Dynamics of Land and Water Resources and Utilization of Cultivated Land in the Yellow River Beach Area of China

Yadi Run 1,2, Mengdi Li 1,2, Yaochen Qin 1,2, Zhifang Shi 1,2, Qian Li 1,2 and Yaoping Cui 1,2,3,*

1 Key Laboratory of Geospatial Technology for the Middle and Lower Yellow River Regions, Henan University, Ministry of Education, Kaifeng 457004, China; run@henu.edu.cn (Y.R.); lmd@henu.edu.cn (M.L.); qinye@henu.edu.cn (Y.Q.); shizhifang@henu.edu.cn (Z.S.); liqian@henu.edu.cn (Q.L.)
2 College of Geography and Environmental Science, Henan University, Kaifeng 457004, China
3 Henan Science and Technology Innovation Center of Natural Resources/Land Consolidation and Rehabilitation Center of Henan Province, Zhengzhou 450041, China
* Correspondence: cuiyp@lreis.ac.cn; Tel.: +86-1393-7858-607

Abstract: Image analysis of the Yellow River beach area since 1987 provided land use and water body patterns to support effective agricultural and environmental management. Landsat and Sentinel-2A/B images, and data from the Third National Land Survey, were used to examine the water body and land use patterns. The continuous beach land since 1987 was calculated from annual vegetation and water body indexes while that of cultivated land was extracted from the Third National Land Survey. Object-Oriented Feature Extraction was used to extract staple crops. The results showed that 58.26% of the beach area was cultivated land. Continuous beach land covered an area of 1630.98 km² and was consisted of scattered patches that were unevenly distributed between the north and south banks of the Yellow River. The staple crop types in the beach area, winter wheat and summer corn accounted for 72.37% and 68.03% of the total cultivated land. Affected by the strategy on the Yellow River basin in China, as the ecological space and protection continue to increase, this study provides basic scientific references for the correct use of cultivated land resources and protection of the balance of soil and water resources dynamic utilization and balance of cultivated land protection and ecological protection.

Keywords: Yellow River; cultivated land; Object-Oriented Feature Extraction; wheat; corn

1. Introduction

The Yellow River beach area is a vast, relatively flat area between the main channel of the Yellow River and the river’s flood control levee. The beach area has been flooded and filled with silt from the river several times [1]. Since the completion of the Yellow River Xiaolangdi Dam, the floods have been controlled effectively and much of the beach area has been used as fertile cultivated land [2]. Since 2019, when the ecological protection and high-quality development strategy of the Yellow River basin were proposed in China, the local governments have increased the protection of the beach area [3–5]. To support the government’s strategy, studies of the beaches and the cultivated land are needed to provide basic land use information, which will form the space basis for improving the safe protection and governance of the water and land resources in the beach area.

There have been some previous studies on the Yellow River beach area [6,7]. Some scholars have considered how the water body and beach land have developed and transformed spatially and temporally [8], and what the ecological benefits accrued from developing the cultivated land was [9–13]. The cultivated land and the water area were closely related, and the progress of water area means the retreat of cultivated land, and vice versa [14]. As various flood control projects and engineering repairs have been successfully implemented, both the speed and flow of the river have decreased, resulting in a decrease
in the water area and an increase in the area of exposed beaches [15]. However, the relationship between cultivated land and water body in the Yellow River beach has not been fully explored. It thus is a primary task to identify the balance between water, land, and cultivated land structure.

Recently, remote sensing images have been used increasingly to support land use analysis and research [16–18]. Satellite data like Landsat, Sentinel images can be used free of charge to support land use mapping and cultivated land monitoring [19–24]. Traditional methods for extracting ground objects mainly consider the gray value of pixels; however, this does not adequately use information about the image space and texture and may result in a low classification accuracy [25]. In the Third National Land Survey of China, based on the information from remote sensing images, the land use types are classified into 13 primary categories, such as wetland, cultivated land, and forest land [26]. However, the data of the Third National Land Survey cannot distinguish crop types, nor does it take into account the unique geographical environment, which means that there is insufficient information about crop growing activity in the beach area. Additionally, based on the support of high-resolution remote sensing data like Sentinel, mapping crop types have been widely explored in many studies [27,28]. Therefore, Sentinel data has great potential to accurately extract the information of cultivated land.

The purpose of this study is to study the dynamics of water and soil resources and the utilization of cultivated land in the Yellow River beach area. In this study, the area of cultivated land in the beach area was extracted from the Third National Land Survey. The area of continuous beach land over the last 34 years was extracted and the spatial and temporal changes from beach land to cultivated land were discussed. Object-Oriented Feature Extraction was used to extract staple crops from Sentinel-2A/B images. The results can provide a reference for the management and protection of cultivated land resources in this special area.

2. Data and Methods

2.1. Study Area

The study area is the section of the Yellow River that flows through Henan Province (Figure 1), which has the greatest extent of cultivated beach along the river [29]. The length of the river channel involved in the beach is 464 km, flowing through the middle reaches of the Yellow River (19.35%) and the lower reaches (80.65%), with a total area of 2673 km\(^2\) [30]. The Taohuayu section is characterized by hilly terrain in the west and an alluvial plain in the east, with sediment deposits and an elevated river bed caused by frequently changing flow [31]. About a million people live here and the beach area is a semi-natural farming environment managed by humans. [31,32].

2.2. Data

We used the Landsat and Sentinel-2A/B images to extract the continuous beach land and staple crops. Landsat images with a long-time span were used to identify the continuous beach land on a scale of pixels. Sentinel-2A/B images have a spatial resolution of 10 m and numerous studies have used Sentinel images to identify crop types [33,34]. Therefore, Sentinel-2A/B images were used to identify crop types in this study.

Google Earth Engine (GEE) (https://earthengine.google.org (accessed on 7 March 2021)) is a cloud computing platform that provides a wealth of geospatial data [35,36]. Landsat Thematic Mapper (TM), Enhanced Thematic Mapper + (ETM+), and Operational Land Imager (OLI) for the Yellow River beach area from 1987 to 2020 were acquired from the GEE platform. The surface reflectance Landsat images from the GEE platform were geometrically and atmospherically corrected and were cross-calibrated between different sensors [37], and images with 0–20% cloud cover have been selected. A total of 4722 valid Landsat images (Figures 1 and 2) have been obtained. For each image, clouds, cloud shadows and snow pixels were removed using the data quality layer from a cloud masking method, CF-Mask, which helped to prepare the Landsat data for change detection [38–40].
2.2. Data

We used the Landsat and Sentinel-2A/B images to extract the continuous beach land and staple crops. Landsat images with a long-time span were used to identify the continuous beach land on a scale of pixels. Sentinel-2A/B images have a spatial resolution of 10 m and numerous studies have used Sentinel images to identify crop types [33,34]. Therefore, Sentinel-2A/B images were used to identify crop types in this study.

Google Earth Engine (GEE) (https://earthengine.google.org (accessed on 7 March 2021)) is a cloud computing platform that provides a wealth of geospatial data [35,36]. Landsat Thematic Mapper (TM), Enhanced Thematic Mapper + (ETM+), and Operational Land Imager (OLI) for the Yellow River beach area from 1987 to 2020 were acquired from the GEE platform. The surface reflectance Landsat images from the GEE platform were geometrically and atmospherically corrected and were cross-calibrated between different sensors [37], and images with 0–20% cloud cover have been selected. A total of 4722 valid Landsat images (Figures 1 and 2) have been obtained. For each image, clouds, cloud shadows and snow pixels were removed using the data quality layer from a cloud masking method, CF-Mask, which helped to prepare the Landsat data for change detection [38–40].

The Sentinel 2A/B mission of Copernicus Europe comprises a multispectral and high-resolution sub-satellite that employs a Multi-Spectral Imager (MSI) with 13 bands [41,42]. In this study, 72 Level 1C images of Sentinel-2A/B with sub-1% cloudiness for the Yellow River bank area from 2019 to 2020 were downloaded from the European Space Agency website (https://scihub.copernicus.eu (accessed on 15 March 2021)), which had undergone orthorectification and sub-pixel geometric fine correction [43]. The Sen2cor plug-in (http://step.esa.int (accessed on 3 April 2021)) was used to radiometrically calibrate and geometrically correct the images, and finally Level 2A atmospheric bottom reflectivity data
was obtained [41,43]. The range of the Yellow River beach area, the data of the type of cultivated land within the beach area were from the Third National Land Survey.

2.3. Methods

2.3.1. Technical Framework

Based on Landsat images downloaded from the GEE platform, water bodies were first identified using the relationship between the water body and vegetation indexes. Then water body frequency maps were created and continuous beach lands were extracted based on thresholds. Using the data of the Third National Land Survey, the cultivated land information within the beach area was extracted. Finally, Object-Oriented Feature Extraction was used to extract crops (Figure 3).

\[ mNDWI = \frac{\rho_{Green} - \rho_{Swir1}}{\rho_{Green} + \rho_{Swir1}} \]  

\[ NDVI = \frac{\rho_{Nir} - \rho_{Red}}{\rho_{Nir} + \rho_{Red}} \]  

\[ EVI = 2.5 \times \frac{\rho_{Nir} - \rho_{Red}}{1.0 + 6.0\rho_{Red} + 7.5\rho_{Blue}} \]

where \( \rho_{Blue}, \rho_{Green}, \rho_{Red}, \rho_{Nir}, \) and \( \rho_{Swir1} \) are the surface reflectance values of bands Blue, Green, Red, Near-infrared and Shortwave-infrared-1 in the Landsat images.

Figure 3. Technical framework.

2.3.2. Water Bodies and Continuous Beach Land Identification

(1) Water body identification. The relationship between water body and vegetation indexes was used to identify water body, following the approach adopted in previous studies [44–46]. The modified Normalized Difference Water Index (\( mNDWI \)), Normalized Difference Vegetation Index (\( NDVI \)) and Enhanced Vegetation Index (\( EVI \)) were used. The formulas for these water and vegetation indices are as follows:
When $mNDWI > EVI$ or $mNDWI > NDVI$, the signal of water body in this area was stronger than that of vegetation. In order to further remove the noise, the mixed pixels of water and vegetation were removed using $EVI < 0.1$. Only the pixels that met the conditions (i.e., $(mNDWI > EVI \text{ or } mNDWI > NDVI)$ and $(EVI < 0.1)$) were classified into water body, while others were non-water pixels.

(2) Annual Water Frequency Calculation [40]:

$$ F(y) = \frac{1}{N_y} \sum_{i=1}^{N_y} W_{y,i} \times 100\% $$

where $F$ is the water frequency of the pixel, $y$ is the specified year, $N_y$ represents the total numbers of Landsat satellite observations for the pixel in that year and $W_{y,i}$ represents whether a pixel is water in that year, where 1 is water and 0 is non-water. The water frequency map shows the annual presence or absence of water in each pixel since 1987.

(3) Continuous Beach Land

Most of the noise caused by poor data quality can be eliminated by choosing an appropriate water frequency threshold [30]. The area of beach with 0–25% of simultaneous water frequency from 1987 to 2020 was extracted and recognized as continuous beach land. The pixels with continuous beach land indicated stable non-water-covered areas were considered to be available beach land.

2.3.3. Object-Oriented Feature Extraction

In this study, Object-Oriented Feature Extraction was used to extract crops. Pixels with similar internal features were composed into new objects, and staple crops were extracted according to specific rules. These were mainly divided into two processes, namely multi-scale segmentation and object feature extraction [47,48] (Figure 3).

(1) Multi-Scale Segmentation [49]

In this process, a boundary-based segmentation algorithm was used for multi-scale segmentation, where pixels with similar spectral features were combined, and the average value was calculated and compared. Each segmentation object with similar internal feature information was filled in this scale. Each segmented object has a rich spectrum, texture, space and other information. Each segmentation object with similar internal feature information was filled in this scale. The object was the basic unit of object-oriented image processing based on rule classification. During image segmentation, some objects will be misclassified, and some objects may be divided into many parts, these problems can be solved by merging merge scale.

(2) Object Feature Extraction

The Object-Oriented Feature Extraction model is based on the principle of decision tree classification. The decision tree classification method is carried out layer by layer [50]. In this process, the areas were classified as vegetation-covered areas and non-vegetation-covered areas using $NDVI$ and spectral values of the crop. When $NDVI$ was greater than 0.35, it was a vegetation-covered area and when $NDVI$ was less than 0.35, it was a non-vegetation-covered area [51]. The vegetation-covered areas were then further distinguished using the spectral values of winter wheat and summer corn as the rules.

2.3.4. Accuracy Verification

This process follows the concept of an error matrix [52]. the producer’s accuracy, the user’s accuracy, and the overall accuracy, were used in the accuracy assessment.

Producer’s accuracy includes producer accuracy ($Pa$) of goal region and producer accuracy ($Pn$) of non-goal region. They are defined as follows:

$$ Pa = \frac{TP}{TP + FN} $$

$$ Pn = \frac{TN}{FP + TN} $$
User’s accuracy includes user accuracy \((Ua)\) in goal region and user accuracy \((Un)\) in non-goal region. They are defined as follows:

\[
Ua = \frac{TP}{TP + FP} \quad (7)
\]

\[
Un = \frac{TN}{TN + FN} \quad (8)
\]

where \(TP\) (true positive) is the number of goal pixels correctly extracted; \(FN\) (false negative) is the number of goal pixels extracted as non-goal; \(FP\) (false positive) is the number of non-goal pixels extracted as a goal, and \(TN\) (true negative) is the number of non-goal pixels correctly extracted.

Overall accuracy \((Oa)\) is:

\[
Oa = \frac{TP + TN}{TP + TN + FP + FN} \quad (9)
\]

where \(TP + TN\) is the number of correctly extracted true goal and non-goal pixels; \(TP + TN + FP + FN\) is equal to the number of total pixels in the image. The overall accuracy can be used to evaluate the correctness percentage of the detection algorithm.

For each land cover type, based on different phases of Sentinel-2 high-resolution images, sample points were randomly generated by GEE for accuracy verification, here 400 sample points were generated for each water body, winter wheat and summer corn, respectively. Water bodies were verified using the method of Wang et al. [53], a water body with water frequency \(\geq 25\%\) in 2020 water frequency image was used as verification. Some sampling points were shown in Figure 4. The overall accuracy of water body (96%), winter wheat (97.1%), and summer corn (94.55%) met the needs of this study (Table 1).

Figure 4. Spatial extraction accuracy. (a–c) compare the extracted accuracy with high-resolution RGB images of winter wheat, summer corn, and water bodies, respectively.
Table 1. Error matrix for accurate evaluation.

| Water Body | No Water Body | Winter Wheat | No Winter Wheat | Summer Corn | No Summer Corn |
|------------|---------------|--------------|----------------|-------------|----------------|
| Producer’s accuracy (100%) | 95.71% | 96% | 97.02% | 96.26% | 94% | 95.05% |
| User’s accuracy (100%) | 94.06% | 96.90% | 98.96% | 97.17% | 95% | 94.11% |
| Overall accuracy (100%) | 96% | 97.10% | 94.55% | | | |

3. Results

3.1. The Proportion of Cultivated Land in the Beach Area

The statistics from the Third National Land Survey indicated that a large proportion of the Yellow River beach area was cultivated land. Cultivated land, garden land and other agricultural land accounted for 66.04% of the total beach area. Among them, cultivated land accounted for the largest proportion (58.26%) and covered an area of 1557.19 km² (Figure 5). Irrigable land, paddy field and dry land accounted for 97% and 3% of the cultivated land, respectively.

![Figure 5. Area proportion of various land use types in the Yellow River beach in 2020.](image-url)

The area of dry land accounted for 2.20% of the cultivated land, which was unevenly distributed between the north and south banks of the Yellow River, counties and cities along the Yellow River beach were shown in Figure 5. Of the dry land, 82.84% distributed throughout seven counties on the south bank and 17.16% distributed through six counties on the north bank. Gongyi county had the largest area of dry land (9.95 km²), followed by Xiangfu district (8.68 km²). Six counties, including Lankao, Puyang, Longting, Mengzhou and Wuzhi, had no areas of dry land.
The cultivated land was unevenly distributed through the counties and cities of the Yellow River beach area (Figure 6). To reflect cultivated land information more clearly, five areas were randomly selected and magnified, the same areas were magnified in the figures below. Xinxiang, Puyang and Jiaozuo cities accounted for 73.13% of the cultivated land in the beach area. Xinxiang, with 41.84%, had the largest area of cultivated land in the beach area, across 651.57 km$^2$. Puyang followed, with 18.14% of the total cultivated land area across 282.40 km$^2$. Jiaozuo had 13.15% of the cultivated land area, across 204.80 km$^2$. The counties with a large area of cultivated land were Yuanyang and Changyuan. Xinxiang and Jiaozuo cities had a large area of irrigable land, and Yuanyang, Changyuan were counties with large irrigable land area, Yuanyang, with an area of 275.76 km$^2$, accounted for 42.32% of the cultivated land area in Xinxiang city and 18.21% of the total irrigable land in the beach area. The cities with a large area of dry land were Zhengzhou, Kaifeng and Luoyang, the counties with large dry land areas were Gongyi, Mengjin and Xiangfu district. Gongyi county had a dry land area of 9.95 km$^2$, which accounted for 0.05% of the cultivated land area in Zhengzhou city and 28.90% of the total dry land in the beach area. Luoyang, Kaifeng and Puyang cities had the largest area of paddy field, with the largest area in Mengjin and Lankao counties. Paddy field in Mengjin county covered an area of 6.39 km$^2$, which accounted for 21.74% of the cultivated land in Luoyang city and 66.01% of the paddy field total in the beach area (Figure 7).

![Figure 6. Distribution of cultivated land in the Yellow River beach in 2020.](image-url)
3.2. The Distribution of Continuous Beach Land

During the study period, continuous beach land covered an area of 1630.92 km$^2$, scattered across 18,243 patches, and accounted for 61.02% of the total area in the Yellow River beach (Table 2). None of these patches were inundated by water over the 34 years. There were 29 continuous beach patches $\geq 1.0$ km$^2$, which covered an area of 1544.29 km$^2$ and accounted for 94.68% of the continuous beach land area. Most of these patches were in Xinxiang (nine patches), Zhengzhou (seven patches) and Puyang (six patches) cities; there were 10 continuous beach patches $\geq 10.0$ km$^2$, which covered an area of 1492.11 km$^2$ and accounted for 91.49% of the continuous beach land area, mainly in Zhengzhou (three patches), Xinxiang (two patches) and Puyang (two patches) cities; and there were 151 patches with continuous beach land areas $\geq 0.1$ km$^2$, which covered an area of 1577.66 km$^2$, and accounted for 96.73% of the continuous beach land area; there were 18,085 continuous beach patches $\leq 0.1$ km$^2$, scattered across the beach area of numerous cities. Xinxiang was the prefecture-level city with the largest continuous beach land area, followed by Puyang and Jiaozuo cities, ranking second and third, respectively.

Table 2. The number of continuous beach land patches in the Yellow River beach in 2020.

| County | Luoyang | Jiaozuo | Zhengzhou | Xinxian | Kaifang | Puyang | Summary |
|--------|---------|---------|-----------|---------|---------|--------|---------|
| $\geq 0.1$ km$^2$ | 8       | 9       | 28        | 50      | 38      | 18     | 151     |
| $\geq 1.0$ km$^2$ | 3       | 2       | 7         | 9       | 2       | 6      | 29      |
| $\geq 10.0$ km$^2$ | 1       | 1       | 3         | 2       | 1       | 2      | 10      |

There was a gap in the distribution of continuous beach land on the left bank, right bank and coastal cities in the Yellow River beach. The continuous beach land area covered 1260.09 km$^2$ on the left bank in the Yellow River beach and 370.89 km$^2$ on the right bank. The 34 years' continuous beach land areas were mainly distributed in Xinxiang, Puyang, Jiaozuo and other cities on the left bank of the Yellow River. The continuous beach land area in Xinxiang, Puyang and Jiaozuo cities accounted for 43.94%, 18.83% and 14.49% of
the total continuous beach land, respectively. Luoyang city (29.60 km²) accounted for only 1.81% of the total continuous beach land in the Yellow River beach area.

3.3. Proportion of the Cultivated Land for the Staple Crops

Winter wheat and summer corn was the staple crops grown on the cultivated land in the Yellow River beach. Winter wheat covered a larger area than summer corn. Winter wheat covered 1126.94 km² and accounted for 72.37% of the total cultivated land (Figure 8). The harvested area of winter wheat covered 1063.95 km² and accounted for 94.44% of the cultivated area of winter wheat and 68.32% of the cultivated land. The area of summer corn covered 1059.30 km² and accounted for 68.03% of the total cultivated land (Figure 9). The harvested area of summer corn was 1010.89 km² and accounted for 95.43% of the cultivated area of summer corn and 64.92% of the cultivated land.

Figure 8. Distribution of winter wheat in the Yellow River beach in 2020.

Figure 9. Distribution of summer corn in the Yellow River beach in 2020.
The area of winter wheat and summer corn varied between the counties and cities (Figure 10). The city with the largest winter wheat area was Xinxiang, with an area of 475.82 km², accounted for 44.92% of the total winter wheat area in the beach area, followed by Puyang and Jiaozuo cities, which accounted for 18.69% and 13.37% of the total winter wheat area, respectively. Luoyang had 152.20 km², which was the smallest area of winter wheat. Yuanyang, with 225.20 km², accounted for 19.98% of the total winter wheat area in the beach area, while Changyuan accounted for 16.91% of the total winter wheat area. Jinshui district in Zhengzhou city had only 0.3 km², which was the smallest area of winter wheat. Xinxiang city had the largest area of summer corn (Figure 10), which covered 475.82 km² and accounted for 44.92% of the total summer corn area in the beach area. Puyang and Kaifeng cities followed, with 16.93% and 13.01% of the total summer corn area, respectively. Luoyang city had the smallest area of summer corn, with only 15.22 km² or 1.35% of the total summer corn grown in the beach area. The counties statistics (Figure 11) indicated that Yuanyang and Changyuan had a large area of winter wheat. Yuanyang, with 225.20 km², accounted for 19.98% of the total winter wheat area in the beach area, while Changyuan accounted for 16.91% of the total winter wheat area. Jinshui district in Zhengzhou city, with only 0.79 km², had the smallest area of summer corn.

![Figure 10. Distribution of crops in each city in the Yellow River beach in 2020.](image1)

![Figure 11. Distribution of crops in each county in the Yellow River beach in 2020.](image2)
4. Discussion

It is important to strengthen the monitoring and utilization of agricultural cultivated land resources in beach areas. In the continuous beach land, the cultivated land occupied a relatively high area proportion. Consistent with previous studies, grain production was a major land use in the Yellow River beach area. However, it is worth noting that there are beach lands that have been waterless for many years, and these beach lands have been developed into cultivated land resources. These cultivated land resources need to be protected in terms of ensuring food security for the million people in the Yellow River beach area or even at Henan province [54]. However, the extent of the cultivated land resources in the beach area cannot be expanded infinitely. Cultivated land accounts for a large area proportion in the whole beach area, while other land use types such as wetlands cover relatively small areas correspondingly. Optimizing and adjusting the ratio of cultivated land to ecologically protected land is essential to regional balance, secure land (Sustainable Development Goals 15), and ensuring food security.

The Yellow River beach area was dominated by agriculture, and the construction of agricultural infrastructure should be strengthened to enrich the types of crops. As showed by this study, the agricultural planting types in this area were mainly winter wheat, summer corn. The fact that the crops have a single structure and few crop types are not conducive to future development. The single structure of agricultural production does not adapt to the diversity of natural resources, and it is greatly affected by market price fluctuations [55]. However, given that the beach area has benefited from a large irrigation project (the Yellow River Diversion Irrigation Project), the agricultural output is relatively high and the harvest area of both winter wheat and summer corn all exceeds 94% indicating the importance of advanced irrigation facilities.

Rapid socio-economic development in the past decades has increased the consumption of water and land resources, leading to negative impacts and making the ecological environment of the Yellow River beach area very fragile [56–58]. However, due to the narrow span of the left and right banks of the Yellow River, although this study has preliminary discussed the spatial-temporal dynamics of water and land resources, it is still insufficient to study the fragile ecological environment. Generally speaking, as the channel of flood discharge, there should be more wetland in the beach area [59,60]. According to our finding, there are large continuous lands without water body historically in the beach area. These beaches are suitable for cultivating and some of them have been developed into cultivated land, which contributes to the food security in the region. Regardless of whether it is based on the national Yellow River protection strategy or according to our study results, the cultivated land resources in the beach area are already relatively large and “we should not stop eating because of choking”, namely, blindly pursue the expansion of ecological protected area and neglect the original farming resources and suitable farming environment. Therefore, the beach area should have a fine strategy that protects the cultivated land and ecological land resources and promotes the development of agriculture rather than extensive development. While protecting the ecological environment, it is necessary to combine the actual conditions of the residents in the beach area to ensure the sustainable development of agriculture and practice the national strategy of ecological protection and high-quality development of the Yellow River basin.

By combining water extraction methods and the Third National Land Survey data, this study accurately measured the area of water body and cultivated land. However, this study was not able to comprehensively explore the factors influencing the pattern of continuous beach land and staple crops in the Yellow River beach area. In future, more attention should be paid to the reason analysis.

5. Conclusions

The beach area along the floodplains of the middle and lower reaches of the Yellow River comprises valuable cultivated land resources. Based on the Third National Land Survey data and remote sensing images. This study analyzed the spatial and temporal
changes of continuous beach land and cultivated land. Our study revealed that cultivated land occupied a large area of the total beach area (1557.19 km$^2$) and most of the beach area was covered by continuous beach area (61.02%). Patch area of the continuous beach area that more than 0.1 km$^2$ accounted for 96.73% of the total area of continuous beach lands, which provides numerous land resources for cultivating. The staple crops in the Yellow River beach area were winter wheat and summer corn, which implies that the beach area plays an important role in ensuring regional food security for millions of people living in the study area. When protecting the ecological environment in the beach area, the cultivated land should be protected too.

Author Contributions: Conceptualization, Y.R., Y.C., and M.L.; methodology, Y.R.; software, Y.R., Z.S., Q.L. and M.L.; formal analysis, Y.Q., and Q.L.; writing-original draft preparation, Y.Q., Y.C.; writing-review and editing, Y.C., Y.Q.; supervision, Y.Q., Y.C.; funding acquisition, Y.Q., Y.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by National Key Research and Development Program of China [2021YFE0106700], National Natural Science Foundation of China [42071415], Outstanding Youth Science Foundation Project of Natural Science Foundation of Henan province [202300410049], Key Laboratory of Land Surface Pattern and Simulation, Chinese Academy of Sciences [LB2021006], and Special project of natural resources development in Henan province (Ecological product value and Ecological carbon sink).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Landsat image from Google Earth Engine (GEE) (https://earthengine.google.org/ accessed on 9 September 2021), and water data processing in the GEE. Sentinel L1C data is downloaded from ESA (https://scihub.copernicus.eu/ accessed on 29 November 2021).

Acknowledgments: Thanks to Henan Provincial Department of Natural Resources for the support of this research data, thanks to Leonie Seabrook for the detailed revision of this paper.

Conflicts of Interest: The authors declare no conflict of interest.

References
1. Run, Y.; Cui, Y.; Qin, Y.; Hu, Y.; Fu, Y.; Liu, X.; Shi, Z.; Li, Q.; Fan, L. A study on the spatial and temporal dynamics of water and soil in the Yellow River. Yellow River 2021, 43, 85–89.
2. Xu, J. Study on high-efficient sediment-transporting floods in the Lower Yellow River. Int. J. Sediment Res. 2009, 6, 54–59.
3. Xi, J. Speech at the symposium on ecological protection and high-quality development of the Yellow River basin. China Water Resour 2019, 20, 1–3.
4. Zhao, Q. Study on coastal tidal flat management. Ocean. Dev. Manag. 2014, 31, 15–18.
5. He, Z.; Cui, J.; Yao, G.; Sun, X. The impact of safety construction on the environment in Henan Yellow River beach area. Yellow River 2009, 31, 117.
6. Luo, Y.; Yang, S.; Liu, X.; Liu, C.; Song, W.; Dong, G.; Zhao, H.; Lou, H. Characteristics of land use change in Hekou town Tongguan section of the Yellow River from 1998 to 2010. Acta Geogr. Sin. 2014, 69, 42–53.
7. Zhang, R.; Wang, Y.; Chang, J.; Li, Y. Response of land use change to human activities in the Yellow River basin based on water resources zoning. J. Nat. Resour. 2019, 34, 56–69.
8. Wang, X.; Zuo, L.; Zhao, X. Remote sensing monitoring of the age and productivity index of newly cultivated land in the Yellow River delta. J. Geo-Inf. Sci. 2013, 15, 461–468.
9. Wang, F.; Liang, W.; Fu, B.; Jin, C.; Yan, N. Analysis on the spatial and temporal changes of cultivated land and the quantity of cultivated land with safe rations in the Loess Plateau in recent years. Arid. Land Geogr. 2020, 43, 161–171.
10. Li, Y.; Liu, C.; Liu, X.; Liang, K.; Bai, P.; Feng, Y. Influence of vegetation restoration project on land use/cover change in the middle reaches of the Yellow River. J. Nat. Resour. 2016, 31, 2005–2020.
11. Zhao, G.; Lin, G.; Fletcher, J.; Yuili, C. Cultivated land changes and their driving forces—A satellite remote sensing analysis in the Yellow River delta, China. Pedosphere 2004, 14, 93–102.
12. Meng, H.; Zhao, T.; Zhang, H.; Xu, H. Characteristics of rainfall runoff and non-point source pollution in Mengjin Yellow River beach area. J. Soil Water Conserv. 2008, 22, 48–51.
13. Pietz, D. On the Ecological Margins: The Yellow River the problem of water in modern China. Methods Enzymol. 2015, 288, 84–108.
14. Yang, J.; Xie, B.; Zhang, D.; Tao, W. Climate and land use change impacts on water yield ecosystem service in the Yellow River basin, China. Environ. Earth Sci. 2021, 80, 72. [CrossRef]
15. Zhao, Z. Study on comprehensive development and utilization of land resources in Yellow River beach area of Kaifeng. Yellow River 2009, 31, 1–2.
16. Gao, Z.; Liu, J.; Deng, X. Spatial features of land use/land cover change in the United States. J. Geogr. Sci. 2003, 13, 63–70. [CrossRef]
17. Mustafa, A.A.; Singh, M.; Sahoo, R.; Ahmed, N.; Khanna, M.; Sarangi, A.; Mishra, A. Land suitability analysis for different crops: A multi criteria decision making approach using remote sensing and GIS. Researcher 2011, 3, 61–84.
18. Tang, X.; Cui, Y.; Li, N.; Fu, Y.; Liu, X.; Run, Y.; Li, M.; Zhao, G.; Dong, J. Human activities enhance radiation forcing through surface albedo associated with vegetation in Beijing. Remote Sens. 2020, 12, 837. [CrossRef]
19. Claverie, M.; Ju, J.; Masek, J.G.; Dungan, J.L.; Vermote, E.F.; Roger, J.C.; Skakun, S.V.; Justice, C. The harmonized Landsat and Sentinel-2 surface reflectance data set. Remote Sens. Environ. 2018, 219, 145–161. [CrossRef]
20. Wulder, M.A.; Loveland, T.R.; Roy, D.P.; Crawford, C.J.; Masek, J.G.; Woodcock, C.E.; Allen, R.G.; Anderson, M.C.; Belward, A.S.; Cohen, W.B.; et al. Current status of Landsat program, science, and applications. Remote Sens. Environ. 2019, 225, 127–147. [CrossRef]
21. Johnson, D.M. Using the Landsat archive to map crop cover history across the United States. Remote Sens. Environ. 2019, 232, 111286. [CrossRef]
22. Zhang, M.; Wu, B.; Yu, M.; Zou, W.; Zheng, Y. Crop condition assessment with adjusted NDVI using the uncropped arable land ratio. Remote Sens. 2014, 6, 5774–5794. [CrossRef]
23. Kyrtatzis, A.C.; Skarlatos, D.P.; Menexes, G.C.; Vamvakousis, V.F.; Katsiotis, A. Assessment of vegetation indices derived by UAV imagery for durum wheat phenotyping under a water limited and heat stressed Mediterranean environment. Front. Plant Sci. 2017, 8, 1114. [CrossRef]
24. Yu, X.; Her, Y.; Zhu, X.; Lu, C.; Li, X. Multi-temporal arable land monitoring in arid region of northwest China using a new extraction index. Sustainability 2021, 13, 5274. [CrossRef]
25. Tan, L.; Zhao, S.; Luo, Y.; Zhou, H.; Wang, A.; Lei, B. Automatic classification of multi-temporal remote sensing land cover in hilly areas of Shandong Province based on object features. Acta Ecol. Sin. 2014, 34, 7251–7260.
26. Lai, Y.; Qi, Q.; Liu, Y.; Yu, F.; Kang, M.; Su, S.; Wong, M. Study on the optimization design of land use map of the third national land survey. J. Geomat. 2021, 46, 111–115.
27. Ghosh, S.M.; Saraf, S.; Behera, M.D.; Biradar, C. Estimating agricultural crop types and fallow lands using multi-temporal sentinel-2A imageries. Proc. Natl. Acad. Sci. India Sect. A Phys. Sci. 2017, 87, 769–779. [CrossRef]
28. Wang, J.; Xiao, X.; Liu, L.; Wu, X.; Qin, Y.; Steiner, J.L.; Dong, J. Mapping sugarcane plantation dynamics in Guangxi, China, by time-series Sentinel-1, Sentinel-2 and Landsat images. Remote Sens. Environ. 2020, 247, 111951. [CrossRef]
29. Qiang, H.; Cui, Y. Study on comprehensive management and high-quality management and protection of the Yellow River beach area. Nat. Resour. Econ. China 2020, 33, 39–43.
30. Wu, B.; Xia, J.; Fu, X.; Zhang, Y.; Wang, G. Effect of altered flow regime on bank full area of the lower Yellow River, China. Earth Surf. Process. Landsc. 2008, 33, 1585–1601. [CrossRef]
31. Wang, Z.; Liu, B.; Wang, L.; Shao, Q. Measurement and temporal & spatial variation of urban eco-efficiency in the Yellow River basin. Phys. Chem. Earth, Parts A/B/C 2021, 122, 102981.
32. Wohlfart, C.; Kuenzer, C.; Chen, C.; Liu, G. Social–ecological challenges in the Yellow River basin (China): A review. Environ. Earth Sci. 2016, 75, 1066. [CrossRef]
33. Jun, X.; Prasad, T.; James, T.; Murali, G.; Pardhasaradhi, T.; Adam, O.; Russell, C.; Kamini, Y.; Noel, G. Nominal 30-m cropland extent map of continental africa by integrating pixel-based and object-based algorithms using Sentinel-2 and Landsat-8 data on Google Earth Engine. Remote Sens. 2019, 11, 9065. [CrossRef]
34. Joanna, P. Review on multi-temporal classification methods of satellite images for crop and arable land recognition. Agriculture 2021, 11, 999.
35. Gorelick, N.; Hancher, M.; Dixon, M.; Ilyushchenko, S.; Thau, D.; Moore, R. Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sens. 2017, 202, 18–27. [CrossRef]
36. Patel, N.N.; Angiuli, E.; Gamba, P.; Gaughan, A.; Lisini, G.; Stevens, F.R.; Tatem, A.J.; Trianni, G. Geoinformation, multi-temporal settlement and population mapping from Landsat using Google Earth Engine. Int. J. Appl. Earth Obs. Geoinf. 2015, 35, 199–208. [CrossRef]
37. Zurqani, H.A.; Post, C.J.; Mikhailova, E.A.; Schlautman, M.A.; Sharp, J.L. Geospatial analysis of land use change in the Savannah River basin using Google Earth Engine. Int. J. Appl. Earth Obs. Geoinf. 2018, 69, 175–185. [CrossRef]
38. Dwyer, J.L.; Roy, D.P.; Sauer, B.; Jenkinson, C.B.; Lymburner, L. Analysis ready data: Enabling analysis of the Landsat archive. Remote Sens. 2018, 10, 1363–1382.
39. Zhu, Z.; Woodcock, C.E. Automated cloud, cloud shadow, and snow detection in multi-temporal Landsat data: An algorithm designed specifically for monitoring land cover change. Remote Sens. Environ. 2014, 152, 217–234. [CrossRef]
40. Zhou, Y.; Dong, J.; Xiao, X.; Liu, R.; Zou, Z.; Zhao, G.; Ge, Q. Continuous monitoring of lake dynamics on the Mongolian Plateau using all available Landsat imagery and Google Earth Engine. Sci. Total Environ. 2019, 689, 366–380. [CrossRef]
41. Wulder, M.A.; White, J.C.; Loveland, T.R.; Woodcock, C.E.; Belward, A.S.; Cohen, W.B.; Fosnight, E.A.; Shaw, J.; Masek, J.G.; Roy, D.P. The global Landsat archive: Status, consolidation, and direction. Remote Sens. Environ. 2016, 185, 271–283. [CrossRef]
42. Ren, Y.; Lin, Q.; Li, M.; Zhou, Q. Study on water extraction in complex areas based on Sentinel-2 image. Geosp. Inf. 2020, 18, 5–9.
43. Vanhellemont, Q. Adaptation of the dark spectrum fitting atmospheric correction for aquatic applications of the Landsat and Sentinel-2 archives. Remote Sens. Environ. 2019, 225, 175–192. [CrossRef]
44. Zou, Z.; Xiao, X.; Dong, J.; Qin, Y.; Doughty, R.B.; Menarguez, M.A.; Zhang, G.; Wang, J. Divergent trends of open-surface water body area in the contiguous United States from 1984 to 2016. Proc. Natl. Acad. Sci. USA 2018, 115, 3810–3815. [CrossRef][PubMed]
45. Chen, F.; Zhang, M.; Tian, B.; Li, Z. Extraction of Glacial Lake outlines in Tibet Plateau using Landsat 8 imagery and Google Earth Engine. IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. 2017, 10, 4002–4009. [CrossRef]
46. Zou, Z.; Dong, J.; Menarguez, M.A.; Xiao, X.; Qin, Y.; Doughty, R.B.; Hooker, K.V.; Hambright, K.D. Continued decrease of open surface water body area in Oklahoma during 1984–2015. Sci. Total Environ. 2017, 595, 451–460. [CrossRef]
47. Cai, X.; Li, Q.; Luo, Y.; Qi, J. Object-oriented mining area feature extraction combined with deep learning method. Remote Sens. Land Resour. 2021, 33, 63–71.
48. Zhang, B.; Miao, C. Evolution and driving force of land use spatial and temporal pattern in the Yellow River basin. Resour. Sci. 2020, 42, 460–473.
49. Liu, J.; Du, M.; Mao, Z. Scale computation on high spatial resolution remotely sensed imagery multi-scale segmentation. Int. J. Remote Sens. 2017, 38, 5186–5214. [CrossRef]
50. Han, D.; Yang, S.; Zhao, Q.; Han, L.; Yang, Z.; Cui, C. Building information extraction from Object-Oriented high-resolution remote sensing images. J. Atmos. Environ. Opt. 2021, 16, 358–364.
51. Luo, W.; Kuang, R. Information extraction of orchards in Dongjiangyuan area using environmental satellite images. Sci. Surv. Mapp. 2014, 39, 135–139.
52. Mostafa, Y. A review on various shadow detection and compensation techniques in remote sensing images. Can. J. Remote Sens. 2017, 43, 545–562. [CrossRef]
53. Wang, R.; Xia, H.; Qin, Y.; Niu, W.; Pan, L.; Li, R.; Zhao, X.; Bian, X.; Fu, P. Dynamic monitoring of surface water area during 1989-2019 in the Hetao plain using Landsat data in Google Earth Engine. Water 2020, 12, 3010. [CrossRef]
54. Lu, D.; Sun, D. Comprehensive management and sustainable development of the Yellow River basin. Land 2019, 74, 2431–2436.
55. Brenda, B. Resilience in agriculture through crop diversification: Adaptive management for environmental change. Bioscience 2011, 61, 183–193.
56. Zhang, W.; Wang, L.; Xiang, F.; Qin, W.; Jiang, W. Vegetation dynamics and the relations with climate change at multiple time scales in the Yangtze River and Yellow River basin, China. Ecol. Indic. 2020, 110, 105892. [CrossRef]
57. Wohlhart, C.; Mack, B.; Liu, G.; Kuenzer, C. Multi-faceted land cover and land use change analyses in the Yellow River basin based on dense Landsat time series: Exemplary analysis in mining, agriculture, forest, and urban areas. Appl. Geogr. 2017, 85, 73–88. [CrossRef]
58. Yin, D.; Li, X.; Li, G.; Zhang, J.; Yu, H. Spatio-temporal evolution of land use transition and its eco-environmental effects: A case study of the Yellow River basin, China. Appl. Geogr. 2020, 9, 514. [CrossRef]
59. Cui, M.; Liu, S.; Zhang, R.; Zhu, Y. A preliminary study on channel improvement scheme in the lower Yellow River. Yellow River 2018, 1, 36–39.
60. Liang, G.; Ding, S. Impacts of human activity and natural change on the wetland landscape pattern along the Yellow River in Henan Province. J. Geogr. Sci. 2004, 14, 339–348.