Article

Dynamic Evaluation of the Impact of Human Interference during Rapid Urbanisation of Coastal Zones: A Case Study of Shenzhen

Lin Yi [1] , Jing Qian [1,]*, Muhammadjon Kobuliev [2,3], Pengpeng Han [4] and Jun Li [5]

[1] Center for Internet of Things Computing, Shenzhen Institution of Advanced Technology, Chinese Academy of Sciences, Shenzhen 518055, China; lin.yi@siat.ac.cn

[2] Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China; kobuliev@list.ru

[3] Institute of Water Problems, Hydropower and Ecology of the Academy of Sciences of the Republic of Tajikistan, Dushanbe 734042, Tajikistan

[4] Huizhou Traffic Planning and Construction Affairs Center, Huizhou 516000, China; hz_hpp@126.com

[5] Key Laboratory of Metallogenic Prediction of Nonferrous Metals and Geological Environment Monitoring (Ministry of Education), School of Geosciences and Info-Physics, Central South University, Changsha 410083, China; gislijun@csu.edu.cn

[*] Correspondence: jing.qian@siat.ac.cn

check for updates

Abstract: Coastal ecosystems undergoing rapid urbanisation have characteristics of both natural and artificial ecosystems. How we evaluate the dynamic impact of human activities on coastal ecosystems is important for coastal zone management and development. In this study, we first developed a method to extract both the natural and artificial features of coastal land cover, and classified the coastal landscapes impacted by human activities from an ecological service perspective. We then constructed an ecological interference index for classification to evaluate the impact of coastal human interference on both artificial and natural ecosystems during rapid urbanisation. Lastly, we verified our method by applying it to the coastal zone in Shenzhen, China. Our results show that this method can describe the effects of human activities on coastal zones in more detail. The distribution of human activity was mainly associated with the geomorphology of the coastal zone. Changes in human interference were seen strongly in proximity to both the landward and coastal boundaries of the study area, in close correlation with the public's increasing conscience for ecological environment protection.

Keywords: human activities; human interference; anthropogenic activities intensity; rapid urbanisation; coastal area; Shenzhen

1. Introduction

Urbanisation is a trend of progress and development in society which symbolises human civilisation and social progress [1]. Coastal cities often become the centres of human activities and economic development because of their special geographical location and abundant resources [2,3]. However, with the growth of the urban population, the conflict between people and land is prominent [4–6]. The coastal zone plays an important role in alleviating the conflict between people and the land in coastal cities during rapid urbanisation.

Due to the coastal zone's special location where sea and land intersect to form a sensitive and fragile ecosystem [7,8], significant changes to land cover patterns have been made by increasing human activities. A large amount of ecological and agricultural land has been converted to residential and industrial land. These large changes in regional ecological patterns [9–11] may lead to a series of

ecological and environmental problems, such as coastal erosion [12], wetland loss [13], deterioration of offshore water quality [14], etc. How to quantify the anthropogenic interference in coastal zones under the influence of rapid urbanisation is an important question to answer for coastal scientific governance and sustainable development [8,15].

Presently, quantitative evaluation methods of human activities in the coastal zone mainly focus on research using environmental vulnerability indices or ecological risk indices [16–18]. Researchers have also discussed interference caused by individual elements of human activity on the coastal landscape, such as agricultural activities [19] and deforestation [20]. Because the coastal zone is influenced by urbanisation and the coupled ecosystem of land and sea, it shows typical dual characteristics of both an urban zone and the vulnerabilities of a coastal zone. Therefore, it is necessary to quantitatively evaluate the impacts of human activity on coastal zones under the influence of rapid urbanisation from both artificial and natural ecosystem perspectives to reveal the rate and extent of anthropogenic impacts on landscape patterns in the coastal zone [8].

Human interference assessment methods based on the Hemeroby index (HI) are widely used to quantitatively evaluate human interference in different types of ecosystems such as forests, grasslands, wetlands, agricultural areas and cities [21–26]. These methods were built on the basis of anthropogenic interference theory [27] to evaluate the impact of human activities on plants. This theory has been gradually developed into an important indicator to measure human disturbance in the ecosystem [28–30]. The basic theory is based on the regional land cover types and assigns a disturbance index for different types of human activities [31].

In this paper, considering coastal zones undergoing rapid urbanisation are often disturbed by both natural evolutionary processes and human activities such as urban construction and land expansion, human activities here are classified into either positive or negative ecological element types. Remote sensing and Geographic information systems were used to construct the feature extraction method for classifying coastal land cover under rapid urbanisation. To take into account the different ecological effects of natural and artificial ecosystems, the ecological interference index was built to evaluate the impacts of human interference on both natural and artificial ecosystems. Lastly, this paper analysed the characteristic changes in human interference during the urbanisation process (1980–2015) in the Shenzhen coastal zone, revealing the spatial-temporal differences caused by human activities during a period of rapid urbanisation.

2. Study Area

The study area was the coastal zone of Shenzhen city, Guangdong province, China (Figure 1). As a typical coastal city, Shenzhen was the first special economic zone in China since the 'reform and opening up' (an important historical Chinese policy for the open economic development of industrialisation and modernisation), which created the so-called 'Shenzhen speed'. Human activities such as coastal development and reclamation are intense in coastal zones, which is key to support rapid urbanisation.

Because of its quite different geomorphology between east and west coastal zones, this coastal ecosystem shows both typical natural (mainly in the west) and artificial (mainly in the east) characteristics, which makes it an ideal study area to quantitatively research the impact of human interference from an ecological perspective. The west coast rises from Dongbao Estuary in the north to Shenzhen Bay in the south and is mainly mudflats; the east coast dominated by natural coast (rocky coast and sandy beach) includes Daya Bay and Dapeng Bay, whose coastlines are full of twists and turns [32]. These differences in geomorphology mean that spatial distribution in the land cover types shows a typical east-west split, which leads to human activities of different intensities.

The Shenzhen coastal zone covers a 10 km buffer zone on the landward side of the coastline across the boundary with Hong Kong (this is a commonly used spatial range of coastal zone surveys in various countries, extending about 10 km inland [33]). The area of this coastal zone is about 1185.3 km^2 and the coastline is about 457 km long.
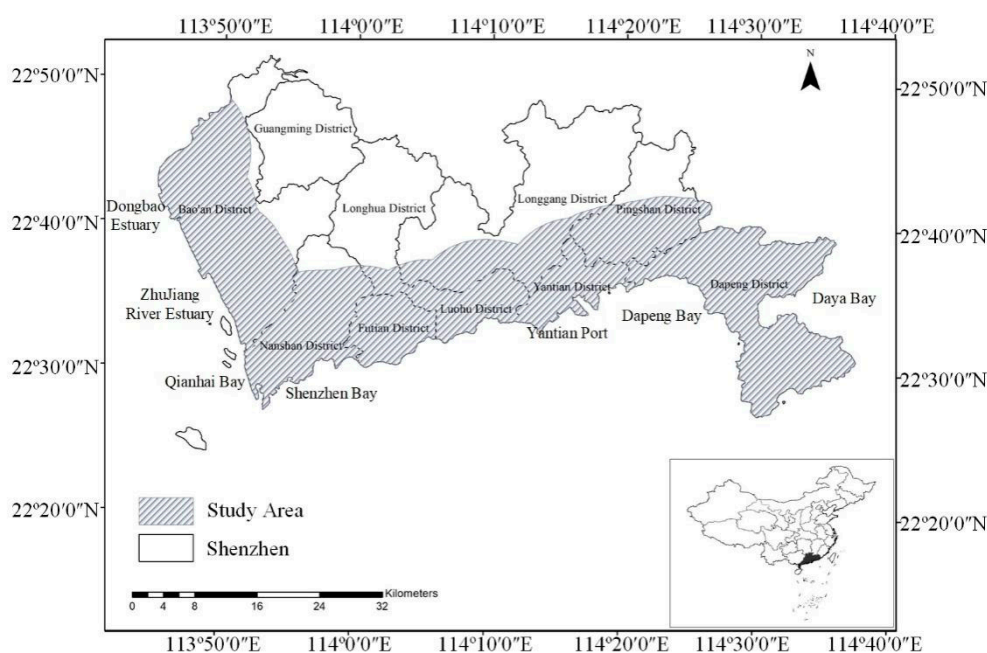
Figure 1. Location of study area.

3. Data and Methods

3.1. Data Collection and Pre-Processing

Reflecting the fact that rapidly urbanised coastal zones are greatly affected by human activities, artificial surfaces rapidly become the main land cover type in these areas. Land cover data from 1980, 1990, 2000, 2010 and 2015 were used as the basis for human interference assessment. Partial time series (1990, 2000 and 2010) came from the 30 m landcover dataset provided by the project 'National Change in Ecological Environment over a Decade (2000–2010) Remote Sensing Survey and Assessment' [34]. In 1990 and 2000, the land type classification accuracy of this data was 85% [35], and the land type classification accuracy of this data at level I in 2010 was 86% [36].

Furthermore, adopting the classification system of the above data, we combined it with multi-source remote sensing images (Table 1, http://glovis.usgs.gov/) and topographic data (a Digital Elevation Model (DEM) and slope), coastline data, GF-1 satellite data and Google map data (1979/12, 2015/12). From these, land cover data from 1980 and 2015 were extracted using eCognition and Arcmap software. The coastline data extracted from the remote sensing images were used in combination with the geomorphological features of the coastal sections in the Shenzhen coastal zone (rocky, muddy and artificial coast).

Table 1. Data sources.

Data Set	Path Number	Row Number	Landsat MSS/OLIdate
1980	130	44	1979-09-30
	131	44	1979-10-19,1975-11-18
2015	121	44	2015-02-13,2015-08-08
	122	44	2015-01-03,2015-10-18

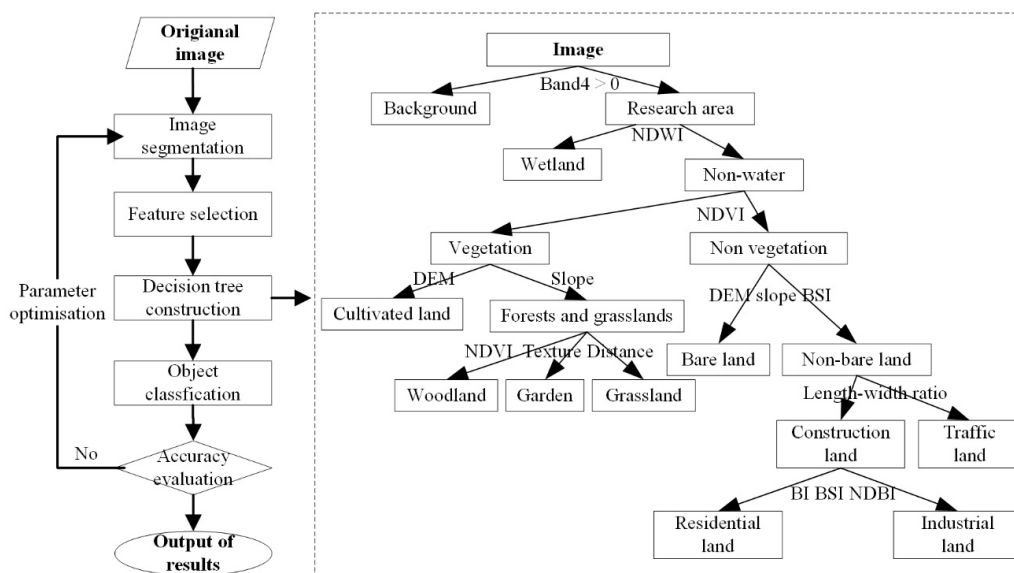### 3.2. Land Cover in Rapidly Urbanised Coastal Zones

The land cover in the Shenzhen coastal zone in 1980 and 2015 was classified by combining spectral reflectance and textural characteristics. The exact classification steps are shown in Figure 2. The land cover classification in coastal zone was built (Table 2). Firstly, the fused image is segmented,

then feature selection is carried out. Finally, a decision tree is built to classify objects and extract land cover types.

Table 2. Coastal land cover classification with rapid urbanisation.

Land Cover Types	Meaning	Land Cover Types	Meaning
Wetland	Forest marshes, shrub marshes, rivers, reservoirs and aquaculture	Bare land	Natural, loose surface
Woodland	Natural forest, plantation, sparse forest	Traffic land	Main highway, general highway, ridge
Garden plot	Arbor garden, shrub garden	Residential land	Residential land
Grassland	Herbaceous green space	Industrial land	Land for mining, oil and gas Exploitation and industrial enterprises
Cultivated land	Paddy field, land for xerophytic crops	-	-

Detailed land cover classification is based on the extraction of a combination of spectral and textural features. NDWI (Normalized Difference Water Index, [37]), which is sensitive to water body information, is used to distinguish 'wetland' versus non-water based landcover types. NDVI (Normalized Difference Vegetation Index, [38]) is sensitive to vegetation information, therefore, a threshold is set to distinguish vegetation from non-vegetation. 'Cultivated land', 'forests' and 'grasslands' can be distinguished based on the DEM and slope. Because the coastal zone is relatively flat, most cultivated land is located there. By combining texture and distance, 'woodland' and 'grassland' types can be distinguished. The non-vegetation areas are divided into bare land and non-bare land by the DEM and the Bare Soil Index (BSI). For non-bare land, 'construction land' and 'roadways' are distinguished by calculating the length-width ratio, while 'residential land' and 'industrial land' are identified by using BI (the brightness index), BSI and NDBI (Normalized Difference built-up Index, [39]), and classified according to the difference in their reflectivity.

Figure 2. Land cover classification in rapid urbanised coastal zones.

In order to evaluate the accuracy of the classification results, for 1980, 285 verification points on Google Earth (historical images) were chosen for calculating a confusion matrix and Kappa coefficient based on visual interpretation (Table 3). For the classification in 2015, 285 ground sampling points were used to calculate a confusion matrix and Kappa coefficient (Table 4). The overall score was more than 85%, which satisfies the accuracy requirements.

Table 3. Accuracy evaluations of land cover in 1980.

	Type	Woodland	Grassland	Wetland	Cultivated Land	Garden Plot	Industrial Land	Roadways	Residential Land	Bare Land	Total	Accuracy
	Woodland	164			1	2					167	98.20
	Grassland	2	7	2	1						12	58.33
	Wetland	3	2	18		2					25	72.00
Reference images	Cultivated land		1		6						7	85.71
	Garden plot	5			2	23					30	76.67
	Industrial land						4		1		5	80.00
	Traffic land						1	9	2	1	13	69.23
	Residential land							1	18		19	94.74
	Bare land								2	5	7	71.43
	Total	174	10	20	10	27	5	12	21	6	285	
	User's accuracy	94.25	70.00	90.00	60.00	85.19	80.00	75.00	85.71	83.33		

Overall accuracy = 89.12%; Kappa coefficient = 82.35%.

Table 4. Accuracy evaluations of land cover in 2015.

	Type	Woodland	Grassland	Wetland	Cultivated Land	Garden Plot	Industrial Land	Roadways	Residential Land	Bare Land	Total	Accuracy
	Woodland	148	1	1	1	2					153	96.73
	Grassland	1	8		2						11	72.73
	Wetland	1		7		1					9	77.78
Reference images	Cultivated land		1		8	1					10	80.00
	Garden plot	2				35					37	94.59
	Industrial land						5	1	4	2	12	41.67
	Traffic land							10		1	11	90.91
	Residential land						1	3	26		30	86.67
	Bare land						1	1		10	12	83.33
	Total	174	152	10	8	11	39	7	15	30	13	285
	User's accuracy	94.25	97.37	80.00	87.50	72.73	89.74	71.43	66.67	86.67	76.92	

Overall accuracy = 90.18%; Kappa coefficient = 85.47%.

3.3. Method for Assessing the Impact of Human Interference in Coastal Zones Undergoing Rapid Urbanisation

Different patterns in regional landscapes are a reflection of the different effects of human activities. To express human activities in more detail, the landscape types were classified into positive and negative ecological elements [40], representing positive and negative ecological effects (Table 5). To accomplish this, an ecological interference index was built based on the Hemeroby index [41] to assess the impacts that different aspects of human activity have on coastal zones undergoing rapid urbanisation.

This system was based on a land cover classification system for urban ecosystems. The grade of land use from an ecological perspective was also considered [42] along with the contribution rate of ecosystem services across different land cover types [43]. The degree of human interference in a landscape can be divided into 'no interference', 'half interference' and 'total interference'. Among them, positive ecological factors correspond to 'no interference' and 'half interference', as these provide certain ecological services. Negative ecological factors correspond to 'total interference', that is, man-made surfaces and bare land (mainly unused land for reclamation), which is the main type of landscape associated with human activity in the coastal zone. With the above classification and previous research results [29,43], the ecological interference index for the main landscape types (Table 5) was determined to measure the ecological interference of human activities in a coastal zone undergoing rapid urbanisation.

Table 5. Ecological interference index classification of landscape types in a coastal zone undergoing rapid urbanisation.

Ecological Types	Primary Type	Secondary Type	Ecological Interference Index
Positive ecological elements	No interference	Wetland	0.25
	Half interference	Woodland	0.55
		Garden Plot	0.55
		Grassland	0.55
		Cultivated land	0.70
Negative ecological elements	Total interference	Bare land	0.80
		Traffic land	0.95
		Residential land	0.95
		Industry land	0.98

4. Results and Analysis

4.1. Dynamic Analysis of the Spatial Distribution of Human Activities in a Coastal Zone

Land cover data from 1980 to 2015 are shown in Figure 3. As can be seen, changes in land cover were mainly concentrated in the western coastal zone due to the differences in geological structure between the eastern and western zones [44]. In 1980, woodland, garden plot and cultivated land types were widely distributed, however residential land and industrial land were scattered in the background of these otherwise positive ecological elements. After a decade of rapid development in the 'reform and opening up', great changes had taken place in the western part of Shenzhen by 1990. There was almost 450.86 hm^2 of land reclaimed per year from 1978 to 1994, which was an amazingly rapid acceleration in reclamation [42]. During this period, cultivated land almost disappeared and only a small area remained, embedded in the background of residential land areas. Many different types of land transferred into residential land in this period. After 2000, with the progression of further urbanisation, the speed of reclamation accelerated. Urbanisation of the land extended to the sea; residential and industrial land continued to increase and further adjustments between different land cover types resulted in higher spatial connectivity and greater regularity in the shape of the land cover areas. In detail, the distribution of the residential areas gradually began to extend inland and the scale of industrial land near the coastline gradually expanded. The rapid urbanisation of the coastal zone was at a cost, with the reduction and removal of positive ecological elements such as woodland, grassland, garden plot and cultivated land types. Cultivated land was the first to go, followed by

grassland, garden plots and then finally woodlands, which reflects the gradual urban enhancement made by urban planners, countered by managers' awareness of the need to protect the ecological environment. For instance, from 2010 to 2015, the positive ecological elements in the western coastal areas increased.
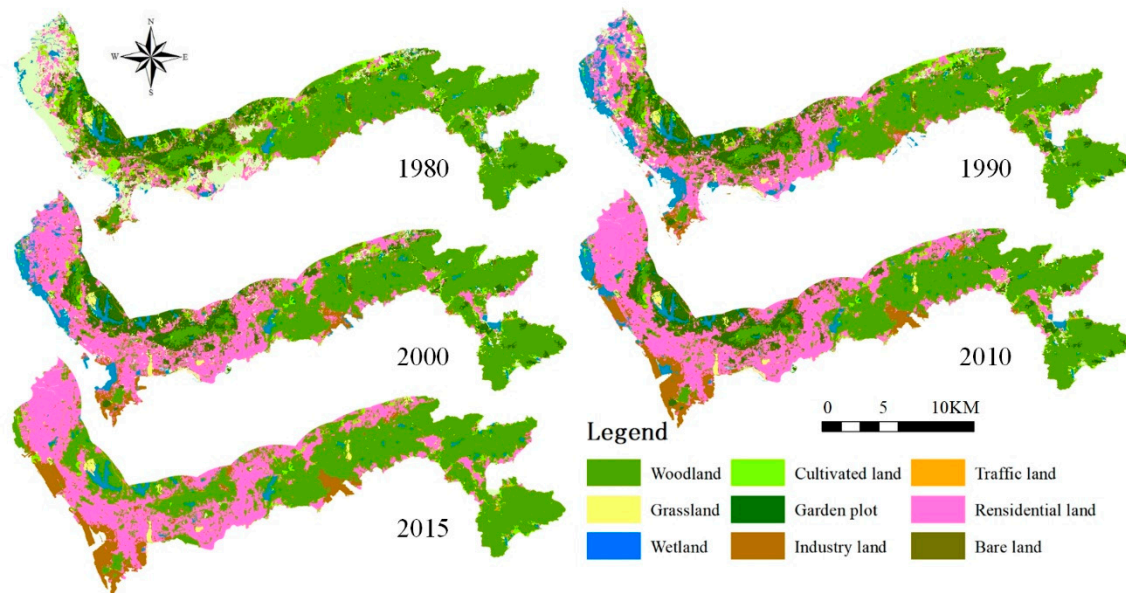

Figure 3. Dynamic detection of coastal land cover from 1980 to 2015.

*4.2. Evaluation of the Impact of Human Interference*

Here we take 2015 as an example to explain the evaluation of human interference using our method.

4.2.1. Spatial and Temporal Changes in Ecological Elements

In order to analyse the changing characteristics in the utilisation of different land cover types during urbanisation, area ratio (the ratio of the total area of each land type to the total area of the research area) was calculated for each time point (Figure 4).

Among the positive ecological elements (Figure 4a), the proportional area of wetlands and grasslands changed little, and this area was small. Wetlands decreased from 0.04 (1980) to 0.02 (2015), and the grassland increased from 0.004 to 0.008. The proportional area of cultivated land declined continuously from 1980 to 2015 (0.23 to 0.02). The proportional area of woodlands decreased slowly and continuously from 1980 to 2010 (0.48 to 0.39) but increased to 0.52 from 2015. The increased woodland area was mainly located in coastal areas (mostly mangroves). The area ratio of the garden plots decreased slowly from 1980 to 2015 (0.13 to 0).

Based on the analysis of the negative ecological elements (Figure 4b), the proportional area of bare land and roadways was small and showed little change, with a decrease by 0.001 and increase by 0.003 respectively across 35 years. The proportional area of residential land increased the most, from 0.086 in 1980 to 0.334 in 2015, and it was the largest growing land cover type in the process of coastal urbanisation. In detail, there were three stages: a rapid growth period (growth 0.129) in 1980–1990, a sustained growth period (growth 0.113) in 1990-2010 and a stable period (growth 0.005) in 2010-2015. The growth of the industrial land could also be divided into three periods: a rapid sustained growth period in 1980-2000 (0.008 to 0.042), an accelerated growth stage from 2000 to 2010 (increased 0.031) and a stable period in 2010-2015 (0.073 to 0.077), which reflects the transformation of the city from an era of industrialisation to science and technology.
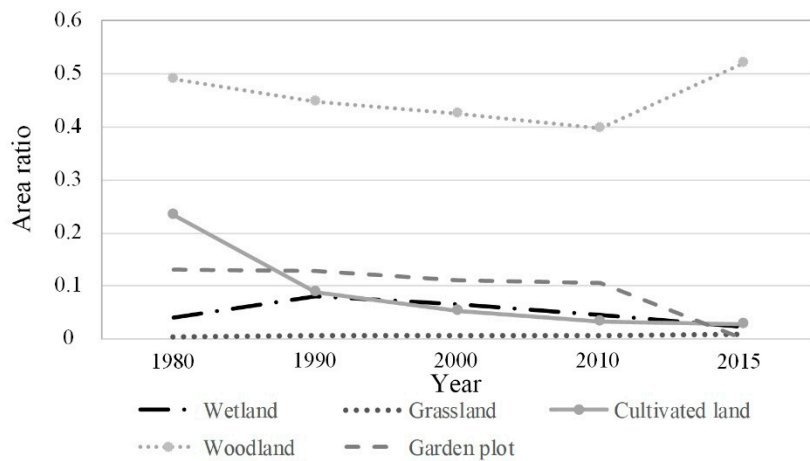
**a.** Changes in area ratio of positive ecological elements from 1980 to 2015.
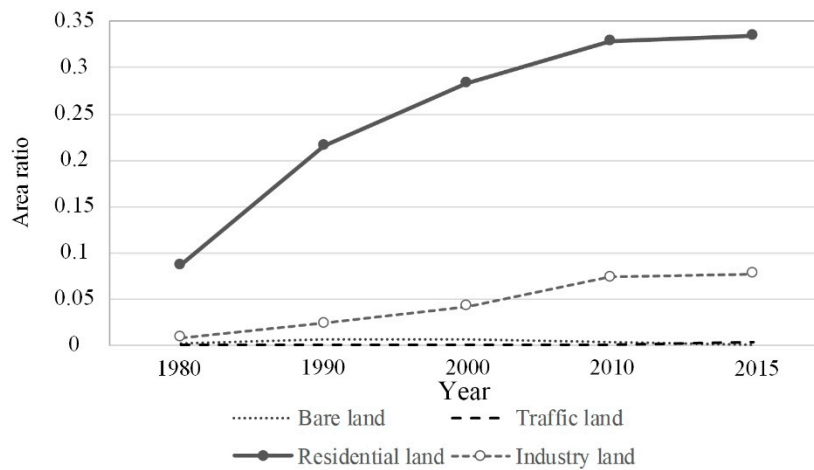
b. Changes in area ratio of negative ecological elements from 1980 to 2015.

**Figure 4.** Changes in area ratio of ecological elements from 1980 to 2015.

4.2.2. Evaluation of Positive and Negative Ecological Elements

Different types of human activities with different ecological values show different spatial distribution patterns (Figure 5a,b). After comparing and analysing the spatial distribution of human interference for both negative and positive ecological elements in the study area in 2015, we found that negative ecological factors were relatively concentrated in the western part of the coastal zone, showing a strong spatial aggregation effect. The interference indices for the residential, industrial and roadway areas were high, at 0.95, 0.98 and 0.95, respectively. Most of these land cover types have continuous distributions and therefore cause wide range destruction. Positive ecological elements were relatively concentrated in the east and inland areas of the west. The interference index of cultivated land was calculated at 0.70, but the distribution was sporadic and discontinuous. The development of the city on the eastern coast is influenced by geomorphology and other factors, so the positive ecological elements in this area were relatively concentrated and mainly woodland (interference index: 0.55). As a result, the interference index is small and the ability to withstand the impact of human activities is strong. However, the positive ecological elements on the west coast were scattered, of which the main types were wetland and grassland, with interference indices of 0.25 and 0.55, respectively. The intensity of interference in the west is stronger than that in the east, and interferences from human activities are greater.
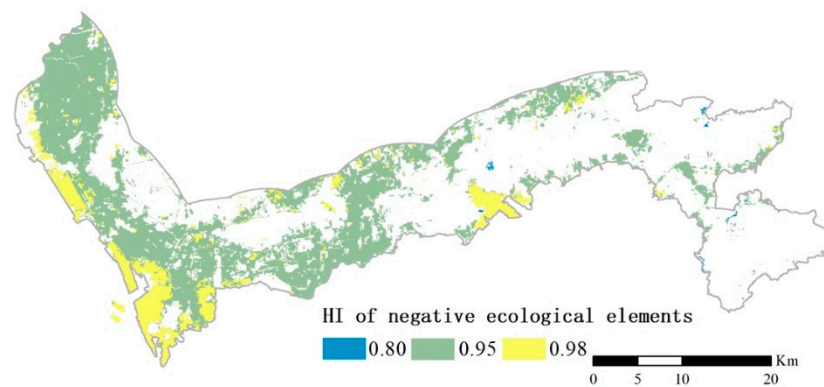
a. Human interference of negative ecological elements in 2015.
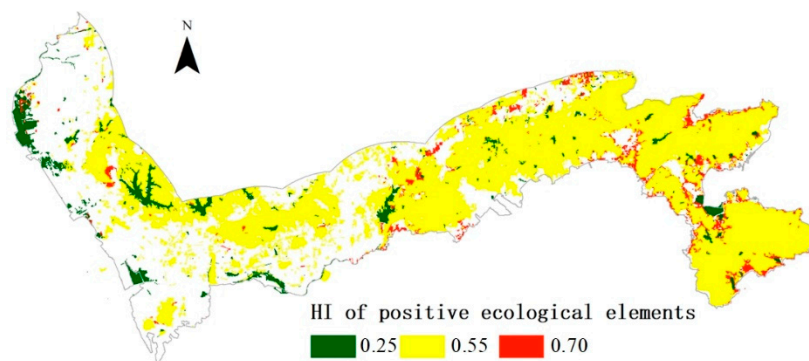
b. Human interference of positive ecological elements in 2015.

Figure 5. Human interference of ecological elements in 2015.

Overall, the spatial distribution of human interference shows significant east-west differences. The intensity of human interference in the western region decreases gradually on an axis orthogonal to the coastline from the coastline inland, indicating a trend in increasing intensity of human activities extending to the sea. While the high intensity of human activities in the eastern region (greater than 0.95) was mainly distributed along the coastline and in inland zone areas far from the coastline. The highest interference values in the study area were mainly distributed in the area near Qianhai Bay and Yantian Port. The intensity of human interference in the Shenzhen Bay Mangrove Nature Reserve was low. The interference value in the wetland area was predominantly zero, though this was fragmented, and the Patch Density (PD) changed from 0.002 to 0.068, calculated by the software ArcMap. The distribution of human interference is closely related to the distribution of different types of human activities, limited by coastal landscape patterns.

4.3. Dynamic Change in Human Interference (1980 to 2015)

4.3.1. Transfer between Positive and Negative Ecological Elements

Table 6 shows the area transferred between positive and negative ecological elements. The transfer area from positive ecological elements to negative ecological elements initially reduced from 158.77 km^2 (1980–1990) to 88.15 km^2 (1990–2000), but then rapidly increased to 120.27 km^2 during the period of 2000 to 2010, with a final fast decrease down to 6.66 km^2 (2010–2015). At the same time, the area of transfer from negative ecological elements to positive ecological elements continuously increased. The transfer area from 1980 to 1990 was 0.14 km^2, the period from 2000 to 2010 was 6.69 km^2, and this increased to 51.87 km^2 from 2010 to 2015. When coastal urbanisation causes ecological damage, people begin to rebuild positive ecological elements, so the transfer area from negative ecological elements to

positive ecological elements grew bigger. This revealed that the coastal urbanisation came at a cost for the environment. The speed and degree of the sacrifice to the environment depended on the increasing consciousness of human beings towards protecting the ecological environment when developing land in the coastal zone.

Table 6. Transfer between positive and negative ecological elements.

Year	Transfer Types	Transfer Area (km^2)
1980 to 1990	Positive to Negative ecological elements	158.77
	Negative to Positive ecological elements	0.14
1990 to 2000	Positive to Negative ecological elements	88.15
2000 to 2010	Positive to Negative ecological elements	120.27
	Negative to Positive ecological elements	6.69
2010 to 2015	Positive to Negative ecological elements	6.66
	Negative to Positive ecological elements	51.87

4.3.2. Dynamic Change in Human Interference from 1980 to 2015

Dynamic changes in the scale of human interference in the Shenzhen coastal zone from 1980 to 2015 are shown in Figure 6. The intensity of human interference in the Shenzhen coastal zone rapidly increased from 1980 to 2000 but slowed down from 2000 to 2015. Overall, in the past 35 years the total area affected by human interference rapidly increased and was mainly concentrated in the western coastal zone. Human activities mainly changed from 'non-interference' types to 'total interference' types. This was because the land reclamation and development/management were mainly concentrated on the west coast [45]. Spatially, the areas with greater interference and more drastic changes were mainly concentrated in the western coastal zone and in the eastern towns, coastal beaches, and ports where human activities are frequent. This is consistent with the conclusion by Yi et al. [46] that the western coast is a muddy coast with comprehensive development, and where reclamation is the main human activity; while in the east, the rocky coastal area is only partially reclaimed, while the sandy coastal area is fully developed for tourism but the development intensity is weak. From 1980 to 2010, the fragmentation of the highest human interference gradually collated (the PD changed from 0.007 to 0.0005), especially in the western region. From 2010 to 2015, the impact of human interference changed little and the average value was higher in the western region. So, it can be seen that the change in intensity of human interference does not show a gradual trend of decreasing from the coastline inland, but rather extends for a certain distance along both the coastline and inland region. The growth rate towards the coastline is higher than that towards the inland boundary, moreover, the degree of spatial aggregation of the interference factors is higher on the seaside than on the land side. Pan [47] also found that the distance from the coastline is one of the key factors affecting the spatial distribution of land use in the eastern and western coastal zones while simulating the land-use change in the Shenzhen coastal zone based on a CLUE-S model.
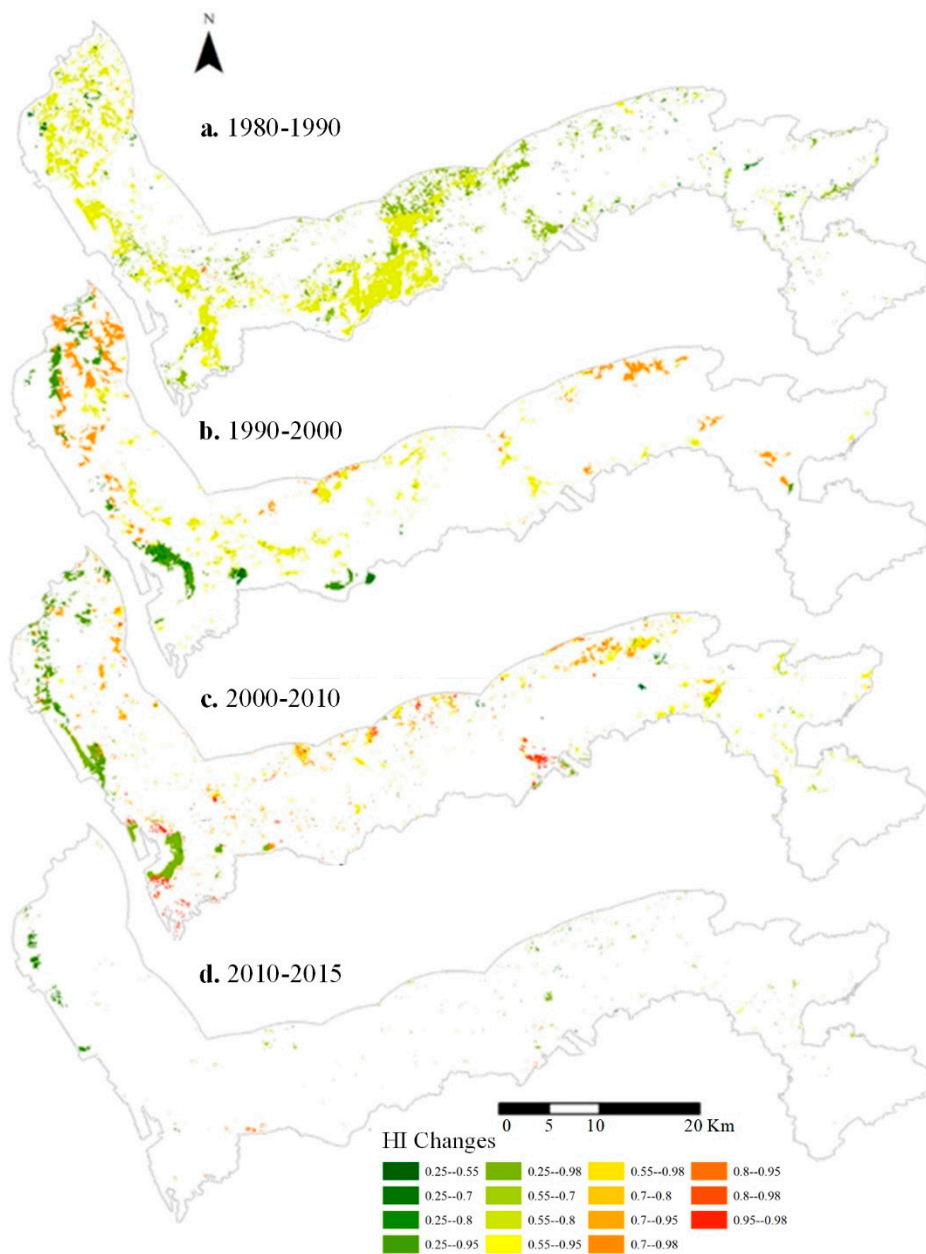
Figure 6. Dynamic change in human interference in Shenzhen's coastal zone from 1980 to 2015.

5. Discussion and Conclusions

Considering that coastal zones undergoing rapid urbanisation are characterised by both natural and artificial ecosystems, we built a classification index with positive and negative ecological elements to define human activities with different effects. This paper then proposed an ecological interference index to uniformly evaluate the impact of coastal human activities on natural and artificial ecosystems. Finally, we characterised human interference since the 'reform and opening up' (1980–2015) of Shenzhen to verify this method.

High-precision extraction of land cover features is key for guaranteeing accurate evaluation of human interference. The method of land cover feature extraction we proposed used object-oriented classification, combining spectral reflectance and textural features to construct decision trees, giving an accuracy of more than 85% which meets the requirements of previous research. Evaluation of the results obtained by this method showed that it can reveal different spatial distribution patterns of interference from different types of human activities with different ecological values. Negative

ecological factors had a strong spatial aggregation effect on the west coastal zone while the positive ecological factors were mainly distributed in the east. The impacts of human activities were limited in the east due to the greater challenges for development in this coastal zone. Coastal geomorphology in the east of Shenzhen is more complicated than in the west, so urbanisation in the west is easier than in the east. This led to significant east-west differences in human interference, with the west bearing greater interference than in the east.

Many factors drive coastal development including national policy, Gross National Product (GDP), permanent population size, etc., which all determine how the intensity of human interferenceinterference is distributed. Under the guidance of the national policy 'reform and opening up', GDP and the permanent population of Shenzhen increased sharply, which led to land shortages and faster urbanisation in this city than other coastal cities, even faster than that of Shanghai, which is one of the most rapidly developing economies in the world [48]. Shanghai was still a stage of rapidly urbanisation in 2005 when the urbanisation rate in Shenzhen had already reached 100% [49]. We can see features of this urbanisation process from dynamic analysis of human interference in Shenzhen's coastal zone. Across the period from 1980 to 2015, the intensity of human interferenceinterference gradually plateaued. During the first decade of this period, most of the ecological elements went from experiencing low-intensity interference to high-intensity interference (0.25 to 0.98, 0.55 to 0.95), while maintaining continuous spatial distributions. Over time, this process began to change and more ecological elements were transferred into the highest-intensity or lowest-intensity brackets; elements subject to lower-intensity interference moved to the lowest-intensity bracket, while elements subject to higher-intensity interference shifted to the highest-intensity bracket (0.7 to 0.98, 0.8 to 0.95). This transferral process to the extremes of low and high intensity gradually decreased toward 2015. Overall the intensity of human interferenceinterference in this period first increased sharply, before gradually stablilising. This is consistent with the trends in GDP and permanent population size [40]. These findings reflect the variable features that drive the intensity of human interference during the transformation from industrial-based urbanisation to a science and technology focus.

Land cover also reveals spatial-temporal distribution features of human activity [50]. The changes in land cover from 1980 to 2015 showed that coastal urbanisation in Shenzhen occurred mainly to resolve the shortage of residential and industrial land. These changes converged towards the coastline and were at the cost of a reduction in woodland, grassland, garden plots, and cultivated land. This is consistent with the known characteristics of the social and economic development of Shenzhen [46]. Consideration of the changes in the spatial distribution of land cover types, shifts in the proportional area of positive versus negative ecological elements and the transfer between these areas revealed that the coastal urbanisation process initially began in a stage of industrialisation, which then developed to a focus on science and technology after 2010. During this process, people's awareness of the need to protect the ecological environment gradually became stronger. There was also a trend of increasing human interference at a certain distance along both the coastline and the inland boundary of the study area.

Due to the different types of human activities distributed in the west than the east and the corresponding differences in landscape types, the same level of human interference on these different landscapes should have different effects. In the future, evaluations of human interference also need to consider the heterogeneous effects of human activities.

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

References

1. Listengurt, F.M.; Pokshishevskiy, V.V. Social development, urbanization and the environment. *Geojournal* **1980**, *4*, 59–61. [CrossRef]
2. Liu, J.L.; Wen, J.H.; Huang, Y.Q. Human settlement and regional development in the context of climate change: a spatial analysis of low elevation coastal zones in China. *Mitig. Adapt. Strateg. Glob. Chang.* **2015**, *20*, 527–546. [CrossRef]
3. Baser, V.; Biyik, C. The problems and resolution approaches to land management in the coastal and maritime zones of Turkey Ocean. *Coast. Manage.* **2016**, *119*, 30–37.
4. Anindita, D.; Dubravko, J.; Erick, S. Coastal land loss and hypoxia: The 'outwelling' hypothesis revisited. *Environ. Res. Lett.* **2011**, *6*, 2.
5. Lin, S.F.; Sun, J.; Marinova, D. Effects of Population and Land Urbanization on China's Environmental Impact: Empirical Analysis Based on the Extended STIRPAT Model. *Sustainability* **2017**, *9*, 825. [CrossRef]
6. Liu, X.; Cao, G.Z.; Liu, T. Semi-urbanization and evolving patterns of urbanization in China: Insights from the 2000 to 2010 national censuses. *J. Geogr. Sci.* **2016**, *26*, 1626–1642. [CrossRef]
7. Yao, H. Characterizing landuse changes in 1990–2010 in the coastal zone of Nantong, Jiangsu province, China Ocean. *Coast. Manage.* **2013**, *71*, 108–115.
8. Zhou, Y.K.; Ning, L.X.; Bai, X.L. Spatial and temporal changes of human disturbances and their effects on landscape patterns in the Jiangsu coastal zone, China. *Ecol. Indic.* **2018**, *93*, 111–122. [CrossRef]
9. Brommer, M.B.; Bochev, L.M.; Burgh, V.D. Sustainable Coastal Zone Management: A Concept for Forecasting Long-Term and Large-Scale Coastal Evolution. *J. Coast. Res.* **2009**, *25*, 181–188. [CrossRef]
10. Bulleri, F.; Chapman, M.G. The introduction of coastal infrastructure as a driver of change in marine environments. *J. Appl. Ecol.* **2010**, *47*, 26–35. [CrossRef]
11. de Andres, M.; Barragan, J.M.; Sanabria, J.G. Relationships between coastal urbanization and ecosystems in Spain. *Cities* **2017**, *68*, 8–17. [CrossRef]
12. Mars, J.C.; Houseknecht, D.W. Quantitative remote sensing study indicates doubling of coastal erosion rate in past 50 yr along a segment of the Arctic coast of Alaska. *Geology* **2007**, *35*, 583–586. [CrossRef]
13. Lee, S.Y.; Dunn, R.J.K.; Connolly, R.M.; Dale, P.E.R.; Dehayr, R.; Lemckert, C.J.; Mckinnon, S.; Powell, B.; Teasdale, P.R.; Welsh, D.T. Impact of urbanization on coastal wetland structure and function. *Austral Ecol.* **2006**, *31*, 149–164. [CrossRef]
14. Brando, V.E.; Dekker, A.G. Satellite hyperspectral remote sensing for estimating estuarine and coastal water quality. *Ieee Trans. Geosci. Remote Sens.* **2003**, *41*, 1378–1387. [CrossRef]
15. Sun, Y.G.; Zhao, D.Z.; Wu, T.; Wei, B.Q.; Gao, S.G.; Li, Y.; Cao, F.F. Temporal and spatial dynamic changes and landscape pattern response of Hemeroby in Dayang estuary of Liaoning Province, China. *Acta Ecol. Sin.* **2012**, *32*, 3645–3655.
16. Kumar Srinivasa, T.; Mahendra, R.S.; Nayak, S. Coastal Vulnerability Assessment for Orissa State, East Coast of India. *J. Coast. Res.* **2010**, *26*, 523–534. [CrossRef]
17. Newton, A.; Weichselgartner, J. Hotspots of coastal vulnerability: A DPSIR analysis to find societal pathways and responses. *Estuar. Coast. Shelf Sci.* **2014**, *140*, 123–133. [CrossRef]
18. Zheng, Y.; Yu, G.; Zhong, P.L.; Wang, Y.X. Integrated assessment of coastal ecological security based on land use change and ecosystem services in the Jiaozhou Bay, Shandong Peninsula, China. *Chin. J. Appl. Ecol.* **2018**, *29*, 4097–4105.
19. Caplat, P.; Lepart, J.; Marty, P. Landscape patterns and agriculture: modeling the long–term effects of human practices on Pinus sylvestris spatial dynamics (CausseMejean, France). *Landsc. Ecol.* **2006**, *21*, 657–670. [CrossRef]
20. Günlü, A.; Kadıoğulları, A.I.; Keles, S.; Baskent, E.Z. Spatio-temporal changes of landscape pattern in response to deforestation in Northeastern Turkey: a case study in Rize. *Environ. Monit. Assess.* **2009**, *148*, 127–137. [CrossRef]
21. Peterseil, J.; Wrbka, T.; Plutzar, C. Evaluating the ecological sustainability of Austrian agricultural landscapes-the SINUS approach. *Land Use Policy* **2004**, *21*, 307–320. [CrossRef]
22. Fanelli, G.; Tescarollo, P.; Testi, A. Ecological indicators applied to urban and suburban floras. *Ecol. Indic.* **2006**, *6*, 444–457. [CrossRef]

23. Battisti, C.; Fanelli, G. Applying indicators of disturbance from plant ecology to vertebrates: The hemeroby of bird species. *Ecol. Indic.* **2016**, *61*, 799–805. [CrossRef]

24. Szilassi, P.; Bata, T.; SzabóbB, S.; Czúczc, B.; Molnárc, Z.; Mezősia, G. The link between landscape pattern and vegetation naturalness on a regional scale. *Ecol. Indic.* **2017**, *81*, 252–259. [CrossRef]

25. Inkoom, J.N.; Susanne, F.; Klaus, G. A framework to assess landscape structural capacity to provide regulating ecosystem services in West Africa. *J. Environ. Manag.* **2018**, *209*, 393–408. [CrossRef] [PubMed]

26. Hou, W.; Zhai, L.; Qiao, Q.H. Monitoring the intensity of human impacts on anthropogenic landscape: A mapping case study in Beijing, China. *Ecol. Indic.* **2019**, *102*, 382–393. [CrossRef]

27. Jalas, J. Hemeroby and hemerochore of plant species. *A terminological reform effort Actasoc.Faunaflora Fenn* **1995**, *72*, 1–15.

28. Steinhardt, U.; Herzog, F.; Lausch, A. Hemeroby index for landscape monitoring and evaluation. In *Environmental Indices: Systems Analysis Approach (Proceedings of the First International Conference on Environmental Indices Systems Analysis Approach, St. Petersburg, Russia, July 7–11, 1997)*; Pykh, Y.A., Hyatt, E.D., Lenz, R.J., Eds.; EOLSS: Oxford, UK, 1999 7 July; pp. 237–254.

29. Hill, M.O.; Roy, D.B.; Thompson, K. Hemeroby, urbanity and ruderality: bioindicators of disturbance and human impact. *J. Appl. Ecol.* **2010**, *39*, 708–720. [CrossRef]

30. Rüdisser, J.; Tasser, E.; Tappeiner, U. Distance to nature—A new biodiversity relevant environmental indicator set at the landscape level. *Ecol. Indic.* **2012**, *15*, 208–216. [CrossRef]

31. Walz, U.; Stein, C. Indicators of hemeroby for the monitoring of landscapes in Germany. *J. Nat. Conserv.* **2014**, *22*, 279–289. [CrossRef]

32. Wu, J.D.; Li, N.; Li, C.H. Change and threats of coastal wetlands in Shenzhen. *Mar. Environ. Sci.* **2008**, *27*, 278–282.

33. Hou, X.Y.; How, W.; Wu, T. Shape changes of major gulfs along the mainland of China since the early 1940s. *Acta Geogr. Sin.* **2016**, *71*, 118–129.

34. Zheng, Z.J.; Zeng, Y.; Zhao, Y.J.; Gao, W.W.; Zhao, D.; Wu, B.F. Analysis of land cover changes in southwestern China since the 1990s. *Acta Ecol. Sin.* **2016**, *36*, 7858–7869.

35. Lü, Y.H.; Fu, B.J.; Feng, X.M. A Policy-Driven Large Scale Ecological Restoration: Quantifying Ecosystem Services Changes in the Loess Plateau of China. *Plos One* **2012**, *7*, e31782. [CrossRef] [PubMed]

36. Zhang, L.; Li, X.S.; Yuan, Q.Z. An object-based approach to national land cover mapping using HJ satellite imagery. *J. Appl. Remote Sens.* **2014**, *8*, 1–19. [CrossRef]

37. Mcfeeters, S.K. The use of normalized difference water index (NDWI) in the delineation of open water features. *Int. J. Remote Sens.* **1996**, *17*, 1425–1432. [CrossRef]

38. Maselli., F.; Romanelli, S.; Bottai, L. Use of NOAA-AVHRR NDVI images for the estimation of dynamic fire risk in Mediterranean areas. *Remote Sens. Environ.* **2003**, *86*, 187–197. [CrossRef]

39. Zha, Y.; Ni, S.X.; Yang, S. An effective approach to automatically extract urban land-use from TM imagery. *J. Remote Sens.* **2003**, *7*, 37–40.

40. Yi, L.; Chen, J.S.; Jin, Z.F.; Quan, Y.M.; Han, P.P.; Guan, S.J.; Jiang, X.L. Impacts of human activities on coastal ecological environment during the rapid urbanization process in Shenzhen, China. *Ocean Coast. Manag.* **2018**, *154*, 121–132. [CrossRef]

41. Chen, A.L.; Zhu, B.Q.; Chen, L.D. Dynamic changes of landscape pattern and eco-disturbance degree in Shuangtai estuary wet-land of Liaoning Province, China. *Chin. J. Appl. Ecol.* **2010**, *21*, 1120–1128.

42. Zhuang, D.F.; Liu, J.Y. Study on the model of regional differentiation of land use degree in China. *J. Nat. Resour.* **1997**, *12*, 10–14.

43. Yu, H.B.; Mo, D.W.; Wu, J.S. Study on the dynamic changes and driving forces based on remote sensing images of land reclamation in Shenzhen. *Prog. Geogr.* **2009**, *28*, 584–590.

44. Tian, C.; Li, S.P. Impacts of land use changes on ecosystem service value in western China-with the case of Baoji city. *Wuhan Univ. Technol. (Soc. Sci. Ed.)* **2010**, *23*, 340–344.

45. Li, Y.; Wang, Y.L.; Peng, J.; Wu, J.S.; Lv, X.F. Research on dynamic changes of coastline in Shenzhen city based on Landsat image. *Resour. Sci.* **2009**, *31*, 875–883.

46. Yi, L.; Chen, J.S.; Zhu, F.; Wang, Y.R.; Zhang, Y.N. Spatial-temporal evolution characteristics of ecological environment in seashore city's coastal zone - A case in Shenzhen. *Mar. Environ. Sci.* **2017**, *36*, 229–236.

47. Pan, R.Q.; Luo, Q.Y.; Xiao, D. Stimulation on land use change of Shenzhen coastal zone based on CLUE-S model. *Geomat. Spat. Inf. Technol.* **2016**, *39*, 32–40.

48. Chen, Z.L.; Liu, P.F.; Xu, S.Y.; Liu, L.; Yu, J.; Yu, L.Z. Spatial distribution and accumulation of heavy metals in tidal flat sediments of Shanghai coastal zone. *Sci. China E* **2001**, *44*, 197–208. [CrossRef]

49. Zhang, E.J.; Zhang, J.J.; Zhao, X.Y.; Zhang, X.L. Study on urban heat island effect in Shenzhen. *J. Nat. Disasters* **2008**, *17*, 19–24.

50. Piana, P.; Faccini, F.; Luino, F.; Paliaga, G.; Sacchini, A.; Watkins, C. Geomorphological Landscape Research and Flood Management in a Heavily Modified Tyrrhenian Catchment. *Sustainability* **2019**, *11*, 4594. [CrossRef]