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An urban extent dataset in late imperial China in 15th-19th centuries

Qiaofeng Xue[1], Xiaobin Jin[1], Yinong Cheng[2], Xuhong Yang[1], and Yinkang Zhou[1]
[1]School of Geography and Ocean Science, Nanjing University, Nanjing 210023, China
[2]College of History and Archives, Yunnan University, Kunming 650091, China
Correspondence: Xiaobin Jin (jinxb@nju.edu.cn)

Abstract. Long-term urban extent data are highly desirable for understanding urban land use patterns and achieving sustainable development goals. However, urban observation data based on remote sensing are typically confined to recent decades. In this study, we advance in this arena by reconstructing the urban extents for China that extend back from 15th century to 19th century based on multiple historical documents. Cities in late imperial China (the Ming and the Qing Dynasties, 1368-1911) generally had city walls, and these walls were usually built around the urban built-up area. By restoring the scope of the city walls, the urban extend in this period could be restored. Firstly, we collected the years of construction or reconstruction of city walls from the historical data. Specifically, the period in which the scope of the city wall keeps unchanged is recorded as a lifetime of it. Secondly, specialization of the scope of the city wall could be conducted based on the urban morphology method, and variety of documentation, including the historical literature materials, the military topographic maps of the first half of the 20th century, and the remote sensing images of the 1970s. Correlation and integration of the lifetime and the spatial data would produce China City Wall Areas Dataset (CCWAD) in late imperial. Based on the proximity to the time of most of the city walls, we generated China Urban Extent Dataset (CUED) in the 15th-19th centuries in six representative years (i.e., 1400, 1537, 1648, 1708, 1787, and 1866). These datasets are available at https://doi.org/10.6084/m9.figshare.14112968.v1 (Xue et al., 2021)

1 Introduction

As cities are one of the most obvious phenomena on the earth surface arising from human activities, human productivity has increased significantly since the industrial revolution, which has led to the expansion of population and the acceleration of urbanization (Mumford, 1968; Roberto, 2005). The rapidly expanding urban built-up area has serious impacts on regional and global changes by modifying the characteristics of the underlying surface while exacerbating human activities such as fossil fuel combustion (Seto et al., 2012; Rodriguez et al., 2018). With complex interactions happening in global environmental changes, the evolution of urban scale and spatial distribution is an important part of global change research (Solecki et al., 2013; Seto et al., 2016; Goldewijk et al., 2017; Bai et al., 2018; Kuang et al., 2021). Long-term data on historical urbanization trends and patterns will be conductive to contextualize the current urbanization, as well as to predict future trajectories on its process. In particularly, China has a history of urban construction for thousands of years, and it is also one of the countries with a relatively fast urbanization process in the world today (Gong et al., 2019; Liu et al., 2020). However, China's industrial revolution did not start slowly until the end of the 19th century, while the pattern of cities in late imperial China in the Ming and Qing Dynasties (1368-1911) laid the foundation for Chinese cities in modern time (Skinner, 1977). Rebuilding the urbanization process during this period will benefit exploration of the China's sustainable urbanization in the context of global change (He et al., 2002).

https://doi.org/10.5194/essd-2021-62
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Open Access Earth System Science Data Discussions

The data using for the study in the historical period must take into account the availability and integrity even though there are many methods and indicators to assess the level of urbanization. The widely used data is the statistical material about the population and area of cities for the study of urbanization before the industrial revolution (Doxiadis, 1970). Significantly, population is an effective indicator of the level of urbanization for most current studies to estimate the historical urbanization levels (Chandler, 1987; Reba et al., 2016; Letk et al., 2020). However, in the case of late imperial China, population is not fully applicable to the study of China's urbanization during the Ming and Qing Dynasties for obvious limitation and flaw on the data when the data on urban population was usually originated from the regional level where it included cities, thus few separate statistics data on the number of urban residents could be found, although the official demographics of China during this period were detailed and generally credible (Ho, 1959; Perkins, 1969; Cao, 2001a). Therefore, the flaws in the original materials have led to a great controversy over the different versions of estimation on Chinese urban population during this period (Li, 1998; Cao, 2000; Cao, 2001b).

Another way to explore the urbanization process in the historical period is restoration of the urban extents or the built-up areas of cities (He et al., 2002; Hedefalk, et al., 2019; Lin et al., 2017; Qin et al., 2019; Uhl et al., 2021). However, before the popularization of scientific Cartography in the 20th century, maps in China generally lacked the basis of surveying and mapping (Yee et al., 1994; Cheng, 2019), and could not be used to restore the urban built-up areas in late imperial period precisely. In addition, there was a lack of statistical data on urban area in late imperial China. Therefore, researchers generally use alternatives to represent the built-up areas of Chinese cities in late imperial period, and the one of the most commonly used indicator are the scope city walls (Skinner, 1977; He et al., 2002; Qin et al., 2019). That was because most cities in late imperial China built city walls, and these walls were usually built around the urban built-up area (Yannis et al., 2017). The main residential areas of cities, as well as government offices, markets, schools, military camps and important temples were mostly located within the city walls. In other words, the city wall could be regarded as the boundary of the city. Through the study of the scope of city walls, it can approximately restore the urban extent at that time. Historical materials in the Ming and the Qing Dynasties in China recorded the length and construction time of the city wall of each administrative city above the county level in detail, which provided reliable information for restoring the scale of the city walls. Researchers have estimated the built-up area of Chinese cities in late imperial period by converting the perimeter of the city wall into the area of the city wall (He et al., 2002; Cheng, 2007). However, due to the shape of the city walls were often irregular and their construction years were different from each other, the mentioned urban built-up area estimation often produces large errors. There is still lack of urban extent datasets with high resolution and definite age of late imperial China.

The aim of this project was to collect multiple historical data related to the city walls (urban boundaries) of late imperial China, digitize it, and make China City Wall Areas Dataset (CCWAD) and China Urban Extent Dataset (CUED) in late imperial in the 15th-19th centuries. We used a similar method to product a dataset of urban extent areas in Northwest China in the Ming and the Qing dynasties (Xue et al., 2018). And in this new database, we improved the research methods and extended the study area across China. Firstly, based on the historical urban morphology theory (Conzen, 1969), we restored the scope and construction time of walls of each administrative city in the Ming (1368-1643) and the Qing (1644-1911) dynasties, and made the CCWAD product.

https://doi.org/10.5194/essd-2021-62
Preprint. Discussion started: 18 May 2021

Open Access Earth System Science Data Discussions

Then, we analyzed the years and sites of the construction of the city walls, and we found out six representative years that could illustrate the general level of urban extent in China of this period. Based on this strategy, we developed the product of the CUED product in 1400, 1537, 1648, 1708, 1787, and 1866 across China. These datasets provide a foundation for understanding cities in the traditional agricultural society, and they will also be helpful in current and future research and practices in urban environmental and cultural sustainability.

2 Study area

This research aims at the cities in China in 15th-19th centuries. Definition of city is the same as the general research practice of ancient Chinese cities, namely administrative cities, including *county*, *Zhou*, *Fu*, and *Ting*. In addition, the military cities of the Ming Dynasty, *Wei* and *Suo*, and the *Eight Banner cities of Manchu* of the Qing Dynasty were added.

The research period consisted of the Ming and the Qing Dynasties, and there were some differences in the territory of the two dynasties. In order to explore the temporal and spatial characteristics of lat imperial China's urban extent, the study area is divided into five sub-regions based on landform types, local socio-economic history and ethnic distribution, as shown in Figure. 1. (I) The Northeast Region, which mainly covers the area to the east of Daxing'anling mountain and the north of the Great Wall of the Ming Dynasty. This region was sparsely populated until the influx of large numbers of immigrants in the 18th-19th century, and a number of cities were established at the end of the 19th century and the beginning of the 20th century. (II) The North Region includes the Inner Mongolia Plateau, the Ordos Plateau and the Hetao Plain. This region was to the north of the Great Wall and was inhabited by Mongolian herdsmen in 15th-19th centuries. (III) China Proper Region was densely populated, with many cities and a long history. (IV) The Northwest Region, mainly includes Xinjiang Province. This region was located in the continental interior, and the population was concentrated in oasis. This region became the territory of the Qing Dynasty after the mid-18th century. (V) The Qinghai-Tibet Plateau Region is mainly located on the Qinghai-Tibet Plateau, which is the highest-elevation plateau in the world. There were some historic cities on the edge of the region, but the administrative cities within the region were established very late.

3 Data sources

3.1 City wall records in historical literature

We regarded the city wall as an alternative of urban boundary, and there were detailed and systematic records of city walls in Chinese historical literatures, such as the *Book Integration of Ancient and Modern Times* (edited in 1701-1728), *Book Integration of Ancient and Modern Times* (edited in 1842), and more than three thousand *Local Chronicles* edited before 1949 all over China. There was a tradition of compiling *Local Chronicles* in the Ming and Qing Dynasties. Most of these literatures were compiled by local governments, and the city wall, as an important achievement, had been paid much attention. These records detailed the construction and transformation of local city walls, such as their construction time, scale and form (see Figure 2). And the *Book Integration of Ancient and Modern Times* and *Book Integration of Ancient and Modern Times* were collections of *Local Chronicles*. The historian in our research team have systematically collated and studied these literatures, and compiled a series of Data Compilations (Cheng, 2016a, 2016b, 2016c). And the historical literatures of this study were from these Data Compilations.

3.2 Old maps and remote sensing image

https://doi.org/10.5194/essd-2021-62
Preprint. Discussion started: 18 May 2021

Spatialization of the text of historical data was the next step to make this database. Most of the city walls of Chinese cities were demolished after 1949, which made it impossible for us to spatialize them directly on today's map. Fortunately, the 1: 25,000, 1: 50,000, and 1: 100,000 military topographic maps produced by the bureau of surveying and mapping of the Republic of China (1912-1949) and the Japanese army in 1910s-1930s drawn the location of the city walls, making it easier to restore these walls on modern maps (Figure 3a). These topographic maps were mainly plotted in the periods of 1916-1925 and 1930-1939, and they are mainly collected in Taiwan and Japan at present (Jiang, 2017). More than sixty thousand digitalized maps covering 25 provinces in China can be viewed online on various websites, and an integrated query system has been launched (http://map.rchss.sinica.edu.tw).

In addition, we also need some remote sensing images for auxiliary work. The 1970s China remote sensing image form the U.S. Geological Survey (USGS) website (https://earthexplorer.usgs.gov/) was the most important (Figure 3b). That is because before the 1980s, the city of Chinese mainland has not started large-scale expansion, and the ancient relics can be clearly indentified from these remote sensing images. And the modern remote sensing images are obtained from Google Earth.

3.3 City sites and their lifetime

We need obtain the amount of cities in China during the study period including where they were located, what time they appeared, and when they disappeared contributes. As mentioned above, the research object was administrative city. If a site was chosen as a local administrative center, it would be regarded as the birth of a new city; if all the administrative agencies mentioned above were abandoned or moved, then it will be regarded as the abandoned city; and the period between them was called the city's lifetime. Most of the city's lifetime information can be obtained from the China Historical Geographic Information System (CHGIS, Version: 6.0, 2016; available at https://dataverse.harvard.edu/dataverse/chgis_v6). In addition, we supplemented and corrected some missing and mistaken data of CHGIS based on the *Historical Atlas of China* (Tan et al., 1982) and *General History of Administrative Regions in China* (Zhou et al., 2007-2016). Through the above work, the city site point layer of the Ming and Qing Dynasties could be obtained, as well as the time records they set up or abandoned, including 2,560 lifetime records for 2,376 city sites in total (Figure 1), functioning as the basis for the next step to make the CCWAD and the CUED products.

4 The strategy of developing the CCWAD product

4.1The historical urban morphology theory

The historical urban morphology theory was proposed by British architect Michael Conzen, emphasizing the importance on studying the urban plan pattern from the perspective of morphology (Conzen, 1969). It was believed that the plan pattern retaining the residual characteristics of each stage of its development process was a complex record of the development of urban form space. Therefore, based on the evolutionary perspective, it is a worthwhile analysis method to study and reveal the potential history from the existing planning pattern. The urban morphology theory focuses on large-scale city map, combine with field research and literature analysis, to analyze the urban plane pattern based on the perspective of evolution, and interprets it as three elements complex: street and its layout in the street system; burgage and its agglomeration in the block; and block-plan of a building. And the city wall are generally considered as an important "fixation line" that has the role of defining the static edge of the city (Conzen, 1969).

https://doi.org/10.5194/essd-2021-62
Preprint. Discussion started: 18 May 2021

Open Access Earth System Science Data Discussions

Conzern also put forward a series of basic concepts to describe the urban form and its evolution phenomenon, which is of great significance to the study of urban historical form in China (Li et al., 1992; Zhong, 2015; Lai, 2019). Chinese researchers often combine historical text data and old maps to fix the lack of systematic ancient cadastral records. The main elements of the urban flat pattern are appropriately adjusted to aggregation including streets, water systems and bridges, city walls, moats, government offices, and temples for analysis. Thus, a relatively clear urban plan pattern was obtained on several time sections in the pre-industrialization period. The production of our database does not involve the restoration of streets and buildings, but focuses on the restoration of the location of the city walls, thus reducing the difficulty of practice and the requirements for the fineness of the original materials. With the historical urban morphology theory, it is not difficult to restore the location of city walls in late imperial China by combining historical literature data, old maps and remote sensing images with some necessary field investigations, thus helping to understand the urban extent of this period in China.

Figure 4 provides a schematic overview of dataset construction and is referred to throughout the methods section to clarify the dataset development process.

4.2 Restoration of the scope of the city walls

Sorting out the city wall records in historical records and tabulating them by Microsoft Excel involved much work on filtering the city wall information in the historical literature data since it is lengthy, messy, and mixed with many literary descriptions. Besides, the perimeter of the city walls recorded is often not accurate and can only be used as a reference. Therefore, it is focus on extracting information about construction time and reconstruction time. The literary descriptions of city walls in the historical records were helpful to the interpretation of remote sensing images, and were retained as for reference.

We georeferenced and digitized the military topographic maps and the 1970s remote sensing images. In the georeferencing process, we used modern topographic web maps and Google Earth to identify common points in the historic maps and 1970s remote sensing images, such as temples, city gates, city walls, drum-towers, and crossroads. Using all of the above processed materials, it is allowed to identify the location of city wall ruins, or other associated ruins, on the Google Earth platform. Then, according to the literary description in historical records, the correspondence between the text records and the identified ruins are judged, thereby identifying the time of the ruins.

Although most of the city walls of Chinese cities were demolished after 1949, there were still many associated relics, such as the moat parallel to the city wall, or a ring road built after the city wall was demolished, as well as the radial spread of multiple roads often implies the location of the city gate. These associated relics could be investigated from remote sensing images of the 1970s, and even in modern remote sensing images (e.g., see Fig. 3 b, c, d). For example, Figure 5 and 6 show the scope of the city walls of several famous Chinese cities from 1368 to 1911, and the red lines on these figures are the location of city walls presented in the dataset. The eight cities shown in Figure 5 did not change the scope of the city walls during the period, while the six cities in Figure 6 changed to varying degrees. Among these cities, Nanjing in Figure 5 and Xi'an (1368-1642) in Figure 6 have retained relatively complete city walls today, so it is not difficult to restore their scopes on the remote sensing images. Chengdu, Hangzhou and Suzhou in Figure 5 retained their city moats, so their city walls were located inside the moats. Shanghai and Kunming in Figure 5 and Beijing, Shenyang, Tianjin (1369-1860) and Urumqi in Figure 6 demolished their

https://doi.org/10.5194/essd-2021-62
Preprint. Discussion started: 18 May 2021

Open Access Earth System Science Data Discussions

city wall and built ring roads on its old site, for example the "Second Ring Road" in Beijing and the "Renmin Road" in Shanghai, so their city walls position overlaps with these ring roads. The the scope of city walls in other cities were verified through various ground markers and Local Chronicles. In cities where the scope of the city walls changed, most of the newly built walls were located outside the old city gates (e.g. Xi'an, Lanzhou) or around the old cities (e.g. Shenyang, Tianjin). This was to protect the newly urban built-up areas. There were also cities that built a new city wall far from the old city (e.g. Urumqi).

The maps and remote sensing images were transformed using a piecewise interpolation method (spline). Target geographic objects, such as city walls, city gates, moats, and ring roads built after the city walls demolished, were digitized as temporal snapshots from the maps. The georeferencing and digitalization steps were performed by using ArcGIS Desktop 10.3 (http://www.esri.com/software/arcgis/arcgis-for-desktop). It would be next step to generate layers in .kml format on Google Earth, marking their corresponding lifetime, and then use ArcGIS Desktop 10.3 to covert .kml layers into .shp format. The .shp layers are associated with the Excel table that previously saved the Local Chronicles data, thereby generating the .shp layer of the scope of the city walls area with spatio-temporal attributes.

This section shows the process of making the CCWAD product during the Ming and Qing Dynasties. Users could query and obtain the nationwide city wall area data for any year during 1368 to 1911 by GIS software from this dataset. This dataset is the basis for the further development of CUED product.

5 Extract representative years and develop the CUED product

To produce the dataset of the scope of the city walls of the Ming and Qing Dynasties (CCWAD) did not mean that we have a dataset of the urban extent (CUED) in late imperial China. Although the construction of city walls of Chinese cities during the Ming and Qing Dynasties were often consistent with the urban boundaries at that time, after the city walls were built, the scope of the city walls generally did not change with the built-up areas over time. In addition, the urban boundaries before the construction of the city wall were practically unknown. Finally, some special cities, such as those established in the northeast of China at the end of the Qing Dynasty, and the colonial cities (such as Hong Kong and Qingdao) and urban concessions (such as the Shanghai concession) established by foreigners in the 19th century, often did not build city walls. Therefore, to make the dataset of city extent (CUED) during the late imperial period, it is necessary to extract some suitable representative years to make the time of city boundaries in close proximity to the time of most of the city walls built. It should to analysis the time series of the changes in the area of the city walls scope, the number of city walls built, the total number of cities in China, and the total number of cities that built the city wall, during the study period.

We plotted the time series of the number of city walls built (Fig. 7b), the total number of cities (Fig. 7d), the total number of cities that built the city wall (Fig. 7e), and its percentage of the total number of cities (Fig. 7c). It can be seen from Figure 7b that there were some correlation between the number of wall constructions and the area of the walls scope. The periods of more constructions were often of faster area growth, and the less construction periods were always of area decline or unchanged. In 1368, there were 1,375 cities in China, of which 851 had city walls, accounting for only 62% of the total (Fig. 7c, d, e). However, in the year 1393, 70% of cities had city walls; in 1469 it reached 80%, in 1540 it was 90%, and in 1576 it was 95%. Since then, even though the number of cities fluctuated to a considerable extent, the proportion of cities with walls

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Preprint. Discussion started: 18 May 2021

Open Access Earth System Science Data Discussions

to the total cities has remained stable between 95%-97% for a long time. But after 1868, this percentage began to decline, and after 1900 it dropped sharply.

According to the above facts, we selected six base years where the area of the city wall scope were closest to the urban boundary from the six time periods (i.e. 1368-1404, 1405-1564, 1565-1662, 1663-1727, 1728-1860, and 1861-1911.), to product the CUED product in 15^{th}-19^{th} centuries. The selection criteria for the base year are as follows. Firstly, the proportion of cities with walls in the total cities should be higher. The proportion should generally be more than 90%, except in the 14th and early 15th centuries. Secondly, after the city walls were built, the scope of the city walls generally did not change with the built-up areas over time, so the base years should be within only one or two years after the end of a large-scale construction activities of the city wall period. In addition, the base year should be selected at a moderate level of changes in the scope of the city wall within the period. Finally, the base year should avoid major political, military events and severe natural disasters in order to reflect the general level of urban development in that period.

Therefore, we selected 1400, 1537, 1648, 1708, 1787, and 1866 as the representative year to develop the CUED product in 15^{th}-19^{th} centuries.

6 The accuracy of the CCWAD and CUED

Due to the differences in data richness and existing relics in various cities, the accuracy of urban extent would also be different. Reliability is a necessary factor to allow researchers and data users to be aware of the accuracy of the data and the subsequent analytical results. So we established an accuracy ranking system for the entire dataset to test consistency. This ranking system consists of a five-tiered structure with ranks of A, B, C, D, and BW. Cities holding a rank of A are considered most accurate, while those of rank C are least accurate. Cities holding a rank of D indicates that they had never built city walls. And those of rank BW indicates that the city did not build a city wall during this lifetime, but it was built later (next lifetime). Ranks were determined through consistency of results.

This ranking system was created with the intention of allowing researchers to subset the dataset to the most suitable level of accuracy for each specific analysis. For example, for studies where the most exact information is required, cities with a certainty ranking of C or D could be rejected. Furthermore, improvement and enhancement of the dataset can be better targeted to those cities where geo-locations are suspect—cities with an accuracy value of B or C.

7 Results

Based on the CCWAD product, we plotted the time series of the changes in the area of the city walls scope. Taking the scope of the city walls area of 1368 AD (=1,087.06 km^2) as the origin, the Figure 7a reflecting the change in the area of the city wall area in the Ming and Qing Dynasties of China. It can be seen that in the 14^{th}-20^{th} centuries, the scope of the city walls area grown at slow rate. The minimum is located in 1373 (=1,040.98 km2) and the maximum is in 1911 (=1,367.22 km2). According to the change of the slope of the Figure 7a, the area change of the city wall scope can be divided into six periods: 1368-1404, 1405-1564, 1565-1662, 1663-1727, 1728-1860, and 1861-1911. Period 1369-1404 was in the early years of the Ming Dynasty, many cities were abandoned due to years of war, which led to a decline of city wall areas. However, these cities were quickly rebuilt as well as many military cities were built, making the built-up area soon exceed the level of 1368. At the beginning of the 15^{th} century, the Ming Dynasty abandoned the area north of the Great Wall, and most of the cities in this area were abandoned. After that, in the

https://doi.org/10.5194/essd-2021-62
Preprint. Discussion started: 18 May 2021

period 1405-1564, the city wall scope area grew slowly. Since the middle of the 16th century, the situation in the north and southeast was tense, and many cities there built outer city walls, which accelerated the growth of the city wall scope area (period 1565-1662). In the middle of the 17th century, the city wall scope area fell again, partly because of the war in the late Ming and early Qing dynasties, and also because the Qing government abolished many military cities built by Ming Dynasty (period 1663-1727). The growth of the city wall scope area in the period 1728-1860 was very slow. Until the middle of the 19th century, the government opened up immigrants to the northeast of China, and the city wall scope area began to grow rapidly.

Figure 8 based on the CUED product shows the urban extent areas in some provinces in each representative year. Combine with Table 1 and Figure 1, it could be seen that provinces in the northeast of the Region III had the largest urban extent area in late imperial period in 15^{th}-19^{th} centuries. Hebei, where the capital Beijing was located, had the largest urban area. Jiangsu and Shanghai, an economically developed area, ranked second, and Henan, a populous province, ranked third. Shandong, Shanxi and Zhejiang also have large urban areas. During the study period, the urban extent of the above provinces increased steadily or slowly, but Zhejiang province decreased slightly in 1708. That was because the Qing Dynasty issued an order to demolish some coastal cities at that time. The urban extents of other provinces in the Region III were roughly the same. Among them, Anhui, Guangxi, Hubei, Hunan, Jiangxi, Sichuan and Chongqing had long history of land development, and the urban extent had remained stable during in 15^{th}-19^{th} centuries. Fujian, Guangdong and Hainan decreased slightly in 1708 by the same reason with Zhejiang. Yunnan and Guizhou province developed intensively and built a number of cities in the early Ming Dynasty. In the middle and late Ming Dynasty, the urban extent of Shaanxi, Liaoning, Gansu and Ningxia increased rapidly because of the severe military pressure faced by nomads at that time. Taiwan began large-scale development only after the 18^{th} century, and some small cities were built mainly on the west coast.

Jilin and Heilongjiang, located in the Region I, had no administrative cities in the Ming Dynasty. After the mid-18^{th} century, with the influx of immigrants, a number of cities were established. Inner Mongolia, located in the Region II, had a certain number of cities in the Yuan Dynasty (1271-1368) and the early Ming Dynasty, but by the middle of Ming Dynasty, these cities were gradually abandoned. It was not until the late 18^{th} century that Inner Mongolia rebuilt some cities with the influx of immigrants. Xinjiang, located in the Region IV, was not under the rule of the Ming Dynasty. In the late 18th century, the Qing Dynasty completely conquered Xinjiang and established a number of administrative cities. And Qinghai Province, located in the Region V, only had some cities in the Valley of Yellow River and Huangshui River in the east of Qinghai Tibet Plateau.

8 Data availability

The datasets include the CCWAD in 1368-1911 and the CUED in 1400, 1537, 1648, 1708, 1787, and 1866 are publicly available and can be downloaded from https://doi.org/10.6084/m9.figshare.14112968.v1 (Xue et al., 2021)

9 Conclusion and outlook

Ultimately, we view the CUED dataset as a beginning compilation of a richer historical, city-level urban extent database in late imperial China. Despite of the current reliability gaps, the dataset does provide a spatially explicit, long-term historical record of urban extent of China especially no alternative geo-coded dataset at such resolution exists. As a result, this dataset could be used as a

https://doi.org/10.5194/essd-2021-62
Preprint. Discussion started: 18 May 2021

foundation to build a full and accurate record of urban built-up areas through history, creating systematic, global built-up area data to measure urban growth at a long timescale.

However, we caution potential CCWAD and CUED users of the following limitations and dataset details:

1. The urban extent dataset (CUED) is based on the scope of the city wall (CCWAD). Strictly speaking, the scope of the city wall cannot be completely equal to the scope of the urban extent. The data may better reflect the urban extent in which year the city wall was built. The lifetime of each urban extent provided by the CCWAD is a period of time, and the urban extent of any year within the time period can be intercepted. However, if the year of interception is too far from the year of construction of the city wall, the actual urban extent may have a large difference with the wall's scope. Before the construction of the city wall, in fact, we were hardly to know the actual scope of the urban extent, and only the later wall's area was referred to. More often, after the city wall was built, as time goes by, the area farther away from the city gates and the center were gradually becoming uninhabited and even becomes cultivated land; the area with convenient transportation outside the city gates forms new built-up areas. Therefore, we recommend that potential CCWAD users should be careful not to be too far away from the year of construction of the city wall when choosing the research years. And this was why we generated six representative years in the CUED product in 15^{th}-19^{th} centuries China.

2. In general, the increase or decrease of the city wall range often means the increase or decrease of the urban extent, but they are not completely synchronized in time. The expansion of urban extent is often caused by economic development and population growth while the construction of the city wall is often caused by the stimulation of wars. Therefore, a paradox is that the expansion of the city wall area often happened in the period of wars. Users should understand that it is not the war that has led to the expansion of urban extents, but the expansion of the city wall reflects the development of the city's economy and the increase of population before the outbreak of wars.

3. To sum up, the reliability of this dataset is acceptable, but users need to be aware of whether the reliability rating of the area has fallen when it comes to smaller areas. In the 15th-19th centuries, cities in some regions generally did not built city walls, such as some cities in southwestern of Zhejiang province. When researching these areas, be sure to pay attention to the reliability rating.

Author contributions. JX, XQ and CY originated, conceived and designed the work. CY collated and studied the historical literatures. XQ, JX, YX and ZY developed and analyzed the dataset. All authors contributed to the writing of the manuscript.

Competing interests. The authors declare that they have no conflict of interest.

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https://doi.org/10.5194/essd-2021-62
Preprint. Discussion started: 18 May 2021

Open Access Earth System Science Data Discussions

395

396 **Figures and figures legends**

397 **Table 1.** Provincial distribution of urban extents in 15th-19th centuries.

Province	Urban extent area (km^2)					
	1400	1537	1648	1708	1787	1866
Anhui	52.68	53.54	53.64	53.39	53.19	54.55
Fujian	40.33	42.04	43.77	37.88	38.55	38.71
Gansu & Ningxia	32.76	49.71	52.29	51.64	53.47	53.41
Guangdong & Hainan	40.26	44.92	51.32	49.47	44.05	44.30
Guangxi	22.34	23.95	25.46	24.83	26.24	26.24
Guizhou	13.08	14.72	18.34	15.89	18.18	18.00
Hebei, Beijing & Tianjin	168.88	154.87	182.13	175.69	180.04	201.36
Heilongjiang	0	0	0.29	5.81	17.53	18.30
Henan	102.62	112.01	113.74	111.26	112.58	114.32
Hubei	41.05	41.80	42.28	42.10	42.73	42.73
Hunan	26.85	26.27	27.70	26.59	27.26	27.77
Inner Mongolia	28.59	3.16	2.90	0.79	10.60	10.60
Jiangsu & Shanghai	122.06	120.26	127.08	126.27	127.39	124.55
Jiangxi	44.74	45.38	46.97	46.68	47.08	47.08
Jilin	0	0.18	0.18	4.22	4.68	5.51
Liaoning	21.34	26.02	37.73	37.71	38.93	39.69
Qinghai	2.23	2.21	2.66	2.66	3.03	3.28
Shaanxi	47.82	51.63	58.74	57.96	60.04	63.80
Shandong	87.22	92.51	94.80	93.38	90.56	104.98
Shanxi	79.68	91.50	98.37	97.65	94.13	93.65
Sichuan & Chongqing	55.24	58.71	59.59	55.30	58.91	59.72
Taiwan	0	0	0	3.31	4.03	4.64
Xinjiang	0.33	0.15	0.15	0.15	20.79	20.96
Yunnan	29.28	32.50	35.05	31.54	35.10	35.21
Zhejiang	82.62	87.44	87.92	73.91	74.18	74.41

398

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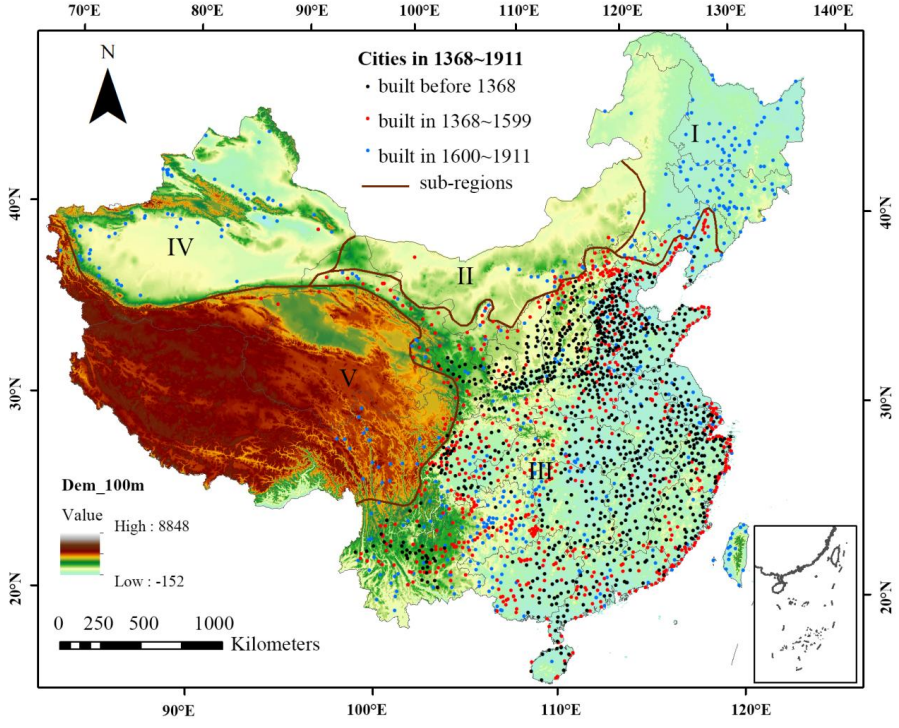

Figure 1. Cities in the Ming and Qing Dynasties (1368-1911). The study area is divided into five natural sub-regions (I, II, III, IV and V).

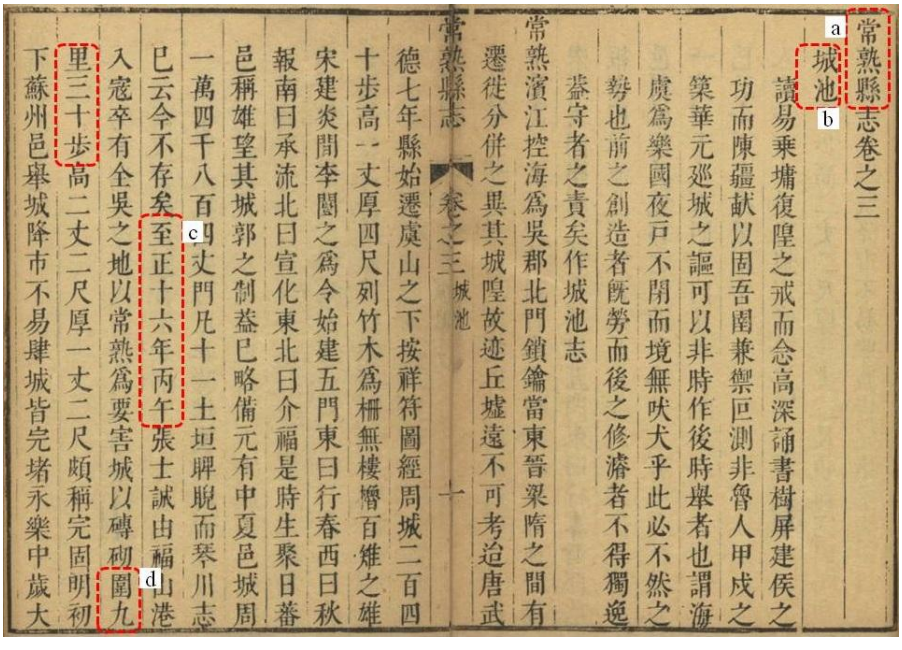

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Figure 2. The image of the record of the city wall in a *Local Chronicles* of the 17th century (*Kang-Xi Changshu county's Chronicle*). (a) City's name: Changshu (Jiangsu Province). (b) Chapter name: city wall and moat. (c) Year of the city wall built: the 16th year of *Zhizheng* in the Yuan Dynasty (1356 AD). (d) The perimeter of the wall: around 4.6 kilometers (actual about 5.44 kilometers).

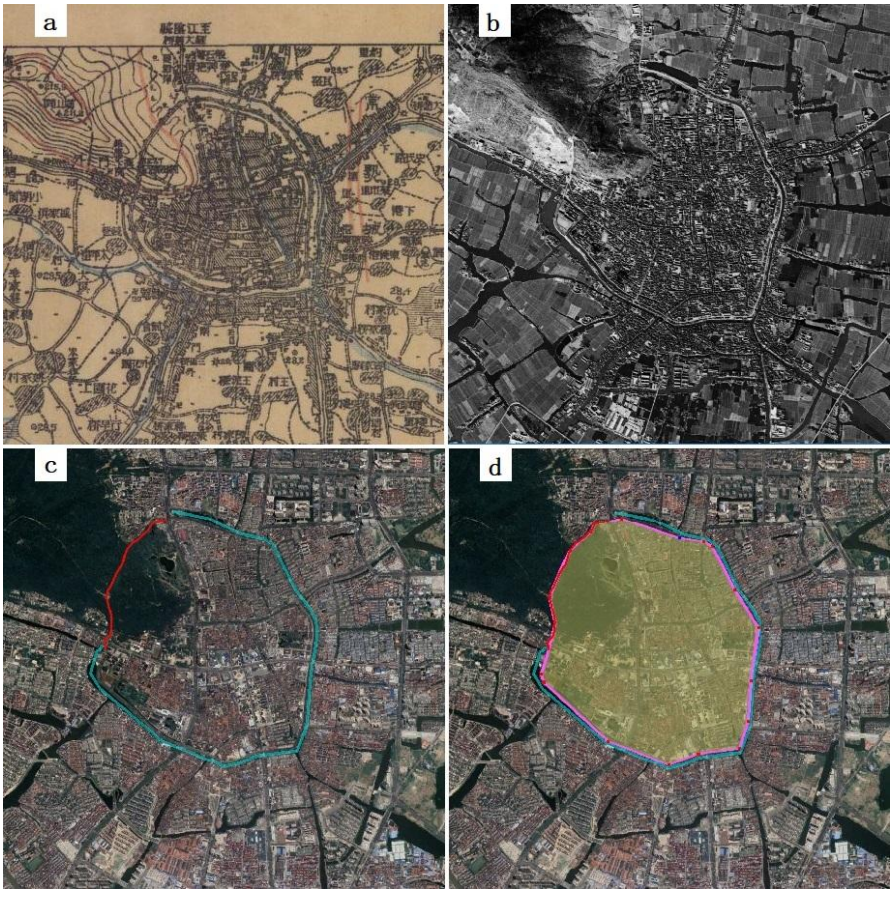

Figure 3. Maps and remote sensing images that show the city wall and associated relics of Changshu, Jiangsu Province. (a) The 1:50,000 military topographic maps made in 1928. The jagged line on the map represents the city wall and the double line represents the river. (b) The 1970s remote sensing image form USGS. (c) The remaining city walls (tagged as red line) and moats (tagged as blue line) are still clearly visible. The map is based on © Google Earth image, 2018. (d) According to the remains of the city walls and the moat, the scope of the city wall is drawn (yellow area). The map is based on © Google Earth image, 2018.

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Preprint. Discussion started: 18 May 2021

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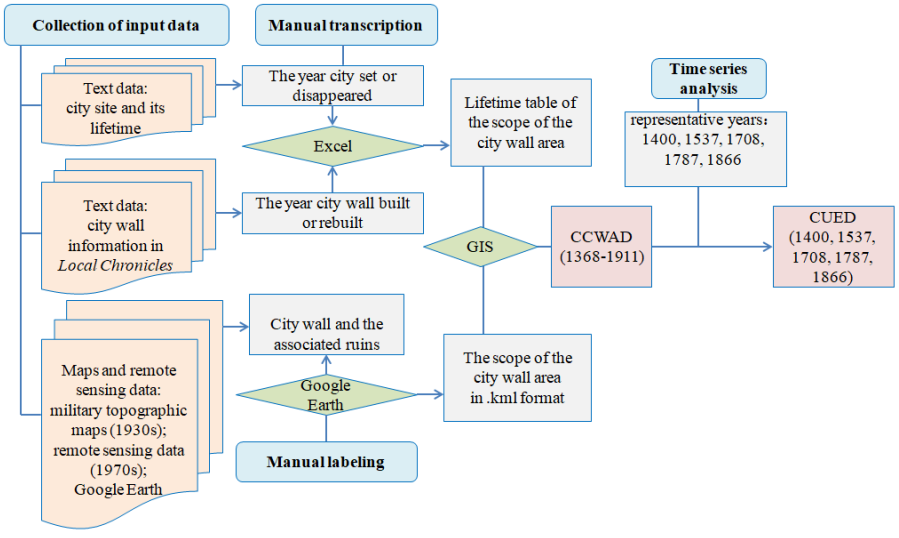

Figure 4. A flowchart of the methodology used to generate the China City Wall Areas Dataset (CCWAD) and China Urban Extent Dataset (CUED) in 15th -19th centuries in late imperial China

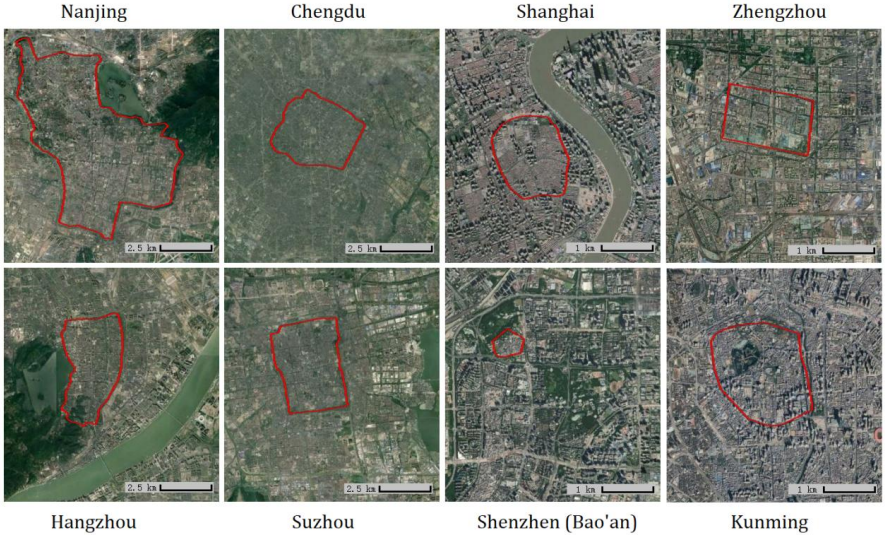

Figure 5. Several scope of city walls of Chinese cities from 1368 to 1911. The red aerials are from the China City Wall Areas Dataset (CCWAD) which illustrate the location of city walls. These maps are based on © Google Earth image, 2020.

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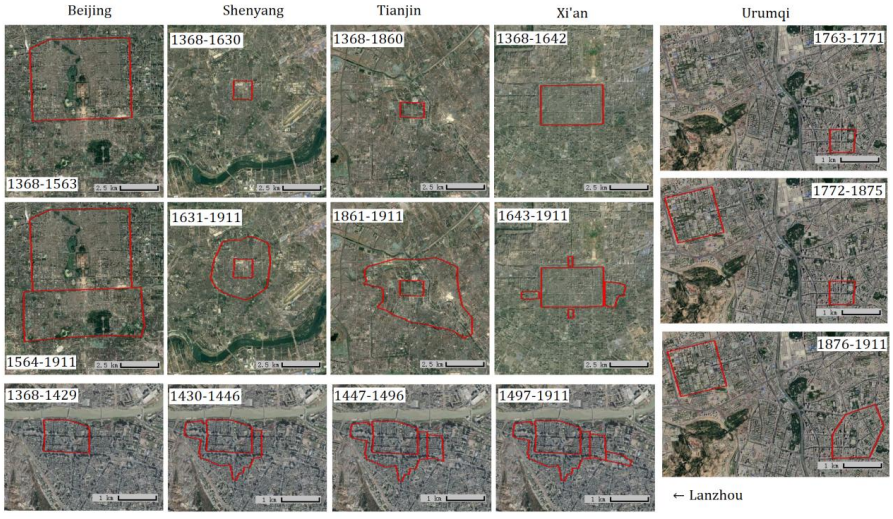

Figure 6. Several scope of city walls of Chinese cities from 1368 to 1911. The red aerials are from the China City Wall Areas Dataset (CCWAD) which illustrate the location of city walls. These maps are based on © Google Earth image, 2020.

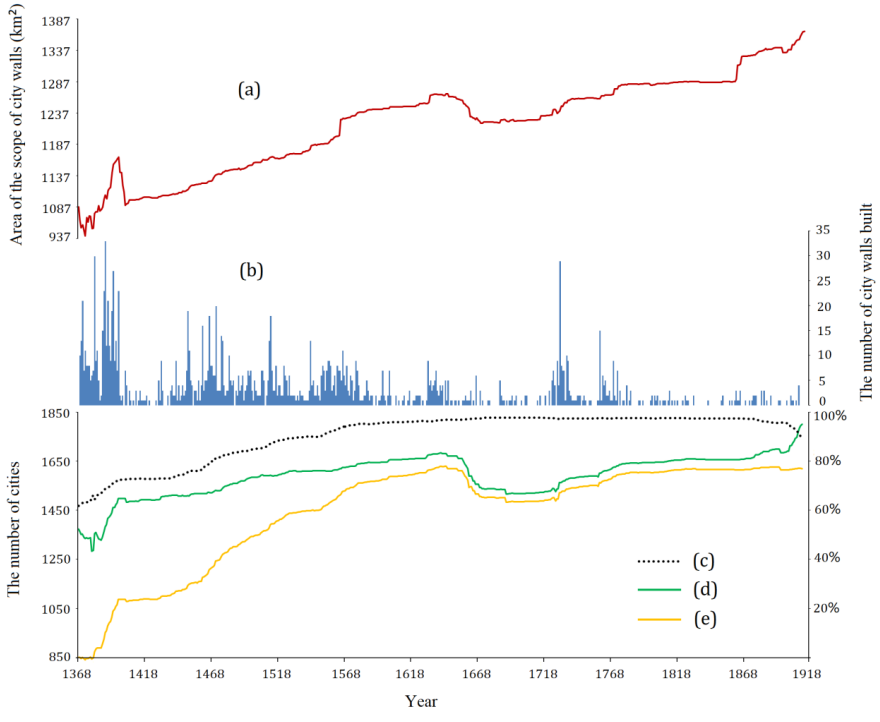

Figure 7. Time series of cities and city walls in the Ming and Qing Dynasties (1368-1911). (a) The time series of the area of the scope of city walls. (b) The number of city walls built. (c)

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Preprint. Discussion started: 18 May 2021

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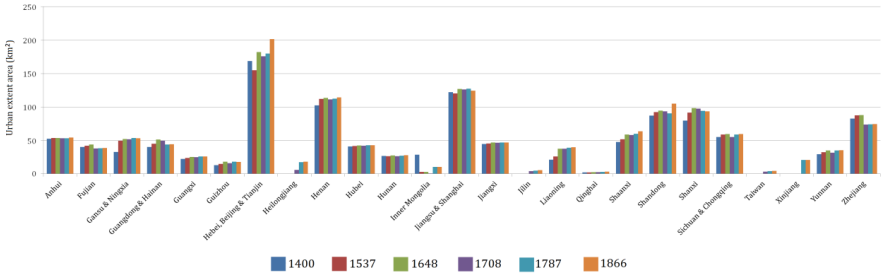
435 **Walled cities' percentage of the total number of cities. (d) The total number of cities. (e) The**
436 **total number of walled cities.**
437



438

439 **Figure 8. Provincial distribution of urban extents in 1400, 1537, 1648, 1708, 1787 and 1866.**
440

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