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The polder systems legacies in the early twentieth century affect the contemporary landscape in the Jianghan Plain of Hubei, China

Yikai Li[1], Hemiao Dai[1], Zhiyun Dai[1] and Li Zhang[1*]

Abstract

The long-term interaction between the environment and humans has significantly shaped contemporary landscapes worldwide. As a heritage landscape, the polder is essential for understanding the impact of the past human activities on contemporary landscape on low-lying area of land. In this case study, we reconstructed the regional spatial distribution of the polders in the early twentieth century and examined their coherence over the past century using historical maps and other materials in the Jianghan Plain. The results revealed several key findings: (1) In the early twentieth century, there were 1571 polders covering an area of 11,826.1 km^2 with a perimeter of 17,035.9 km. (2) These polders exhibited a J-shaped distribution, with few large-scale polders despite their substantial areas. (3) The shape of these polders reflected an ability to balance human needs and the natural environment. (4) Considerable regional differences in these polders were attributed to centuries-old interactions between humans and the environment. (5) The remnants of these early twentieth century polders have had a lasting influence on the contemporary landscape, particularly in rural areas. This case study underscores how taking into account a broader historical perspective can enhance our understanding of present-day landscapes and, more importantly, the role that past human actions have played in shaping them.

Keywords Human–environmental interaction, Floodplain, Historical landscape, Polder, Jianghan Plain

Introduction

Since the Holocene, human activity has gradually altered the natural environment from its original state, resulting in the emergence of landscapes with distinctive human characteristics [1, 2]. The process of humans reshaping landscapes has laid the foundation for the natural environmental change and socioeconomic history since time immemorial. A research estimates that humans have utilized more than three-quarters of the ice-free surface of the global landmass at present [3, 4]. This indicates that most of the landscapes that we see now are the legacy of earlier environmental changes and the consequence of long-term interactions between human and natural environment [5, 6]. It helps to comprehend the contemporary landscape by studying the interaction between human activities and natural environment changes over the past [7, 8].

The areas with the most often human activities are frequently smooth terrain, suitable temperatures, and abundant water resources, particularly in flood plains at mid to low latitudes [9, 10]. For thousands of years, humans have engaged in large-scale activities in these areas for their own survival and development, including agricultural cultivation, settlement, hydraulic engineering, and soon [11, 12]. These activities have led to significant landscape changes and contributed to the contemporary landscape, such as changing land cover

*Correspondence:
Li Zhang
kirazhang@snnu.edu.cn
[1] Northwest Institute of Historical Environment and Socio-Economic Development, Shaanxi Normal University, Xi'an 710119, Shaanxi, People's Republic of China

and reshaping the surface water environment pattern, and play an important role in the river–lake-floodplain system (RLFS) [13, 14]. Academics have carried out diverse case studies on the history of human activities shaping the environment in these areas, such as in North America [15], Latin America [16], and Europe [17]. Due to the socio-cultural diversity and the natural environmental complexity, there are distinct regional differences on different temporal and spatial scales [18, 19]. More studies in typical regions can help deepen our understanding of the influence of past human activities on the landscape at present.

The polder, as a heritage landscape, is an essential component of the RLFS. It is a system of water conservancy facilities constructed on low-lying areas of land, widely scattered near rivers, lakes, and the sea [20]. Polder relies on dikes to reduce the disturbance of exterior water and utilizes drainage systems to discharge internal water [21]. Polder expansion has altered the original landscape from wetlands to long-term artificial land cover types, such as cropland, pasture, and buildings [22]. At the same time, the polder has also attained protection for internal cropland, settlements, and infrastructure [23]. For thousands of years, a lot of polders were constructed in many plain areas to promote agricultural activities, driving the development and growth of many important economic regions. Among them, the most renowned region is the Netherlands [24]. In addition, the polders are also widely distributed worldwide, such as in Europe [25, 26], America [27], Asia [28], and so on. Studying the polder systems unlocks new opportunities for the evolution of long-term human-land relationships for low-lying areas of land.

The Middle and Lower Changjiang River Plain (the Middle-lower Yangtze Plain) in China, characterized by dense population and complex environmental changes, is a typical area for research on the polder [29, 30]. This area is very suitable for human survival and development, due to its flat terrain, suitable temperature, abundant precipitation, and convenient transportation, which are conducive to agricultural production [31, 32]. But this area is prone to flood events because of its environmental characteristics such as concentrated precipitation and numerous rivers, causing a threat to human survival [33]. Significant polders were thus constructed in this region in order to effectively expand and protect human facilities for millennia [34, 35]. These polders exist to this day and have become an important foundation for human settlement and development [36]. Accompanied by impoldering several lakes and rivers have also decreased and shrunk, profoundly affecting the current regional environment [37, 38].

The Jianghan Plain is a portion of the Middle and Lower Changjiang Plain in its middle reaches, and has a process of a gradual construction of polder throughout the last few centuries [39]. The society in this area is very dependent on these polders, even though many historical polders have been transformed into ordinary land. There are currently about 24 million people living on the land protected by the polders, with a cropland of about 20,000 km^2 in this area [40]. The grain and cotton production from land protected by polder accounts for 40% and 50% of the province's total, respectively [40]. Due to the polder expansion, this area has become one of the most significant areas for grain production in China, which is one of the nine national commodity grain bases [41]. This means that the entire agricultural economy of the country also benefits from these regional polders. This area provides a foundation for future research on the long-term impacts of human–nature interactions in the Middle and Lower Changjiang River Plain, even other low-lying areas with the polder cover around the world.

Reconstruction of the polder system in the early twentieth century is the key to understanding the current natural environment and socio-economic conditions in the Jianghan Plain. This is because the turning point of the polder history was the early twentieth century in this area, which might also indicate a transition from tradition to modernity. Direct evidence of the polder construction in this area dates back to the middle of the fourteenth century. With the increase in the population in the fifteenth and sixteenth centuries, the polders were constructed on a vast scale. Nonetheless, several disruptions in the early to middle seventeenth century were the cause of the polder system's contraction. The polder then extended to an unprecedented magnitude until achieving saturation under the conditions at that time from the middle of the seventeenth century to the early nineteenth century, because society increasingly stabilized and the population continued to grow. The creation of certain new polders and the disappearance of some old polders as a result of flooding and river diversion changed the original polder system in the middle to late nineteenth century. The development of polders was driven by a number of societal elements after the middle of the twentieth century, including technology, organizational capacity, and human contribution, which culminated in the 1980s. Since the 1980s, the polder system has dynamically adjusted according to flood control needs and entered a stable state without new polder construction. Therefore, the polder system in the early twentieth century had been a result of the complicated dynamic between human activity and the lake and river before the twentieth century. What is more importantly, the polder system in the early twentieth century was the foundation for the polder expansion over the past century.

We took the Jianghan Plain as a case study to investigate the change and persistence of the polder over the past century using a combination of historical maps and other materials. First, we identified polder units and extracted them from geo-referenced maps in the early twentieth century. Second, we analyzed the spatial distribution pattern of the polder in the early twentieth century and observed the coherence of the polder landscape in the past century. Third, we explored the impact of these polders on the microtopography, habitations, and transportation of this area today. The goal of this paper is to understand the inheritance of contemporary landscape from past human activities on low-lying areas of land through a case study.

Materials and methods

Study area

The study area is the Jianghan Plain (111° 36′–114° 17′ E, 29° 19′–31° 11′ N), located in the central southern part of Hubei Province in the middle reaches of the Changjiang River (Fig. 1). The study area is relatively low and flat compared to the surrounding area, with an altitude between 20 and 40 m. The southern part is the same plain as the Dongting Plain, with the provincial boundary as the boundary between the two [42]. The north, west, and east are low mountains and hills, with elevations ranging from tens to hundreds of meters. The temperature in the study area is suitable, with an average annual temperature of 15–17 ℃. This area has sufficient heat, with an annual effective accumulated temperature exceeding 5000 ℃. The precipitation is abundant, with an average annual precipitation of 1100–1300 mm, mainly concentrated from April to September. The research area is densely populated with rivers, mainly including the Changjiang River (known as the Jingjiang River in this area) and the Hanjiang River (the largest tributary of the Changjiang River), forming a complex water network structure. There are numerous regional lakes that have undergone complicated changes over thousands of years. The total area of lakes has decreased from more than 7000 km^2 in the 1930s to 2428 km^2 in 2000 [43]. The largest contemporary lake is the Honghu Lake. Due to hundreds of years of continuous cultivation, a widely distributed type of agricultural land use has been formed in the region.

Research materials

Historical map

Historical maps offered the best opportunities for assembling a complete polder map in the early twentieth century. The historical maps used in this study were mainly large-scale topographic maps (1:50,000) obtained during the Republic of China period (1912–1949). The central government of the Republic of China initiated surveying and mapping large-scale topographic maps in various provinces in 1913. These maps were the main basis for observing the natural environment and socio-economic

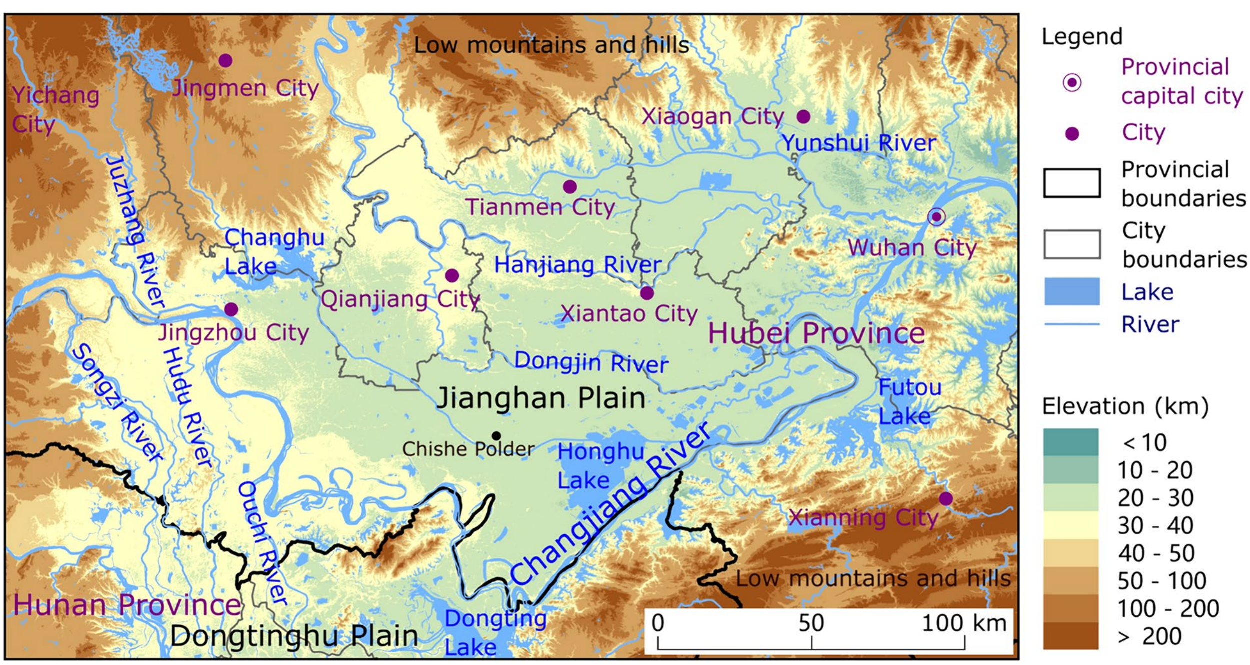

Fig. 1 The Jianghan Plain

conditions at that time, especially providing relatively accurate spatial information. The surveying and mapping work in Hubei began in 1917. The surveying and mapping work related to the Jianghan Plain was mainly concentrated around 1920, and a small number of areas were completed from 1920 to 1930. These maps show geographic details about the Jianghan Plain around the 1920s, including rivers, lakes, land, settlements, roads and so on. The information about the legend of these maps is a separately printed manual. Moreover, these maps plainly identify a substantial amount of efficient and detailed toponym name information.

Considering the quantity of maps collected was limited, the current map databases had also been used as a supplement. Some research institutions have established multiple map databases, which include large-scale topographic maps from the Republic of China era. The Department of History at Shanghai Jiao Tong University in China and the Third Department of the History of Science at the Max Planck Institute (MPI) in Germany collaborated to establish the CHMap database (https://chmap.mpiwgberlin.mpg.de/). This database has accurately geo-referenced over 4000 maps from the Republic of China era and is publicly accessible for academic research. The Institute of Chinese Historical Geography at Fudan University in China also established a Chinese Historical Geography Information Platform (https://timespace-china.fudan.edu.cn/) online. These two databases cover multiple provinces or regions, involved in the Hubei Jianghan Plain in this study.

Corona spy satellite imagery

The surface landscapes of the study area from the 1960s to the 1970s could be observed using Corona spy satellite imagery. Since the 1960s, the Central Intelligence Agency (CIA) of the United States has taken many aerial photographs of China using U-2 reconnaissance aircraft and KeyHole series reconnaissance satellites. Presently, a portion of this satellite data's images are accessible for public access after being decrypted. This batch of Corona spy satellite imagery is key information for studying issues since the 1960s. Using Corona spy satellite imagery facilitates the extension of the data record of space borne observation of the earth by one to two decades earlier than what is possible with satellite datasets [44]. The Corona spy satellite imagery was obtained from USGS EarthExplorer (https://earthexplorer.usgs.gov/). The spatial resolution is in meters.

Remote sensing image data

The current state of polder depends on understanding from remote sensing image data. Meanwhile, the features of remote sensing images are also important references for geo-referencing historical maps and Corona spy satellite imagery. Remote sensing image data obtained from the Hubei of Tianditu (Map World) (https://hubei.tianditu.gov.cn/).

Modern digital elevation model

The reshaping of landforms due to the polders is one of the contents of this study. Considering the significant differences in the polder scale, some small polders only have narrow dikes that are a few meters wide. Therefore, it is necessary to use Digital Elevation Model (DEM) data with sufficiently fine spatial resolution. The DEM data used in this study is ALOS PALSAR, obtained from the Alaska Satellite Facility (ASF) (https://search.asf.alaska.edu/). The spatial resolution is 12.5 m. It should be emphasized that the current DEM data does not adequately capture the geomorphic features of the previous century due to the combined effects of environmental changes and human activity.

Modern human activity data

The spatial characteristics of current human activities can be characterized using land cover data, POI data (Point of Interest), and modern road data. Considering the availability of data, these datasets were obtained from open-source websites. First, the land cover data used in the study is SinoLC-1 (https://doi.org/https://doi.org/10.5281/zenodo.7707461) with a resolution of 1 m. The SinoLC-1 data covers the entire China, with a total of 11 land cover types in 2021 [45]. The land cover types involved in the research area include tree cover, cropland, buildings, roads, water, and so on. Second, modern road data was obtained from the Open Street Map (OSM) (https://www.openstreetmap.org/) in 2023. Third, POI is a type of point data representing actual geographical entities. POI data includes spatial information such as longitude and latitude, address, and attribute information such as name and category. The time for POI data is 2023.

Local gazetteers

Government agencies in the research region have been compiling different kinds of local gazetteers since 1949. These local gazetteers are now essential resources for learning about the regional socioeconomic and environmental elements. Some local gazetteers involve regional polders, especially the water conservancy and the polder gazetteers, including *the Polder Gazetteers of Jingjiang River* [46], *the Polder Gazetteers of Hanjiang River* [47], *the Water Conservancy Gazetteers of Jingzhou* [48] and soon. These local gazetteers can provide relevant information such as the construction time, length, and height of the polder, which helps to knowledge of the coherence and variation of the polders in this region.

Methods

Geo-referencing historical maps

Using ArcGIS 10.2, each historical map was individually geo-referenced on the platform according to the actual situation. It should be noticed that there is actually an offset in the geo-referenced historical maps obtained in this step.

The typical geographical features from Tianditu (Map World) were used as the control points to calibrate the historical maps, mainly less changeable geographical features. Among them, the most important control point was the iconic physical geographical elements, especially mountains and hills. The second major point was rivers that have not experienced any diversion, particularly those that flow through hilly regions. The third type of r point was the historic downtown sections of significant cities like Wuhan and Jingzhou.

The previous historical map databases were also used to supplement the information. This is because the historical maps we have collected are restricted and there are missing maps. Moreover, the previous historical map databases were used as the references to verify geo-referencing results.

All historical maps were concatenated to obtain map data of the Jianghan Plain around 1920. The research area involves historical maps of more than 80 pieces.

Geo-referencing Corona spy satellite imagery

The geo-referencing results are dependent on the researcher's familiarity with the landscape at various times in their study area because Corona spy satellite imagery does not display any textual information. Tianditu (Map World) was applied as a reference to carry out these works in an effort to increase the accuracy of the reconstruction results. Additionally, to make sure that the results are sufficiently dependable, we spoke with a number of individuals who have resided in the Jianghan Plain for a long time and are acquainted with geographical features. During this step, the existing research scheme was also referred [49].

Extraction of the polder data

It is determined that there are four polder forms on the maps combining all historical maps and their legends. We took different approaches to handling these polders according to the toponym and the polder dike. Additionally, the kind of terrain on which the polder was situated was also considered.

First, the toponym contained clear information such as the polder or dike, and the polder had distinct dikes on the maps. It should be noted that there were many lakes or lakes within these polders in addition to cropland and settlements. These polders could be extracted directly with the dikes as the boundary.

Second, the toponym did not involve information about the polder or dike, but there was a recognizable dike in its complete shape on the maps. These polders were generally small in scale, leading to difficulty displaying toponyms on the maps. These polders could be extracted like the first type.

Third, the toponym did not have the polder or dike, only a portion of the dike could be identified. These polders were normally distributed on the riverbank. As a result, one side of the polder needed to be constructed with a dike to reduce the flood loss, while the other side did not need to be constructed. In extraction processing, one side was bounded by a dike, and the other side was bounded by hills, lakes, and soon.

Fourth, there were no identifiable dikes on the maps, but the toponym clearly included the polder or dike. The toponym implied that the land in this place had been once protected by the dikes and meant that the polder had formed in earlier periods. The dikes had lost their function of protecting the land at that time due to environmental change and human activity like river diversion or cultivation. Considering the difficulty in confirming the boundaries of the polders and the small number of these polders, these polders were not extracted.

After determining the types of polders that require extraction, the polder cover in the Jianghan Plain of Hubei in the early twentieth century was reconstructed according to the manual visual interpretation. Although the traditional way was time and labor consuming, it was still a necessary method because only it could effectively identify the dikes on the historical maps. It is very difficult that the identify polder units was based on supervised classification or more intelligent methods, especially in cases where there were texts on many dikes.

Statistics of the polder information

First, the polder perimeter and area were calculated in order to analyze the natural environment and socio-economic background of the polder formation.

Second, the polder boundary was taken as the historical dike. The dike data was analyzed as a buffer zone with a radius of 10 m for the convenience of calculation and observation.

Third, the elevation difference was observed within the buffer zone of the dike data to explore the connection between the historical polder and contemporary landscape.

Fourth, the building and road in the land cover type were extracted within the buffer zone of the dike data.

Fifth, the relationship between the dike data and modern human activity data (the POI data and the road data from OSM) was investigated by using an overlay analysis method.

Calculating the polder landscape metrics

The landscape metrics were used to analyze the characteristics of the polder further quantitatively (Table 1). The study area was divided into five zones based on rivers to examine the regional differences of the polders. Among them, the Han-North Zone (HN) was located in the north of the Hanjiang River, the Han-Dongjing Zone (HDJ) was located between the Hanjiang River and the Dongjing River, the Chang-Dongjing Zone (CDJ) is located between the Changjiang River and the Dongjing River, the Chang-West Zone (CW) was located in the western part of the southern bank of the Changjiang River, and the Chang-East Zone (CE) was located in the eastern part of the southern bank of the Changjiang River. The landscape metrics were calculated for different zones separately in Fragstats4.2. The specific metrics used are shown in the table below.

Results and discussion

Mapping the polders in the Jianghan Plain in the early twentieth century

The number of the polders was 1571 in the early twentieth century in the study area. It must be acknowledged that this statistic had overlooked some smaller polders [39]. Most of the land with a height of no more than 40 m was covered by the polders in the Jianghan Plain in the early twentieth century (Fig. 2). This shows how polders were necessary for local human activities like farming and houses. These polders formed a complete polder system to maintain social stability in the area [50]. Meantime, the extensively dispersed polders also showed how human activity affected the environment. These polders had changed the distribution of surface water resources in the area and created a sophisticated system of regional human-land relationships.

There were three main causes for the polder-free sections in this plain. First, it is difficult for humans to construct some polders under traditional technological conditions due to the distribution of large lakes in the region, as shown in the picture near the Paihu Lake. Second, humans could achieve land protection relying on dikes such as the Changjiang River and the Han River. These dikes could also be seen as a large-scale polder. Third, humans did not need to construct a polder to effectively cultivate because the region was far away from large rivers and lakes, and there were few little rivers.

The polder scale in the Jianghan Plain in the early twentieth century

The polder scale can be characterized by its perimeter and area, which can further understand the relationship between human and land at that time. The sum of the perimeter of all polders was 17,035.9 km, which was equivalent to 2.7 times the length of the Changjiang River and 10.8 times the length of the Hanjiang

Table 1 List of the landscape metrics used in the study

Landscape metrics	Abbreviation	Unit
AREA	AREA	hm^2
Number of Patches	NP	$n \geq 1$
Largest path index	LPI	%
Landscape Shape Index	LSI	
Patch area distribution_Mean	AREA_MN	hm^2
Patch area distribution_Area-weighted Mean	AREA_AM	hm^2
Patch area distribution_Standard Deviation	AREA_SD	hm^2
Patch area distribution_Coeffient of Variation	AREA_CV	%
Shape index distribution_Mean	SHAPE_MN/ MSI	
Shape index distribution_Area-weighted Mean	SHAPE_AM/ AWMSI	
Perimeter-area fractal dimension index	PAFRAC	
Perimeter-area ratio distribution_Mean	PARA_MN	
Perimeter-area ratio distribution_Area-weighted Mean	PARA_AM	
Patch fractal dimension distribution_Mean	FRAC_MN/ MPFD	
Patch fractal dimension distribution_Area-weighted Mean	FRAC_AM/ AWMPFD	
Patch fractal dimension distribution_Standard Deviation	FRAC_SD	
Patch fractal dimension distribution_Coeffient of Variation	FRAC_CV	

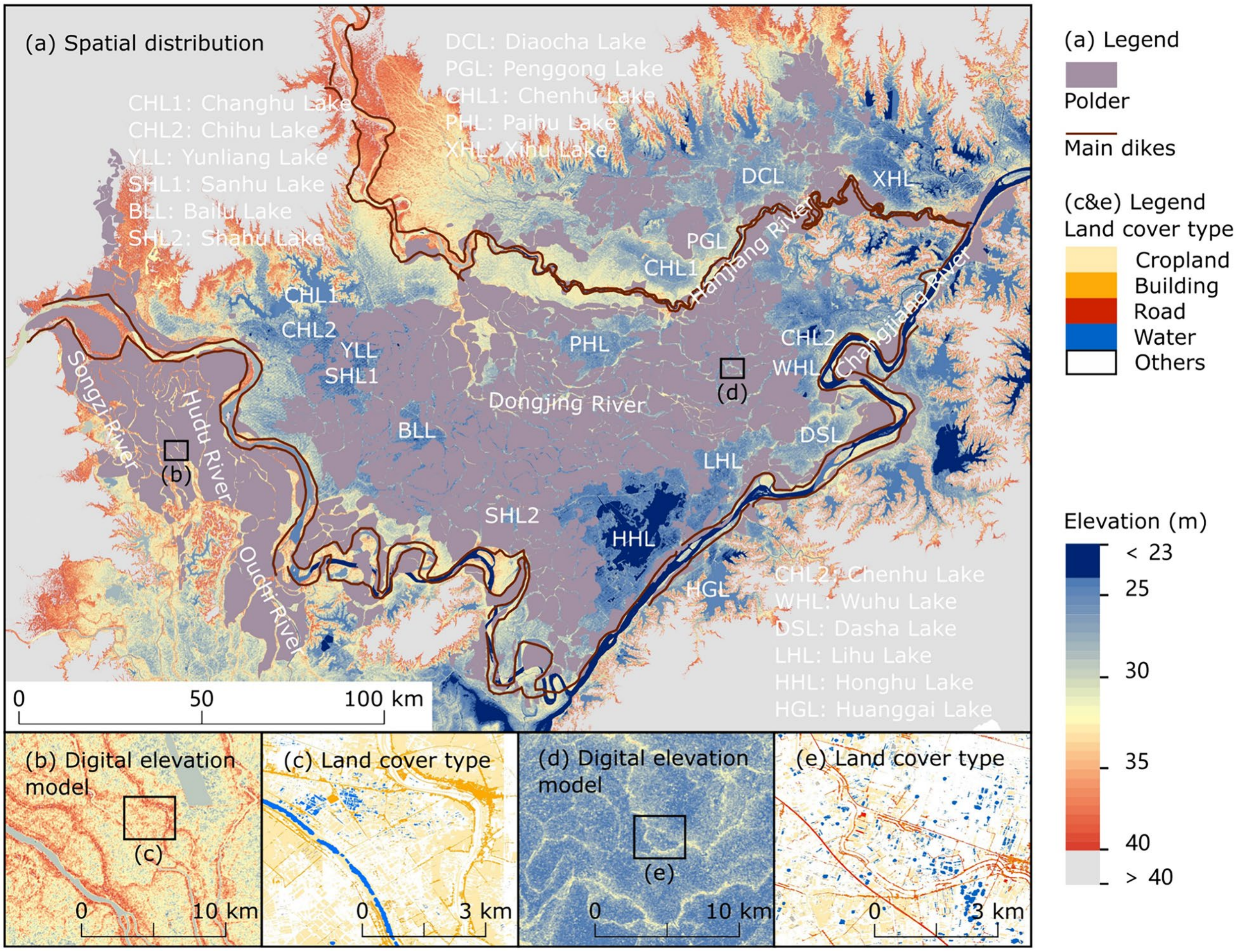

Fig. 2 Spatial distribution of the polder in the Jianghan Plain in the early twentieth century (**a**). A case of digital elevation model (**b**) and land cover (**c**) in the eastern part of the region. A case of digital elevation model (**d**) and land cover (**e**) in the eastern part of the region

River, respectively (Fig. 3). The polders covered an area of 11,826.1 km^2, equivalent to 6.4% of the area of Hubei Province. These numbers showed the size of the polder scale. The longest perimeter of a single polder was 77.6 km, and the largest area was 158.7 km^2 (Fig. 4). Of course, the actual area and perimeter of the polder are larger than these statistics.

There were very distinct differences in the scale of the polder. Despite the modest number of large scale polders, these polders were obviously dominant in terms of area and perimeter. These polders were mainly distributed in the eastern and western parts of the region, and were close to the Changjiang River or large lakes. There were just 69 polders with a perimeter of more than 30 km, but their combined perimeter made up 16.8% of all polders' perimeter. And, only 82 polders had an area larger than 30 km^2, but the area of these polders accounted for 38.8% of the total perimeter of polder. These polders were often constructed with government attention. The government sometimes provided stronger technological and financial support for construction [40]. These polders were often better equipped to withstand floods because there were more people living on these polders. Of course, these larger polders effectively withstand floods only if the local people had strong organizational coordination, otherwise, it was difficult for these polders to play their role [41].

Although there were numerous smaller polders, their total area and perimeter were smaller. These polders were mainly distributed in the central and northern parts of the region. There were 959 polders with a perimeter of less than 10 km, accounting for 61.0% of the total number of the polders, while the sum of their perimeter constituted only 30.5% of the total perimeter of polder. And, the proportion of the polder with an area of less than 10 km^2 was 81.4%, but their combined area only comprised 30.7% of the total area of the polder. There were 370, 658, and 251 polders with an area of less than 1

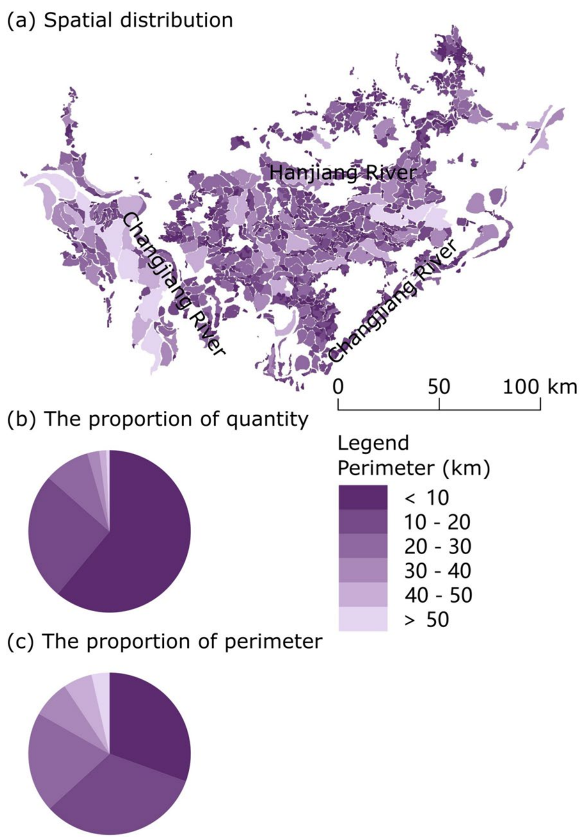

Fig. 3 The spatial distribution (**a**), quantitative proportion (**b**), and perimeter proportion (**c**) of the polders with different scales (perimeter)

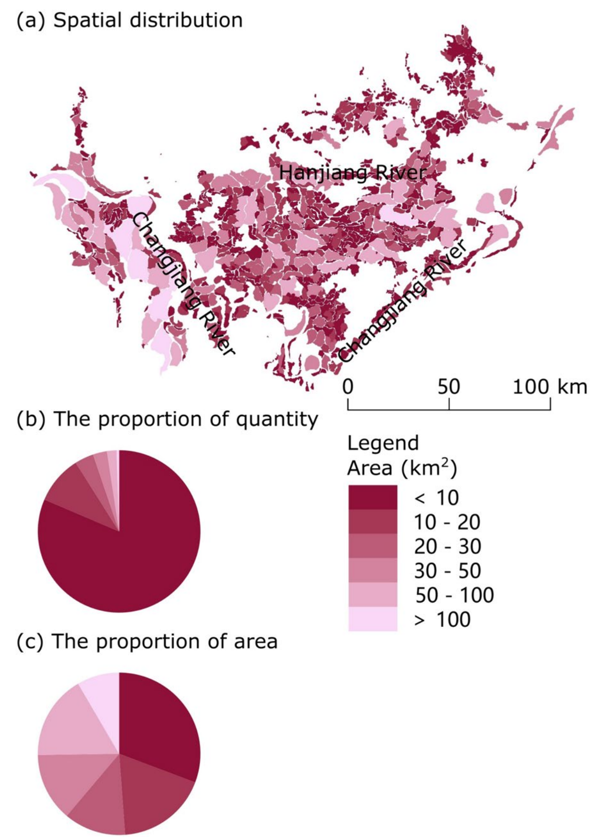

Fig. 4 The spatial distribution (**a**), quantitative proportion (**b**), and area proportion (**c**) of the polders with different scales (area)

km^2, 1–5 km^2, and 5–10 km^2, respectively. These polders were constructed by social forces. There were a few settlements and people distributed within these polders because these polders only provided limited land [39]. The people living on these polders had relatively limited ability to resist natural risks such as floods [41].

The polder shape in the Jianghan Plain in the early twentieth century

As an irregular polygon, the polder shape reflected the complex interaction between man and land. From the perspective of humans, the ideal model constructed polder was to use less materials, costs, and labor, as well as to shorten the construction time. Moreover, it is necessary to protect more land and settlements in the event of inadequate construction materials and other conditions. In general, the form that is closer to a circle has a greater area under the same perimeter condition, whereas the shape that is closer to a circle has a shorter perimeter under the same area constraint. A circular or almost circular polder seems like a more sensible option from this angle. Compared to other shapes, a nearly circular polder could protect more land area; while protecting the same land area, a nearly circular polder requires less materials and labor.

However, the polder shape tended to be more analogous to other shapes rather than circular in the Jianghan Plain in the early twentieth century. Overall, the polder area increased with the perimeter, displaying a non-linear relationship (Fig. 5). The fitting of the area (S) and the perimeter (C) yields, the relationship was obtained, namely, $S = 0.0604C^{1.8363}$. By contrast, this coefficient indicated that the shape was closer to a square shape. Furthermore, some polders can be categorized as one of these polders, even tended to have more asymmetrical geometries.

The occurrence of results that did not conform to human needs was related to the physical environment. The topography was the foundation of the polder construction and affected the polder shape. The majority of these polders were probably constructed on both banks of the rivers or reclaimed land from the river since they resembled reflections of the topography of the rivers. Furthermore, current remote sensing indicates that certain polder shapes in this region are microgeomorphic

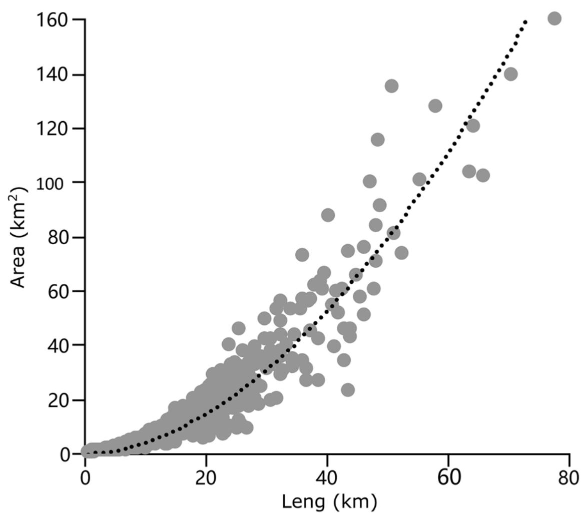

Fig. 5 The relationship between the polder perimeter and the polder area

Table 2 The polder landscape metrics in the five regions

	HN	HDJ	CDJ	CE	CW
AREA/hm^2	120,123.9	235,139.4	526,111.3	31,467.8	269,767.7
NP	318	247	804	24	175
LPI	0.5254	0.9042	0.7729	0.6364	1.4073
LSI	22.1347	20.666	34.9493	7.3339	15.8096
AREA_MN/hm^2	377.3191	941.7049	654.1825	1315.039	1543.41
AREA_AM/hm^2	1503.8581	3296.1792	2525.4688	3294.6868	6947.1701
AREA_SD/hm^2	644.6045	1473.7836	1094.183	1603.8601	2853.0039
AREA_CV/%	176.7092	161.8801	173.0078	126.1544	191.2034
SHAPE_MN	1.5212	1.574	1.5361	1.7679	1.6469
SHAPE_AM	1.6646	1.737	1.6505	1.7523	1.6969
PAFRAC	1.1068	1.1075	1.102	1.1841	1.0611
PARA_MN	94.3768	76.5759	67.5541	32.2506	57.6693
PARA_AM	26.501	17.6845	19.9943	17.1582	12.6314
FRAC_MN	1.0571	1.0579	1.0567	1.0700	1.0651
FRAC_AM	1.0610	1.0583	1.0630	1.0644	1.0589
FRAC_SD	0.0253	0.0248	0.0235	0.0246	0.026
FRAC_CV	2.3916	2.3417	2.2277	2.3030	2.4438

types created by the flow process, like the adjacent Dongting Plain [51]. Among all natural factors, river topography is the most critical factor. This indicates that although human activities have strongly altered the surface landscape of this region, they still adjusted their own preferences based on the actual situation of the physical environment. As a result, the polder shape reflected the skill of striking a balance between human needs and the physical environment, having been shaped by both rivers and human activities.

Regional differences in the polder in the Jianghan Plain in the early twentieth century

There was an obvious regional difference among polders according to landscape metrics (Table 2). First, more than half of the polders were located in the CDJ. The area of the polder distributed in this area was also close to half of the total area of the polder. Second, the polder area in the CE was larger, while the polder area in the HB was smaller. However, because there were a lot of smaller polders in the CE, the area variances between the polders were the biggest in the five regions. Third, the polders along the Changjiang River's southern part (CE and CW) had a more intricate shape than those in other areas. These polders also presented a more irregular appearance.

The obvious regional differences in these polders were related to the long-term interaction between environment and human [39, 41]. The polders in the HN were generally smaller. This implies that the land on which these polders were constructed was previously densely populated with rivers. The polders in the HDJ and CDJ demonstrated complexity and diversity in terms of area, shape, and soon. These polders were a result of the reclamation on the rivers and lakes, and were connected to the dense distribution of rivers and lakes in the region. Meantime, the scale of these polders also was reshaped by long-term flood disturbances from huge rivers. Such as, the distribution of the polders had changed due to the expansion of the Honghu Lake since the middle to late nineteenth century [50]. The polders in the CW were related to the formation of the Songzi River and the Ouchi River in the middle and late nineteenth century, having relatively more advanced technology than other regions. Of course, there were some small-scale polers in the crevasses of these rivers. The polders in the CE were generally long and narrow in size because they were located between the hills and the Changjiang River.

All things considered, the regional differences in the polders reflected human adaptation to the environment in traditional societies. In the plains, topographical variations caused by factors like rivers resulted in disparities in how people used their land. In the areas with relatively dense river networks, humans constructed smaller levees to reduce the impact of floods from rivers on agricultural production. On the contrary, to accommodate more farming and population, humans constructed as many large polders as these polders could in areas with relatively scarce river networks.

Coherence of the polder in the Jianghan Plain during the recent century

In the last century, although the polder in the Jianghan Plain has experienced a complicated process of change, there has also been a definite coherence. Stated differently, historical polders left behind present polders as their legacy. The distribution of contemporary rivers and lakes in the area results from long-term interactions between the environment and humans, which are directly linked to the creation and growth of these polders. In the interim, this interaction can also be understood as shaping the current microtopography of the Jianghan Plain. Furthermore, due to this interaction between humans and the environment, the land cover types of the present Jianghan Plain have developed, providing the framework for human activities, including towns and transportation networks. As a result, a larger historical horizon must be considered in order to fully comprehend the ecosystem of today and the role that past human actions played in it.

We illustrated how polders have stayed in the century-old interaction using the Chishe polder in Jianli County as an example (Fig. 6). The meaning of this toponym is red water gushing out from the ditch according to folklore. Based on geographical name data, the Chishe polder was first recorded in the late Qing Dynasty, that is, it had already existed by the late nineteenth century. The Chishe polder was shown in its position and size on the historical maps of the early twentieth century, along with the villages that were located within. The polder and its farmed land and settlements were still clearly visible from satellite photos taken in the 1960s. Naturally, the polder dike had undergone extensive repair and reinforcement at this time due to the background of promoting agricultural productivity and building water conservancies at the time, making the dike taller than it had previously been. Even though river diversions had rendered the dike ineffective and the polder significance had diminished by the early twenty-first century, there are still distinctly visible polder remnants, such as roads and towns.

The contemporary landscape near the Chishe polder is a cumulative legacy of past human activities (Fig. 6). First, the location of the polder dike was indicated by a reasonably full ring of elevated ground that could be seen in conjunction with DEM. The reason for this elevation disparity is that dikes were either erected immediately on relatively elevated terrain or tall enough to isolate sources of water. Because of this, the area around the dike was noticeably higher than the surrounding terrain, and it eventually developed into an artificial microtopography with unique features. Second, linear building structures and associated roadways were easily visible from the land cover type map. These structures and roads line up with the locations of dikes or dikes that have been removed. This is so that the risk of flooding was decreased and the possibility of waterlogging was avoided due to the raised topography next to the dikes. As a result, settlements have formed near the dikes, and roads connecting different settlements have evolved. The varieties of land cover in the

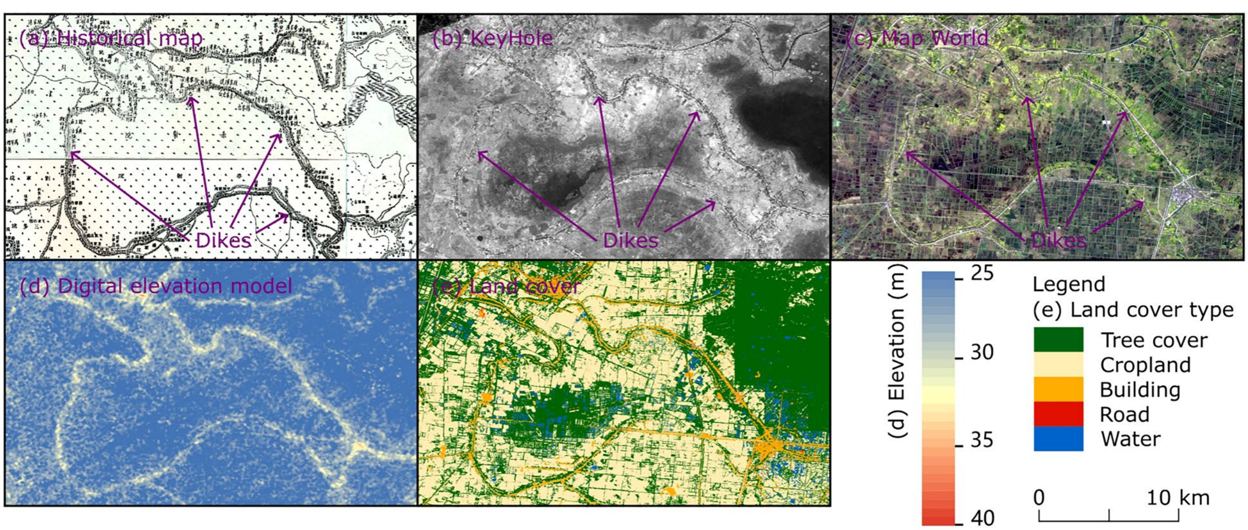

Fig. 6 The Chishe polder over the past century. Among them, this polder on the historical maps (**a**), Corona spy satellite imagery (**b**), and Tianditu (Map World) (**c**). Its digital elevation model (**d**) and contemporary land cover (**e**)

area have been significantly impacted by the dikes, even though some of them are no longer in operation.

This inheritance is not only present in the Chishe polder, but is widely spread throughout the region (Fig. 2). It should be noted that some polders have evolved into ordinary land due to their dikes having lost their function. The entire region prevents floods relying on the main dikes of the Changjiang River and the Hanjiang River [40].

There is a close connection between the formation of the microtopography and the dikes in the Jianghan Plain. Humans often constructed artificial dikes on the natural levees of rivers to carry out reclamation work. Alternatively, they constructed artificial dikes directly to achieve reclamation by taking advantage of the low water levels in lakes [50]. At that time, these dikes located in the land were significantly higher than the surrounding area. Humans also continued to widen and thicken the dikes, which led to an even bigger elevation differential between the dikes and the surrounding terrain. Overall, more than half of the historical dike clearly corresponds to the current relatively elevated terrain. What is noteworthy is that the spatial resolution of the DEM data is 10 m, while the actual width of some of the dikes is less than 10 m. With finer spatial resolution of the DEM data, the correspondence results may be significantly improved.

The relationship between current human activities and historical polders is observed using three sets of data. First, there is a close relationship between the historical dike and the building and road in the land cover type data. Of these, approximately 45% and approximately 40% of the total building area and road area are located within the buffer zone of the dike data, respectively. Second, the road data from OSM is also relatively concentrated near the polder. The roads distributed within the buffer zone of the dike data account for one-third of all roads, excluding urban internal transportation roads and expressways. Third, because less than 20% of the POI data is dispersed throughout the buffer zone, the association between the POI and the dike is marginally weak. Considering that POI data is typically more concentrated in urban areas than in rural areas with a large distribution of the polders. Hence, the legacies of the early twentieth century polder affected the contemporary landscape in the Jianghan Plain of Hubei, especially in rural areas.

Uncertainty and prospect

China's land surrounding its rivers and lakes is among the areas most impacted globally by high-intensity human activity [52]. China's floodplains are covered with land cover types, such as agricultural and building land, that are intimately tied to human activity [53, 54]. This is due to the interaction between a densely populated area, a complex natural environment, and a lengthy history [55]. Since ancient times, there has been a very significant population in this country living along the banks of rivers [56]. According to a comparative analysis, before the Industrial Revolution, China's Changjiang River Delta plain had ten times more people living there than Britain did [57]. As a result, over hundreds of years, human activity gradually gained control over rivers due to the development of water conservation projects, significantly altering the surrounding natural environment and social economy [58]. China has undoubtedly emerged as a crucial area for a thorough and in-depth comprehension of long-term problems with human–land interaction along rivers and lakes.

Due to China's surveying and mapping technology falling behind Europe and America after the Industrial Revolution, large-scale maps of China only began to multitudinous appearance from the late 19th to early twentieth century. On the other hand, the environment at this time was especially valuable to study. This period is a crucial period for China's gradual modernization. Afterwards, the factors that affect the spatial and temporal distribution of the landscape become more diverse. By making good use of these maps and combining them with other materials, we can further study China's environmental change issues. Our research shortcomings will provide experience for future research.

First, there are discrepancies in the landscape depicted between the historical maps and the actual situation. For example, the shapes of the Chishe polder shown on the historical maps have similarities to those on the remote sensing images in general, but there are discrepancies in the details. The reason for this problem was due to the map drawing technology at that time. Of course, a portion of the polder scan be corrected to obtain more accurate shapes using remote sensing images. However, there is still another portion of the historical polders that have completely disappeared, leaving no traces at present. Considering the integrity of the data, we remained the original state of the polders from the historical maps and did not modify the shapes of all polders. Our results will undoubtedly be questionable as a result of this. This uncertainty affects the study reconstruction of historical landscapes using such historical maps. For this reason, it's critical that future research use a more suitable methodology using historical maps in order to recreate the historical landscapes more precisely.

Second, this study had overlooked some smaller polders. The information that we could identify is not precise enough on the historical maps. Because the information needed enough space when it was mapped by the mapmaker. There was some actual information that was too small to display on the maps. Moreover, the more complex the information, the larger the space needed to display it. Consequently, the maps only allow us to identify and extract information that exceeds a certain area. This scale issue must be considered when performing quantitative analysis and data comparison, especially for research with abundant data sources.

It is necessary to think about how to combine historical maps and other research materials to conduct research more fully. Due to the special social background and limitations of technology, the surveying and mapping did not fully cover the whole of China at that time. Moreover, some historical maps have been lost because of the turmoil since then. This meant that these large-scale maps could only display a portion of the historical landscape of the area. Of course, these historical maps still have great application prospects for research on historical landscapes in the future.

Conclusion

Using historical maps and other data, we conducted a case study of the Jianghan Plain to examine how the polder changed and persisted throughout the previous century. In the early twentieth century, the number of the polder was 1571. These polders covered a great part of the land with an altitude of no more than 40 m in the Jianghan Plain. These polders presented a J-shaped distribution. The large-scale polders were clearly dominant in terms of area and perimeter, despite their relatively small number. The shape of these polders was closer to a square shape, which balanced human needs and the physical environment. The polders showing regional differences were caused by the environment and human interaction over an extended period, reflecting human adaptation to the environment in traditional societies.

Our research shows the lasting impact of historical polders on the regional contemporary landscape. It is clear that over half of the old dike are coincident with the moderately raised topography that exists today. Meanwhile, current human activities, such as transportation and land cover types, are connected to these historical dikes, particularly in rural areas. The combined effects of earlier human activity have created the contemporary landscape. Therefore, in order to completely understand the landscape of today and the influence that past human actions played in it, a greater historical horizon needs to be considered.

Author contributions

Conceptualization, Y.L., H.D. and L.Z.; methodology, Y.L. and H.D.; software, Y.L. and H.D.; data collection, Y.L., H.D. and Z.D.; validation, Y.L. and H.D.; formal analysis and investigation, Y.L. and H.D.; writing—original draft preparation, review and editing, Y.L., H.D. Z.D. and L.Z; funding acquisition, Y.L. and L.Z; All authors have read and agreed to the published version of the manuscript.

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Availability of data and materials

No datasets were generated or analysed during the current study.

Declarations

Competing interests

The authors declare no competing interests.

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