Applying Google Earth Engine for geospatial analysis of land use/land cover change in Can Gio district, Ho Chi Minh City, Vietnam

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ABSTRACT

As a gateway of Ho Chi Minh City to the sea, Can Gio district plays an important role in economy, society, defense, environment and international integration with a famous Can Gio biosphere reserve forest area. In the coming time, Can Gio district will have many large national projects. The development of Can Gio will also be associated with tasks and solutions to protect the biosphere. Therefore, monitoring land use/land cover (LULC) changes contributes to support sustainable Can Gio planning. In this study, multi-temporal Landsat satellite image data was used to extract land use information by Google Earth Engine (GEE). At the same time, the Geographic Information System (GIS) method was also used to process data layers and calculate LULC changes in 1990, 2000, 2010 and 2024. Research results showed that, from 1990 to 2024, the bare land or wasteland in Can Gio has been effectively converted. That had increased the area of land types such as: forest, residental- contructional and aquacultural land. Because of the forest restoration and forest protection policies of Government, local officials, youth volunteers and residents, the area of mangrove forest had been increased in Can Gio (1.8 times with 15,441 ha). Besides, the increase of population and economic development led increasing residental and constructional land areas (4.2 times with 875 ha). Study results also showed that GEE geospatial processing service is a useful solution for LULC analysis on a large scale such as Can Gio district. It contributes to quickly and effectively support the supervision of local authority in master planning, land use planning… where comprehensive and sustainable development is needed.

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1. Introduction

Land cover is one of the important factors affecting the conditions and functions of ecosystems (Lunetta et al., 2022). In particular, land cover fluctuations show the interaction between human activities on the ecological environment (Nguyen et al., 2014). Detecting land cover fluctuations quickly will help support making reasonable decisions for land resource use and management (Mallupattu & Reddy, 2013). Currently, Can Gio has an opportunity for outstanding development when there are two national projects which are being implemented: Sea reclamation tourist urban area and international container transshipment port. Therefore, to ensure the development in accordance with the land use planning of Can Gio district, it is necessary to monitor closely and regularly land use management.

The application of Remote Sensing (RS) and Geographic Information System (GIS) in managing land use changes is convenient for observing on a large scale (Congalton et al., 1998). In Can Gio, there have also been many studies applying radar and optical satellite images, which mainly focus on mangrove management (Pham et al., 2019; Singh et al., 2021). However, the creation of land use/land cover (LULC) maps for a large area over a long period of time requires a large data source (Wan et al., 2015). Thanks to significant advances in satellite image processing and storage technology, the Google Earth Engine (GEE) platform is a powerful solution for multi-temporal mapping (Shelestov et al., 2017). Therefore, some recent studies have applied GEE to create LULC maps, instead of using RS image processing software as before. In this study, multi-temporal Landsat satellite image data is used to create a map of LULC in Can Gio district for the period 1990 - 2024 based on the GEE platform. At the same time, spatial analysis methods are also used to overlay maps and calculate the changing area of land types. From there, the study conducted an assessment of developments and changes in land use types in Can Gio district in the period of 1990 - 2024. The research results are expected to contribute for providing a scientific and practical basis to assess the situation and trends of LULC changes in the case study by the application of GEE. From there, the desired result is to encourage local agencies to increase the application of RS technology and GIS in monitoring and managing the implementation of land use planning.

2. Materials and Methods

2.1. Study area

Can Gio, a coastal district, locates in the southeast of Ho Chi Minh City with the area occupying about 1/3 of the total area of Ho Chi Minh City and its geographic coordinates is from 106°46’12” to 107°00’50” East longitude and from 10°22’14” to 10°40’00” North latitude (Figure 1).

Can Gio is the gateway of Ho Chi Minh City to the East Sea with international maritime routes in the East Sea, the project of Can Gio international container transshipment port is considered to have many advantages to attract international commodities from countries in the region (Pham et al., 2022). In addition, the government has also approved the expansion of the Can Gio sea reclamation tourist urban area project, which aims to develop infrastructure for marine economic sectors and marine urban space (Nguyen, 2019). Major projects are planned currently and will start constructing in 2025. This will help awaken the potential of Can Gio district, creating a motivation for the city to develop strongly in the coming period. Besides, the benefits of economic development, many aquaculture, rice, and vegetable farming areas were abandoned when large project planning information was disseminated in the study area. These mean that it is necessary to monitor quickly the LULC fluctuation process, which contributes to supporting the comprehensive and sustainable planning of Can Gio.

2.2. Dataset

To extract LULC information, this study collected the Landsat surface reflectance dataset with a spatial resolution of 30 m. This data is hosted by the United States Geological Survey (USGS) and available in the GEE cloud database. The images in 1990, 2000 and 2010 are from the Landsat 5 thematic mapper (TM) sensor. In 2024, the images are from Landsat 9 operational land imager (OLI) sensor. In addition, the Can Gio district Land Use Status Quo Map dataset was also collected to serve as a reference for identifying objects on satellite images. Statistics and analysis reports on land use history in Can Gio were also collected, which supported the assessment of LULC change processes in the locality. Details of the data used in this study are described in Table 1.

Table 1. The table describes detailed information about the used data

Datasets	Year	Spatial resolution	Data source
LANDSAT/LT05/C01/T1_SR	1990, 2000, 2010	30 m	USGS
LANDSAT/LC09/C01/T1_SR	2024	30 m	USGS
Can Gio District Land Use Status Quo Map	2010, 2014, 2020	1/25.000	The Can Gio District Department of Natural Resources and Environment
Field GPS data	March 2024		Authors
Google Earth data	April 2024		Google
Statistics on Area of Land Types	2023		People's Committee of Can Gio District

USGS: United States Geological Survey.

The sample size in this study was determined by the binomial distribution according to the formula to $N = Z^2(p)(q)/E^2$ (Van Genderen & Lock, 1977), where $Z = 2$, p is the expected percentage accuracy, $q = 100 - p$ and E is the allowable error. Therefore, if the expected result of the post-classification accuracy (p) is 85% with the allowable error (E) of 5%, then the number of evaluation samples is 204 samples. In this study, a sample dataset of 212 points was collected to aid in image interpretation and evaluate the accuracy of the classification results for the year 2024. Because the study area has a dense river system and mangrove forests covering 50% of the area, there is an uneven spatial distribution of the samples surveyed by GPS. That also leads to this study, the Judgmental Sampling sampling method is applied to the GPS survey points, while the GE survey points are applied according to the Simple Random (Mu et al., 2015). Of these, land cover information of 52 points was collected from GPS field surveys by the authors in March 2024, and land cover information of 160 points was collected from high-resolution satellite imagery of Google Earth in April 2024. The locations of the evaluation points are identified as shown in Figure 1.

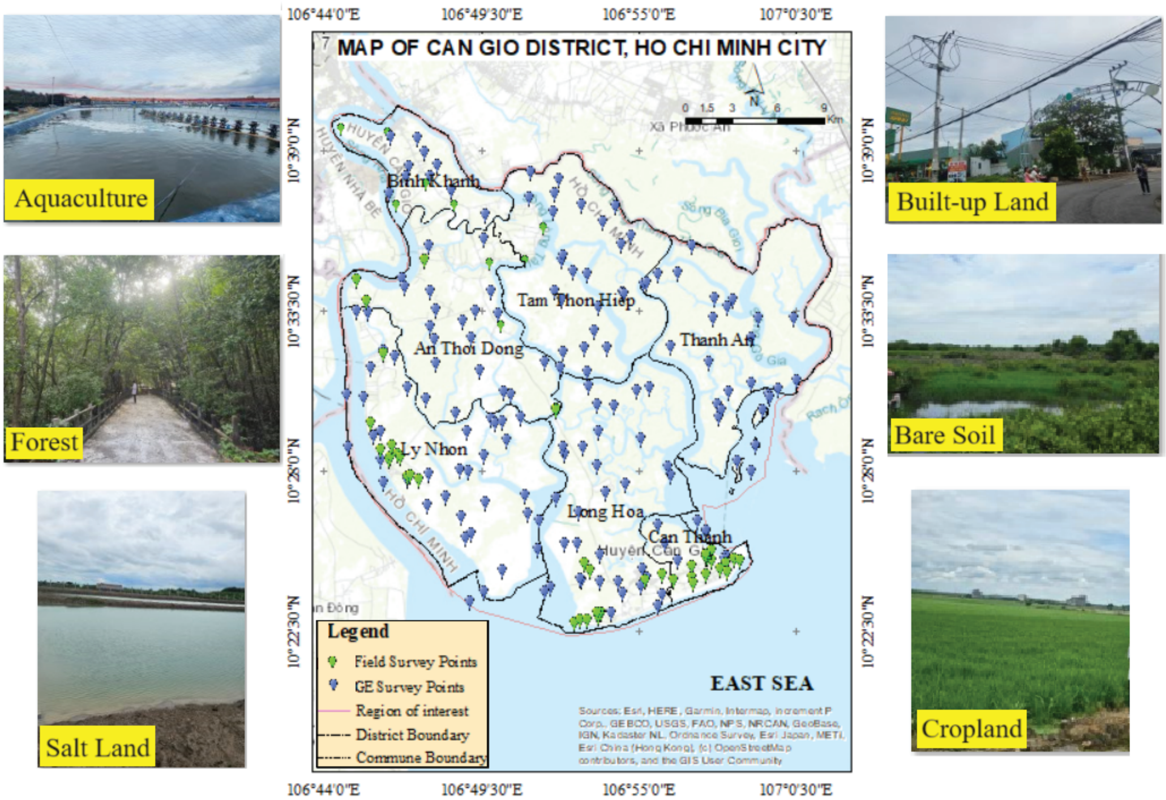

Figure 1. Map of the study area and location of evaluation samples.

3. Methods

In this study, to extract LULC information, the data processing steps were performed including image preprocessing, preprocessing, creating training sets, classification, data export, post-classification processing, accuracy assessment, and result statistics. The above operations were performed on the GEE platform, ArcGIS software, and Excel. The flowchart (Figure 2) shows the methodology applied in this study to achieve the objectives.

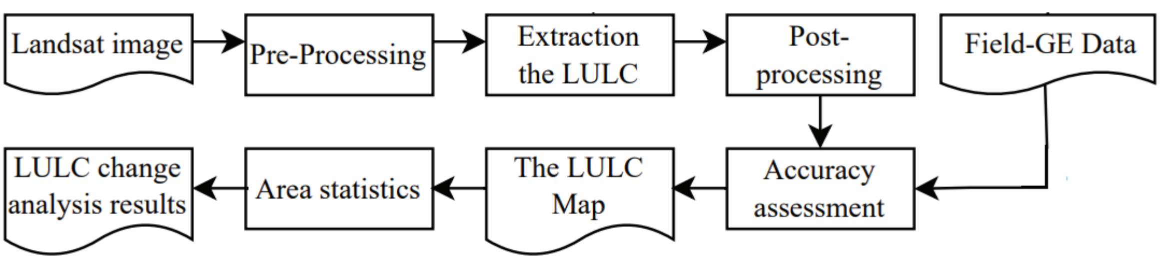

Figure 2. Flowchart of the methodology. LULC: Land use/land cover.

3.1. Pre-processing

This study used Landsat surface reflectance datasets to extract land cover information over time. These data were atmospherically corrected using the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) for Landsat 5 and the Landsat 8 Surface Reflectance Code (LaSRC) for Landsat 8. To minimize the influence of elements such as clouds and shadows, the cloud filtering function "QA_PIXEL" was applied to remove these unwanted components. The GEE cloud computing platform allows users to create composite images from individual images in the collection "ee.ImageCollection". Therefore, the "filterDate" function was used to create a composite image for the dry season (January to March) for all study periods. With filtered collection, a composite is created using the median reducer "ee.Reducer.median()". Reducers are the GEE way to aggregate data over time, space, bands, arrays, and other data structures. Furthermore, the "clip()" function is then used to clip the composite into the study area. To display the image of the preprocessing results, the "Map.addLayer" function is used with the visParams argument.

3.2. Extraction of the LULC

3.2.1. Determination of LULC classification system

In this study, LULC was divided into eight classes as follows: Forest, Cropland, Aquaculture, Salt Land, Built-up Land, Bare Soil and Water, which were based on the characteristics of the study area and the resolution of satellite image data. The detailed description of the Land use/Land cover classes is shown in Table 2.

Table 2. Land use/land cover system

LULC	Description
Forest (F)	Including natural forests and planted forests.
Cropland (C)	Including perennial crop land, annual crop land and rice land.
Aquaculture (A)	Used specifically for the purpose of aquaculture in brackish, saltwater and freshwater.
Salt Land (SL)	Land for salt production.
Built-up Land (BL)	Built-up or under-construction land area.
Bare Soil (BS)	Uncultivated or abandoned land.
Water (W)	Water surface of canals, rivers, streams.

LULC: Land use/land cover.

3.2.2. Creating training samples

The training data is a FeatureCollection with a property storing the class label and properties storing predictor variables. A set of polygon training samples for 4 years was selected directly on the GEE platform, which were selected based on the classifier's experience and Can Gio District Land Use Status Quo Map. The detailed number of training samples is shown in Table 3.

Table 3. The detailed number of training samples

LULC	No. of Polygons			
	1990	2000	2010	2024
Forest (F)	152	171	132	144
Cropland (C)	59	42	46	65
Aquaculture (A)	154	157	189	238
Salt Land (SL)	77	103	163	94
Built-up Land (BL)	7	13	27	76
Bare Soil (BS)	44	36	24	35
Water (W)	88	95	132	104
Total	581	617	713	756

LULC: Land use/land cover.

3.2.3. Classification and post-classification of LULC

Google Earth Engine (GEE) provides users with a variety of supervised classification algorithms, such as Support Vector Machine (SVM), Classification And Regression Tree (CART) and Random Forest (RF), Naïve Bayes (NB). Among the popular supervised machine learning algorithms, the RF algorithm has been proven effective in resisting noise and outliers (Pelletier et al., 2016). At the same time, this algorithm is more effective for mapping in wetlands or mangrove forests (Berhane et al., 2018; Amani et al., 2019; Ghorbanian et al., 2021). For that reason, it is used in this study to create the LULC map of Can Gio. The Random Forests is a Machine Learning-based method, which was proposed by Breiman in 2001 (Breiman, 2001). The Random Forests classifier is an ensemble classifier that produces multiple decision trees, using a randomly selected subset of training samples and variables. In GEE, the Random Forest algorithm can be defined using the function "ee.Classifier.smileRandomForest". The training samples data variable is specified as the training data in the features argument, which is fed into the processing pipeline via the "classifier.train() function".

The image classification results are exported to vector format for post-classification processing, which is done using the "classified. reduceToVectors" function. Then, the data layers are processed to redistribute objects between layers and generalize objects through GIS methods. Finally, overlay and statistical techniques are used to count areas, analyze changes and create LULC maps in Can Gio district over time.

3.3. Accuracy assessment

To assess the reliability of the LULC 2024 results, the study used an evaluation dataset of 212 points, which were collected in 2024. Of these, 52 points were from GPS field data sources and 160 points were from GE high-resolution satellite imagery sources (Figure 1). After the error matrix was established, the Kappa coefficient and overall accuracy were used to evaluate the agreement between the evaluation data and the classification results (Cohen, 1960). In addition, statistical data on land area in Can Gio district in 2023 were also collected to assess the difference between classification results and actual data.

4. Results and Discussion

4.1. LULC information extraction results

Figure 3 showed the LULC classification results from Landsat satellite images in Can Gio district in the years 1990, 2000, 2010 and 2024.

The classification results were evaluated for accuracy by comparing with the evaluation sample set at time 2024, which was shown in Table 4. The results of the accuracy assessment of 2024 LULC had an overall accuracy and Kappa coefficient of 87% and 0.84, respectively. Thus, the LULC extraction results in Can Gio district had a fairly high level of reliability, which was performed by using the Random Forests algorithm through the supervised classification method on the GEE platform. The evaluation results showed that misclassification mainly occurs in the land types: Aquaculture, Salt Land and Bare Soil, which have similar spectral reflectance properties. The reasons were explained as follows: 1/ Aquaculture land and salt land are cultivated alternately by farmers; 2/ Land serving aquaculture and salt production is not economically efficient, so farmers leave it fallow for a long time, becoming flooded bare land.

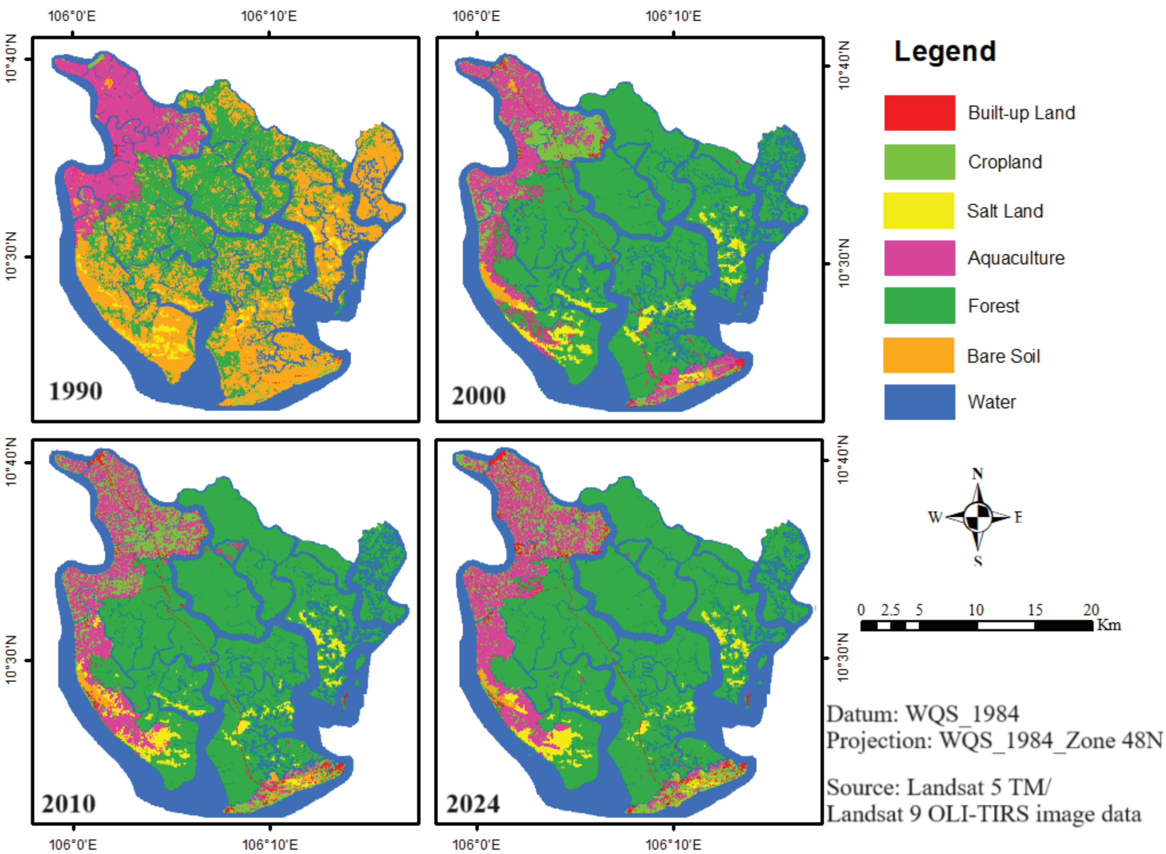

Figure 3. LULC of Can Gio district. LULC: Land use/land cover.

Table 4. Classification result error evaluation matrix

Classified data \ Evaluation Data	F	C	A	SL	BL	BS	W	Total
F	53	2				1		56
C		19			2	1		22
A	4		34	1		1	2	42
SL	1		2	25	1			29
BL		1		1	17	1		20
BS		2				13	1	16
W	2		2				23	27
Total	60	24	38	27	20	17	26	212

Table 5. Percent accuracy of classification results compared to statistics

LU LC	2024 Classification (ha)	2023 Statistics (ha) (*)	Difference (%)
F	34631	34349	0.8
C	4789	4115	16.4
A	6281	6100	3.0
SL	1866	2245	16.9
BL	1149	1696	32.3
BS	445	1029	56.8
W	21343	20906	2.1

LULC: Land use/Land cover.

(*) PC HCMC (2024).

Comparing the difference between the 2024 classification results and 2023 published statistical data (Table 5) shows that: Forest, Water and Aquaculture have the lowest difference, corresponding to 0.8% (281 ha), 2.1% (437 ha) and 3.0% (181 ha). In contrast, Bare Soil and Built-up Land have the highest difference, corresponding to 56.8% (584 ha) and 32.3% (547 ha). This high difference is explained by the difference in the definition of land types in this study with published statistical data on Current Land Use Status in 2023: 1/ In this study, Bare Soil is defined as land that is in a state of abandonment. Meanwhile, according to published statistics in Can Gio, Bare Soil is unused land on the coast or around islands. 2/ Built-up Land in this study is defined as areas of land that have been built or are under construction. According to published statistics in Can Gio, areas that are already in the construction planning area are also considered as Built-up Land.

4.2. LULC fluctuation analysis results

From the LULC classification results from Landsat satellite images, the study analyzed LULC fluctuations in Can Gio district from 1990 to 2024. The calculated data on LULC area results in 1990, 2000, 2010 and 2024 were shown in the Figure 4 and Table 6.

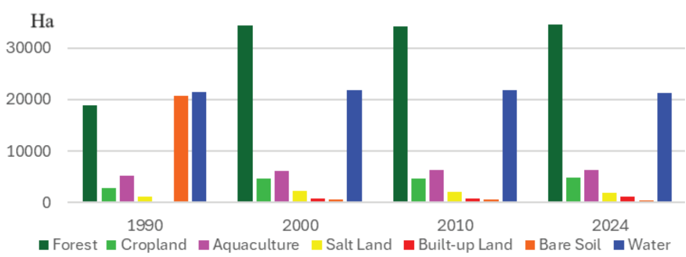

Figure 4. Graph of LULC changes in the period of 1990 - 2024.

Table 6. Statistics results of LULC area

LULC	Area (ha)			
	1990	2000	2010	2024
F	18909	34391	34277	34631
C	2836	4621	4717	4789
A	5284	6209	6254	6281
SL	1088	2174	2149	1866
BL	274	692	823	1149
BS	20719	550	536	445
W	21394	21867	21748	21343

LULC: Land use/Land cover.

An, Long Hoa and part of Ly Nhon. And since 2000 to present, the mangrove forest area has been protected and maintained stably, despite the pressure of the rapid urbanization process in Ho Chi Minh City. The restoration of Can Gio Mangrove Forest contributed greatly to the process of socio-economic development, national defense and security and environmental protection. At the same time, this activity helped people who are contracted to protect the forest to improve their lives and increase their income.

The analysis of LULC fluctuations also showed that the area of Built-up Land in Can Gio district has a tendency to increase continuously. The Bare Soil (Wetlands) converted to urban land occur in scattered riverine or coastal areas. In 1990, Built-up Land occupied a very small area of 274 ha. The urban population was sparsely concentrated, mainly in coastal areas. It can be seen that the concentrated residential areas of the district have been formed since the 1980s such as: Binh Khanh ferry area, An Thoi Dong ferry and Can Thanh. In the following period, there was a rapid increase in the area in densely populated areas since Duyen Hai district changed its name to Can Gio district in 1991. In the 2000s, in addition to the three existing residential areas, new residential areas began to appear such as: Long Tau riverside, Dong Hoa wharf, 30/4 coastal tourism services and Thanh An island commune. In particular, when Can Thanh town was established in 2003, which played the role of a heart of Can Gio district, it helped the rapid expansion of urban areas in coastal areas. The government began to focus on urban management and development. Transport infrastructure (bridges, roads, ferry terminals, ferry terminals, etc.), electricity, clean water, residential housing, irrigation systems, schools, hospitals, and rural markets were invested in and built (PCHCMC, 2021).

The analysis results of LULC change at 1990 and 2024 show: the land types with the most fluctuating areas were Forest, Bare Soil and Built-up Land. Of which, the Bare Soil area decreased significantly, from 20,719 ha to 445 ha (equivalent to a decrease of 29% to 1%). In contrast, there was a clear increase in Forest cover from 18,909 ha to 34,631 ha (equivalent to an increase from 27% to 49%). In addition, the Built-up Land area also increased from 274 ha to 1,149 ha (equivalent to an increase from 0.39% to 2%). From 1990 to 2024, the remaining LULC types also fluctuated but at a negligible rate.

More specific analysis showed that, in the period 1990 - 2000, there was a significant increase in the area of mangrove forests (increased by 15,482 ha, equivalent to 1.8 times). Before that, from 1961 to 1971, Can Gio forest was heavily sprayed with reclamation chemicals due to the war. Almost all the trees of the mangrove forest here were destroyed. In 1978, the Ho Chi Minh City government launched a campaign to replant Can Gio forest (Le et al., 2021). In 2000, the United Nations Educational, Scientific and Cultural Organization (UNESCO) recognized this as the first Biosphere Reserve in Vietnam, belonging to the world biosphere reserve system (Nam, 2014). This achievement was thanks to the forest restoration policies of the Government, local officials, Youth Volunteers and residents, who helped the mangrove forest in Can Gio regenerate. This result was also considered a miracle because in the early 1970s, American ecologists estimated that "It will take about 100 years to restore the Can Gio mangrove ecosystem" (VAN, 2012). Thanks to the above achievements, a large area of Bare Soil land has been converted to Forest throughout Can Gio district, specifically in communes covered with forests such as: Tam Hiep, An Thoi Dong, Thanh

All of these changes created the premise for the economic development of the district in the next period. By 2010, the Urban Planning had ensured the aesthetic architecture of rural areas and formed an eco-tourism area. The locality had also basically completed the concreting of rural roads. Environmental management had positive changes, creating favorable conditions for urban development and new rural construction. Some new residential areas were systematically formed, such as along Rung Sac road in Binh Khanh commune, the center of Ly Nhon commune, residential areas along Duyen Hai and Luong Van Nho roads. At the same time, planned residential areas were also formed, such as Phuoc Loc residential area and Tac Suat residential area near Can Gio - Vung Tau ferry terminal. In addition, information about important projects licensed for implementation in Long Hoa commune and Can Thanh town which made the status of the complicated land use conversion (Nguyen, 2021). By 2024, the Built-up Land area increased rapidly (1,149 ha) due to trends of population growth and migration from other areas. Previously established residential areas will continue to expand. Shops, factories and houses will be built along old roads and upgraded roads such as Ly Nhon and Duyen Hai. At the same time, some residential areas will also appear in some areas along large bridges such as Vam Sat bridge, An Nghia bridge and Soai Rap river. Local authorities developed various solutions to improve and develop the urban area. In the coming time, the Government's main goal is to develop Can Gio district following the direction of a marine ecological urban area associated with the implementation of the Smart Urban Project so that the quality life of the local people is improved more and more.

5. Conclusions

The study extracted successfully LULC information from Landsat satellite images in Can Gio district in the years of 1990, 2000, 2010 and 2024 on the GEE platform. The results of the accuracy assessment of the classification results in 2024 showed that the overall accuracy and Kappa coefficient were 87% and 0.84, respectively. Besides, the results of comparing the differences with the published statistics in 2024 show that: Forest, Water and Aquaculture land have the lowest differences; Bare Soil and Built-up Land have the highest differences. The failure to assess the accuracy of the classification results in the years 1990, 2000, and 2010 is a limitation of this study.

The results of the land cover change analysis showed that the Bare Soil area decreased by 20,274 ha from 1990 to 2024. In contrast, Forest increased by 15,441 ha, which was achieved thanks to effective forest restoration efforts after the War in Can Gio. The study also showed that the Urban Land area in Can Gio district increased steadily over the years, this is suitable with development trend of the case study area.

Currently, many large projects are about to be implemented such as: Can Gio sea reclamation tourist urban area, Can Gio international container transhipment port and Can Gio Bridge, which will contribute to economic growth and LULC changes.

The above results showed that monitoring LULC changes through GEE Cloud Computing Platform allowed users to effectively exploit the search and processing features of RS data, which was done quickly and accurately. The study also showed that Landsat satellite images are a suitable data source to assess LULC changes over long periods of time and over large areas. From there, it showed that RE and GIS are useful in supporting land management for local government, especially in coastal areas where are affected by climate change and urbanization.

Conflict of interest

All authors declare that they have no conflict of interest.

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