J. Geogr. Sci. 2018, 28(3): 291-305
DOI: https://doi.org/10.1007/s11442-018-1473-1

An index-based spatial evaluation model of exploitative intensity:

A case study of coastal zone in Vietnam

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Abstract: Coastal zones play a major role in the conservation of marine ecosystems and the sustainable use of resources not only because of their special geographical environment but also because of their high temporal and spatial variability. With the development of urbanization, the exploitation and utilization of coasts have become important issues in the debate. To evaluate variations in the intensity of the land resource exploitation of coastal zones, an index-based model has been proposed in this paper, and coastal Vietnam has been established as the study area. The model is based on four normalized indexes to realize rapid evaluation of the spatial distribution of the exploitative intensity after zoning. The model was established to characterize the different exploitative intensities in different segments of the coast and to graphically present a sequence of decision choices for decision-makers. The results are as follows. (1) The simplicity and rapidity of the index operations can address the fast-changing characteristics of coastal exploitation and meet the desired precision. (2) The choices of the landward buffers fit well with the banded characteristics of the coastal zone. The buffers are horizontally divided into equidistant subregions, which can quantify the spatial differentiation of the exploitative intensity along the coast and perpendicular to the coast. (3) The average exploitative intensity is low, and the proportion of area that is to be exploited accounts for approximately 50%.Considering its spatial variation from north to south, the land exploitative intensity in the north is higher than that in the south. Compared to the intensity of land resource exploitation in the 20 km and 10 km buffers, the land exploitative intensity in the 5 km buffer is higher. The state of the intensity of land resource exploitation and how it can be used by stakeholders to manage coastal resources are then discussed.

Keywords: coastal zone; intensity of land exploitation; built-up; Vietnam

Received: 2017-01-09 **Accepted:** 2017-06-26
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1 Introduction

Being the interface between continental landmasses and the ocean, coastal areas are affected by the highly dynamic processes of nature and human activity (Privmavera, 2006; Pak and Majd, 2011). As humans have always had a close relationship with the coasts (Goudarzi, 2006; Jacobson *et al*., 2014), studies on coastal exploitation have become the most general and effective approach to characterize coastal management (Wu *et al*., 2014). Therefore, there is an ongoing need to evaluate the status of the intensity of land resource exploitation in coastal zones.

Many traditional studies about the exploitative intensity in coastal zones are based on classification (Anderson, 1976; Azab and Noor, 2003; Giri *et al*., 2005; Shalaby and Tateishi, 2007). While the extraction and classification of data have been fulfilled based on knowledge acquired from both field surveys and visual interpretation (Wu *et al*., 2014), the classification-based method needs both fieldwork and a process known as ground-truthing (Green *et al*., 1996), after which the classification can be extended over the entire dataset. To build an index of the degree of coast utilization, Wu *et al*. (2014) conducted ten field surveys that covered the whole coastal zone of China and obtained more than 7000 site photos and 578 control points, after which classified datasets of the mainland coastline from the 1940s to 2012 were created by digitizing the topographic maps and visually interpreting remote sensing imagery. Lin *et al*. (2010) analysed the spatial-temporal land use change of Xiamen Island in the last 100 years by using man-machine interactive interpretation. The assessment of coastal zone development by Sun Xiaoyu (2008) was also based on manual interpretation and field investigations. TM (Thematic Mapper) images were also employed for supervised classification in coastal zones to monitor land use change (Muttitanon and Tripathi, 2005). Although the accuracy of these classification-based methods is high, they consume a great deal of human effort and time. Because coasts exhibit extreme variations in their areal extent, spatial complexity, and temporal variability (Klemas, 2012), the planning and management of land resources often requires an efficient method (Willem, 2013).

Another way to assess the exploitation of coast resources is to compute geoindicators to measure the exploitative intensity. This kind of study involves the use of a great deal of reliable data (e.g., land use data, GDP per capita, arable land per capita, and crop yield per unit area). Xiao (2012) established an integrated exploitative intensity evaluation model of coastal zones by establishing evaluation indexes and statistical analyses with matrix calculations. Although the results of such an evaluation are comprehensive, this method necessitates a considerable amount of computational efforts (Zhou *et al*., 2000). The demands on the quantity and quality of basic information data are high. Devoting a long period to the collection and preparation of geographical and statistical information is essential for the accuracy of the original data and directly determines the accuracy of the evaluation results. When intuitively expressing the status of the exploitative intensity in a spatial context for an analysis, the statistical results continue to face serious challenges of visualization.

Numerous efforts (Hildebrand and Norrena, 1992; Sekhar, 2005; Nagothu, 2005; Ballinger *et al*., 2010; Ye *et al*., 2014; Schernewski *et al*., 2014) have been made simultaneously to evaluate the exploitative intensity of coastal zones using ICZM (Integrated Coastal Zone Management, Earth Summit, 1992). Land use maps from 2000 to 2010 for China’s coastal zones were produced, and the land use intensity comprehensive index (LUICI) was calculated to analyse land use spatial patterns and land-ocean gradient characteristics (Di *et al.*, 2015), following which the land use vector map was transformed into a gridded dataset of land use data at a 1 km scale for presentation. Different segments of coast generally develop under different environmental, natural, demographic, and socio-economic conditions. These conditions often vary and have a direct impact on the exploitative intensity (Muttitanon and Tripathi, 2005).The unbalanced distribution of development among different subregions results in the inability to obtain a decent solution (Zhang *et al.*, 2012), and thus, the banded characteristics of coastal zones should be taken into consideration.

The purpose of this paper is therefore to propose a scientifically sound and practical model for the assessment of the exploitative status in coastal zones by extracting exploitative information based on the integration of three normalized indexes within regular spatial units and by focusing on the calculation of quantitative exploitative intensity values in GIS.

2 Methodology

2.1 Study area

The study area for this research is Vietnam, which is located along the eastern coast of the Indo-China Peninsula between 8°10'N–23°24'N and 102°09'E–109°30'E. Vietnam is immediately adjacent to southern China. With a coastline/area ratio of 0.011, Vietnam can be regarded as a marine nation (Anh *et al.*, 2008).

Vietnam is characterized by 3260 km of coastline and presents an S-shaped pattern in a north-south vertically long strip. Among the 64 provinces of Vietnam, 28 are situated on the coast. Over 50% of its population lives in coastal zones. In general, the economic activities in coastal zones, such as shipping, fishing, tourism, and industry, increase as the population grows, and vice versa (Hiroshi *et al.*, 2014). Some of the major characteristics of the country of Vietnam are as follows.

(1) Mountainous area. Three-fourths of Vietnam is composed of mountains or plateaus, the majority of which is situated in northern and central Vietnam. Low-lying areas are found in the east near the ocean, while the higher elevations are found in the western inland region.

(2) Fertile plains. The Red River Delta in the north and the Mekong Delta plain in the south are the two largest plains in Vietnam. Because of their fertility, they are the densest populated areas in Vietnam. In addition, several smaller plains are distributed within the north-south coastal zone. Most of these plains are located above the latitude 18°N, including the Thanh Hoa, NgheAn, Ha Tinh and Hue plains. Smaller plains are also located to the south of Hue, near Quang Nam and Binh Dinh. Widespread fertile plains are suitable for the development of large-scale agriculture.

(3) Abundant natural resources. Vietnam currently has 3.5 billion tons of coal reserves and 6.0 billion tons of oil reserves. In addition, Vietnam has many timber reserves. Up to more than 2000 species of fish live in the sea within Vietnamese borders, and its fishery resources are approximately 300 million tons (Gu, 2007). Such conditions contribute substantial to the industry and fishery of Vietnam.

(4) Tropical monsoon climate. Vietnam has abundant sunshine and rainfall, which constitutes a suitable climate for crops. More than 900 acres of arable land are found in Vietnam. Rice is the main planting crop, followed by corn and sweet potatoes, and its economic crops

are coffee, tobacco and pepper.

2.2 Data source and data preprocessing

Landsat 5 TM data acquired in 2009 and 2010 were used in this study. The data preprocessing methods employed include radiometric calibration and gap filling. Satellite images used in the study can be seen in Table 1.

Table 1 Satellite images used in the study

Path/row	Acquisition date
123/50	2010.01.28
123/51	2011.06.08
123/52	2011.06.08
124/49	2011.02.17
124/50	2010.02.04
124/52	2009.12.18
124/53	2009.12.18
125/48	2010.07.05
125/49	2010.02.11
125/53	2009.02.08
125/54	2009.12.09
126/45	2010.11.01
126/46	2010.12.27
126/47	2009.07.09
126/48	2009.02.15
127/47	2010.02.25

2.3 Division of coastal zones

Coastal zones are typical areas that are characterized by long and narrow strips. For convenience, we geometrically divided the coastal zone into a number of boxes while ignoring administrative divisions and natural geographical units. Zoning is an efficient way to compare the results of an evaluation both laterally and longitudinally, which can more clearly reflect the variations of the exploitative intensity. The zoning was performed as described below.

(1) Lateral zoning. From the coastline landward, we draw the study area into different regions that are parallel to the coastline with buffers of 5 km, 10 km and 20 km. Different natural and geographical conditions in the study area lead to different widths of the buffers.

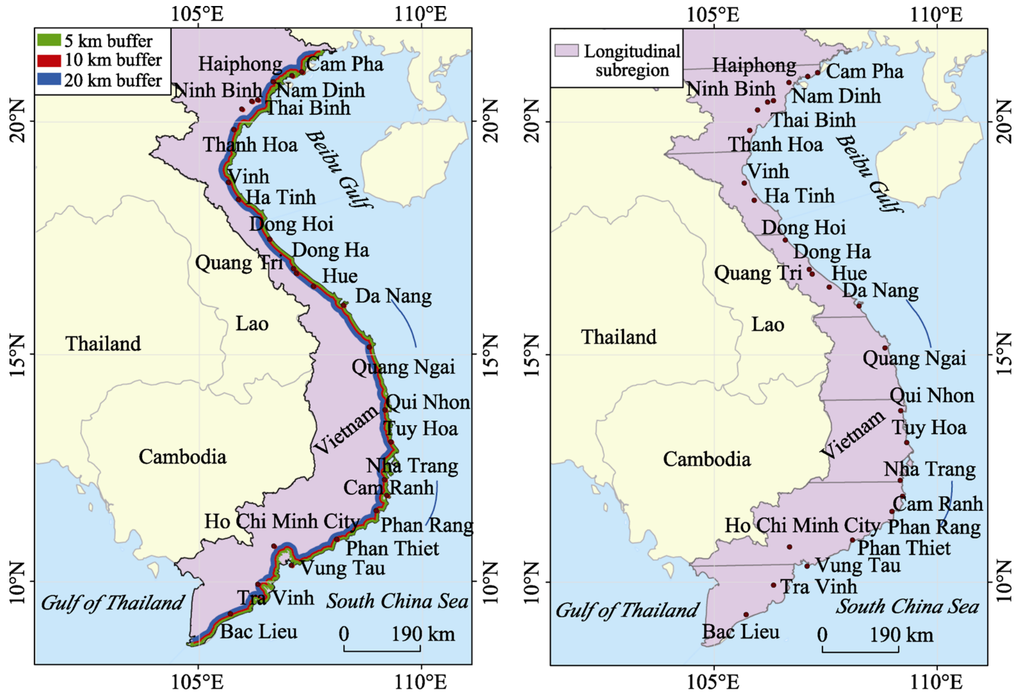
(2) Longitudinal subregions. We divide the landward buffers into a number of equal-width regions by a unit of some selected miles. The selected mileage should not be too long to ensure the exploitative intensity in each region would not change dramatically. In addition, each subregion is relatively independent.

The results of zoning are presented in Figure 1.

The advantages of the locations in separate areas are different. Natural conditions, such as the climatic and topographic conditions, hydrological conditions and vegetation distribution, also demonstrate some differences. As a result, the socio-economic conditions and exploitative intensities are different. Subdividing the area can provide an average of the summed exploitative intensity. There is no doubt that our method can only roughly estimate the average exploitative intensity of each region. However, a greater number of subdivisions will lead to a more accurate set of evaluation results and a more efficient use of time and manpower. An appropriate number of subdivisions is thus required according to our actual needs.

2.4 Extraction and calculation

Given the required amount of traditional manual interpretation work, we use an exponential method to extract the exploited regions. The principle of normalized indexes is discussed below, which we use to calculate the magnitude of the intensity of exploitation.



(a) Lateral zoning (b) Longitudinal subregions

Figure 1 An example of coastal zoning

2.4.1 Normalized index

The NDVI (Normalized Difference Vegetable Index) (Rouse *et al*., 1974) is the most common and widely applied index (Robin *et al*., 2011). Similarly, other easy-to-calculate, simple and practical normalized difference indexes have been proposed as imitations of the NDVI in recent years. This type of index can be used individually without other image data. The basic principle is to find the bands with the strongest and weakest reflections of the object of interest among multiple spectral bands. Then, placing the strongest reflection in the numerator and the weakest reflection in the denominator, the gap between the two can be expanded by a normalized ratio operation. The primary objective of this approach is to obtain the maximum brightness enhancement of the generated index images while generally suppressing other information (Xu, 2008). A spectral graph of common coastal land use classes is given in Figure 2 using the samples of classes from imagery in the research area.

(1) NDISI (Normalized Difference Impervious Surface Index)

An impervious surface is a man-made or natural geomorphic object through which water cannot perco-

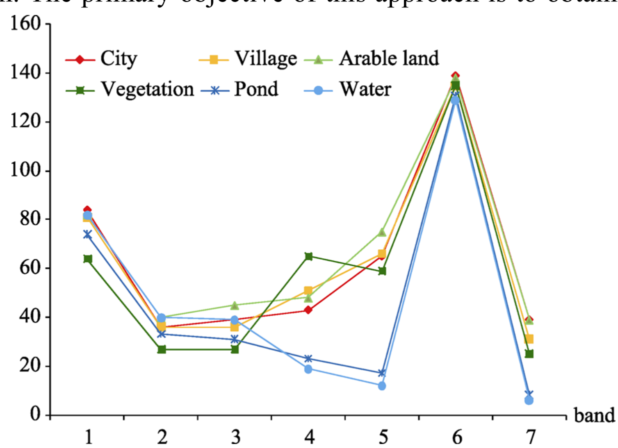


Figure 2 Spectral graph of six coastal land use classes

late into the soil, including roofs, roads, driveways, sidewalks, and parking lots (Slonecker *et al*., 2001). It has a close relationship with human activities and human life. From a remote sensing perspective, an impervious surface usually refers to a construction area with a smaller permeability relative to vegetation and soil and is characteristic of a city area (Lin *et al*., 2007).

The NDISI was proposed by Xu (2008). Building materials composed of impervious surfaces generally have characteristically high radiance in the thermal-infrared band and low reflectance in the near-infrared band. In accordance with the principle of normalized indexes, the ratio of the two reflectances is used to enhance impervious surface information. Impervious surfaces composed of cement primarily have high thermal radiation, and vegetation cannot grow on them. The thermal-infrared band represents the intensity of thermal radiation on the ground, and the near-infrared band represents the amount of vegetation. The ratio of these two can increase the distinction between them and highlight impervious surface information to the greatest extent (Xu, 2008, 2010). The NDISI is defined as follows (Xu, 2010):

$$\text{NDISI} = \frac{\text{TIR} - (\text{MNDWI} + \text{NIR} + \text{MIR})/3}{\text{TIR} + (\text{MNDWI} + \text{NIR} + \text{MIR})/3} \tag{1}$$

where TIR is the thermal-infrared band, such as band 6 in TM and ETM+ images, NIR is the near-infrared band, such as band 4 in TM and ETM+ images, and MIR is the mid-infrared band, such as band 5 in TM and ETM+ images.

When using this index, we make a 0–255 linear stretch for the thermal-infrared band and the MNDWI (Modified Normalized Difference Water Index) to make them consistent with the other bands (Xu, 2010). In the NDISI image, the value of an impervious surface is the biggest, followed by those of arable land and vegetation, while the value of water is the lowest. The NDISI has a high sensitivity to high-intensity building areas. The BSI (bare soil index) was used in rural areas as it has the advantage of being able to distinguish between low-intensity building areas and arable land.

(2) BSI (Bared Soil Index)

The BSI was proposed by Rikimaru (1996). It is based on the differences of the spectral signatures in the MIR and visible Red bands between bare soil and the background. In a BSI image, the value of bare soil or arable land is the biggest, followed by those of cities and low-intensity building areas (e.g., villages), while the values of water and vegetation are the lowest. The BSI may make mistakes while distinguishing between a city and arable land, but it is effective in distinguishing villages from arable land. It is defined as follows:

$$\text{BSI} = \frac{(\text{MIR} + \text{RED}) - (\text{NIR} + \text{BLUE})}{(\text{MIR} + \text{RED}) + (\text{NIR} + \text{BLUE})} \tag{2}$$

where RED represents band 3 in TM and ETM+ images, and BLUE represents band 1 in TM and ETM+ images.

(3) MNDWI (Modified Normalized Difference Water Index)

As is well known, the reflectance of buildings is suddenly strengthened from the near-infrared band to the mid-infrared band, while the reflectance of water in the mid-infrared band continues to decline. This approach makes the contrast between buildings and water obviously enhanced and reduces confusion and background noise greatly (Xu, 2005). Although the NSIDI and BSI are highly sensitive to water, some information from mudflats is also included. The MNDWI can facilitate the extraction of mudflat information from the built-up information. Xu defined the index as follows:

$$\text{MNDWI} = \frac{\text{Green} - \text{MIR}}{\text{Green} + \text{MIR}} \tag{3}$$

where Green represents band 2 in TM and ETM+ images.

(4) NDBI (Normalized Difference Built-up Index)

The NDBI was derived from the in-depth analysis of NDVI, and it was first proposed by Yang (2000) and subsequently renamed by Zha *et al*. (2003) as the NDBI. The reflectance of vegetation in the near-infrared band is larger than that in the mid-infrared band, which is the opposite relationship for built-up areas. The NDBI is established as follows:

$$\text{NDBI} = \frac{\text{MIR} - \text{NIR}}{\text{MIR} + \text{NIR}} \tag{4}$$

We use the NDBI to help screen out vegetation information that is otherwise mistakenly extracted by the NDISI as a referential index.

2.4.2 Index-based evaluation model

The use of a single index such as the NDISI or BSI may introduce the problem of an incorrect pixel. To enhance the precision, this paper uses the MNDWI, the BSI and the NDBI to assist the NDISI. The MNDWI is used for reducing water noise. The NDBI is applied for reducing vegetation noise. The MNDWI in conjunction with the NDBI may eliminate interference and improve accuracy.

An appropriate threshold is chosen for the extraction of information from the Landsat imagery after a number of attempts, the detailed processes for which are shown in Figure 3.

We set high intensity built-up and low intensity built-up as A and B. The water is set to C and the vegetation is set to D. After the binarization images are acquired, we need to establish a logic operation and retrieve the desired exploited regions.

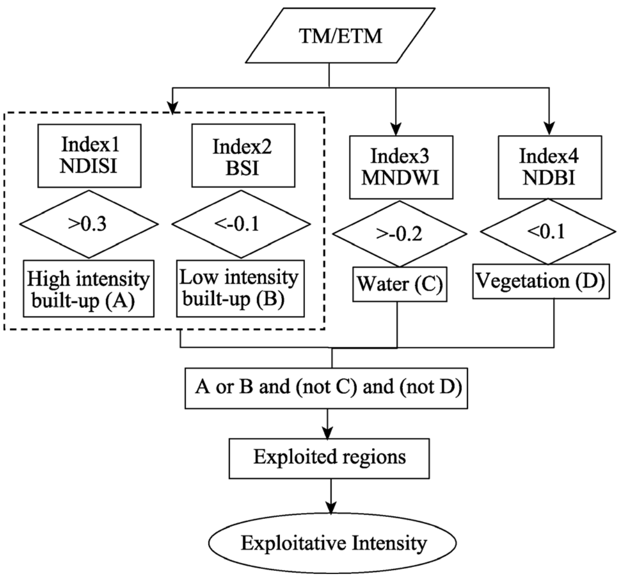
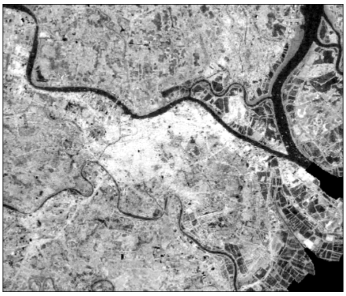
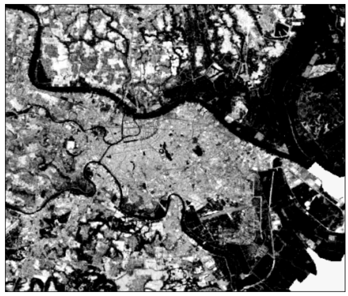


Figure 3 A flowchart of the extraction and calculation

The original image and enhanced images using the above mentioned indexes are shown in Figure 4. The binarization results for each of the indexes are shown in Figure 5. The results of the logic operation are shown in Figure 6. A multi-resolution segmentation operation has been performed in both Figures 5 and 6.

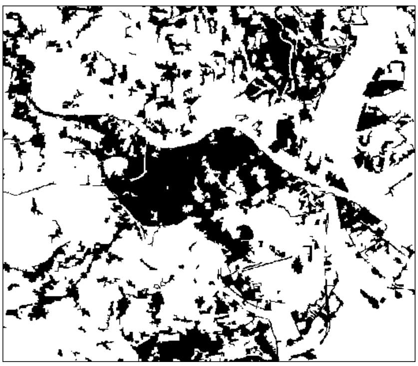
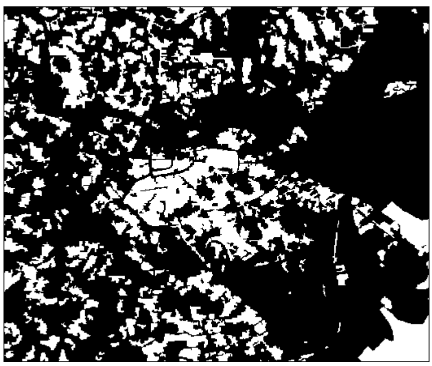
After the above processes, we calculate the percentage of the exploited area in each subdivided region to represent the exploitative intensity (EI). A higher proportion of the EI means the region is more exploited while a lower proportion means the region is less exploited.

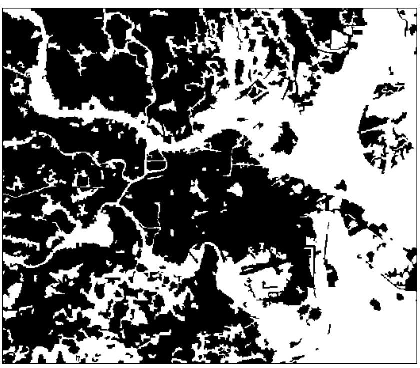
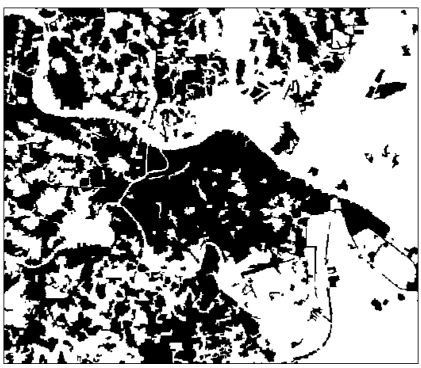
(a) Original image (b) NDISI image (c) BSI image


(d) MNDWI image (e) NDBI image

Figure 4 Original image (a) and enhanced images using the NDISI (b), BSI (c), MNDWI (d) and NDBI (e)

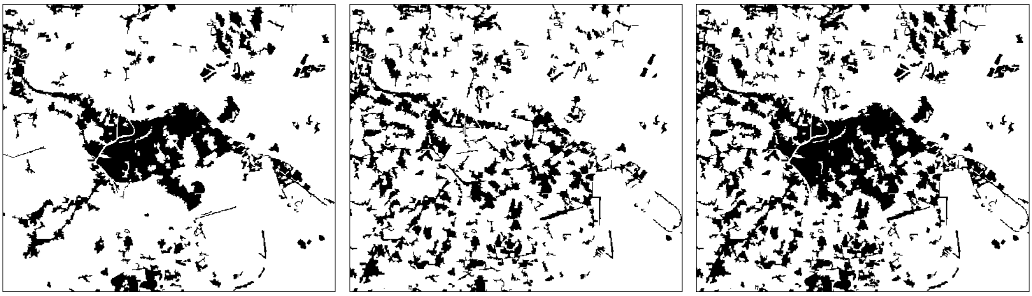



(a) NDISI image (b) BSI image

(c) MNDWI image (d) NDBI image

Figure 5 Binarization results for the NDISI (a), BSI (b), MNDWI (c) and NDBI (d)



(a) High intensity built-up (b) Low intensity built-up (c) Amalgamated built-up

Figure 6 Logic operation results of high intensity built-up (a), low intensity built-up (b) and amalgamated built-up (c)

$$\text{EI}=\frac{\text{Exploitated area}}{\text{area of a sub-region}} \tag{4}$$

EI stands for the exploitative intensity in each subregion.

2.5 Classification and evaluation

To intuitively express the grade of the EI, we separate the intensity index range into several intervals by the desired number of classes. We first choose the specific number of classes we need, after which we modify the range of each class according to the calculated intensity index. Obviously, this method is subjective and demonstrates a certain relativity. The results must vary according to different classification boundaries. However, it can adjust to the demands of the decision maker to some extent for operational convenience (Wijdeven, 2002). For example, we can adjust the boundaries to equalise the number in each class for balance purposes. At the same time, the classification results can show spatial variations among the exploitative intensity intuitively.

3 Results and discussion

3.1 Results

Considering the conditions of the South China Sea and Vietnam coastlines (Boateng, 2012), we choose 5 km, 10 km and 20 km as three different landward buffers for coastal Vietnam in the study area. We first divide the study area by units of 10 km. From south to north, it is divided into 151 subregions. Then, we calculate the proportion of the exploited area in each subregion. The evaluation and classification of the intensity of land resource exploitation are based on the calculated results.

According to the range of proportions in coastal Vietnam, we classify the buffers into 4 classes as follows: to be exploited (≤0.05), less exploited (0.05–0.15), moderately exploited (0.15–0.4) and highly exploited (>0.4). The area of each class is shown in Tables 2–4.

Table 2 Classification of the intensity of costal land resource exploitation in Vietnam and the South China Sea with a 20 km buffer

Class	EI	Number of regions	Percentage
To be exploited	<0.05	78	51.7%
Less exploited	0.05–0.15	43	28.5%
Moderately exploited	0.15–0.4	29	19.2%
Highly exploited	>0.4	1	0.7%

Table 3 Classification of the intensity of costal land resource exploitation in Vietnam and the South China Sea with a 10 km buffer

Class	EI	Number of regions	Percentage
To be exploited	<0.05	76	50.3%
Less exploited	0.05–0.15	40	26.5%
Moderately exploited	0.15–0.4	31	20.5%
Highly exploited	>0.4	4	2.6%

Table 4 Classification of the intensity of costal land resource exploitation in Vietnam and the South China Sea with a 5 km buffer

Class	EI	Number of regions	Percentage
To be exploited	<0.05	75	49.7%
Less exploited	0.05–0.15	37	24.5%
Moderately exploited	0.15–0.4	29	19.2%
Highly exploited	>0.4	10	6.6%

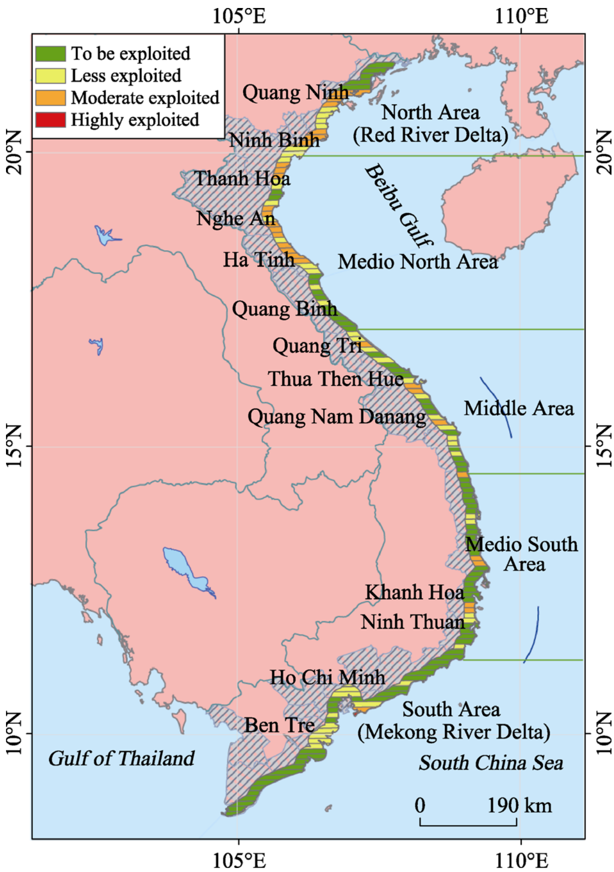


Figure 7 A classification map of the intensity of land resource exploitation in coastal Vietnam with a 20 km buffer (2010)

As the tables show, the exploitative intensities throughout the coastal zones of Vietnam are not very high. The proportions increase from highly exploited intensity classes to lower exploitation classes. The proportion of the area to be exploited accounts for approximately 50%, which indicates the great potential for development. An overall difference of exploitative intensities coexists, and the weakly exploited classes are more prominent. The development and utilization of coastal areas require improvement to a great extent.

The classification of the intensity of land resource exploitation in coastal Vietnam is shown below in Figures 6–8.

3.2 Analysis of spatial variation

To clearly analyse the results, we partition coastal Vietnam into five regions from north to south for the sake of simplicity. The region stretching from the northern Vietnam border to Ninh Binh Province is labelled the North Area (the Red River Delta), that from Thanh Hoa Province to Quang Binh Province is labelled the Medio North Area, that from Quang Tri Province to Quang Ngai Province is labelled the Middle Area, that from Binh Dinh Province to Khanh Hoa Province is labelled the Medio South Area and that from Ninh Thuan Province to the southern Vietnam borderis labelled the South Area (the Mekong River Delta) (Figures 7–9).

(1) Spatial variation from the north to the south

The intensity of coastal exploitation exhibits extreme variations with the areal extent. The land exploitative intensities in the North and Medio North areas are obviously higher than in the Middle and South areas. In the vast areas of the Red River Delta plain and the Thanh Hoa - Nghe An - Ha Tinh plains, a great deal of arable land contributes to the development of cities and villages. Meanwhile, the land exploitative intensity in the Mekong River Delta plain is generally low except for within some dense-ly populated areas such as Ho Chi Minh and Vung Tau. In the Middle Area, moderately exploited and highly exploited areas are scattered throughout the small coastal plains.

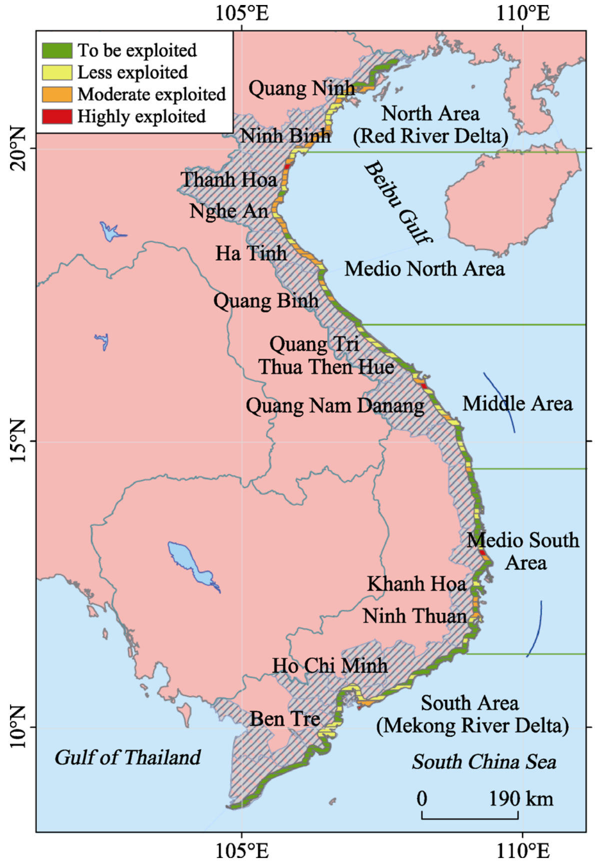


Figure 8 A classification map of the intensity of land resource exploitation in coastal Vietnam with a 10 km buffer (2010)

(2) Spatial variation by vertical direction

The distribution of land use types shows different characteristics of zonation with different offshore distances. A statistical analysis of the results on the offshore buffers is applied to obtain the proportion of the area with the same exploitation intensity among the different buffers. The offshore exploitative intensity of the 5 km buffer is higher than those of the 10 km and 20 km buffers. Inshore locations are advantageous due to their good conditions for transportation. In most port cities such as Da Nang, the exploitative intensity is higher closer to the coast. Port economies have a significant influence on the exploitative intensity. Meanwhile, the situation is opposite in some places. As Figure 9 shows, urban agglomeration cannot be illustrated in the 5 km buffer due to the influence of sediment deposition from the river, such as in the Port of Haiphong in the Red River Delta. Additionally, Quy Nhon in the Medio South Area is not particularly close to the coast. Coastal lands here cannot be utilized entirely for exploitative purposes due to restrictions presented by landforms in the 5 km buffer. Meanwhile, areas in the 10 km and 20 km buffer are highly developed.

3.3 Discussion

Deltaic plains are often highly exploited. As shown in Figure 7, the Red River Delta is obviously highly exploited in 20 km buffer, and Haiphong and Ha Long are also well exploited (Figures 8 and 9). Haiphong is the biggest port in northern Vietnam, while Ha Long is a famous tourist city. In addition, Nam Dinh, Ninh Binh and Taiping are more relatively exploited. The city of Ho Chi Minh, which is located in the north eastern part of the Mekong River Delta, is a typical representation of a highly developed area (Figure 7). It is the largest city in Vietnam with convenient transportation facing the sea towards the south. Deltaic plains are low-lying areas with an average elevation of less than 2 m that contain many rivers and fertile soil. The Mekong River Delta is one of the most productive food regions in the world, and it is relied upon by the approximately 18 million people living within it as a primary food source (Ishida *et al*., 2007).

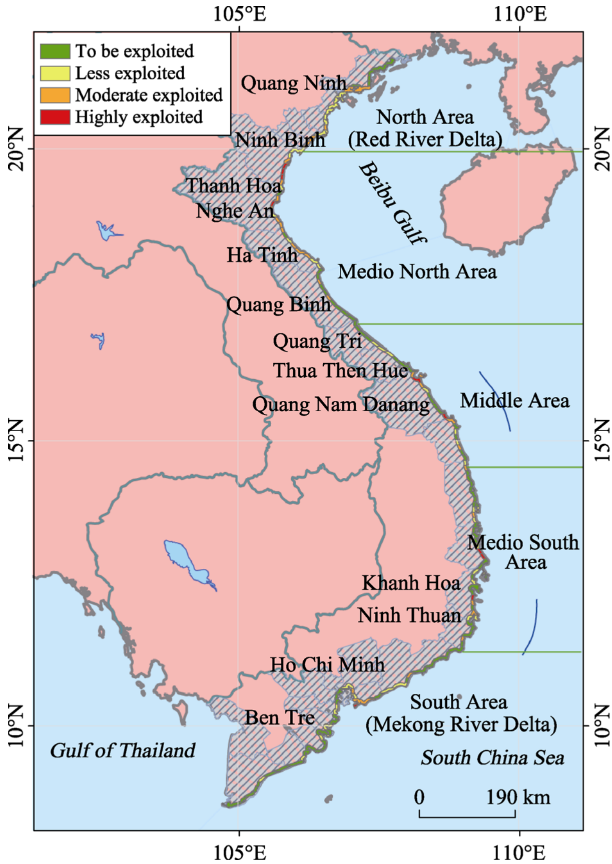


Figure 9 A classification map of the intensity of land resource exploitation in coastal Vietnam with a 5 km buffer (2010)

Harbours are also well exploited. Many major cities are on or near good harbours and have port facilities. For example, Da Nang and Hue (Figure 5) are two of the more highly exploited cities in the Middle Area. Approximately 8 km east of Hue is the coastline. It is located to the south of Da Nang, and it is the rice centre of Vietnam (Wang Peng, 2010). Coastal areas serve as the centre for not only human settlement but also a variety of commercial services (David, 2009; Fletcher *et al*., 2011). Haiphong is the biggest port in northern Vietnam. A port is an important aspect of coastal zone exploitation and management.

On the whole, the exploitative intensity in Vietnam is low and unbalanced, but the conditions of land use are superior (Figure 10). The coastal regions greatly need to be exploited. The ocean provides humanity with both animate and inanimate natural resources, such as food, materials, essential substances, and energy (Visbeck *et al*., 2014). Vietnam can sustain development by strengthening its management and moderately exploit its resources. Some decisions must be taken to achieve sustainable development under the balanced consideration of sustainability and resource shortages. Residents, who are associated with the development of industry, including that of tourism, can create more value by maintaining the excellent conditions of the coastal zones (Figure 10).

4 Conclusions

Since coastal zones tend to be spatially complex and exhibit high temporal variability, this paper aims to establish an index-based spatial heterogeneity evaluation model of the exploitative intensity in coastal zones. Based on the understanding of the evaluation of exploitative intensity (Esteves *et al*., 2003), four normalized indexes were combined to obtain the classification. This model has three advantages suitable for the characterization of the intensity of coastal resource exploitation, as summarized below.

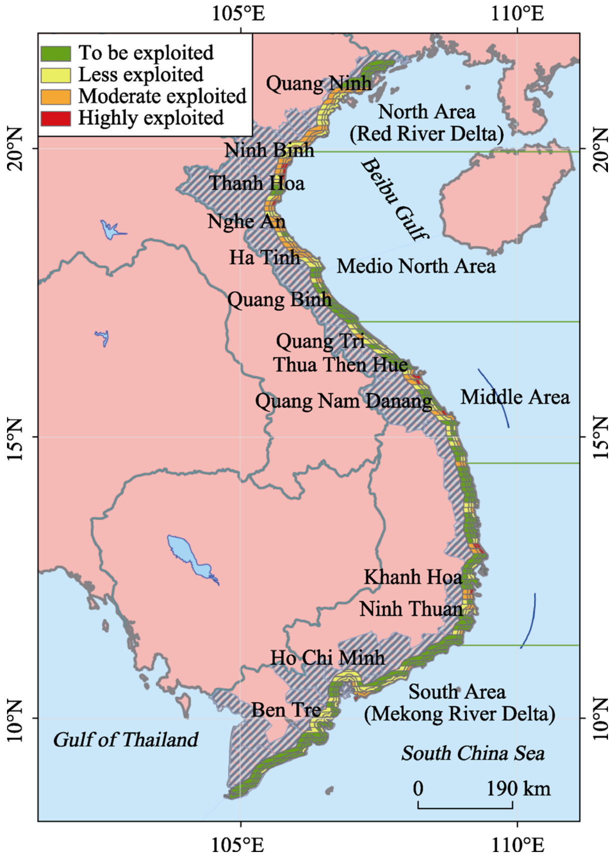


Figure 10 Comparison of the intensity of costal land resource exploitation with 5 km, 10 km and 20 km buffers

(1) Efficiency. With the continuous development of human society, the development and utilization of coastal zones are changing. Due to the high temporal and spatial variability of coastal regions, up-to-date the intensity of coastal exploitation needs to be recalculated frequently. The simplicity and rapidity of the index operations in this model can address the fast-changing characteristics of coastal exploitation efficiently. Stakeholders can easily use it because of the simplicity of the processes and the generalization of the results (Debaine *et al*., 2012).

(2) Zonation. Coastal zones are typically shaped as long strips. In the study area, Vietnam appears as a north-south extension with a length of 3260 km. Coastal exploitation has regional characteristics. Different regions vary in their location, economic development and existing industries. Therefore, a zonation for striped buffer areas is suited for the coastline. This model can show the distribution of exploitation intensities directly.

(3) Visualization. The classification of the exploitation intensity makes the results easy to read. Decision-makers can observe the exploitative status of the study area clearly using the figures. The exploitation intensities were not only analysed, but also visualized, which is more intuitive to show the status land resources in this area.

These results provide useful information that is fundamental to the successes of coastal management and future studies. However, the method of grading is not absolute. The classification boundaries may impose different influences on the evaluation results.

Additionally, there are some shortcomings in the model and the method of analysis, and further improvement is expected. This index-based model is focused on the quick extraction of built-up information to satisfy continually changing coastal zone characteristics, which means that the precision may be differently influenced to some extent, especially in the ability to distinguish between built-up and bare land. As a result, the model needs subsequent manual revisions. The longitudinal segmentation method is effective for a north-south oriented coastline, while a latitudinal segmentation approach is better for a west-east oriented coastline. Meanwhile, if the fractal index of the coast is high, it may not perform well.

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