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Original Article

Assessment of land use change and crop water requirements in Dong Hung district in the Red River Delta of Vietnam using GIS and satellite imageries

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Abstract

Monitoring land use changes plays crucial role for the management and use of land in a reasonable and effective manner. As land use change is associated with increasingly dynamic socio-economic activities, tracking land use change becomes more difficult with larger amounts of data to be processed. In this study, the modern technology of GIS and Remote Sensing was applied for the assessment of land use change and crop water requirements in Dong Hung district in the Red River Delta of Vietnam. Databases of land use for 2013 and 2018 comprising 2492 and 3473 land parcels with 32 and 36 land use types, respectively, were built from land use map and land use status report. The databases were then used to construct a database of land use change for the period of 2013-2018, which was finally used for land use change assessment. In addition, Landsat-8 OLI data was used to detect land use change for Summer-Autumn and Winter-Spring seasons of 2013 and 2018. Moreover, MODIS satellite data was also used to estimate the crop water requirements for the rice fields for the mentioned seasons in the district. The study revealed that there was a complicated conversion among land use types, but in general agricultural land decreased by 485.9 ha, while non-agricultural land increased by 493.23 ha mainly with the expansion of residential land and land for infrastructure development. Among agricultural land use types, however, only annual cropland, which mostly includes paddy land was narrowed down by nearly 770ha, meanwhile other agricultural land increased. Crop water requirement was found to change slightly during the study period. Although the changes in land use in the study area imply the progress of urbanization, infrastructure improvement and economic restructuring, since Thai Binh province is the heart of the Red River Delta and critically contributes to the rice production in the region, the decline in paddy land is of great concern that should be taken into account for land management and planning of the province and the district.

Keywords: GIS, Land use change, Land use status map, Landsat, MODIS

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Introduction

Land is a priceless but limited resource. The increase in population along with the process of industrialization and urbanization leads to increasing human demands for land, and socio-economic activities make the land constantly change in shape, area, and especially the intended use (Pham, 2020). The change from natural land cover to residential and urban land or even to agricultural land use puts fundamental pressure on our environment. It causes degradation, fragmentation, loss of native vegetation, and a variety of adverse impacts on the ecosystem such as causing soil erosion and loss of nutrients, sedimentation of water bodies and pollution of rivers and streams, destruction of natural habitat and biodiversity, etc. (USEPA, 2017). At the global scale, "change in landuse and land cover considerably alters the Earth's energy balance and biogeochemical cycles, which contributes to climate change and in turn affects the land surface properties and the provision of ecosystem services" (Song et al., 2018). Monitoring landuse changes therefore plays a very important role for actions aiming at environmental sustainability as well as for the conduct of a reasonable and effective land use direction for the future. As land use change is an ongoing process associated with increasingly dynamic socio-economic activities, and the adoption of traditional volatility tracking methods based on maps and paper documents is no longer appropriate. Therefore, the application of modern technologies and techniques in monitoring land use change is essential.
Geographic Information System (GIS) alone or in the integration with other technologies has been being widely applied in the field of natural resources and environmental management around the world, including monitoring and assessment of land use change. For instance, Liu and Yang (2015) monitored land changes in an urban area of Atlanta metropolitan area, Georgia, the United States using satellite imagery, GIS and landscape metrics. Hegazy and Kaloop (2015) assessed land use change and urban growth with GIS and remote sensing techniques in Daqahlia governorate Egypt from 1985 to 2010. Basse et al. (2016) applied a hybrid approach integrating GIS, cellular automata and decision learning tree models to explore the nonlinear relationship between land use types and geospatial driving factors in the cross-border region of Luxembourg. Brovelli et al. (2016) designed a WebGIS platform to publish land use and land cover maps of Europe at a continental scale from that land use change can be assessed. Mansour et al. (2018) employed GIS and CA-Markov modeling techniques to monitor land use and land cover changes in the mountainous cities of Oman.
The land use change detection and assessment of spatially distributed crop water requirements for paddy fields is a great challenge over large areas. Remote sensing is an appropriate tool and has been successfully applied for land use change detection and crop water requirements by the researchers worldwide (Ke et al., 2015; Aik et al., 2020; Almamalachy et al., 2020). In Southeast Asia, Spruce et al. (2020) implemented land use change and land cover (LUCC) mapping for the period 1997-2010 for the lower Mekong - LMB (Laos, Thailand, and Cambodia regions) using Landsat satellite imagery and MODIS combined with analyzing and overlaying maps using QGIS software. In Vietnam, Nguyen (2016) used satellite imagery of Landsat, Spot 5, VNRedsat1, and GIS to study the impact of urbanization on land use change in Hue city in the period of 1995-2013. Huynh et al. (2017) applied GIS and MARKOV chain method to study land use changes in Nha Trang city, Khanh Hoa province. Tran et al. (2020) used Landsat satellite images, GIS, and Delphi method to study the causes and impacts of land use change in the coastal area of Ca Mau province for 30 years from 1989 to 2018.
In this study, Remote Sensing and GIS technologies were used to establish comprehensive databases for the assessment of land use change and crop water requirements in Dong Hung district, Thai Binh province in the period of 2013 - 2018. The essence of this approach is that it is based on a comparison of current land use on maps of land use status of the same area at two different times. This comparison is performed by stacking the maps together using GIS softwares. The method has the advantage of the availability of data sources because at present land use status maps in Vietnam are established in land inventory (every 5 years) and annual land statistics from the commune level to the national level. In addition, the maps of current land use are in digital format (usually stored as a Design File *.DGN of Microstation), and thus can be used directly without having to go through the re-digitization process. Moreover, landsat-8 OLI data was also used to estimate NDVI and to distinguish rice from other land use types using signature analysis. MODIS monthly temperature product (MOD11C3) was also used to estimate mean monthly temperature for further assessment of rice crop water requirements for

Summer-Autumn and Winter-Spring seasons. The results of this study would draw a picture of how land use was changed in recent years as well as providing an information system of land use and land use change for land managers and users. It is expected to be helpful scientific information for land resource management and planning aiming at preserving the environment and natural resources.

Material and Methods

The study area

Dong Hung is a rural district in the central area of Thai Binh Province in the Red River Delta of Vietnam. The district covers an area of 199.299 square kilometers and has a population of approximately 250,000 people. The district has borders with Quynh Phu district to the North, Vu Thu district and Thai Binh city to the South, Thai Thuy district to the East, Hung Ha district to the West. It has a convenient transportation system, connecting the district with Hanoi capital, northern delta provinces, and Hai Phong port, making advantages for economic development. The geographic location of Dong Hung district is presented in Fig. 1.

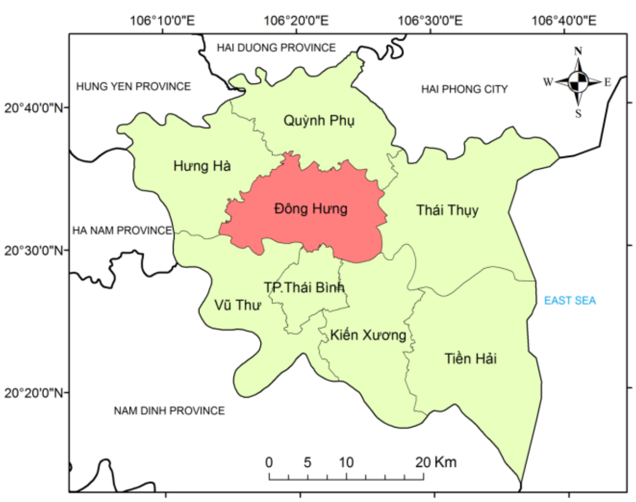

Figure-1. The geographic location of Dong Hung district

Agricultural land use is dominant in Dong Hung district with an area of more than 13,800 ha (as in 2018), accounting for approximately 70% of the total natural area. Among agricultural land, land use for paddy covers the largest area (12,500 ha, accounts for 90% of agricultural land), followed by aquacultural land (863 ha), perennial cropland (573 ha), and other annual croplands (land used by annual crops other than rice – 368 ha). In recent years, there have been considered changes in land use due to the expansion of the industrial sector and urbanization.

Methodology

In the present study, an integrated methodology was applied to establish databases of land use and calculate the change in land use during the 2013-2018 period. The methodology is presented in Fig. 2 and is described in the following sub-sections.

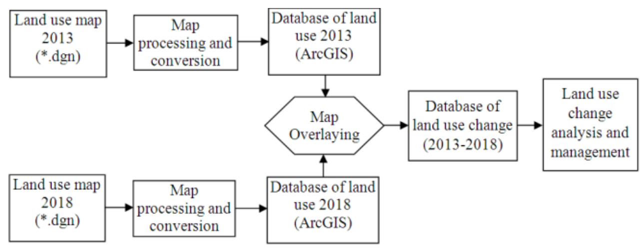

Figure-2. Flowchart of construction of land use databases for land use change analysis and management

Investigation and collection of documents and data

A preliminary survey was conducted to investigate the availability and characteristics of data in the study area. This study collected spatial and attribute data as well as documents related to land use, land use change, and land management.

Spatial data: The study collected digital maps including land use status maps of Dong Hung district in 2013 and 2018, cadastral maps, and administrative maps in *.DGN file format of MicroStation software. The data was collected from the Department of Natural Resources and Environment (DONRE) of the district.

Attribute data: Attribute data on natural conditions, socio-economic conditions, land use, and land management of Dong Hung district were collected from DONRE, Statistical Office and other governmental agencies of the district.

Building GIS databases

In order to build GIS database of land use, land use maps of 2013 and 2018, which are in *.DGN file format, were cleaned and edited using tools and functions of MicroStation software. Land use types were defined following Land Law 2013 (Vietnam National Assembly, 2013) and Circular number 27/2018/TT-BTNMT of Ministry of Natural Resources and Environment (MONRE) regulating land statistics, land inventory, and drawing land use status maps (MONRE, 2018). In MicroStation, each map was divided into appropriate layers and organized in a way that is most convenient for data conversion. The maps were then converted to the Shapefile (*SHP) format in ArcGIS software and defined a Spatial Reference which assigned the georeferencing and coordinate system to the map data (ESRI, 2018). ArcCatalog was used to build Geodatabases that store Feature Datasets and each Feature Dataset store feature classes. Corresponding attribute data was constructed for each spatial database of land use for each year 2013 and 2018. An example of map editing using MicroStation software is shown in Fig. 3.

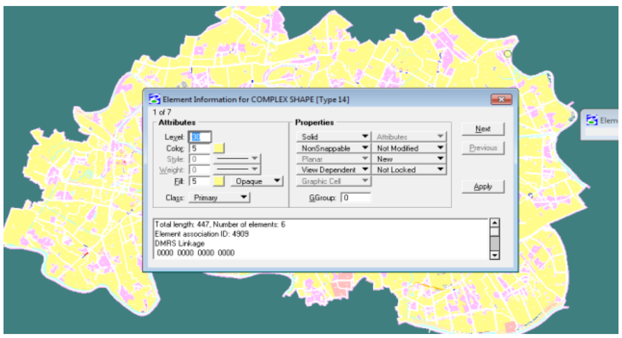

Figure-3. An example of map editing on MicroStation

Map overlaying in GIS

In order to identify land use change between 2013 and 2018, map overlaying was conducted using Spatial Analyst in ArcTool box of ArcGIS software. A map of land use change was then established and a corresponding attribute database was then constructed to store non-spatial information of land use change. Based on this database, land use changes during the 2013-2018 period were visualized and analyzed. Land managers can also use the database for monitoring and management of land use change in the district.

GIS data processing and analysis

Attributes from the stacked map were analyzed using statistical softwares. Specifically, the attribute table of land use change map of the Dong Hung district in the period 2013-2018 was export to Excel file format and consequently converted to a matrix of vertical columns and horizontal rows. From this matrix, a number of statistical methods were used to analyzed and interpreted data.

Assessment of crop water requirement using Satellite Imagery

The Landsat-8 OLI was used to calculate Normalized Difference Vegetation Index (NDVI) using Near Infrared and Red bands as follows;

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad (1)$$

The higher NDVI values were used to distinguish rice crop at its maturity stage from all the other land use types. The NDVI has been used for landuse change detection and for crop monitoring by the researchers worldwide (Townshend and Justice, 1986; Julien et al., 2011; Usman et al., 2015). Crop water requirements is a major challenge (Bastiaanssen et al.,2000) and different earth observation technologies/ systems are being used to estimate it using remote sensing (D'Urso, 2010). In this study MODIS monthly temperature product (MOD11C3) was used to estimate the spatially distributed temperature of the study area for Winter-Spring and Summer-Autumn seasons of 2013 and 2018. The monthly temperature was further used to calculate the potential evapotranspiration using the Blaney–Criddle equation as given below;

$$ET_o = p\,(0.457T_{mean} + 8.128) \qquad (2)$$

Where, T*mean* is the mean temperature in °C and p is the mean daily percentage of annual daytime hours. The crop coefficient of rice for each of its growing stage multiplied with the ET_o to obtain spatially distributed crop water requirements for Winter-Spring and Summer-Autumn seasons of 2013 and 2018.

Results and Discussion

Assessment of land use change in the previous period

Along with human activities and resource exploitation processes for economic development, change in land use is becoming more frequent with a higher intensity. Changes in agricultural land use in Dong Hung district in the period of 2007-2012 are presented in Table 1, whereas changes in non-agricultural land are shown in Table 2.

Table-1. Change in agricultural land between 2007 – 2012

No	Land use	Code	Area 2012	Area 2007	Increase (+) Decrease (-)	%
1	Agricultural land	NNP	14312.72	13969.16	+ 353.56	+2.53
1.1	Land for agricutural production	SXN	13417.69	13163.27	+ 254.42	+1.93
1.1.1	Annual cropland	CHN	12823.57	12833.40	-9.83	-0.08
1.1.1.1	Paddy land	LUA	12517.49	12669.05	-151.56	-1.20
1.1.1.2	Other annual croplands	HNK	306.08	164.35	+ 141.74	+86.24
1.1.2	Perennial cropland	CLN	549.12	329.87	+ 264.25	+80.11
1.2	Aquacultural land	NTS	877.80	794.89	+ 82.94	+10.43
1.3	Other agricultural land (eg. greenhouse, nethouse...)	NKH	17.23	1.01	+ 16.22	+1605.94

Table-2. Change in non-agricultural land between 2007 - 2012

No	Land use	Code	Area 2012	Area 2007	Increase (+) Decrease (-)	%
2	Non-agricultural land	PNN	5237.45	5160.75	+ 76.70	+1.49
2.1	Residential land	OTC	1709,26	1648.31	+ 60.95	+3.70
2.1.1	Rural residential land	ONT	1693.78	1637.69	+ 56.09	+3.42
2.1.2	Urban residential land	ODT	15.48	10.62	+ 4.86	+45.76
2.2	Land with special use	CDG	3065.40	2959.02	+ 106.38	+3.60
2.2.1	Land for construction of offices	CTS	30.56	49.21	-18.65	-37.90
2.2.2	Land for national defense purposes	CQP	6.01	4.93	+ 1.08	+21.91
2.2.3	Land for national security purposes	CAN	2.22	0.33	+ 1.89	+572.73
2.2.4	Land for construction of non-business facilities	DSN	138.84	88.6	+ 49.74	+56.14
2.2.5	Land for non-agricultural production and business	CSK	145.41	45.15	+ 99.99	+221.46
2.2.6	Land used for public purposes	CCC	2743.14	2770.79	-27.65	-1.00
2.3	Land used by religious establishments	TON	32.54	34.36	-1.82	-5.30
2.4	Land used by belief establishments	TIN	23.33	24.15	-0.82	-3.40
2.5	Land used for cemeteries, graveyards	NTD	175.25	195.95	-20.07	-10.24
2.6	Land with rivers, streams, canals...	SON	181,30	172.56	8.74	+5.06
2.7	Land with special-used water surface	MNC	49.21	125.37	-76.16	-60.75
2.8	Other non-agricultural land	PNK	1.17	1.04	0.13	+12.50

From 2007 through 2012, the area of agricultural land increased by 353.56 ha (up 2.53%) due to the increase in land used for agricultural production (254.42 ha), aquacultural land (82.94 ha), and other agricultural lands such as greenhouse and net-house (16.22 ha). It is noticeable, however, paddy land decreased by a considerable area with 151.56 ha. The reduction of paddy land in Vietnam in recent years is a common phenomenon that has been reported by recent studies (Nguyen, 2016; Huynh et al., 2017; Tran et al., 2020). The conversion from rice cultivation to other annual crops such as groundnut, bean, and corn, etc., and to aquacultural purposes with fish farming being the most popular also indicates the transformation within the agricultural sector in response to the need for the market economy and towards achieving higher income from agriculture.

Non-agricultural land increased as a common trend in land use due to the expansion of the residential area, industrial sector, and other commercial and public service purposes. Specifically, residential land expanded by 1648.31 ha including 1637.69 ha of rural residential land and 10.62 ha of urban residential land. The expansion of residential land is inevitable due to population growth and rapid urbanization. During the 2007-2012 period, the population in Dong Hung district grew by approximately 20,000 people (Statistical Office of Dong Hung district, 2014). Land with special use (Land for infrastructure development) increased by 106.38 ha, mostly with a contribution from the increase in land for construction of non-business facilities (49.74 ha) and Land for non-agricultural production and business (nearly 100 ha). However, not all the sub-types of Land with special use increased during the study period as Land for construction of offices was reduced by 18.65 ha and Land used for public purposes was narrowed down by 27.65 ha. Except for a certain proportion of the expansion in residential land made by individuals or households after obtaining consent from a competent authority, changes in Land with special use were the results of the implementation of land use planning in the district.

In this period, unused land increased by 17.44 ha due to the change from 1.18 ha of agricultural land, 7.22 ha of non-agricultural land, and 9.04 ha from other conversions. It means that due to a variety of reasons, a considerable area of land in use was left fallow. In contrast, an area of 19.16 of unused land was converted to agricultural land (13.71 ha), non-agricultural land (0.04 ha), and other conversions (5.41 ha). As a result, the area of unused land decreased by 1.38 ha.

Establishment of databases of land use in 2013 and 2018

The databases of land use of 2013 and 2018 were constructed from maps of land use status following the approach previously described in the Methodology section. The organization of the databases strictly followed the geodatabase storage model of ESRI which structured a geodatabase with three primary components: feature classes, feature datasets, and non-spatial (attribute) tables. For each feature class, a comprehensive attribute table was constructed with appropriate fields which provide sufficient information on land use status of each year. The structure of land use databases of 2013 and 2018 is shown in Table 3 and Table 4, whereas the databases storing on ArcGIS are shown in Fig. 4 and Fig. 5. The database of land use of 2013 includes 2492 land parcels with 32 land use types. These numbers for the database of land use of 2018 are 3473 land parcels with 36 land use types. It is worth noting that on the ArcGIS interface, aliases were displayed instead of field names (Fig. 4 and Fig. 5).

Based on the database established, structured query language (SQL) which is a series of relational functions and operators can be used to create, modify, and query attribute tables and their corresponding spatial data. Moreover, a number of tasks for land management could effectively be performed using SQL and other functions of ArcGIS including basic functions such as information searching, measurement, statistics, calculation, and creating thematic maps, etc. to advance functions using the spatial analyst and network analyst tools.

Table-3. Structure of land use database of 2013

No.	Field name	Field type	Unit	Length	Description
1	STT	Short Integer	N/A	N/A	Order number
2	Madat_2013	Text	N/A	3	Land use code in 2013
3	Mdsd_2013	Text	N/A	50	Land use purpose in 2013
4	Nhomdat_2013	Text	N/A	3	Abbreviation of the major land use type in 2013
5	Vitri_2013	Text	N/A	50	Location of the land parcel
6	Dientich_2013	Float	m^2	10 (2)	Area of the land parcel
7	Ghichu_2013	Text	N/A	50	Other notes

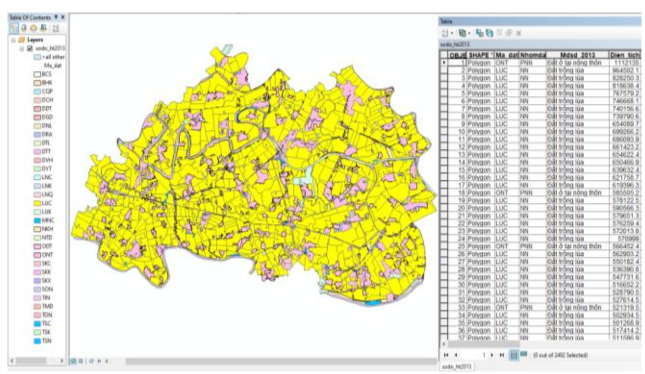

Figure-4. Database of land use of 2013 of Dong Hung district on ArcGIS

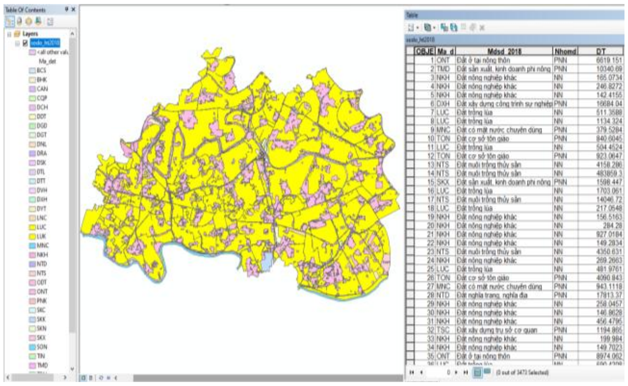

Figure-5. Database of land use of 2018 of Dong Hung district on ArcGIS

Table-4. Structure of land use database of 2018

No.	Field name	Field type	Unit	Length	Description
1	STT	Short Integer	N/A	N/A	Order number
2	Madat_2018	Text	N/A	3	Land use code in 2018
3	Mdsd_2018	Text	N/A	50	Land use purpose in 2018
4	Nhomdat_2018	Text	N/A	3	Abbreviation of major land use types in 2018
5	Vitri_2018	Text	N/A	50	Location of the land parcel
6	Dientich_2018	Float	m^2	10 (2)	Area of the land parcel
7	Ghichu_2018	Text	N/A	50	Other notes

Database of land use change between 2013-2018

From the databases of land use in 2013 and 2018, the map overlaying method was employed to create spatial data of land use change between the two years. An attribute database was then constructed to store non-spatial information of land use change with the change (conversion), the area of change, and the location where the change occurred are the most important information. The structure of the database of land use change between 2013 – 2018 is shown in Table 5, while the database storing on ArcGIS is presented in Fig. 6. It is worth noting that on the ArcGIS interface, aliases were displayed instead of field names.

Table-5. Structure of database of land use change between 2013 - 2018

No.	Field name	Field type	Unit	Length	Description
1	STT	Short Integer	N/A	N/A	Order number
2	Biendong	Text	N/A	10	Land use change
3	Dientich	Float	m^2	10 (2)	Land use change area
4	Vitri	Text	N/A	50	Location of the conversion
5	Giaithich	Text	N/A	50	Description of land use change
6	Ghichu	Text	N/A	50	Other notes

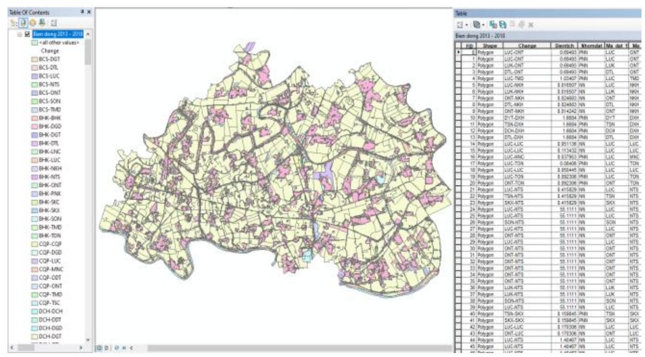

Figure-6. Database of land use change between 2013 - 2018 of Dong Hung district

Similar to the databases of land use of 2013 and 2018, the database of land use change of the period 2013-2018 allows users to perform necessary tasks for managing land resources in general and managing land use change in particular. For land use change monitoring, searching for change information, measurement and statistics of changes, and establishing change thematic maps are the most frequent tasks. Fig. 7 presents an example of searching and statistics of the land parcel that were converted from paddy land (LUC) to rural residential land (ONT). It can be seen that between 2013 and 2018, 1206 land parcels with the purpose of rice cultivation (LUC) were converted to rural residential land (ONT), with a total area of more than 34,766 square meters.

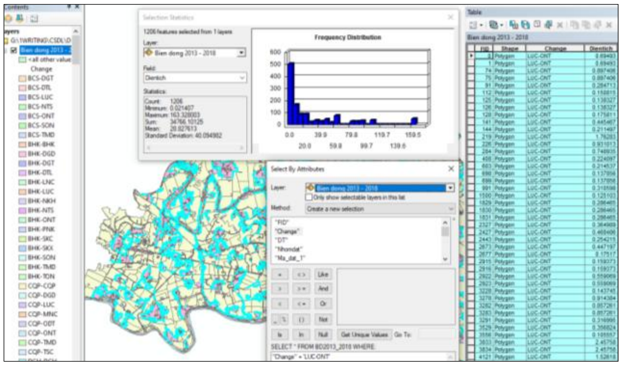

Figure-7. Land use change searching and statistics on the land use change database

Assessment of land use change between 2013-2018

The result of land use change analysis is presented in Table 6 with the abbreviations of land use types defined the same as in Table 1 and Table 2. The analysis clearly shows a decrease in agricultural land and an increase in non-agricultural land. Specifically, in the studied period, agricultural land decreased by 485.9 ha, while non-agricultural land increased by 493.23 ha. Among agricultural land use types, however, only annual cropland was narrowed down by nearly 770ha (note that annual cropland includes paddy land and land for other annual crops such as groundnut, bean, corn, potato, and cassava, etc., of which paddy land area is dominant), meanwhile perennial cropland and aquacultural land expanded by 19.57 ha and 64.57 ha respectively. Although the decline in paddy land is predictable as it is the most common trend in land use conversion in most developing countries, however, since rice is the most important crop which plays a significant role in poverty alleviation and the country's development, this decline would be a great concern for land managers and policymakers. In fact, on a national scale, paddy land accounts for 40% of total agricultural land with approximately 4.0 million hectares, mainly locating in the Mekong River Delta (1.9 million ha) and Red River Delta (0.6 million ha) (Sothy et al., 2017). This helped Vietnam produce more than 46 million tons of rice a year of which 6.6 million tons were exported, making the country the fifth-largest rice producer and the third-largest rice exporter in the world (Maitah et al., 2020).

Table-6. Land use change of Dong Hung district in the period of 2013 - 2018

No		**1**	1.2	1.3	1.4	1.5	**2**	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	**3**	
	Abbre.	**NNP**	CHN	CLN	NTS	NKH	**PNN**	OTC	CDG	TON	TIN	NTD	SON	MNC	PNK	**CSD**	**Decrease**
1	**NNP**	13815.65	12045.43	613.49	941.1	215.63	494.24	56.81	416.83	2.0	1.23	14.96		1.59	0.82	2.83	**497.07**
1.2	CHN	12336.34	12041.82	37.61	77.62	179.29	484.5	51.52	414.34	1.47	0.9	14.96		0.49	0.82	2.73	**781.75**
1.3	CLN	590.87	1.93	573.49		15.45	3.15	2.31	0.51	0.24	0.09					0.1	**20.63**
1.4	NTS	871.56	1.68	2.39	863.48	4.01	6.24	2.91	1.98	0.01	0.24			1.1			**14.32**
1.5	NKH	16.88				16.88	0.35	0.07	0	0.28							**0.35**
2	**PNN**	4.1	2.4	0.2	1.27	0.23	5233.47	1709.75	3075.6	32.53	22.72	175.16	182	34.54	1.17		**4.1**
2.1	OTC	0					1709.26	1708.4	0.86								**0.86**
2.2	CDG	2.53	1.88	0.1	0.38	0.17	3062.88	1.35	3061.4		0.02			0.11			**4.01**
2.3	TON	0					32.54		0.3	32.24							**0.3**
2.4	TIN	0					23.33		0.34	0.29	22.7						**0.63**
2.5	NTD	0.06	0.06				175.19		0.03			175.16					**0.09**
2.6	SON	0					181.3		0				181.3				**0**
2.7	MNC	1.51	0.46	0.1	0.89	0.06	47.8		12.67				0.7	34.43			**14.81**
2.8	PNK	0					1.17		0						1.17		**0**
3	**CSD**	7.07	6.15	0		0.92	3.09		3.0					0.09		44.59	**10.16**
	Increase	**11.17**	**12.16**	**40.2**	**78.89**	**199.9**	**497.33**	**58.16**	**434.03**	**2.29**	**1.25**	**14.96**	**0.7**	**1.79**	**0.82**	**2.83**	
	Change	**-485.9**	**-769.59**	**19.57**	**64.57**	**199.55**	**493.23**	**57.3**	**430.02**	**1.99**	**0.62**	**14.87**	**0.7**	**-13.02**	**0.82**	**-7.33**	

However, Vietnam's paddy land area has been shrinking in recent years, threatening the national food security policy and export capacity. According to Rural Development Information Center (2009), on average, Vietnam's paddy land area decreased by 59,000 ha a year. Taking the reduction in the area of paddy land into a serious consideration, since 1995, Vietnam Government has The Government has issued a directive on "Overcoming the reduction of paddy land and land used by high-value agricultural crops due to transferring to other purposes". Since Thai Binh province is the heart of the Red River Delta and making a critical contribution of rice production in the region, maintaining paddy land in the province in general and in Dong Hung district, in particular, is an important mission for land management and planning actions of the province and the district.

The decrease in annual cropland is in reflection with the increase in other agricultural lands including perennial cropland (+19.57 ha), aquacultural land (64.57 ha), and other agricultural lands (eg. greenhouse, net-house, etc. + 199.55 ha). Although on the one hand, the reduction in paddy land is of great concern for the rice production sector, on the other hand, the increase of other agricultural lands implying a promising restructure of the agricultural sector. In fact, the transformation from rice and other annual crop cultivation with low economic value to other crops or aquaculture is necessary in the market economy. A significant increase in greenhouse and net-house agriculture is also a positive signal for agriculture in the study area since these are modern types of agriculture commonly associated with modern technologies.

During the study period, along with the reduction in agricultural land, non-agricultural land increased considerably, by 493.23 ha, mainly due to the increase in residential land (57.3 ha) and land with special use (430.02 ha). It is worth noting that land with special use includes: land for construction of offices; land for national defense or security purpose; land for construction of non-business facilities, including the construction of cultural, social, health, education and training, sports, science, and technology, and diplomatic facilities and other non-business facilities; land for non-agricultural production and business, including land for industrial parks, industrial clusters, export processing zones; land for trading and service; land of non-agricultural production establishments; land used for mining activities; and land for production of building materials, and pottery; land used for public purposes such as land use for transportation, irrigation, energy facilities, post and telecommunications facilities, markets, waste dumping, and treatment, etc. The expansion of residential land and land with special use indicates the progress of urbanization, industrialization, and modernization processes. This is the common trend of land use change in most regions of the world in general and in developing regions in particular.

Another positive signal of development is that the area of unused land decreased (by 7.33 ha), meaning that the area of unused land was utilized by agricultural and non-agricultural purposes. In fact, during the study period, 10.16 ha of unused land was brought into use. Specifically, 7.07 ha of unused land was converted to agricultural land including 6.15 ha of annual cropland and 0.92 ha of other agricultural lands, meanwhile, 3.09 ha was converted to non-agricultural land including 3.0 ha of land with special use and 0.09 ha of land with special-used water surface. However, an area of 2.83 ha of agricultural land, including 2.73 ha of annual cropland and 0.1 ha of perennial cropland was left unused. The waste of agricultural land in highly productive agricultural areas like the Red River Delta in general and in Thai Binh province in particular was not common previously but is increasing presently due to the overexploitation leading to degradation of soil fertility, and additionally due to the impact of climate change. This issue would draw the attention of land managers as the Vietnam Government has recently promulgated an action plan to implement Conclusion No. 81-KL/TW dated July 29, 2020 on "Ensuring national food security until 2030" which directing economically, efficiently and sustainably use of land and water resources, and terminating the fallow of agricultural land.

Concerning the methodology, from the study, the method of assessment and management of land use change using map overlaying and GIS database was proved to be convenient and effective. However, in order for this approach to achieve a high level of accuracy, land use status maps must be produced using the same method, eg. from land surveying and measuring or satellite imagery classification. In addition, the limitation of land use status maps in this study is that the maps represent land use status for a year, while land use maps for sub-annual scale (eg. monthly or seasonal scale) are lacking. These lead to the difficulty or impossibility to determine changes in land use at specific times.

Crop water requirements

The land use of winter-spring for 2013 and 2018 is presented in Fig. 8 (a). Most of the district is covered with the rice crop for the same season of both the years. In 2013, the northern part of the district is covered with other vegetation which is replaced by the rice crop in 2018. In winter-spring season of 2018, there are some uncertainties in the satellite imagery and some bare soil pixels are misclassified as rice which was clearly shown as bare soil in 2013. The bare soil and water pixels are also very clear in 2013 but little error is also there in 2018 for these mentioned classes.

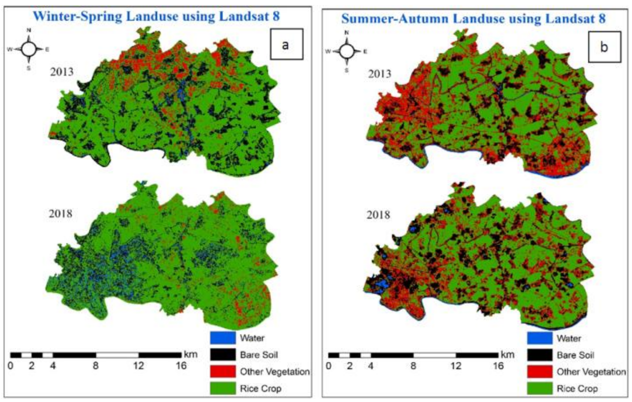

Figure-8. Winter-Spring (a) and Summer-Autumn (b) Landuse for 2013 and 2018

The land use of summer-autumn for 2013 and 2018 is presented in Fig. 8 (b). The bare-land water pixels are similar to each other in both years which reveals a good accuracy of the classification. The other vegetation is more in the western part of the district in the summer-autumn season while the southeastern part also covers other vegetation in 2013. The overall accuracy of the summer-autumn season for 2013 and 2018 is better as compared to the winter-spring season due to clouds in the latter case.

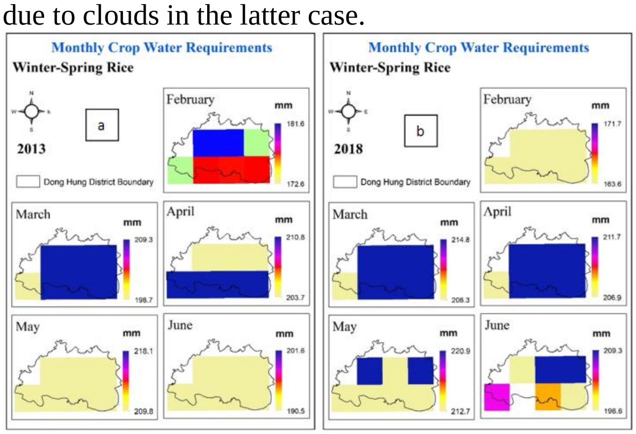

Figure-9. Winter-Spring Rice Crop Water Requirements for 2013 (a) and 2018 (b)

The crop water requirements of the winter-spring season for both years are presented in Fig. 9a and 9b. For 2013, the minimum monthly crop water requirement was observed in February (172 mm) and the maximum was recorded in May (218mm). For 2018, the minimum monthly crop water requirement was observed in February (163 mm) and the maximum was recorded in May (220mm). The possible reason for lower crop water requirements is low temperature and low crop coefficient value in February. The possible reason for higher crop water requirement in May instead of June may be the higher crop coefficient value due to crop maturity in May.

The crop water requirements of the summer-autumn season for both years are presented in Fig. 10 (a & b). For 2013, the minimum monthly crop water requirement was observed in November (120 mm) due to low temperature and lower crop coefficient value, and the maximum was recorded in August (224 mm) due to high temperature and higher crop coefficient value. For 2018, the minimum monthly crop water requirement was observed in November (120 mm) and the maximum was recorded in August (256 mm).

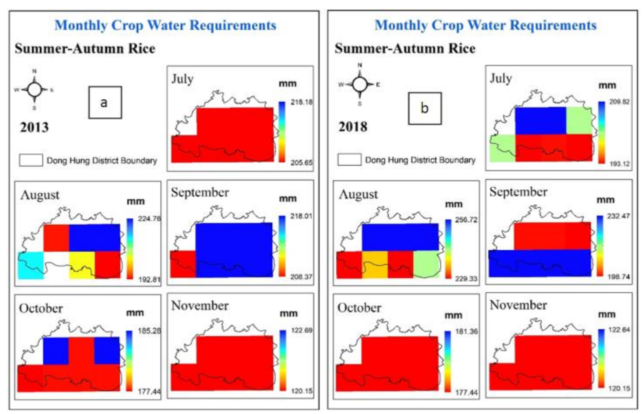

Figure-10. Summer-Autumn rice crop water requirements for 2013 (a) and 2018 (b)

These figures are lower in comparison with those reported for the Mekong River Delta in southern Vietnam (Lee and Dang, 2017). This is due to the difference in temperature between the two regions: the minimum, average, and maximum temperatures in the Red River Delta area all much lower than those in the Mekong River Delta. From the results of the study, it can be seen that between 2013 and 2018 there were slight changes in crop water requirements for both the Winter-Spring and Summer-Autumn seasons, except for a considerable increase in the crop water requirements in August, which changed from 224 mm

in 2013 to 256 mm in 2018. This may be due to the change in temperature between the years. The increase in crop water requirement is predicted to be more common in the future due to the impact of global climate change (Rao et al., 2011; Huang et al., 2016; Boonwichai et al., 2018).
In the present study, there is a lack of observed potential evapotranspiration to validate the estimated crop water requirement, field study is therefore recommended in further research to observe the potential evapotranspiration for the main crops, especially for rice in the study area. In addition, the crop coefficient, which is the main factor determining crop water requirement, depends on many factors, such as the biological characteristics of the crop, soil and cultivation conditions, etc. so crop coefficients change along with time. Furthermore, the same crop usually has different varieties, and different varieties have different crop coefficients. Thus, more detailed investigations of water requirements for each type of crop with finer spatial resolutions are suggested. As rice is the main crop in the study area, the finding of this study on crop water requirement is expected to be useful information for agricultural water management aiming at sustainable rice cultivation in the area.

Conclusion

In this study, the modern technology of GIS and remote sensing was applied for the assessment of land use change and crop water requirements in Dong Hung, a typical agricultural district in the Red River Delta of Vietnam. The study found that during the study period, there was a complicated conversion among land use types, but in general agricultural land decreased by 485.9 ha, while non-agricultural land increased by 493.23 ha with mostly the expansion of residential land. Among agricultural land uses, however, only annual cropland, which mostly includes paddy land was narrowed down by nearly 770 ha. Analysis from satellite imageries shows that between 2013 and 2018 there were slight changes in crop water requirements for both the Winter-Spring and Summer-Autumn seasons, except for a considerable increase in the crop water requirements in August. The decline in paddy land in this study should be taken into account for land management and planning at all levels. In addition, improving water storage and irrigation systems will ensure water supply for agriculture.

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Contribution of Authors

Giang PQ: Designed the study, Data collection, constructed land use databases, Analyzed land use change, and wrote and edited the manuscript
Ali S: Performed satellite imagery classification using collected data and calculated crop water requirements