Spatial-Temporal Analysis of Changes in Rice Field Use in 2012–2021 and Their Impact on Rice Production in Kartasura Subdistrict, Sukoharjo Regency

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Abstract. This study analyzed the spatial and temporal changes in land use and its relationship with rice production, using a secondary data analysis method. The results indicate that land conversion can be observed in every village in the Kartasura Subdistrict. The highest land area change occurred in the Pucangan village, at 322,766.3 m^2, and the lowest in the Kartasura village, at 7,265.2 m^2. The largest change in the use of irrigated paddy fields for residential purposes was in the Pucangan village, at 278,726.3 m^2, and the smallest in the Kartasura village, at 1,766.1 m^2. The average change in the use of irrigated paddy fields for residential purposes from 2012 to 2021 was 95,931.5 m^2. The study found that land use in the Kartasura Subdistrict changed between 2012 and 2021, with a decrease in irrigated rice fields by 1,348,224.2 m^2, an increase in residential areas by 1,226,065.9 m^2, an expansion of industrial buildings by 176,419.7 m^2, a decrease in built-up land by 25,609.6 m^2, and a decrease in mixed gardens by 26,339.6 m^2. The factors driving land conversion include low grain prices, the scarcity of fertilizer subsidies, high land processing and maintenance costs, high land values in the subdistrict, and weak monitoring and supervision by the local government of Sukoharjo. The results also show that the conversion of agricultural land into non-agricultural land has dramatically reduced rice production in the Kartasura Subdistrict. In 2012, rice production reached 5,570 tons, but by 2021, it had decreased to 1,238 tons.

Keywords: analysis · spatial · temporal · changes in land use · rice production

1 Introduction

Essentially, agricultural land conversion occurs because of competition in land use between agricultural and non-agricultural sectors. The competition arises as a result of several economic and social phenomena, including the limited availability of productive land resources, the development of regional infrastructure, and the dynamics of population growth and economic growth.

The increase in population will entail impacts on land needs, especially for housing. The less availability of land for settlements in urban areas and higher prices provoke

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people to switch to rural areas, hence shifting, namely the search for land in suburban areas. The change in land use is mostly a change from agricultural land (rice fields) to non-agricultural.

The phenomenon of land conversion from agricultural to non-agricultural will have positive and negative effects. The positive and negative impacts depending on the type of land use and its management. For instance, if the land used for the industrial sector, education, health, and land use management is well controlled, these changes will have a positive impact such as improved employment and the community economy. If the land change is used for settlement development only and the land use management is uncontrolled, it will bring the opposite, among others, declining productivity of the agricultural sector, social conflicts, and disasters.

Kartasura Subdistrict is a buffer subdistrict of Surakarta City with rapid regional development. The land conversion in Kartasura Subdistrict is generally the shifting from agricultural to non-agricultural (housing, health facilities, educational facilities, economic facilities, and industry). Analysis of changes from agricultural land to non-agricultural in the Kartasura Subdistrict is essential because land use changes have been shown to vastly and significantly reduce agricultural land. The real impact that may result from this change is the decreasing food crop (rice paddy) production. In 2012, the harvest area was 1,080 Ha and the production of rice fields reached 5,570 tons. In 2021, the harvest area was only 439 Ha with a production of 1,238 tons.

The results of field surveys that had been conducted show that the construction of housing clusters in the research area is increasing. The increasing area of land conversion from paddy fields, mixed gardens, and built-up land to uncontrolled non-agricultural (housing, industries) in Kartasura Subdistrict within a certain period of time may cause: (a) decreased productivity of food crops in an area (Parven et al., 2022; Molotoks et al., 2021; Mcconnell & Vina, 2018; Su et al., 2021) and (b) increased potential for disasters such as floods (Sugianto et al., 2022; Adnan et al., 2020), landslide (Rabby et al., 2022; Liu et al., 2021; Firdaus et al., 2021), and environmental ecosystems (Mubarokah & Hendrakusumah, 2022). The declining food crop production will bring an impact on the declining food security of the region. Low food security will increase the number of food imports by the government, which will impose a negative impact on farmers and will be threatened the sustainability of its activities.

One of the efforts that can be performed to control the occurrence of land conversion is monitoring the pattern of development. The pattern of land conversion in a region can be expressed by spatial and temporal models or spatial and temporal models (Paryono et al., 2016; Maulana et al., 2020; Fahad et al., 2020; Amini Parsa & Salehi, 2016). The spatial-temporal model represents the observed natural phenomena in spatial (space) and temporal (time) dimensions (Anna, 2021).

Data analysis on spatial-temporal models considers interregional spatial dependencies of observations and correlations of one or more time lag Fields (Jumadi et al., 2020). Temporal observation tends to be independent but forms a time series. The focus of the study of spatial-temporal models is the approach of spatial aspects or space, temporal aspects or time, and a combination of both.

Along with the development of geospatial technology, spatial and temporal models of land conversion can be processed, analyzed, and presented timely and accurately using Geographic Information System technology (Setianto et al., 2021; Ashlihah et al., 2016). GIS technology was applied in this study as it has several functions, among others: measurement, mapping, monitoring (Setiawan et al., 2020; Wiguna et al., 2022), and modeling. The function of GIS technology in this study is measurement, mapping, and monitoring.

2 Methods

The area of the Kartasura Subdistrict (Fig. 1) in 2021 was recorded at 2,081 Ha or approximately 4.25% of the area of the Sukoharjo Regency (48,912 Ha). The total area of the Kartasura Subdistrict is mostly used for yards (including housing, settlements, buildings, and so on) which covers 72%. Land use of rice fields encompasses 21% and other purposes is 7%. Other lands include swamps, roads, channels, sports fields, and cemeteries, among others. Kartasura Subdistrict is situated 121 m above sea level. The distance from the subdistrict to Sukoharjo Regency is 23.00 km. The number of rainy days in 1 (one) year is 102 days with an average rainfall of 25 mm in 2020. Based on spatial perspective, Kartasura Subdistrict can be seen in Fig. 1 and the boundaries of Kartasura Subdistrict include: (a) North: Karanganyar Regency, (b) East: Surakarta City, (c) South: Gatak Subdistrict, and (d) West: Boyolali Regency.

Spatial analysis is a data analysis that refers to the aspect of space, while temporal analysis refers to time. Spatial analysis is used to assess the distribution of land conversion in a certain area. Temporal analysis is used to assess the number of changes from land conversion based on time.

Spatial and temporal analysis of land use in this study was conducted by utilizing Geographic Information System (GIS) technology. GIS function used in this study is the overlay function map. Spatial and temporal analysis in this study commenced by downloading sentinel-2 images in 2012 and 2021 obtained from the USGS Earth Explorer website.

Furthermore, the obtained sentinel-2 images were then processed using ENVI 5.3 software. The method used to process sentinel-2 image data into land use data is the supervised method. Supervised classification is an image classification using a trace area, which selects an object in the image by creating a polygon in the image area such as a residential area, which then the application will search for a similar area as the polygon that has been created. Classification of land use types in this study refers to the classification of land use types based on RSNI-3 on land cover classification with some modifications. This modification is necessary to adjust to the real land use conditions in the examined area.

After the type of land use was obtained, the next step was to test the accuracy of the interpretation accuracy of the classification of land use types using the confusion matrix method. Confusion matrix is an algorithm used to test classification results. Several terms represent the results of the classification process in the confusion matrix, namely true positive, true negative, false positive, and false negative. A high accuracy value indicates a good classification result and vice versa; if the accuracy value is low, then the classification result is insufficient.

$$\text{Accuracy} = \frac{\text{TP} + \text{TN}}{\text{TP} + \text{TN} + \text{FP} + \text{FN}} \tag{1}$$

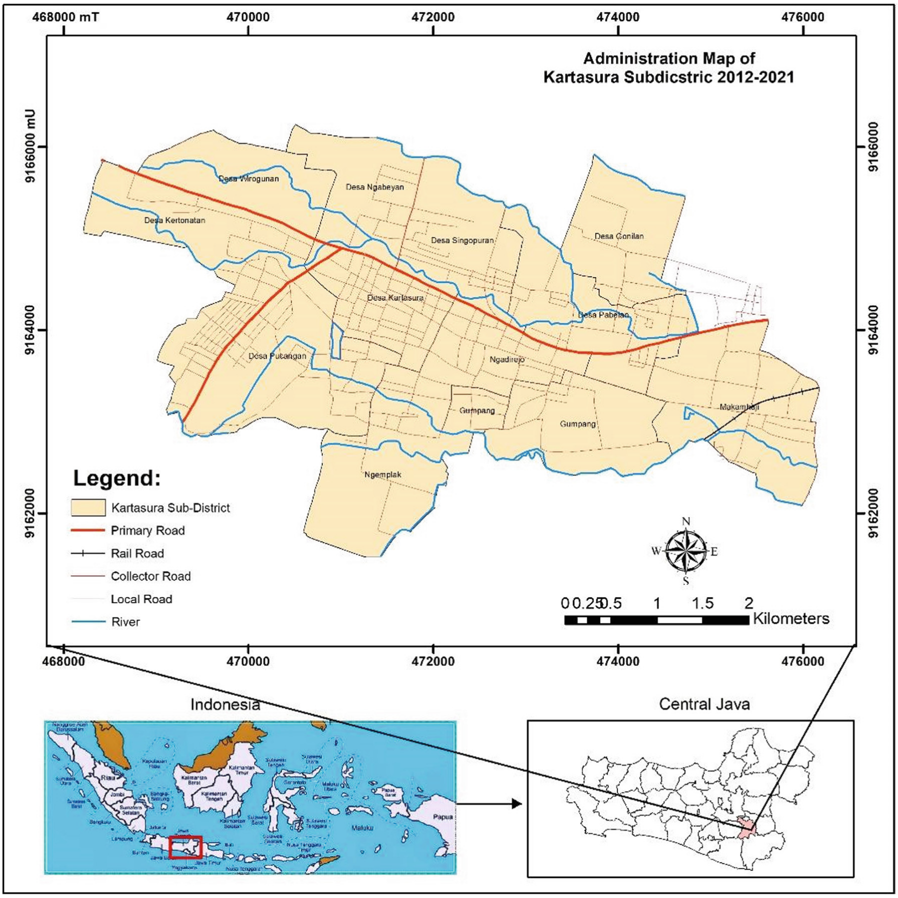

Fig. 1. Administrative Map of Kartasura Subdistrict

Description:

TP: True positive, TN: True negative, FP: False positive, FN: False negative

The accuracy test of land use classification results obtained from the interpretation of sentinel-2 images was carried out using the Matrix confusion method. The classification accuracy test was completed by the overall accuracy method. However, this accuracy is usually overestimated, so it is rarely used as a good indicator to measure the success of a classification as it only utilized pixels located on the diagonal of a contingency matrix. It can be calculated mathematically by the following formula.

$$OA = \frac{N \sum_{i=1}^{r} X_{ii}}{N} 100\% \tag{2}$$

Currently, the recommended accuracy is Kappa accuracy (Jaya, 2014). The accuracy uses all the elements in the Matrix. Kappa accuracy is mathematically calculated by the following formula.

$$K = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} X_{i+}X_{+i}}{N^2 - \sum X_{i+}X_{+i}} \quad (3)$$

Description:
OA: Overall Accuracy
Xii: diagonal values of the i-th row and i-th column contingency matrices
Xi: number of pixels in the i-th column
X = i: number of pixels in the i-th row
N: number of pixels in the example

Spatial and temporal analysis of changes in rice field use to non-rice fields in 2012 and 2021 was conducted using the map overlay method with GIS technology. Factors causing land conversion in Kartasura Subdistrict, Sukoharjo Regency can be understood by field surveys through interview techniques with farmers. The material interviewed is about the triggering or driving factors of the land conversion trend.

The analysis method used to assess the factors that cause changes in the use of rice fields to non-rice fields in the study area is geographic analysis. Geographical analysis is

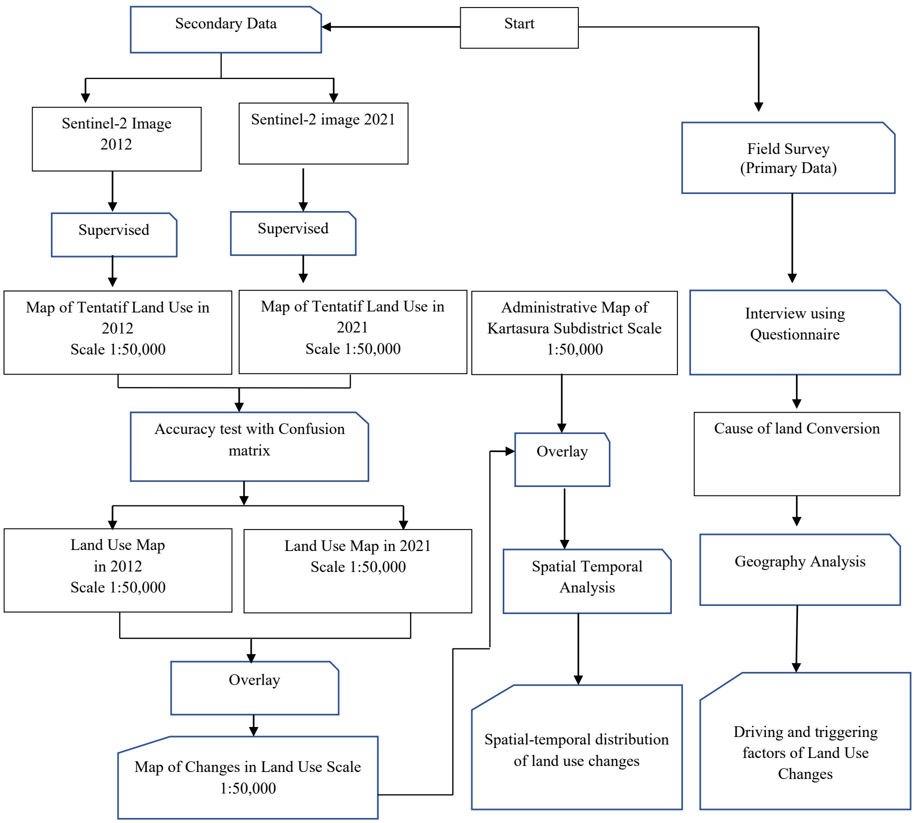

Fig. 2. Research Flow Chart

a method with a main emphasis on the distribution of "elements of space". This analysis is aimed to answer related geographic questions, i.e. what, when, where, why, who, and how. Further, the stages of spatial and temporal analysis of changes in the use of rice fields to non-rice fields in the Kartasura Subdistrict, Sukoharjo Regency can be seen in Fig. 2.

3 Result and Discussion

3.1 Test Results of Land Use Classification Accuracy

The accuracy test of land use classification results obtained from the interpretation of sentinel-2 images was carried out using the matrix confusion method. The classification accuracy test is commonly completed by the overall accuracy method. However, this accuracy is usually overestimated, so it is rarely used as a good indicator to measure the success of a classification as it only utilized pixels located on the diagonal of a contingency matrix (Tables 1 and 2).

Kappa index value (0.9466994) indicates that the classification of land use types using sentinel-2 imagery with the results of field surveys has a very strong agreement or accuracy and falls into the category of very good, thus the Sentinel-2 imagery can be used as an interpretation of land use.

3.2 Spatial-Temporal Analysis of Land Use Changes in 2012–2021

Changes in land use in the research area were obtained from the overlay results between the 2012 and 2021 land use maps. Classification of types of land use in the research

Table 1. Classification of Kappa Coefficient Values

No	Kappa Value (K)	Description
1	>0.75	Very Good
2	0.04–0.75	Good
3	<0.40	Weak

Source: Murti (1997)

Table 2. Kappa Index Confusion Matrix Results

Overall Accuracy	97.62
Kappa Index	0.9466994
N	421
X_{ii}	411
N_{xii}	173,031
$X_i + X_{+i}$	98.255
N^2	177,241

area is based on RSNI-3 with a scale of 1:50,000, therefore in general, the types of land use in the research area include residential areas, irrigated rice fields, mixed gardens, industrial buildings, and built land.

Spatial-temporal study in this study focuses on the time and space elements. The time describes in the period 2012–2021 what types of land use changed and how much the area changed. While the space focuses on the location where the change takes place. The results of the classification of land use types in Kartasura District in 2012 and 2021 are provided in Table 3.

Table 3 shows that in 2012 the highest land area was the residential area of 12,898,714.2 m^2 and the lowest land area is mixed gardens of 360,467.2 m^2. In 2021, the highest land area remained the residential area of 14,124,780.1 m^2 and the lowest land area was mixed gardens with 334,127.6 m^2. The declining number of irrigated rice fields predominantly will have an impact on rice production (Andrias et al., 2017; Harini et al., 2019). Reduced rice production will result in reduced rice availability, thereby reducing regional food security (Bandumula, 2017; Riaz & Zaman, 2021). In regards to spatial, land use in Kartasura Subdistrict in 2012 and 2021 is displayed in Fig. 3 and Fig. 4.

From 2012 to 2021, the type of irrigated paddy fields used contracted by 1,348,224.2 m^2, residential area surged by 1,226,065.9 m^2, industrial buildings increased by 176,419. 7 m^2, built-up land decreased by 25,609.6 m^2, and mixed gardens reduced by 26339.6 m^2. Based on the temporal element, the trend of land use changes can be seen in Fig. 5.

The increase in the residential area demonstrates that the development of the area in the Kartasura Subdistrict grows rapidly (Murtadho et al., 2018; Setiaji et al., 2016). Field surveys conducted also indicate that the vast majority of the existing agricultural land has been converted to settlements. The changes are visually presented in Fig. 6.

Shifts in land use types in Kartasura Subdistrict from 2012 to 2021 were observed in industrial building land, mixed gardens, irrigated rice fields, and built-up land. Land use of industrial buildings switches function in residential areas, built-up land switches

Table 3. Types and area of Land Use in 2012 and 2021 in Kartasura Subdistrict

No	**Types of Land Use**	**Area in 2012 (m^2)**	**Area in 2021 (m^2)**	**Area Change (m^2)**	**Description**
1	Paddy Irrigation	6,825,382.5	5,477,158.3	−1,348,224.2	Reduced
2	Residential Areas	12,898,714.2	14,124,780.1	1,226,065.9	Increased
3	Industrial Buildings	442,515.8	618,935.5	176,419.7	Increased
4	Built-up Land	454,985	429,375.4	−25,609.6	Reduced
5	Mixed Gardens	360,467.2	334,127.6	−26,339.6	Reduced

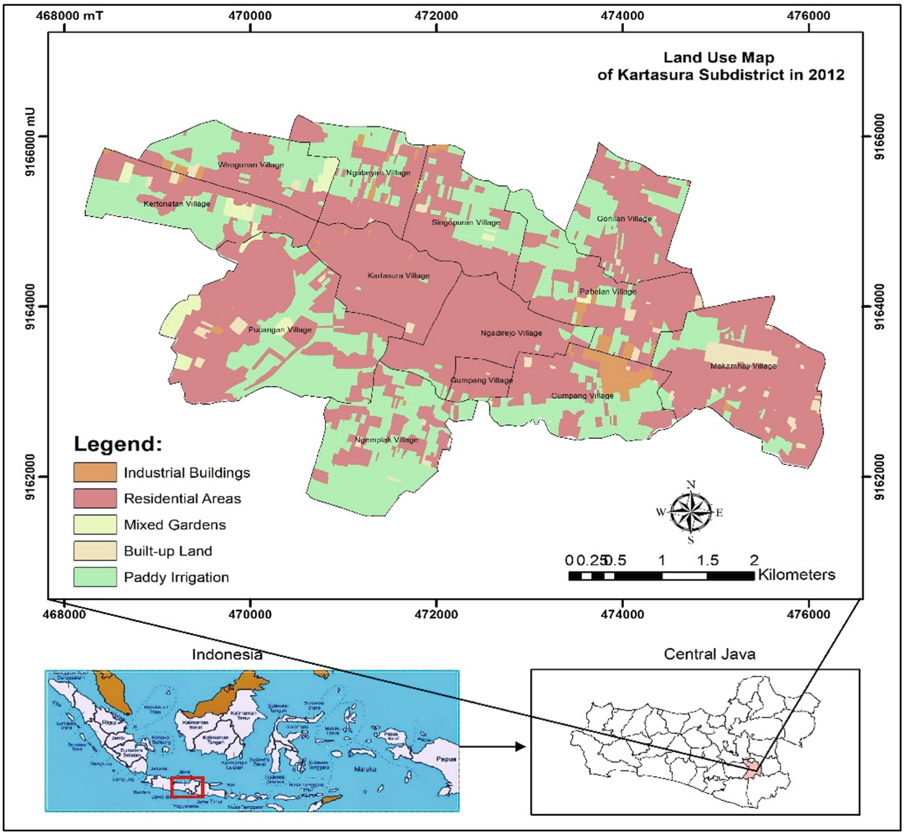

Fig. 3. Land Use Map of Kartasura Subdistrict in 2012

function in industrial buildings and residential areas, mixed garden land switches function in residential areas, and irrigated rice fields switches function in industrial buildings, built-up land, and residential areas. The land conversion is described further in Table 4.

Table 4 shows that the land use changes were found in irrigated paddy fields that switched to industrial buildings, residential areas, and built-up land. The transfer of land functions from irrigated rice fields (agriculture) to non-agriculture needs to be considered and monitored by the Local Government of Sukoharjo regency so that regional food security is maintained and the trend of change in the future is decreasing. The fact of the conversion of agricultural land to non-agricultural functions in the Kartasura Subdistrict, the Local Government of Sukoharjo Regency is expected to make regulations governing the transfer of land functions and regulations that support regional food security. Meanwhile, in a spatial perspective, wide land conversion occurring in the Kartasura Subdistrict also happened in every existing village. More details can be seen in Table 5.

Based on Table 5, it can be inferred that the most types of land use changes in Pabelan Village are five types of land use changes, namely built-up land became into industrial buildings, built land into residential areas, irrigated rice fields into industrial

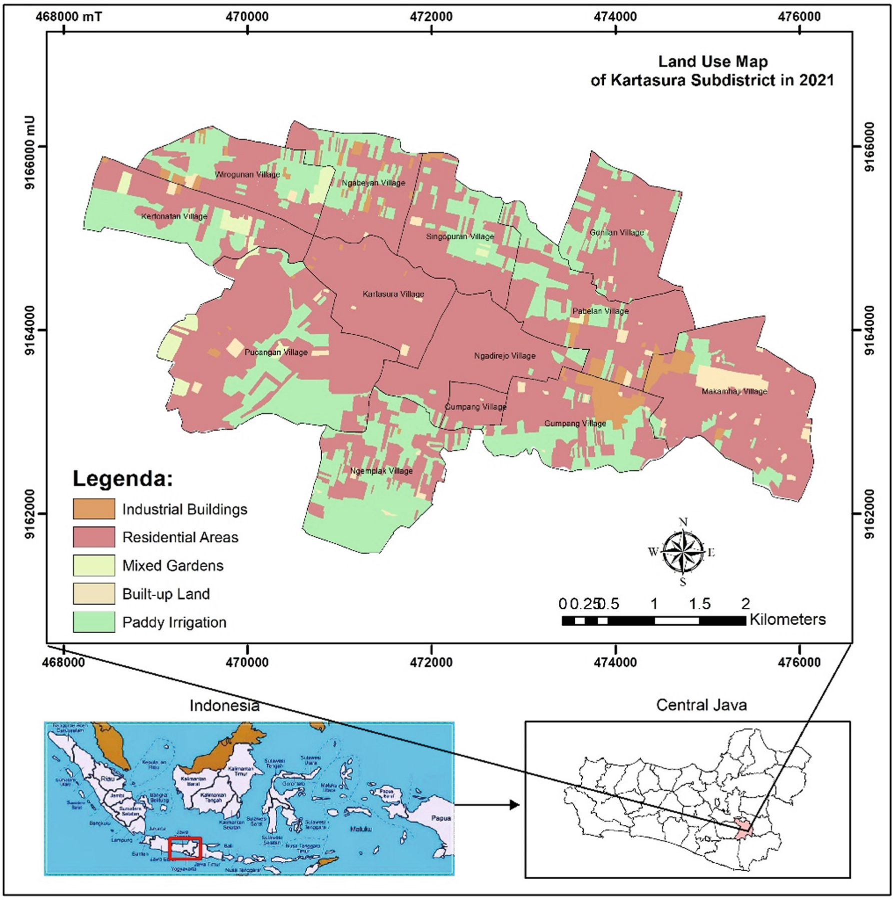

Fig. 4. Land Use Map of Kartasura Subdistrict in 2021

buildings, irrigated rice fields into residential areas, and irrigated rice fields into built land. Meanwhile, the lowest change in Ngadirejo village was only one type of change, from irrigation fields to residential areas. The highest land area change occurred in the village of Pucangan totaling 322,766.3 m^2 and the lowest area was in Kartasura village of 7,265.2 m^2. The largest change in the use of irrigated paddy fields in residential areas was in the Pucangan village of 278,726.3 m^2 and the lowest in the Kartasura village amounted to 1,766.1 m^2. The average change in the use of irrigated paddy fields in residential areas during the period from 2012 to 2021 amounted to 95,931.5 m^2. Spatial changes in the type of land use in the study area can be seen in Fig. 7. Based on Fig. 7, it can be seen that the area experiencing changes from 2012 to 2021 was 1,446,455.4 m^2 or 6.89% of the total area of the Kartasura Subdistrict.

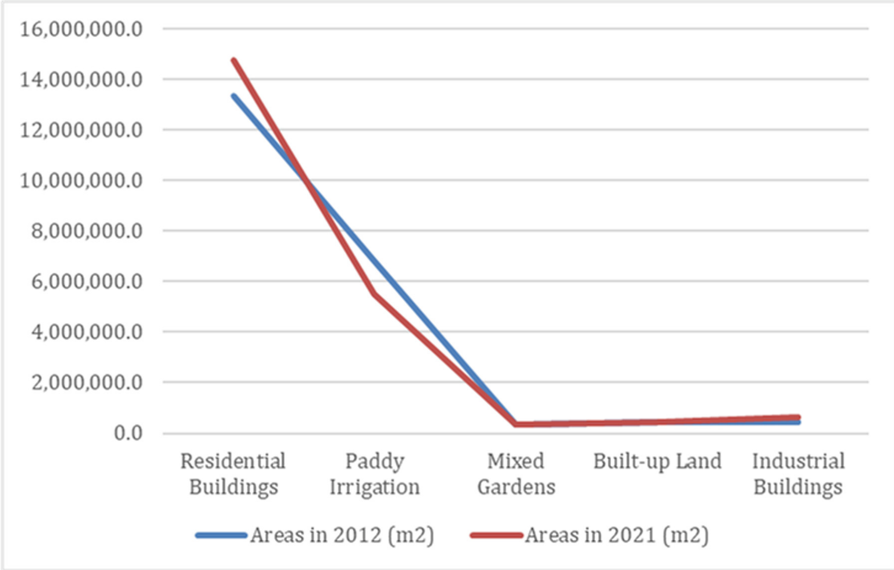

Fig. 5. Graph of land use trends in 2012–2021 in Kartasura Subdistrict

Fig. 6. Transfer of Agricultural Land to Residential in Kartasura Subdistrict

Table 4. Types of Land Use Changes from 2012 to 2021 in Kartasura Subdistrict

No	Types of Land Use Changes from 2012 to 2021
1	Industrial Buildings-Residential Areas
2	Mixed Gardens-Residential Area
3	Built - Up Land-Industrial Buildings
4	Built - Up Land-Residential Area
5	Irrigation Fields-Industrial Buildings
6	Irrigation Fields-Residential Area
7	Irrigation Fields-Built-up Land

3.3 Driving Factors and Triggers of Land Conversion

Based on the results of interviews with respondents, there are several factors that trigger and encourage land conversion in the research area. These factors include: (a) the selling price of grain agricultural products is still low (Santoso, 2016), which is about 7,000.00 IDR–8,000.00 IDR per kg, (b) the availability of subsidized fertilizers is increasingly scarce and the price of non-subsidized fertilizers are expensive (Sakmawati et al., 2019). The current price of non-subsidized Urea fertilizer per 25 kg of urea is 400,000.00, IDR (c) the cost of land processing and rice plant care is expensive and incomparable with the results obtained, (d) the selling value of land in Kartasura District which is a buffer zone of Surakarta City is currently relatively high, reaching more than 1,000,000.00 IDR^2, therefore many farmers are selling their land to be used as housing, and (e) the poor monitoring and supervision of the Local Government of Sukoharjo regency in spatial planning and land use policies so that many rice fields are turning into settlements.

Looking at the various triggering and driving factors behind the conversion of land from rice fields to non-rice fields, there are several solutions provided so that existing rice fields remain productive. The solutions include: (a) local governments implementing the absorption of rice production from farmers at competitive prices, (b) ensuring the availability of subsidized fertilizers to farmers adjusted to the area of land cultivated, (c) providing incentives for farmers, (d) socializing with farmers related to sustainable food agricultural land, and (e) monitoring and supervision of spatial planning, and the importance of land use to be improved.

3.4 Impact of Land Use Change on Rice Production

Changes in the type of land use of lowland rice that occurred in the Kartasura Subdistrict in the period 2012 to 2021 had an impact on rice production. Data from Statistics Indonesia in 2012 show that in 2012 the harvest area of 1,080 Ha and the production of paddy rice was 5,570 tons. In 2021, the harvest area was only 439 Ha with a production of 1,238 tons. Land changes that occur have a correlation with the area of harvest and rice yields in the Kartasura Subdistrict.

Table 5. Land conversion Area in Every Village in the Kartasura Subdistrict

No	Types of Land Use Changes from 2012 to 2021	Villages	Conversion Area (m^2)
1	Irrigation Fields-Residential Area	Gonilan	161,422.9
2	Industrial Buildings-Residential Areas	Kartasura	23.9
	Irrigation Fields-Residential Area		1,766.1
	Irrigation Fields-Built-up Land		5,475.2
3	Built - Up Land-Residential Area	Kertonatan	6,936.7
	Irrigation Fields-Residential Area		62,760.7
4	Industrial Buildings-Residential Areas	Ngabeyan	235.8
	Built - Up Land-Residential Area		6,525.4
	Irrigation Fields-Industrial Buildings		27,752
	Irrigation Fields-Residential Area		71.190
5	Built - Up Land-Industrial Buildings	Pabelan	51.2
	Built - Up Land-Residential Area		11,495.8
	Irrigation Fields-Industrial Buildings		7,098
	Irrigation Fields-Residential Area		128,534.4
	Irrigation Fields-Built-up Land		51.2
6	Mixed Gardens-Residential Area	Pucangan	26,231.2
	Built - Up Land-Residential Area		17,808.8
	Irrigation Fields-Residential Area		278,726.3
	Irrigation Fields-Built-up Land		12,312.1
7	Industrial Buildings-Residential Areas	Singopuran	0.3
	Mixed Gardens-Mixed Gardens		13,762.4
	Irrigation Fields-Industrial Buildings		0.3
	Irrigation Fields-Residential Area		81,562.3
8	Built - Up Land-Residential Area	Wirogunan	4.6
	Irrigation Fields-Industrial Buildings		18,477.2
	Irrigation Fields-Residential Area		84,433.8
9	Irrigation Fields-Industrial Buildings	Gumpang	4,473
	Irrigation Fields-Residential Area		120,120.5
	Irrigation Fields-Built-up Land		4,016.5
10	Built - Up Land-Residential Area	Makamhaji	9,772.7
	Irrigation Fields-Industrial Buildings		118,457.1

(*continued*)

Table 5. (*continued*)

No	Types of Land Use Changes from 2012 to 2021	Villages	Conversion Area (m^2)
	Irrigation Fields-Residential Area		22,976
	Irrigation Fields-Built-up Land		2.669,7
11	Irrigation Fields-Residential Area	Ngadirejo	10,467.3
12	Irrigation Fields-Residential Area	Ngemplak	127,218.2
	Irrigation Fields-Built-up Land		1,644.3

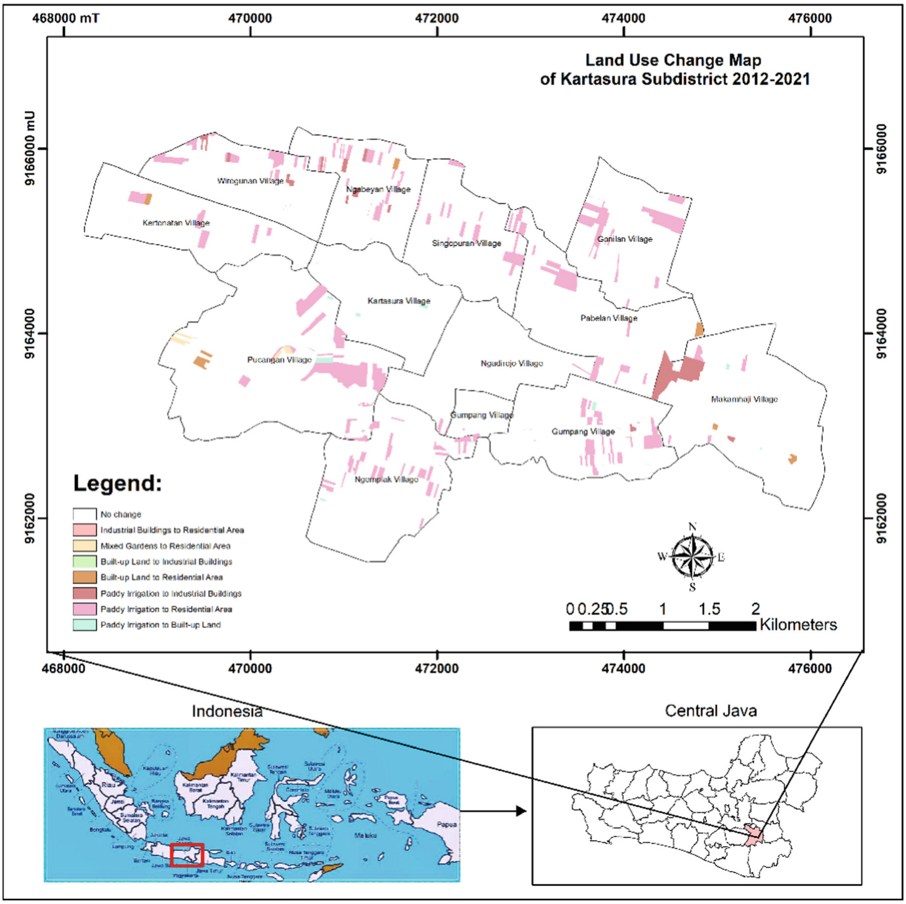

Fig. 7. Changes in Land Use Types in 2012–2021 in the Kartasura Subdistrict

4 Conclusions

In the temporal element, the land use between 2012 and 2021 in the Kartasura Subdistrict has changed. Irrigated rice fields decreased by 1,348,224.2 m^2, the residential area increased by 1,226,065.9 m^2, and industrial buildings increased by 176,419.7 m^2, built-up land reduced by 25,609.6 m^2, and mixed Gardens reduced by 26339.6 m^2.

Changes in land use types that occur include industrial building land, mixed gardens, irrigated rice fields, and built-up land. Land use of industrial building switches function in residential areas, built-up land switches function in industrial buildings and residential areas, mixed garden land switches function in residential areas, and irrigated rice fields switches function in industrial buildings, built-up land, and residential areas.

In the spatial element, the distribution of land conversion occurred in all villages in the Kartasura Subdistrict. The highest land area change occurred in the Pucangan village of 322,766.3 m^2, while the lowest area was in the village of Kartasura of 7,265.2 m^2. The largest change in the use of irrigated paddy fields in residential areas was in the Pucangan village of 278,726. 3 m^2 and the lowest in the Kartasura village amounted to 1,766.1 m^2. The average change in the use of irrigated paddy fields in residential areas during the period from 2012 to 2021 amounted to 95,931.5 m^2.

Factors that encourage and trigger land conversion include: (a) the low selling price of grain agricultural products, (b) the scarcity of fertilizer subsidies, (c) the high cost of land processing and maintenance of rice plants, (d) the relatively high selling value of land in Kartasura Subdistrict, and (e) weak monitoring and supervision of the Local Government Sukoharjo.

Solutions that can be done to prevent the widespread conversion of agricultural land are as follows: (a) to absorb rice production from farmers at competitive prices, (b) to ensure the availability of subsidized fertilizers, (c) to provide incentives for farmers, (d) to socialize with farmers related to sustainable food agricultural land, and (e) to monitor and supervise spatial planning and land use needs to be improved. This policy is important so that the sustainability of farmers' agricultural activities is maintained, thus the regional food security is maintained.

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