ISSN 2959-409X

Utilizing Paleoclimate Data to Analyze the Relationship Between Climate Change and Human Activities

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Abstract:

Our research aims at finding the relationship between climatic cycle-changes and the human activities in ancient China. Most climatic changes show shifts in the precipitation volume and alternations between warm and cold periods. Through other research findings, we find the precipitation volume is closely connected with alternations of warm and cold periods. This report presents a linear comparison between the population of ancient China and the east Asia climate variables and chooses tree rings as the main indicator of the paleo-climate. Through the literature review and the data analysis, we find that (1) The dominant climate pattern in East Asia is East Asia Summer Monsoon system, causing centennial scaled climate periodicities, affecting the ecosystem and the society. (2) There are certain cycles of climate change, in which the warm period and the cold period have a certain influence on the population change. (3) The precipitation has a certain correlation with the population change. However, single temperature and precipitation cannot directly affect the population change, but also need to be combined with social and historical factors specific analysis.

Keywords: climate change, paleoclimate data, human civilization.

1. Introduction

1.1 Driving Mechanism of the Climate Cycle

The climate pattern of the East Asia is known to be dominated by East Asia Summer Monsoon system [1], and the fluctuation of the intensity of the monsoon will cause decadal-centennial scaled climate periodicities, which plays a substantial role in east Asia by affecting both the ecosystem and the anthropogenic activities [2].

Several studies have been carried out to reconstruction decadal and centennial scale periodic climate shifting [3-4], and the driving mechanisms of the oscillations, separated as internal forcing and external forcing [5], have been examined. And the pivotal role regular climate shifts play in intervening human civilization have been noticed. However, though a number of research has been carried out to demonstrate the interaction between cyclic climate change and the rise and fall of civilization in East Asia [6] and the Tibetan Plateau [7], they mainly focus on a specific time period, such as the Medieval Warm Period or the Little Ice Age, and few of them have made a linear comparison between the climate and the civilization under a relatively long time coverage. This is partly because the dearth of a consistent index that can reflect the prosperity of civilization. Thus, Further research is needed to bring a broader view of climate-civilization relationship.

The growth of tree rings are affected by a numbers of factors, including climate variables such as temperature, precipitation, sunlight and wind. Due to its high resolution and stable reliability, tree-rings are considered important proxy in paleo-climate reconstruction [8], particularly in those with relatively short time coverage. In recent years, several research using tree-rings data were conducted, but they were either limited to specific regions like the Qinghai-Tibetan Plateau [9] or covered a short time period, making it hard to make a long-term reconstruction of paleo-climate in east Asia.

1.2 The Relationship between Climate Change and Human Activities

China is an ancient and culturally rich civilization with a long history. We can find numerous historical records related to climate change, which provide essential data for studying historical climate patterns [10-11]. This makes it highly valuable to explore the impact of climate change on ancient Chinese civilization, as there are rich case studies of climate variations and civilization development on this land.

By analyzing these documents, we summarize climate changes mainly into variations in precipitation and alternations between cold and warm periods. According to historical records, in the past two thousand years, the overall trend in China's precipitation has been a decrease. This decrease is primarily due to the reduction in forest coverage. Regional changes in humidity, frequency of droughts and floods, have alternated roughly on a centennial scale with climate changes, a trend we call "gradual drying amid fluctuations." [12] In periods of low precipitation, irrigation systems were under significant pressure, and seasonal droughts were frequent, directly causing reduced grain production.

Returning to the alternation between cold and warm periods, we find that the pattern of climate cold and warm periods aligns with the changes in dryness and wetness. For example, cold periods are often times of significant drought and flood occurrences. As is well known, the growth of crops is influenced not only by precipitation but also by temperature. Therefore, lower temperatures could lead to the southward migration of the agricultural-pastoral transition zone, greatly reducing arable land. Conversely, during warm periods, some border areas became suitable for farming, increasing arable land and boosting grain production.

It is often said that food security is the foundation of a nation and the basis for economic development and social stability. Ancient China was an agricultural country, and the climate changes mentioned above can be traced back to food security issues of that time. Due to the influence of climate, grain production directly affected rice prices, with the two often showing an inverse relationship. In summary, during cold periods, lower temperatures, less precipitation, frequent droughts and floods, and lower grain production led to higher rice prices, significantly increasing people's subsistence pressures. Severe famines causing large-scale unrest meant that society entered an unstable phase, shaking the foundations of civilization, suggesting a decline.

Research shows that major historical events leading to dynastic changes, such as the An Lushan Rebellion (755-763 AD) at the end of the Tang Dynasty, the Jingkang Incident (1127 AD) during the transition between the Song and Jin dynasties, and the peasant uprising at the end of the Ming Dynasty (1627-1664 AD), correspond to historical cold periods, which were also times of frequent droughts and floods. Further analysis of the frequency of wars in Chinese history shows that periods of high warfare coincide with these periods. In general, "cold suppresses, warmth flourishes" [12] is a rough reflection of the development of ancient Chinese civilization. Additionally, population changes also serve as important evidence of this centennial-scale pattern, with population growth and reduction influenced mainly by natural disasters and wars. Although China's population has consistently increased over time, growth rates and short-term population numbers were affected by these factors. The population in ancient China was mainly distributed in areas with high grain production, such as the saying in the Song Dynasty: "When Suzhou and Huzhou are ripe, the world is full." Therefore, during cold periods, the population would migrate southward to regions with abundant grain production.

In conclusion, climate change had multifaceted impacts on the development of ancient Chinese civilization, including grain production, the rise and fall of civilizations, outbreaks of wars, dynastic changes, and population fluctuations. We can understand history through climate and infer historical climate conditions from historical events. In further research, we hope to use modern technological methods to more accurately reconstruct historical climate data and explore the complex relationship between climate change and social development in depth.

2. Materials and Methods

To reconstruct historical climate data for China over the past 2000 years, this article utilized a combination of paleoclimatic proxies and historical documents. According to the study, since 1980, more than 600 papers have been published on the reconstruction of temperature and precipitation (including humidity and runoff) across China, using evidence from tree rings, ice cores, stalagmites, corals and high-resolution lake deposits. Preliminary estimates of sampling sites covered by this literature have exceeded 500. In particular, tree ring, as a key indicator, has become one of the important proxy evidence for quantitative reconstruction of climate change in China over the past 100 to 1000 years due to its significant advantages such as high temporal resolution, wide distribution, accurate dating and easy reproduction [12]. Therefore, this paper will mainly use tree rings as key indicators, supplemented by ice core and pollen data. Since it is difficult to find the reconstructed air temperature and precipitation data with high resolution in the existing database, this paper will analyze the effects of air temperature and precipitation on population in China in the past 2000 years by using previous literature data. Both temperature and precipitation data were obtained from the National Centers for Environment Information Official website, The temperature data was obtained based on the database "Dataset of China Temperature reconstruction from 1 C.E. to 2000C.E."[13] (Fig.1). The Precipitation data were extracted from the database of "China Regional 22,000 Annual Temperature and Precipitation Reconstructions" [14] (Fig.2) The population data is obtained by integrating recommended literature and recommended data from Wikipedia (Fig.3)

Age_CE	NEC	NC	EC	CC	SC	QTP	SWC	NWC	NEC-10th	NC-10th	EC-10th	CC-10th	SC-10th	QTP-10th	SWC-10th	NWC-10th	NEC-90th	NC-90th	EC-90th	CC-90th	SC-90th	QTP-90th	SWC-90th	NWC-90th
-250	-2.12	6.57	-10.11	-13.49	18.63	0.29	8.06	2.07	0.36	17.76	1.06	-1.21	32.74	1.78	9.84	6.07	-4.82	-1.53	-24.68	-29.86	5.06	-0.75	6.88	-0.55
-249	-2.48	7.47	-8.34	-13.8	16.59	-0.07	7.63	1.92	-0.17	20.16	2.82	-1.4	35.7	1.11	9.32	5.73	-5.3	-1.25	-22.34	-30.96	5.95	-1.12	6.2	-0.59
-248	-2.42	6.92	-6.85	-12.25	18.08	-0.55	9.15	1.23	-0.25	19.51	4.2	-0.79	30.72	0.43	12.36	4.17	-5.11	-1.52	-19.79	-27.56	5.14	-1.54	7.94	-0.89
-247	-1.36	7.07	-5.8	-10.74	17.53	-1.56	9.17	0.95	0.62	18.37	7.89	-0.14	32.5	-0.43	12.12	3.7	-3.7	-1.32	-18.76	-25.99	6.07	-3.11	7.93	-0.99
-246	-2.08	8.46	-5.46	-11.73	18.04	-0.53	10.59	1.81	0.22	22.24	8.64	-0.47	31.35	0.37	14.21	5.45	-4.79	-0.99	-19.34	-26.43	5.68	-1.45	8.58	-0.65
-245	-1.5	7.74	-4.87	-11.11	17.87	-1.49	9.85	1.46	0.75	20.87	9.78	-0.2	32.54	-0.4	12.99	4.65	-3.86	-1.22	-18.4	-25.44	6.1	-3.05	8.24	-0.77
-244	-1.43	5.2	-4.45	-9.46	20.64	-1.06	11.6	1.52	0.77	14.97	9.69	0.23	32.75	0	15.93	4.76	-3.76	-1.96	-17.73	-22.27	6.08	-2.17	8.99	-0.76
-243	-1	7.28	1.6	-8.93	18.71	-1.85	9.11	1.05	1.43	19.65	20.23	0.51	38.15	-0.63	12.12	3.77	-3.21	-1.46	-11.7	-22.25	7.47	-3.69	7.88	-0.94
-242	-2.4	2.65	-1.65	-8.38	17.46	-0.83	11.93	-0.38	-0.23	10.83	15.94	0.65	34.75	0.17	15.91	1.17	-5.22	-3.57	-15.29	-20.76	6.45	-1.82	9.11	-1.54
-241	-1.7	1.77	-2.62	-8.17	18.22	0.34	13.67	0.05	0.27	8.38	12.36	0.7	32.61	1.45	18.89	1.96	-4.05	-4.02	-15.98	-20.05	6.18	-0.56	9.77	-1.36
-240	-1.33	-0.5	-0.01	-8.12	18.42	-1.14	12	0.77	0.54	3.36	19.03	0.71	33.95	0.01	17.19	3.21	-3.45	-6.57	-13.15	-20.6	6.67	-2.32	9.09	-1.07
-239	0.74	1.58	5.32	-1.39	20.62	-0.85	11.12	0.98	2.85	6.82	28.27	5.79	34.71	0.13	15.75	3.59	-1.35	-3.62	-8.65	-11.88	7.18	-1.92	8.77	-1
-238	3.34	3.17	9.91	7.48	20.23	-1.36	10.76	0.48	7.86	8.62	32.91	23.09	37.57	-0.28	15.28	2.57	-0.13	-2.34	-6.4	-4.71	7.96	-2.84	8.61	-1.18
-237	2.5	2.41	11.63	4.43	14.52	-1.89	9.49	0.05	6.07	7.28	38.62	16.68	37.55	-0.58	12.72	1.89	-0.5	-2.77	-5.72	-6.85	7.73	-3.65	8.05	-1.31
-236	0.62	-0.33	8.32	3.03	11.38	-0.07	11.16	-0.2	2.96	3.33	29.16	13.54	26.9	0.92	16.14	1.42	-1.33	-4.96	-7.36	-7.62	4.77	-0.92	8.64	-1.42
-235	-0.22	-2.92	4.57	0.31	10.69	-1.57	9.48	-1.16	1.69	0.9	21.38	7.8	20.35	-0.4	12.78	-0.24	-2.02	-8.59	-8.48	-9.5	3.24	-2.99	7.98	-2.08
-234	-0.85	-2.44	6.75	-1.35	11.22	-1.29	8.89	-1.26	0.99	1.18	27.33	5.47	19.12	-0.21	12.29	-0.39	-2.7	-8.44	-7.61	-11.78	2.89	-2.54	7.75	-2.11
-233	-0.38	-0.55	4.28	0.41	10.69	-2.58	5.4	-1.86	1.63	3.21	18.55	8.77	19.38	-1.02	7.43	-0.9	-2.2	-5.58	-8.92	-9.39	3.34	-4.95	2.23	-2.64
-232	-1.37	-1.95	-0.36	-2.29	12.6	-1.58	8.34	-1.26	0.59	1.27	9.89	4.52	19.2	-0.39	10.93	-0.37	-3.27	-7.31	-12.99	-11.43	2.88	-2.94	7.15	-1.98
-231	-1.54	-0.9	0.36	-3.87	14.42	-3.75	6.71	-0.56	0.5	2.29	11.63	3.39	23.03	-1.59	8.31	0.75	-3.42	-6.31	-12.7	-12.97	3.67	-6.9	4.34	-1.58
-230	-2.14	0.58	3.58	-7.85	13.89	-3.06	7.33	-0.23	-0.11	5.4	21.14	0.79	26.44	-1.25	9.09	1.23	-4.51	-5.47	-9	-18.76	4.57	-5.65	5.49	-1.44
-229	-1.11	4.17	2.36	-7.11	13.26	-3.13	7.42	-0.74	0.79	11.73	15.68	0.9	24.96	-1.24	9.04	0.38	-3.42	-2.41	-11.52	-17.57	4.22	-5.68	5.98	-1.73
-228	-1.53	4.82	1.7	-9.75	14.66	-3.36	7.64	-0.74	0.52	13.2	15.73	0.05	24	-1.33	9.61	0.55	-4.04	-2.12	-11.68	-20.84	4.04	-5.98	6.51	-1.73
-227	-2.02	3.53	-0.87	-12.28	15.45	-1.7	10.28	-0.42	0.16	11.54	10.99	-0.88	26.73	-0.46	13.46	1.15	-4.83	-3.42	-13	-25.22	4.42	-3.23	8.4	-1.58
-226	-1.91	4.52	-2.21	-11.22	17.97	-1.5	10.34	0.23	0.18	13.03	8.13	-0.31	27.87	-0.34	13.97	2.41	-4.7	-2.82	-13.33	-23.93	4.86	-2.77	8.44	-1.33
-225	-2.23	5.51	-0.92	-13.51	21.11	-0.62	11.16	-0.13	0.12	15.04	12.21	-1.42	31.97	0.32	15.39	1.83	-5.3	-2.65	-13.42	-28.01	5.92	-1.51	8.88	-1.48
-224	-1.31	7.47	2.92	-9.18	23.28	2.12	13.28	-0.43	0.69	18.7	18.34	0.18	37.61	4.15	18.55	1.42	-3.27	-1.49	-9.07	-20.24	7.31	0.46	9.65	-1.61
-223	-1.04	8.54	2.11	-8.04	24.03	3.84	16.61	-0.42	1.09	21.21	17.39	0.81	41.34	7.14	24.06	1.61	-2.85	-0.9	-10	-18.84	7.85	1.25	10.95	-1.62
-222	-0.43	9.6	7.11	-8.95	27.02	3.18	17.08	-0.3	1.95	22.84	27.13	0.39	43.08	6.13	24.75	1.77	-2.39	-0.51	-7.53	-21.33	8.3	0.96	11.06	-1.57
-221	1.81	12.42	13.01	-2.88	27.49	2.45	14.79	0.91	4.91	26.04	34.94	3.93	48.17	4.66	21.68	3.87	-0.97	0.8	-4.64	-13.55	9.99	0.67	10.26	-1.01
-220	3.87	12.86	13.42	2.09	26.61	1.99	12.64	0.33	8.24	26.6	35.24	10.8	48.78	3.95	17.89	2.4	-0.17	1.3	-4.21	-9.37	10.25	0.45	9.4	-1.28
-219	4.51	12.43	13.4	5.25	28.7	1.2	11.56	-0.46	9.55	25.65	35.56	15.87	46.87	2.64	16.27	1.03	0.03	1.18	-3.94	-7.14	9.79	-0.12	9.03	-1.59
-218	3	11.58	15.94	1.85	28.71	0.77	10.99	0.14	7.42	24.4	42.57	11.27	51.11	2.04	15.34	2	-0.58	0.6	-3.33	-9.15	10.51	-0.35	8.81	-1.32
-217	2.05	11.1	16.87	-0.49	29.03	-0.12	8.55	0.01	6.72	25.29	43.5	6.94	51.59	1.11	11.47	1.9	-0.96	0.39	-3.43	-11.52	10.45	-1.11	7.67	-1.34
-216	1.93	12.45	17.17	0.11	31.3	-1	6.57	-0.13	6.49	27.85	46.1	7.24	52.72	0.27	8.2	1.57	-0.92	0.92	-3.35	-10.64	10.65	-2.3	4.62	-1.39
-215	4.88	14.47	20.61	4.59	32.48	-0.35	7.43	0.17	10.63	29.46	52.37	16.28	57.22	0.89	9.37	2.27	0.14	1.89	-2.06	-7.29	11.4	-1.4	5.99	-1.27
-214	4.67	11.99	17.81	4.31	34.14	-1.98	6.17	0.52	10.08	24.92	45.95	15.48	58.53	-0.58	7.84	2.81	0.08	0.92	-3.2	-7.74	11.72	-3.98	3.81	-1.15
-213	6.22	11.88	22.29	7.28	34.02	-3.27	5.04	0.36	12.84	25.14	55.44	21.11	61.98	-1.3	7.1	2.5	0.76	0.75	-1.2	-5.83	12.39	-6.15	1.67	-1.23
-212	5.87	10.65	22.15	6.85	29.61	-2.92	5.09	0.61	12.02	22.34	54.3	21.02	62.01	-1.11	7.09	3.2	0.6	0.24	-1.19	-5.56	12.27	-5.54	1.93	-1.1
-211	4.32	7.53	17.93	5.58	23.94	-2	7.76	-0.23	9.64	17.04	46.98	18.83	54.18	-0.66	9.69	1.41	-0.05	-1.04	-2.69	-5.77	10.57	-3.86	6.57	-1.45
-210	0.87	4.7	10.11	-1.85	21.64	-2.25	7.85	-1.76	4.31	12.2	32.25	5.94	43.81	-0.82	9.65	-0.83	-1.46	-2.54	-5.73	-10.62	8.19	-4.38	6.15	-2.61
-209	-0.84	6.89	8.64	-5.76	20.89	-0.7	9.56	-2.1	2.89	17.8	31.04	1.73	42.87	0.24	12.14	-0.95	-3.2	-1.87	-6.45	-16.01	7.26	-1.81	8.22	-3.15
-208	-1.35	4.19	6.9	-7.28	16.65	-2.3	8.85	-2.23	1.68	11.92	28.4	0.81	41.97	-0.83	10.73	-1.06	-4.12	-3.54	-7.24	-18.31	7.03	-4.36	7.91	-3.31
-207	-1.78	2.08	2.44	-7.25	14.49	-0.92	10.15	-2.74	0.81	7.79	18.78	0.96	33.13	-0.02	12.49	-1.37	-4.35	-4.3	-9.41	-17.54	5.09	-1.93	8.56	-4.26
-206	-1.77	0.82	1.29	-6.6	12.48	0.72	13.78	-2.76	0.6	5.5	14.3	1.24	28.34	1.96	18.78	-1.4	-4.14	-4.67	-10.37	-17.07	4.15	-0.41	9.84	-4.35
-205	-2.97	-1.13	0.3	-11.59	10.37	0.74	13.57	-2.6	-0.38	2.61	15.55	-0.47	25.59	1.98	18.47	-1.31	-6.23	-7.04	-11.83	-24.92	3.14	-0.41	9.79	-4.05
-204	-4.05	1.44	-1.53	-11.18	6.52	0.24	11.86	-3.23	-0.68	7.59	11.31	-0.57	22.19	1.23	15.95	-1.65	-7.93	-4.87	-13.77	-24.31	1.45	-0.83	9.18	-5.23

Figure 1: The PCA data of China temperature over the past 2000 years

Year_AD	temp-PLS	temp-PLS-up_err	temp-PLS-lo_err	temp-PC	temp-PC-up_err	temp-PC-lo_err
5	0.33	0.66	0	0.18	0.35	0
15	0.39	0.88	-0.1	0.04	0.23	-0.16
25	-0.08	0.16	-0.32	-0.04	0.36	-0.45
35	0.24	0.59	-0.1	0.06	0.33	-0.22
45	0.29	0.68	-0.09	0.06	0.29	-0.16
55	0.3	0.63	-0.04	0.13	0.32	-0.05
65	0.13	0.48	-0.23	-0.01	0.38	-0.4
75	0.02	0.15	-0.11	0.17	0.53	-0.19
85	0.16	0.29	0.02	0.33	0.55	0.1
95	0.29	0.6	-0.03	0.17	0.54	-0.21
105	0.19	0.41	-0.03	0.18	0.58	-0.22
115	0.47	1	-0.07	0.07	0.35	-0.21
125	0.27	0.51	0.03	0.23	0.45	0
135	-0.06	0.09	-0.21	0.1	0.67	-0.46
145	-0.03	0.15	-0.21	0.06	0.6	-0.47
155	0.18	0.35	0.02	0.25	0.43	0.06
165	0.3	0.52	0.09	0.28	0.48	0.08
175	0.32	0.66	-0.03	0.14	0.3	-0.03
185	-0.04	0.2	-0.27	-0.02	0.39	-0.42
195	0.17	0.4	-0.07	0.12	0.31	-0.07
205	-0.28	-0.1	-0.47	-0.05	0.37	-0.47
215	-0.16	0.3	-0.63	-0.35	0.25	-0.95
225	-0.13	0.25	-0.51	-0.23	0.3	-0.76
235	0.03	0.18	-0.12	0.12	0.29	-0.04
245	0.07	0.26	-0.12	0.11	0.31	-0.09
255	-0.21	-0.05	-0.38	0.06	0.29	-0.17
265	-0.33	-0.13	-0.52	-0.06	0.18	-0.31
275	0.12	0.65	-0.41	-0.25	0.21	-0.72
285	-0.01	0.26	-0.28	-0.07	0.34	-0.49
295	-0.14	0.18	-0.46	-0.21	0.1	-0.51
305	0.16	0.72	-0.4	-0.24	0.11	-0.6
315	-0.08	0.23	-0.39	-0.16	0.16	-0.48
325	-0.15	0.24	-0.55	-0.3	0.06	-0.65
335	-0.24	0.17	-0.65	-0.37	0.02	-0.76
345	-0.06	0.27	-0.39	-0.16	0.13	-0.45
355	0.03	0.28	-0.23	-0.01	0.2	-0.22
365	0.21	0.58	-0.16	0.02	0.24	-0.2
375	0.03	0.3	-0.24	-0.02	0.28	-0.32
385	-0.02	0.18	-0.23	0.02	0.26	-0.22
395	0.05	0.44	-0.34	-0.13	0.18	-0.44

Figure 2: The data of China precipitation over the past 2000 years

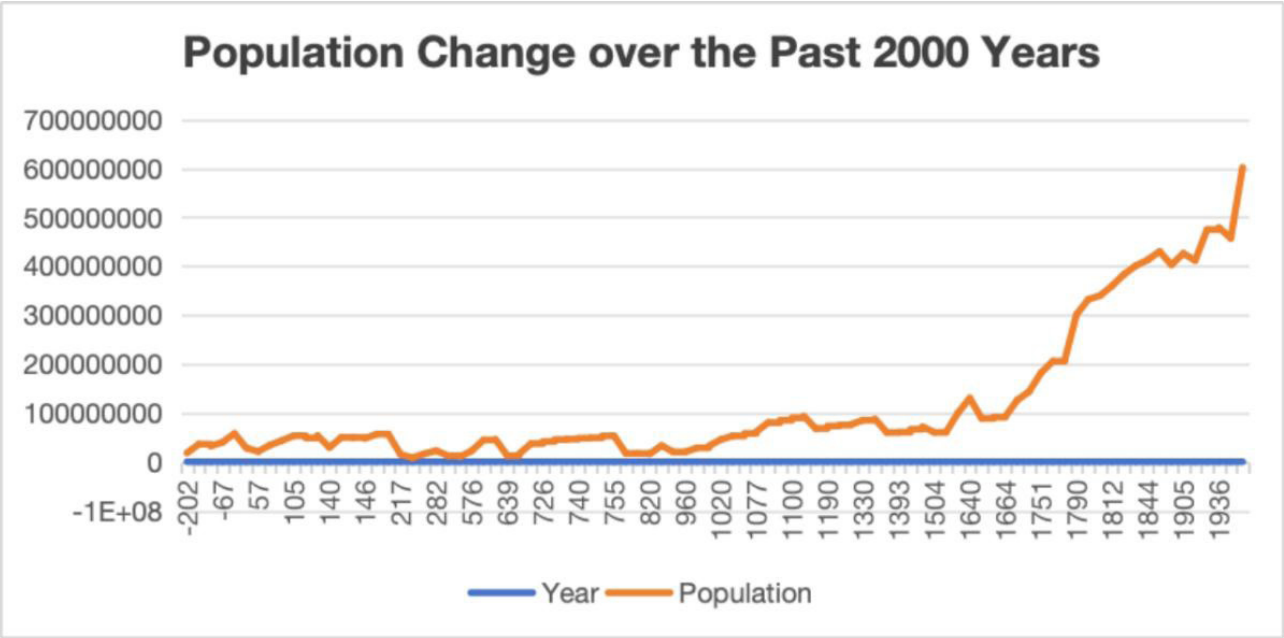

Figure 3: The data of China population over the past 2000 years

To prepare the datasets for analysis, extensive preprocessing was required. For the temperature data, the relevant results will be based on the literature review and the regression analysis. The precipitation data underwent cleaning, with metadata rows omitted and columns realigned to ensure each column accurately represented a region's precipitation measurements. As for the the population data, it was cleaned and structured to include columns for the year, population count, and population growth rate. Then the cleaned temperature, precipitation, and population datasets were merged on the "Year" column, aligning the data points across the different datasets. Finally, two separate regression analyses were conducted to investigate the relationships between climate variables (temperature and precipitation) and population growth rate.

The second regression model examined the effect of precipitation on population growth rate, with precipitation measurements from various regions (Region1 to Region24) serving as the independent variables and population growth rate as the dependent variable. This model also included a constant term (intercept) and was evaluated using similar statistical metrics to the temperature model, focusing on the significance of each region's precipitation data through p-values.

3. Results

3.1 Temperature Cycle

According to Ge et al. (2013), based on the integration of 28 sequences and the reconstruction of the latest series of temperature changes in China in the past 2000 years by using two regression calibration methods and its wavelet analysis results (Fig.4.), researches find that in the past 2000 years, the maximum interdecadal variation of temperature change in China is 1.1 ℃, and the intercentennial variation is 0.6 ℃There are significant periods of quasi-700 years and 200-300 years; There are four warm and cold periods of one hundred feet. The beginning and ending times of the four warm periods are roughly: AD1-200, 550-760, 950-1300 and the 20th century; The four cold periods are roughly in order: AD210-350, 420-530, 780-940, and 1320-1900 [11].

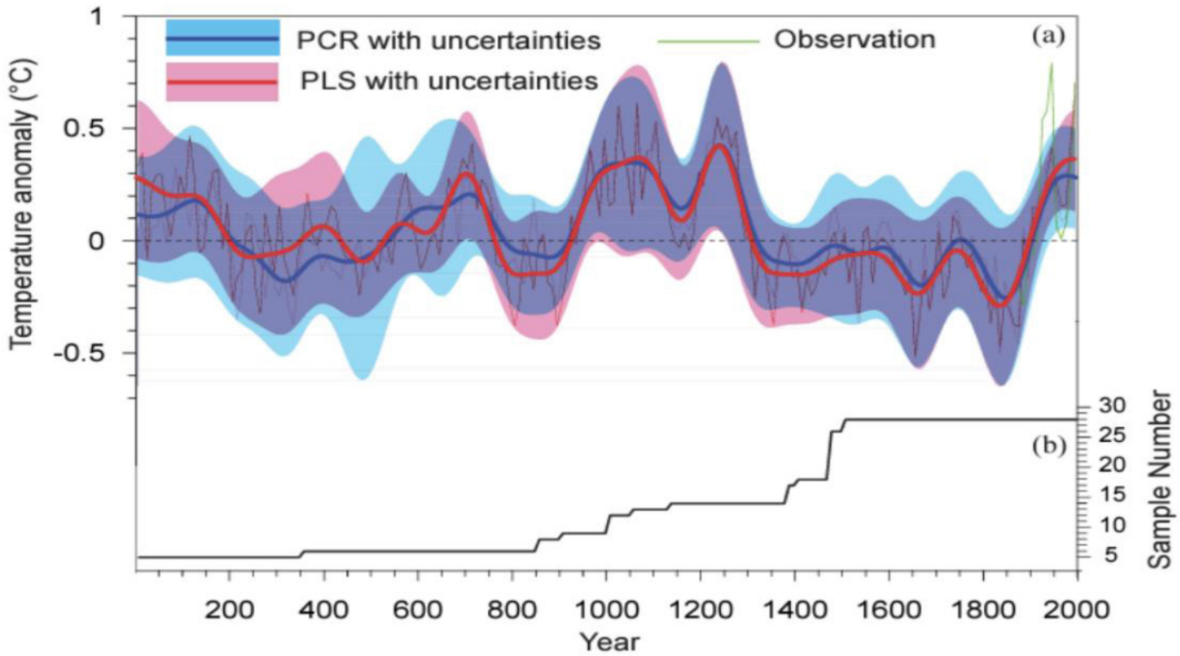

Figure 4: Temperature changes in China (a) and its wavelet (b) during the past 2000 years (Ge et al., 2012).

At the same time, notable periods include the Medieval Warm Period (800-1300 AD) and the Little Ice Age (1300-1850 AD). Temperature reconstructions indicate warmer conditions during the Tang Dynasty (618-907 AD) and cooler conditions during the Ming Dynasty (1368-1644 AD). Precipitation patterns showed substantial regional variability, with notable droughts during the late Ming Dynasty and increased rainfall during the Southern Song Dynasty (1127-1279 AD).

The first regression analysis focused on the relationship between temperature (including Principal Component Analysis (PCA) temperature) and population growth rate. The Ordinary Least Squares (OLS) regression model included temperature as the independent variable and population growth rate as the dependent variable. The model was evaluated using R-squared, adjusted R-squared, F-statistic, and p-values for the coefficients (Fig.5)

- R-squared: The model's R-squared value was 0.046, indicating that only 4.6% of the variance in population growth rate could be explained by the temperature variable.
- A djusted R-squared: The adjusted R-squared value was -0.090, suggesting that the model's explanatory power decreased when accounting for the number of predictors.
- F-statistic: The F-statistic value was 0.337 with a p-value of 0.580, indicating that the overall model was not statistically significant.
- Coefficients: The temperature coefficient was 0.0018 with a p-value of 0.998, and the PCA temperature coefficient was 0.4828 with a p-value of 0.580. These p-values indicate that neither temperature nor PCA temperature significantly impacted population growth rate.

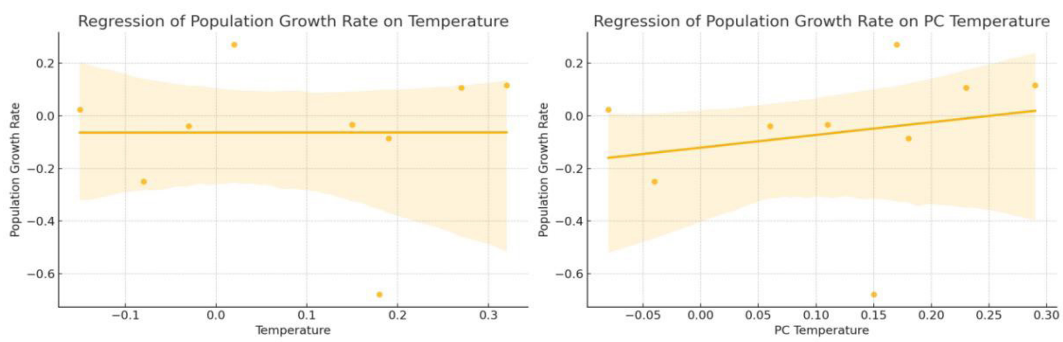

Figure 5: Regression Analysis of Temperature and Population Growth Rate

The results suggest a limited relationship between temperature and population growth rate. The low R-squared and adjusted R-squared values, coupled with the non-significant p-values for the temperature coefficients, imply that temperature variations had minimal influence on population growth over the past 2000 years.

3.2 The Relationship between Precipitation and Population

The second regression analysis (Fig.6.) examined the impact of precipitation on population growth rate. This OLS regression model included precipitation measurements from multiple regions (Region1 to Region 24) as the independent variables and population growth rate as the dependent variable. Simultaneously, the model was assessed using similar statistical metrics.

- R-squared: The model's R-squared value was 0.294, indicating that 29.4% of the variance in population growth rate was explained by the precipitation variables.
- Adjusted R-squared: The adjusted R-squared value was 0.034, showing a substantial decrease, which suggests that many of the predictors may not be contributing significantly to the model.
- F-statistic: The F-statistic value was 1.129 with a p-value of 0.340, indicating that the overall model was not statistically significant.
- Coefficients: The analysis revealed that precipitation in Region2 (coefficient: -0.1963, p-value: 0.049) and Region18 (coefficient: 0.1235, p-value: 0.037) had statistically significant impacts on population growth rate.

However, the other regions did not show significant effects, as indicated by their high p-values. The model demonstrated a moderate explanatory power with an R-squared of 0.294, but the adjusted R-squared of 0.034 suggests overfitting with many non-significant predictors. Only two regions (Region2 and Region18) showed a significant relationship with population growth rate, implying that specific regional precipitation patterns may have influenced demographic changes.

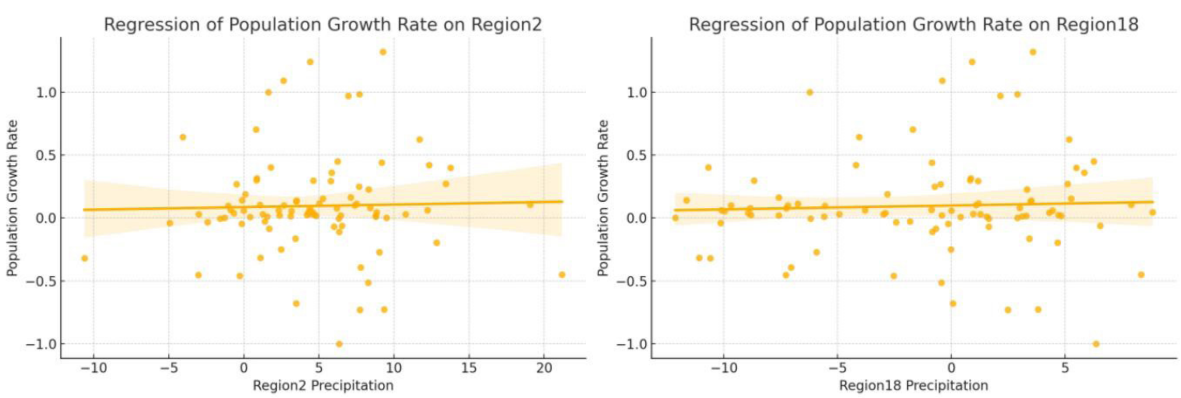

Figure 6: Regression Analysis of Precipitation and Population Growth Rate

4. Discussion

4.1 Temperature Impact

The past 2000 years have seen significant warm and cold periods in China, and population data have also changed dramatically in these years. It shows that climate cycle has certain influence on human activities. However, the results of regression analysis show that the correlation between temperature change and population change is not very strong. In other words, the influence of climate change on socio-economic development does not constitute a straightforward causal relationship of "stimulus-response"[11]. Instead, the effects of climate change on socio-economic development are contingent upon both the nature of climate change itself and the level of vulnerability exhibited by social systems in the face of such change. The vulnerability of social systems is further contingent upon the responsiveness and sensitivity displayed by individuals and communities.

4.2 Water Availability and Societal Stability

The precipitation model indicated a somewhat stronger relationship, with a few regions showing significant impacts on population growth rates. This finding highlights the potential influence of regional precipitation patterns on agricultural productivity and, consequently, population dynamics. However, the overall model's low adjusted R-squared value and lack of significance suggest that other factors, possibly socio-economic or political, played more crucial roles in shaping population trends.

To some extent, these results underscore the complexity of historical population dynamics and the need for multi-faceted analyses that incorporate various environmental, social, and economic variables. Future research could benefit from integrating additional data sources and exploring non-linear relationships to better understand the interplay between climate and population changes over extended periods.

5. Conclusion

In summary, it is found that there are cycles of climate change, wherein the periods of warmth and cold exert a discernible impact on the dynamics of population change. Plus, the regression analyses revealed that historical climate variables, specifically temperature and precipitation, had a limited and region-specific impact on population growth rates in China over the past 2000 years. As for the precipitation, the precipitation model indicated a somewhat stronger relationship, with a few regions showing significant impacts on population growth rates, which highlights the potential influence of regional precipitation patterns on agricultural productivity and, consequently, population dynamics. However, the overall model's low adjusted R-squared value and lack of significance suggest that other factors, possibly socio-economic or political, played more crucial roles in shaping population trends.

Author Statement

l Siyuan Yang: Conceptualization, Methodology, Software, Data Accumulation (temperature and precipitation), Writing (Methods and Material, Results and Discussion), Investigation, Review & Editing, Supervision, Validation

l Xiaoyang Xiao: Conceptualization, Writing (Literature Review), Data Accumulation (Population), Investigation, Validation (Author Statement), Validation

l Xuanyi You: Conceptualization, Writing (Literature Review), Investigation, Validation (References), Data Accumulation (precipitation)

l Shuxian Jin: Conceptualization, Literature Review, Investigation, Data Accumulation (tree-ring)

l Yichen Lu: Writing(Abstract & Conclusion), Investigation

References

[1] Ha, K. J., Heo, K. Y., Lee, S. S., Yun, K. S., & Jhun, J. G. (2012). Variability in the East Asian monsoon: A review. Meteorological Applications, 19(2), 200-215.

[2] Xu, D., Lu, H., Chu, G., Liu, L., Shen, C., Li, F., ... & Wu, N. (2019). Synchronous 500-year oscillations of monsoon climate and human activity in Northeast Asia. Nature communications, 10(1), 4105.

[3] Xu, D., Lu, H., Chu, G., Wu, N., Shen, C., Wang, C., & Mao, L. (2014). 500-year climate cycles stacking of recent centennial warming documented in an East Asian pollen record. Scientific Reports, 4(1), 3611.

[4] Age, L. I., & Anomaly, M. C. (2008). Global Signatures and Dynamical Origins of the. J. Clim, 21, 2283.

[5] Wang, K., & Dickinson, R. E. (2013). Contribution of solar radiation to decadal temperature variability over land. Proceedings of the National Academy of Sciences, 110(37), 14877-14882.

[6] Meng, X., Zhang, C., Li, G. K., Cheng, J., Cai, J., Liu, Y., ... & Zhang, E. (2024). Rapid wet-dry climatic oscillations and large-scale social unrest in ancient China. Science Bulletin, 69(3), 314-318.

[7] Li, H., Xu, D., Shen, C., Cui, A., Zuo, X., Dong, Y., ... & Lu, H. (2021). Multi-centennial climate cycles and their impact on the Tubo Dynasty in the southern Tibetan Plateau. Palaeogeography, Palaeoclimatology, Palaeoecology, 578, 110584.

[8] Briffa, K. R., Osborn, T. J., & Schweingruber, F. H. (2004). Large-scale temperature inferences from tree rings: a review. Global and planetary change, 40(1-2), 11-26.

[9] Sheppard, P. R., Tarasov, P. E., Graumlich, L. J., Heussner, K. U., Wagner, M., Österle, H., & Thompson, L. G. (2004). Annual precipitation since 515 BC reconstructed from living and fossil juniper growth of northeastern Qinghai Province, China. Climate Dynamics, 23, 869-881.

[10] Ge, Q., Zheng, J., Hao, Z., & Liu, H. (2012). General characteristics of climate changes during the past 2000 years in China. Science China. Earth Sciences/Science China. Earth Sciences, 56(2), 321–329. https://doi.org/10.1007/s11430-012-4370-y

[11] Ge, Q., Hao, Z., Zheng, J., & Shao, X. (2013c). Temperature changes over the past 2000 yr in China and comparison with the Northern Hemisphere. Climate of the Past, 9(3), 1153–1160. https://doi.org/10.5194/cp-9-1153-2013

[12] Qing-Bi, F. (2014). Influence of Climate Change to Ancient Population of China over History. Anhui Nongye Kexue. http://en.cnki.com.cn/Article_en/CJFDTOTAL-AHNY201409117.htm

[13] Yang, B., Braeuning, A., Johnson, K. R., & Yafeng, S. (2002). General characteristics of temperature variation in China during the last two millennia. Geophysical Research Letters, 29(9). https://doi.org/10.1029/2001gl014485

[14] Shi, F., Lu, H., Guo, Z., Yin, Q., Wu, H., Xu, C., Zhang, E., Shi, J., Cheng, J., Xiao, X., & Zhao, C. (2021). The position of the current warm period in the context of the past 22,000 years of summer climate in China. Geophysical Research Letters, 48(5). https://doi.org/10.1029/2020gl091940