardens are mainly distributed in traditional agricultural areas, namely the Yellow River and Yangtze River basins. Proximity to rivers provides convenient conditions for agricultural irrigation. Irrigation is one of the main strategies to increase and stabilize agricultural productivity by mitigating the impacts of unpredictable rainfall (Vico & Porporato, 2015). This explains the weak significance and correlation between garden numbers and precipitation in Table 1.

However, despite technological advancements in agriculture, climate still dominates agricultural production (Dumrul & Kilicaslan, 2017). Regarding the impact of temperature, Pei et al. (2018b) directly pointed out that climate change, particularly the decrease in temperature, has a greater influence on triggering social crises (such as war, famine, and epidemics) than population pressure. Due to these social crises, ancient Chinese farmers had to make the decision to migrate to a suitable place for cultivation and political stability. Compared to active migration, this passive population migration is

usually involuntary, unplanned, and involves a large number of people (Castles, 2003; Riaño-Alcalá, 2008). When migrants flood into a place, it increases the demand for housing, which may promote the opening of new lands and the construction of gardens (Saiz, 2007).

From the perspective of the cultural attributes of Chinese gardens, during periods of climate-induced social crises, one possible explanation for the increase in the number of Chinese gardens (especially private gardens) is related to people's desire for stability, safety, and refuge, which further stimulates the demand for garden construction. The social turmoil and suffering brought about by crises lead the literati to feel disappointed and helpless about the social reality. Against this backdrop, classical gardens became a way to seek peace and spiritual freedom. As mentioned earlier, ancient Chinese gardens are a fusion of natural and human landscapes, serving not only as a place for literati to showcase their aesthetic taste and cultural accomplishments but also as a way to express their emotions and ideals (Zhou, 2008). In gardens, ancient Chinese literati could experience the beauty and tranquility of nature and express their criticism of social reality and longing for an ideal life through garden structures (Tang & Fu, 2019).

However, it is worth noting that while housing demand increases, it may also push up housing costs (e.g., rent) at the destination (Gonzalez & Ortega, 2013; Saiz, 2007). Although there is a lack of research in the context of ancient China, current studies point out that the availability of low-cost housing is considered the most important structural determinant of homelessness, i.e., rising housing costs lead to more homelessness (Fazel

et al., 2014). Therefore, this article posits that during climate change, especially periods of decreasing temperature, social crises will generate a large number of involuntary passive migrants under the stimulus of social crises. Among them, relatively affluent and educated individuals may build gardens and settle down for the long term, while the less affluent classes may end up on the streets, becoming homeless.

In summary, climate change, particularly the decrease in temperature, can lead to social crises that stimulate passive migration. These migrations, in turn, affect housing demands and contribute to the increase in the number of Chinese gardens, especially private gardens. The cultural significance of gardens as a refuge and source of spiritual freedom further drives the construction of these spaces during difficult times. However, it is important to consider the potential consequences of increased housing demands, such as higher housing costs and homelessness among less affluent populations.

Royal gardens and Private gardens:

According to Table 1, we found that compared to private gardens, royal gardens have a weaker correlation with population and no correlation with temperature. This paper believes that this is related to their climate resilience and sociocultural attributes.

Climate resilience refers to the ability of a system, community, or society to adapt to, withstand, and recover from the impacts of climate change (Velayudhan, 2021). Royal gardens, with their abundant resources and well-planned design, might be better equipped

to cope with climatic fluctuations and maintain their functionality even under adverse weather conditions. This greater resilience could be a result of advanced engineering techniques, better materials, and the expertise of skilled designers and workers (Wang, 2006; Zhou, 2008). Consequently, royal gardens may have a lower sensitivity to climate changes compared to private gardens, which are often built by individuals with fewer resources and expertise.

From a sociocultural perspective, royal gardens were typically constructed by the ruling class, such as emperors and royalty, as symbols of power, wealth, and prestige. Their construction was mainly driven not by population changes or climatic fluctuations, but by military, economic, or political considerations. Most royal gardens were built within the capital city, such as the Ming Dynasty's decision to establish Beijing as the capital. This choice was made to convey the message that the ruling dynasty had the Mandate of Heaven and that Beijing was the true cosmic center of the world, as well as to strengthen control over the military center, given that the north was the primary region for ethnic conflicts (Baratta and Magli, 2021; L. Liu & H. Liu, 2009). Some scholars have studied the site selection patterns of capitals during thirteen dynasties and concluded that after the Qin Dynasty (including Qin) and before the Sui Dynasty (excluding Sui), the political center (capital selection) clearly shifted with the movement of the economic center. After the Sui Dynasty (including Sui), China's political center gradually deviated from the economic center and moved closer to the military center (L. Liu & H. Liu, 2009).In contrast, private gardens are more directly influenced by population growth and social dynamics, as they are typically constructed by wealthy and educated individuals, such as

landlords, scholars, and merchants. These individuals are more likely to be affected by climate-induced social crises and migrations, leading to increased demand for housing, and subsequently constructing private gardens as a refuge and spiritual sanctuary.

In summary, royal gardens have a weaker correlation with population and temperature compared to private gardens due to their climate resilience and sociocultural attributes. Royal gardens, often built by the ruling class, are driven by military, economic, or political considerations rather than population changes or climatic fluctuations. In contrast, private gardens are more directly influenced by population growth and social dynamics and are often constructed by wealthy and educated individuals as a refuge and spiritual sanctuary.

**Significance and limitations of this study:**

The significance and limitations of this study can be viewed from the following aspects:
Significance of the study:

1. Enhancing understanding of the relationship between historical garden development and climate change: This research reveals the relationship between climate change, population, social crises, and the development of ancient Chinese gardens. By examining the connections between these factors, we can better understand the driving forces and interactions behind the construction of royal and private gardens throughout history.

2. Informing modern urban planning and addressing climate change challenges: Insights gained from this research can provide valuable lessons for contemporary urban planners and landscape designers. For example, by studying how ancient Chinese gardens were influenced by population growth, climate change, and social crises, this research offers insights into how societies adapted to these challenges and how gardens served as physical and cultural spaces for refuge and spiritual freedom. These lessons can guide our approaches to addressing modern challenges, such as the need for sustainable, resilient communities and the importance of urban green spaces.
3. Climate resilience and adaptation: This study demonstrates how ancient societies were affected by climate change and how they adapted to these challenges, particularly through the construction of gardens. This knowledge can inform contemporary climate resilience and adaptation strategies, such as providing more affordable and comfortable living environments to cope with and accommodate climate-induced migration and providing more support for the homeless.

Despite the valuable insights this research provides on the relationship between ancient Chinese gardens, population, and climate change, there are some limitations that should be acknowledged:

1. Data limitations: The data for gardens, precipitation, and temperature is limited to available historical records, which might be incomplete or biased.
2. Temporal and spatial scales: The analysis conducted in this study may not capture

the full complexity of the relationships between gardens, population, and climate change at different temporal and spatial scales. The political, economic, and social backgrounds of different dynasties may also affect the generalizability of the research findings.

3. Causality and confounding factors: The correlations observed in this study do not necessarily imply causality. There may be other confounding factors not considered, which could influence the relationship between population growth, changes in the number and distribution of classical Chinese gardens, and climate change. Identifying and controlling these factors would strengthen the study's conclusions.
4. Generalizability: The results of this study are specific to ancient China and may not be directly applicable to other historical or contemporary contexts. Unique cultural, political, and environmental factors in ancient China may limit the generalizability of the findings to other settings.

**Conclusion:**

This study has examined the relationships between ancient Chinese gardens and climate change in China, spanning from 221 B.C. to 1911 A.D. The research has revealed significant insights into the connections between climate change, population growth, social crises, and the development of royal and private gardens. By employing a

multidisciplinary approach, the study has successfully addressed the current research gaps and limitations in the literature, providing valuable lessons for contemporary urban planning, landscape design, and climate resilience strategies.

The research has shown that climate change, particularly the decrease in temperature, can lead to social crises and migrations, which affect housing demands and contribute to the increase in the number of Chinese gardens. Moreover, the study has demonstrated that population growth and economic development played significant roles in shaping the spatial distribution of ancient Chinese gardens, with private gardens being more directly influenced by these factors. In contrast, royal gardens were found to be more resilient to climate fluctuations due to their sociocultural attributes.

The insights gained from this research can inform modern urban planning and landscape design, as well as contribute to the development of sustainable, resilient communities in the face of climate change. By studying how ancient Chinese gardens served as physical and cultural spaces for refuge and spiritual freedom, contemporary societies can learn from these historical examples and implement strategies to address current challenges. Furthermore, this research highlights the importance of considering social factors and the interplay between nature and human society when examining the impacts of climate change on housing and the built environment.

While this study provides significant contributions to our understanding of the relationships between ancient Chinese gardens and climate change, it is not without

limitations. Future research could further explore the role of different social classes and political systems in shaping garden development and design, as well as investigate the potential consequences of increased housing demands on less affluent populations. Moreover, research on the impacts of climate change on housing could be extended to include other regions and cultures to develop a more comprehensive understanding of human-environment interactions throughout history.

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