https://jurnal.unimed.ac.id/2012/index.php/geo/article/view/52397
https://doi.org/10.24114/jg.v16i2.52397 - (Vol 16, No 2 – 2024)
available at http://jurnal.unimed.ac.id/2012/index.php/geo
e-issn (2549-7057) & p-issn (2085-8167)

A Decade Analysis (2013-2023) of Paddy's Yield Productivity by Using Landsat 8 Imagery in Sukoharjo District, Indonesia

Fitria Nuraini Sekarsih, Guntur Fajar Kusuma
Department of Geography, Faculty of Science & Technology, Universitas Amikom Yogyakarta, Indonesia

ARTICLE INFO
Article History:
Received: October 29, 2023
Revision: June 09, 2024
Accepted: July 01, 2024

Keywords:
Landsat 8
NDVI
Paddy's Productivity
Sukoharjo
Ubinan data

e-mail:
sekarsih.fitria@amikom.ac.id

ABSTRACT
Sukoharjo District has the highest rice productivity in Central Java. Sukoharjo has a strategic location. It makes this area prone to land use changes. It makes a severe impact on Paddy's productivity. This condition needs to be monitored continually. Remote sensing can provide an efficient and accurate method to solve this condition. Using the NDVI from Landsat 8 imagery and ubinan data, the model can be built to calculate and analyze paddy's productivity. The steps were 1) interpretation of paddy fields area; 2) calculation of NDVI's mean values a month before harvesting; 3) interpretation accuracy test; 4) correlation value between NDVI and ubinan data in 2022; 5) calculation of paddy productivity; and 6) analysis. Within a decade (2013-2023), there was a reduction in paddy's yield area for 981.90 Ha. During that period, there was an increase in paddy's productivity, around 38.2 x 10^3 tons. Almost all sub-districts in Sukoharjo's yield had been reduced except for Tawangsari and Weru. Kartasura and Grogol have been an intensive change in paddy's yields to non- paddy's yields. Intensive land use changes affected paddy's productivity. The multi-temporal imagery combined with ubinan data can be used as a tool to monitor paddy's productivity. Forty-one points were calculated to get the equation between y (productivity) and x (NDVI value). The equation resulting from this method (y=6.2212x+6.7444) can be used as a reference for calculating productivity in Sukoharjo District in different periods. From different calculations, the accuracy obtained from this method was 86%.

INTRODUCTION

Rice is the staple food of most people in Indonesia and several countries in Asia (Indrasari & Kristamtini, 2018;Putri et al., 2019). One of the largest rice producers in Central Java is Sukoharjo District. Sukoharjo District has the highest rice productivity in Central Java in 2022 (BPS, 2022). Rice production has also increased. Rice production for food consumption by the population in 2022 has risen from the previous year (BPS, 2023). This data is also supported by FAO's new forecast for global cereal production in 2023 has been raised by 5.9 million tonnes (0.2 percent) in July from the previous month (FAO, 2023).

Sukoharjo, which is directly connected to Surakarta, will be affected by urban activities in the Surakarta area. The existence of a peri-urban area in Surakarta causes the CBD (Central Business District) area around the Sukoharjo called Solo Baru (Wijdania et al., 2023). The population group particularly comes from Surakarta city (growth core) as a form of urban sprawl or urban expansion. Sukoharjo has the highest increase in urbanization rate in Central Java based on 1980-2015 data, it is about 55.6% (Mardiansjah et al., 2018). This activity causes land use change. Alongside with migrant population increase in Sukoharjo District, total housing space also increased from 38,162 units in 2010 to

50,308 units in 2015, or equivalent to 31.8% in five years (Yogi et al., 2022). This land use change certainly affects paddy's yield into built-up areas for economic activities. Along with land use changing, population growth, and an increase in foodstuffs, there is a need for methods to monitor paddy productivity. Traditional methods for determining crop distribution, such as expert knowledge or field measurements, are limited by complex environmental and human interference, with high costs and low efficiency (Zhai et al., 2020).

The quick and precise assessment of paddy distribution by remote sensing technology is important for agricultural development (Zhang et al., 2022). The most popular vegetation index for analyzing crop status is the Normalized Difference Vegetation Index (Panek & Gozdowski, 2020). NDVI can help to predict crop yields (Yu & Shang, 2018). The NDVI correlates with field data on paddy production, so the equation results of these two variables can be used to estimate paddy yields (Yanti et al., 2022). Using Earth observation satellite data, it is possible not only to monitor the current state of the environment and the direction of its transformation but also to predict crop yields and monitor the status of agricultural production at the local and regional levels (Panek & Gozdowski, 2020).

Most available studies have shown that there is a strong linear relationship between these remote sensing indexes and crop yields (Ban et al., 2017). However, It was found that remote sensing-derived NDVI product alone was not sufficient for accurate estimation of crop yield (Islam et al., 2023). This is because paddy takes four months for one harvest. The paddy growing period also went through various phases. To solve this problem, it used one month before harvest recording Landsat 8 imagery. Then, the NDVI value will be matched with Sukoharjo Department of Agriculture data. This data is ubinan Data collected directly from the paddy yield. Ubinan data survey or crop-cutting survey (Ruslan, 2019) is a survey conducted by BPS (Central Statistics Agency) to calculate productivity (yield per hectare) (Ruslan, 2019; Armayani et al., 2021). This ubinan survey uses a tile tool measuring 2.5 x 2.5 meters on randomly selected plots (Inayah et al., 2023). The weight of the wet paddy was recorded. Then, the farmers were interviewed to find out other things related to the respondent's farming activity.

This research aims to analyze productivity in Sukoharjo District in 10 years, 2013 and 2023. This period was chosen because of the availability of Landsat 8 which was launched in 2013. Another reason is the construction of the Jogja-Solo road build during this period which caused the land use change. By using the NDVI method from Landsat 8 imagery and ubinan data and analyzing the impact of land use change in paddy productivity. The limitation of this research is the paddy productivity in wet conditions.

RESEARCH METHODS

The research was carried out in Sukoharjo District. This region has an area of 46,666 Ha. Administratively, Sukoharjo is divided into 12 sub-districts consisting of 167 villages. Polokarto is the largest sub-district in Sukoharjo District with an area of 6,218 Ha or 13% of the Sukoharjo District, while Kartasura has the smallest area with 1,923 Ha or 4% of the Sukoharjo District (BPS, 2022) (Figure 1).

The main data used in this research are ubinan data conducted by BPS in September 2022, Landsat 8 imagery (with surface reflectance correction) recorded in July, August, and September (1 month before harvest), land use data from Rupabumi's map, and field surveying.

The method used in this research consists of 6 major categories: 1) interpretation of paddy fields area; 2) calculation of NDVI values by using (Band 5 - Band 4)/ (Band 5 + Band 4) calculation; 3) interpretation accuracy test; 4) correlation value between NDVI and ubinan data in 2022; 5) calculation of paddy productivity; and 6) analysis. In this research, Landsat 8 imageries were used as the primary data source to classify paddy's and non-paddy yields, calculate NDVI values, and analyze NDVI values with ubinan data.

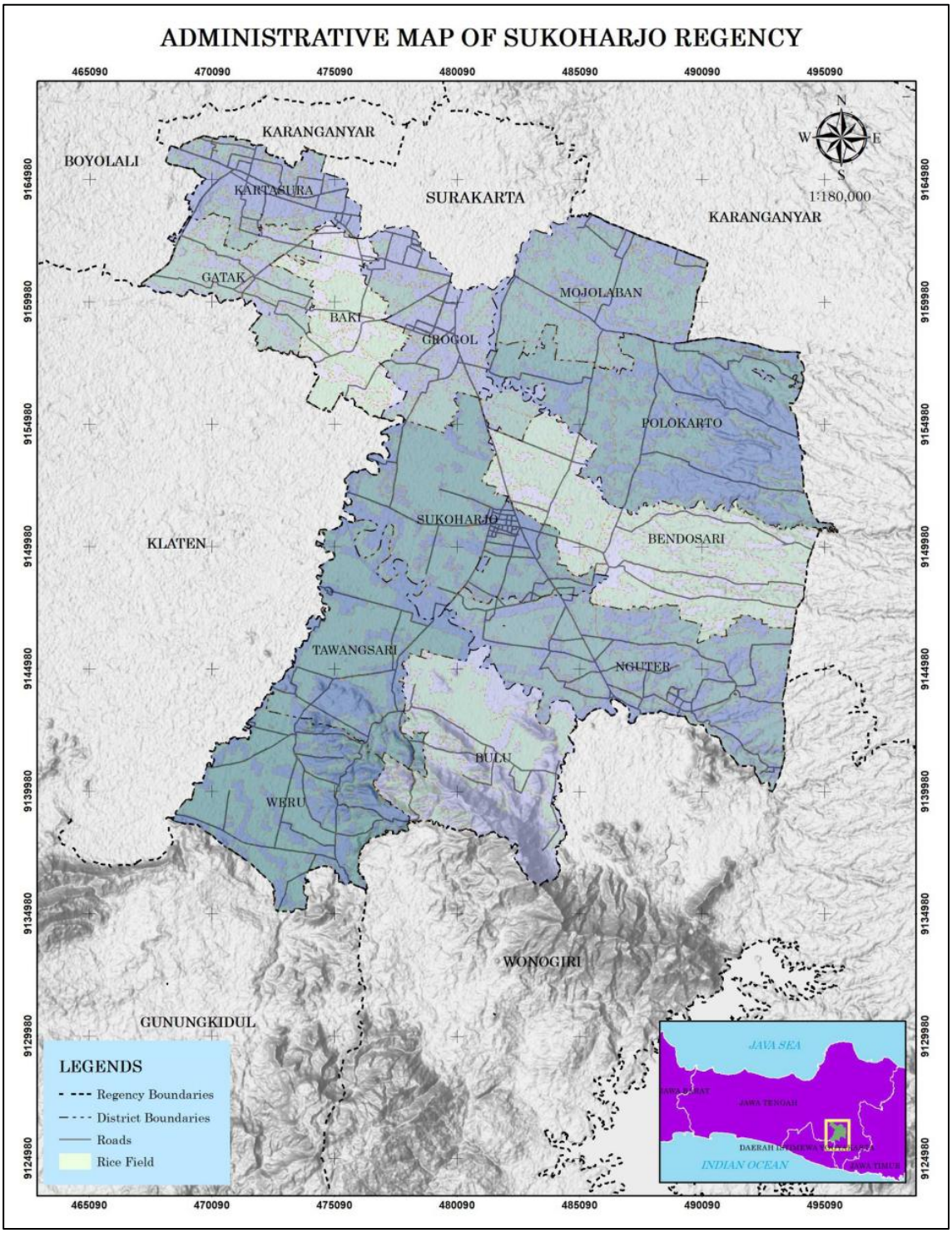

Figure 1. Research Area (Source: Data Processing 2023)

The first step was interpreting the paddy's yield. To differentiate between paddy's yield and non-paddy's yield, land use data from the RBI map was updated. Landsat 8 was used to update the land use through visual interpretation. The result of this first step was the paddy's yield and non-paddy's yield in 2013 and 2023.

Next, the second step was to calculate the NDVI value. NDVI has been used for staple crop management and monitoring since the 1980s (Marques et al., 2022). In this research, NDVI calculation only focused on paddy's yields. NDVI analysis was chosen because it has the highest correlation value with rice productivity compared to MSAVI and AVI (Hisyam et al., 2022).

In this calculation, paddy fields have large differences in vegetation between the pre-harvest and post-harvest periods (Tian et al., 2023). Therefore, the differences in NDVI values in the period leading up to harvest were averaged.

Predicting the grain yield during early to mid-growth stages is important for the initial diagnosis of paddy and quantitative (Zhang et al., 2019). The NDVI value taken is adjusted to harvest data from ubinan survey taken in September 2022. The best NDVI data is taken 1 month before harvest because it has the maximum greenness value. The correlation value of NDVI and ubinan data in 2022 was used to calculate productivity in 2013 and 2023.

For 2023, Landsat 8 imagery recorded in August and September had been used. This month's collection was expected to be able to represent the NDVI's mean value before the harvest period. Meanwhile, for 2013, Landsat 8 imagery recorded in July and August were used.

The third step was testing the accuracy of the interpretation of paddy fields and non-paddy fields. The paddy field uses data from the RBI map, then updated using visual interpretation. The land use selected from the RBI map is irrigated paddy fields. This accuracy test was carried out on the use of non-paddy yields in 2023. The fourth step was to test the correlation between the NDVI values and ubinan data. The ubinan data obtained from the Sukoharjo District Agriculture Service was obtained from the 2022 survey. Therefore, the correlation between the ubinan data and the NDVI value was carried out in 2022. This correlation then to estimate productivity in 2013 and 2023. The ubinan data is data for wet grain.

The fifth step was to calculate the productivity in 2013 and 2023. In this case, the correlation from step 4 was used to estimate productivity in 2013 and 2023. In determining 1-year productivity, the approach used three crop rotations. This is by the Sukoharjo district regulation (Perbup, 2022), where irrigated paddy yields in Sukoharjo have three planting periods. NDVI data was collected one month before the main harvest, in July, August, and September. The NDVI results were then averaged.

The Last was analysis. These steps were to analyze land use change from paddy's yields to non-paddy's yields and their effect on productivity. The resume of this method is summarized in Figure 2.

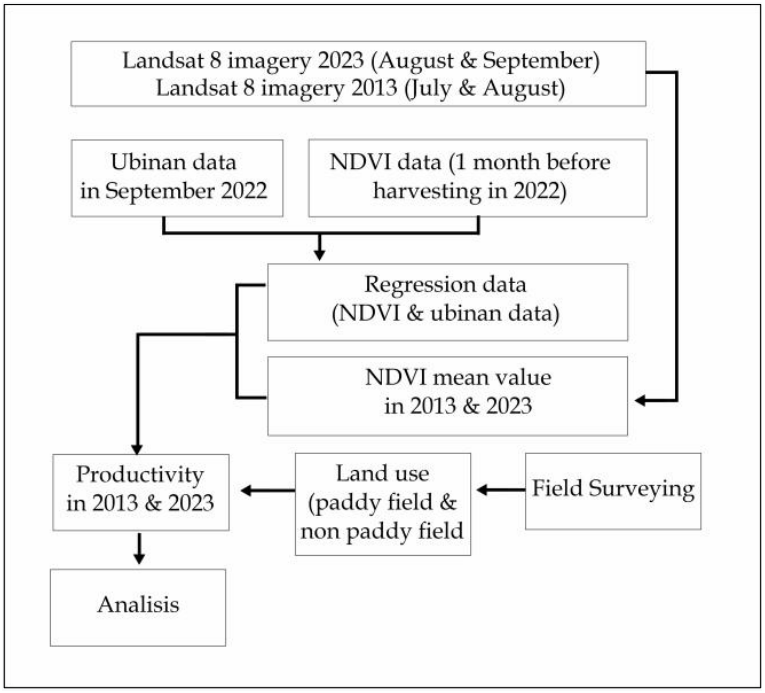

Figure 2. Method Research (Source: Data Processing 2023)

RESULTS AND DISCUSSION

Paddy is considered one of the most important crops in the world (Franch et al., 2021), especially in Asia, Africa, and South America (Faisal, 2019). As the largest paddy producer in Central Java, Sukoharjo has an essential role in food security, especially in Central Java Province. The economic activities centered in the Surakarta area have a significant impact on land use changes in Sukoharjo. A food security study is vital so that the paddy supply is not disrupted due to land use change.

During 2013-2023, many changes had been occurred in Sukoharjo. In this research, the first steps were interpreting the paddy's yields and non-paddy's yields in 2013 and 2023. During a decade, the dominant change that occurred in Sukoharjo District was from paddy yields to the built-up area. This is reinforced by the Solo Baru program, which has a great influence on land use conditions in the northern part of Sukoharjo, especially in Kartasura and Grogol Sub-district. In 10 years, there was a change in paddy's yields to non-paddy's yields from 27.4 x 10^3 Ha in 2013 to 26.4 x 10^3 Ha. This means that there has been a reduction of around 981.9 Ha. Image 3 is a map of land use change from paddy's yields to non-paddy's yields in Sukoharjo District.

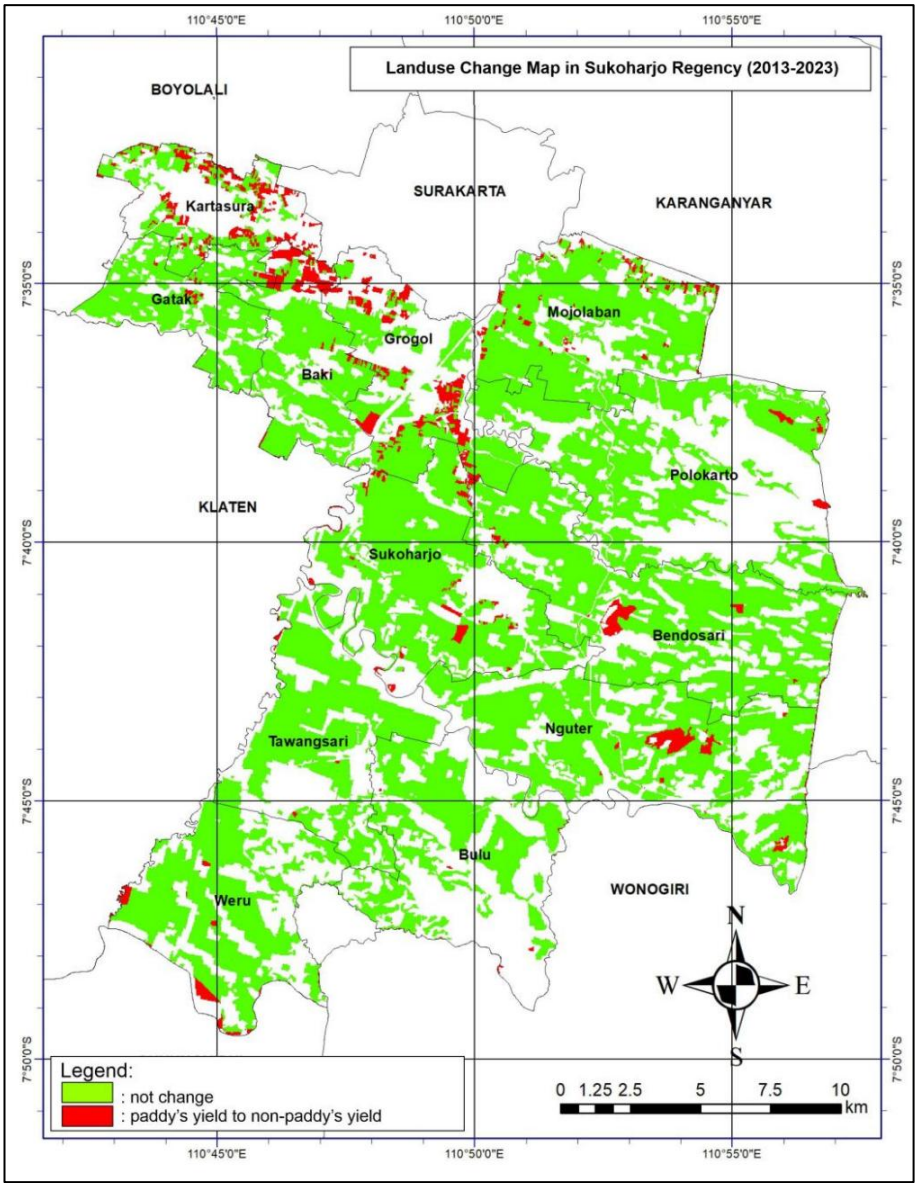

Figure 3. Land use change from paddy's yield to non- paddy's yield in Sukoharjo (Source: Data Processing 2023)

The most intensive change occurred in Kartasura and Grogol Sub-district. The land use change is caused by the increase in the population. There were 23,061 increasing numbers of people during 2011-2021 (Istiqomah & Pramono, 2024). Besides the effect of the Surakarta District, the position of Kartasura, which is located on the main road (Solo-Yogyakarta), has a big contribution to land use change. Sukoharjo cannot be separated from the local toponym "Solo Baru" even though it is not the area of Solo. Solo Baru is also known as a modern business and residential area. In Solo Baru, there are many shophouses and shopping centers, such as malls and entertainment venues (Al Hibbi et al., 2023).

After the land use classification, the paddy's yields will then be mapped based on the NDVI. NDVI algorithm method was used to determine the age of paddy plants, which was then used to estimate paddy productivity (Supriatna et al., 2020). NDVI values are calculated from Landsat 8 images with the formula (Band 5 - Band 4)/ (Band 5 + Band 4). This NDVI was taken from the average value in 1 month before harvest. The image used to calculate paddy productivity in 2023 uses data from August and September, while productivity in 2013 uses data from July and August. The average NDVI can represent the value in 1 month before harvest.

Data on paddy fields sourced from the RBI map of Sukoharjo District, scale 1: 25,000. The latest map update was carried out. So, improvements need to be made due to land cover in Sukoharjo District in 2023. In this research, the accuracy test sample consisted of 396 points, of which 215 points were for paddy's yields and 181 points were for non-paddy's yields. Based on the analysis, the overall accuracy value is 87.88%. Table 1 shows the results of interpretation accuracy tests on paddy's yields in Sukoharjo District.

Table 1. Accuracy Test

Class		Field surveying		Total	User's Accuracy (%)	Commission Error (%)
		Paddy Yield	Non Paddy Yield			
Visual Interpretation	Paddy Yield	177	38	215	82.33	17.67
	Non Paddy Yield	10	171	181	94.48	5.52
Total		187	209	396		
Producer's Accuracy (%)		94.65	81.82	Overall Accuracy (%)		87.88
Omission Error (%)		5.30	18.18	Kappa Index		0.76

Source: Data Processing, 2023

The results of the NDVI value were compared with ubinan data in Sukoharjo District. The ubinan data was collected by BPS. This data is in the form of a sample of wet paddy's grain in kg. The sample size is about 2.5 x 2.5 m. The ubinan data was taken in September 2022. (Berd et al., 2022), the best phase for collecting NDVI data is in the generative phase. In this research, the generative phase is about 1 month before harvest. So this phase is the best time to get NDVI data to predict productivity. This data was used to calculate the correlation between productivity and NDVI. In this productivity calculation, the productivity value is in wet condition.

The NDVI value is obtained from the comparison of Visible Red and Near-Infrared (NIR) channels/bands. The NDVI calculation was carried out by using Landsat 8 on paddy yields in Sukoharjo District. The distribution of NDVI values was in the range of -0.209 to 0.813. Table 2 is the class of NDVI in Sukoharjo District.

Table 2. NDVI value in Sukoharjo District in 2022 (source: data processing 2023)

NDVI	Class	Area (Ha)
0,0036 - 0,240	Very low	1.081,20
0,240 - 0,456	Low	6.124,59
0,456 - 0,652	Moderate	13.489,03
0,652 - 0,884	High	5.998,11

Source: Data Processing, 2023

The results of the NDVI value were then compared with the ubinan data. Productivity calculations were carried out at 41 sample points. The productivity unit used was Ton/Ha. To calculate paddy productivity, use the formula Productivity (tons/ha) = (ubinan yield (kg) x (10,000 m2: ubinan area)) / 1000.

In this study, the level of relationship between X (NDVI) and Y (paddy productivity) is shown in simple linear regression analysis. The NDVI value has a good relationship with plant biomass, which can be used to estimate paddy production (Nie & Peng, 2017). From the regression analysis, an equation model was obtained to estimate paddy productivity. The results of the analysis will produce a model y=aX+b, where y = paddy productivity; X = NDVI value; a = constant; and b = regression coefficient X. Based on the analysis, the NDVI value is closely related to paddy productivity. Figure 4 is a graph of the relationship between NDVI and paddy productivity, and Table 3 is ubinan data and NDVI value in Sukoharjo District.

Table 3. Ubinan data and NDVI Value in Sukoharjo District

No	Ubinan's Sample area	Ubinan Data (ton/ha)	NDVI
1	Baran	8.78	0.368714
2	Begajah	9.15	0.360174
3	Blimbing	8.03	0.389754
4	Bugel	9.76	0.428083
5	Cangkol	9.3	0.301459
6	Cangkol	9.04	0.281698
7	Combongan	8.78	0.346539
8	Dalangan	8.26	0.23374
9	Dalangan	9.6	0.504983
10	Dalangan	10.85	0.608756
11	Dukuh	11.09	0.793297
12	Gedongan	8.43	0.227116
13	Gentan	7.2	0.175596
14	Jati	7.58	0.180829
15	Karangtengah	9.56	0.635938
16	Kateguhan	9.12	0.377585
17	Kateguhan	7.28	0.171255
18	Kateguhan	10.03	0.451317
19	Kemasan	10.05	0.47001
20	Kemasan	12.48	0.706335
21	Krajan	11.07	0.728704
22	Langenharjo	8.9	0.376919
23	Mandan	8.96	0.348806

24	Menuran	8.34	0.2066
25	Mulur	9.02	0.35062
26	Ngemplak	9.06	0.434867
27	Nguter	9.3	0.403354
28	Palur	8.7	0.268378
29	Pojok	11.34	0.703096
30	Puron	7.76	0.162544
31	Puron	9.47	0.426097
32	Sapen	8.99	0.359163
33	Sonorejo	8.7	0.301324
34	Sraten	7.89	0.19751
35	Sukoharjo	9.39	0.402294
36	Sukoharjo	11.62	0.769883
37	Tangkisan	10.91	0.601717
38	Tangkisan	9.76	0.494092
39	Trasan	7.78	0.157806
40	Weru	10.4	0.67917
41	Wirun	9.15	0.389228

Source: Data Processing, 2023.

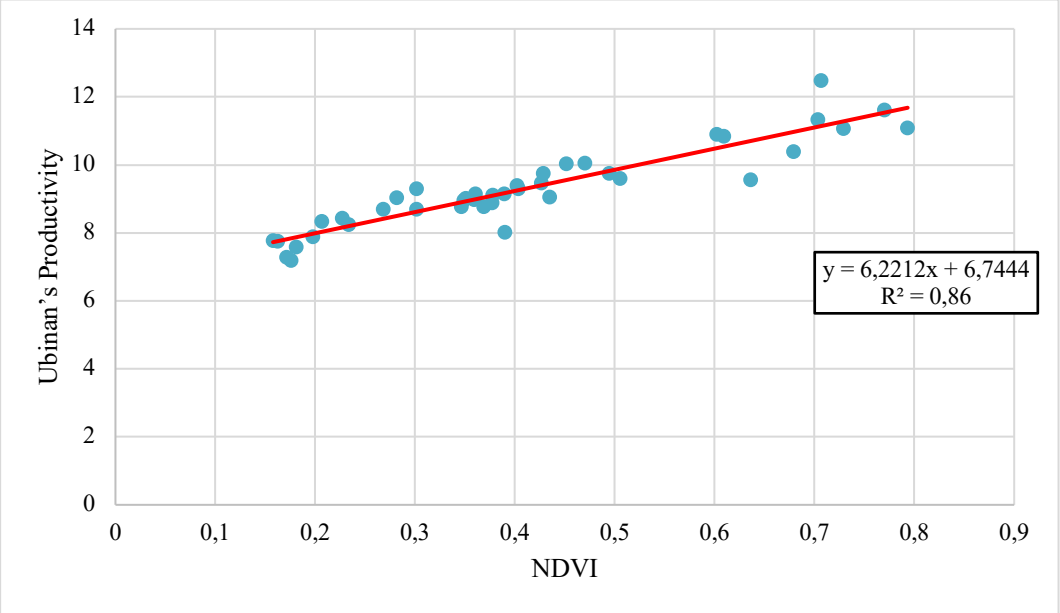

Figure 4 Correlation between NDVI and paddy productivity in Sukoharjo District (Source: Data Processing 2023)

The level of data correlation, shown by the R^2 (R Square) value, is about 0.86 which means the value is strong (Brumbaugh & Guilford, 1943). This value is closely related to X (NDVI) and Y (ubinan productivity). The R square value is the coefficient of determination, which shows that the level of paddy productivity is influenced by NDVI by 86%, and the remaining 14% is influenced by other factors. From the results of the analysis, it can also be concluded that the line equation y=6.2212x+6.7444, where y is paddy productivity, and x is the NDVI value. This equation will be used to estimate paddy productivity for Sukoharjo District in 2013 and 2023.

Remote sensing technology can provide information on spatial continuity and has the advantage of rapid, large-scale

observations (Zhang et al., 2022). From Figure 5 above, it can be seen that there is a positive relationship between NDVI and productivity. This value will then be used to calculate productivity in 2013 and 2023. The following Table 4 represents the NDVI value and its relationship with paddy productivity in 2013 and 2023.

Table 4. NDVI value and productivity in 2013 and 2023 in Sukoharjo District

Year	NDVI		Productivity	
	High	Low	High	Low
2013	0.615	-0.425	10.56	4.79
2023	0.785	-0.166	11.63	5.7

*) the productivity in wet condition
(Source: Data Processing 2023)

During 2013-2023, there was a paddy yield area reduction. Agricultural land area decreased by around 981.9 Ha. During this condition, there was an increase in paddy productivity, from 590.7 x 10^3 tons to 628.9 x 10^3 tons. This means that the productivity increased to 38.2 x 10^3 tons. Table 5 shows the paddy's yield and productivity in 2013 and 2023.

Table 5. The paddy's yield and productivity in 2013 and 2023

Year	**Paddy's yield (Ha)**	**Productivity (Ton)**
2013	27,421.59	590,704.48
2023	26,439.69	628,906.13

*) the productivity in wet condition (Source: Data Processing 2023)

The following result shown in Figures 5a and 5b is the analysis of agricultural land area and productivity in the sub-district in Sukoharjo. The conversion value for the influence factor (86 %) of NDVI and productivity is used to calculate productivity in 2013 and 2023.

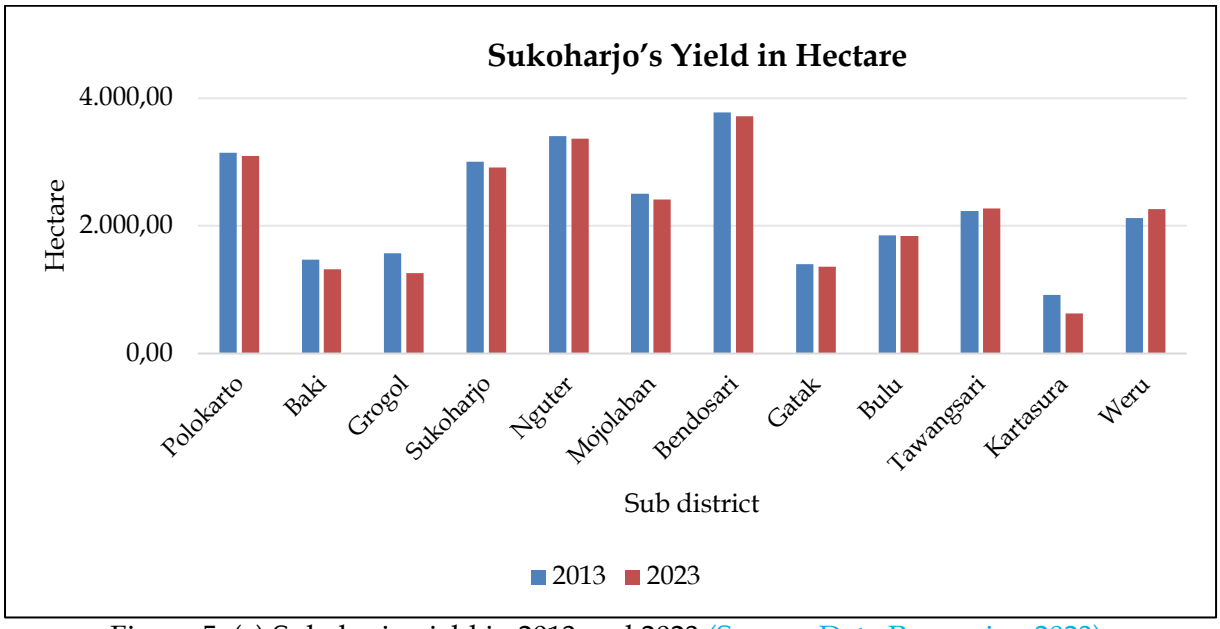

Figure 5. (a) Sukoharjo yield in 2013 and 2023 (Source: Data Processing 2023)

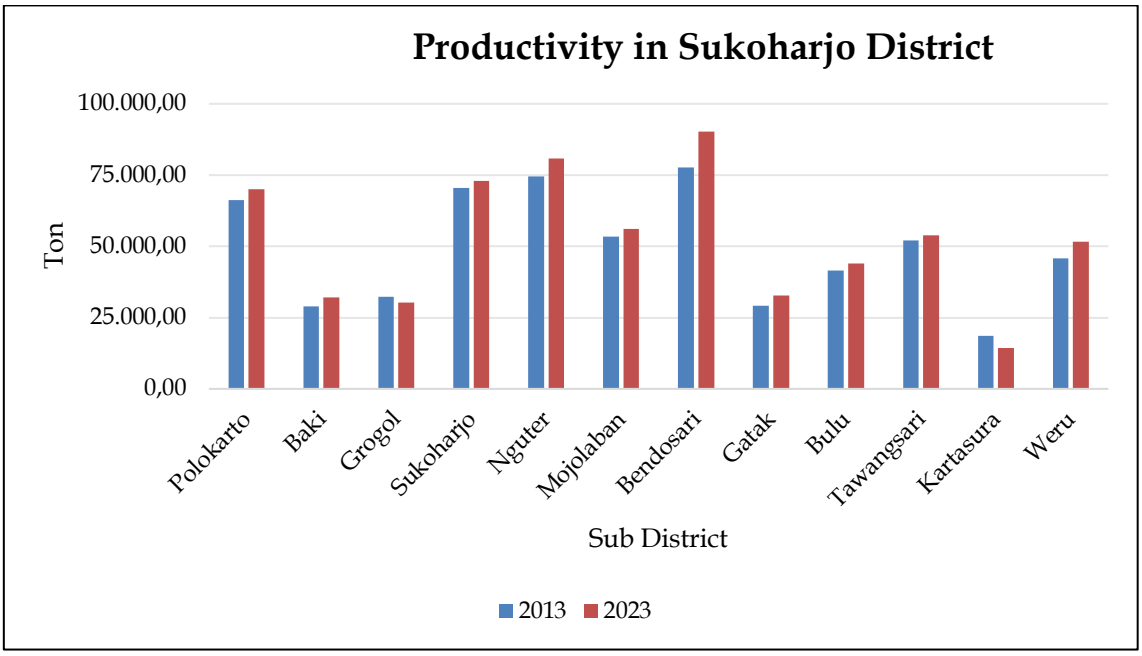

Figure 5. (b) Sukoharjo productivity in 2013 and 2023 (Source: Data Processing 2023)

From Figure 5 (a) and Table 6, most all sub-districts in Sukoharjo land use change had occurred. The paddy's yield reduced in all of the sub-districts except in Tawangsari and Weru. There is an additional paddy yield area in Tawangsari (34.82 Ha) and Weru (137.74 Ha). This additional area is due to the addition of irrigation channels so that the hilly areas in Tawangsari and Weru can produce 3x harvests a year. Several factors that support this increase in agricultural land are the Sukoharjo district regulation, where irrigated paddy yields in Sukoharjo have three planting periods. Another factor is the success of Tegalsari Village, Weru District, becoming a pilot center for the IP 400 program, which has succeeded in developing a 1-year 4x harvest program (DPP, 2023).

From Table 6 Grogol is the sub-district that has the largest reduction. It is about 315.57 Ha. The result inline with is also in line with previous research which concluded that from 2001 to 2018 Grogol District changed from paddy to non-paddy covering an area of 1,230 Ha (Rifai et al., 2021)

Table 6. Productivity and yield changing analysis in 2013 dan 2023

Sub District	Changing	
	Paddy's Yield (Ha)	Produktivity (Convertion 86%)
Polokarto	-49.00	3,979.50
Baki	-155.30	3,089.31
Grogol	-315.57	-1,954.57
Sukoharjo	-85.44	2,434.38
Nguter	-46.25	6,337.83
Mojolaban	-91.78	2,576.96
Bendosari	-65.70	12,483.04
Gatak	-43.83	3,429.39
Bulu	-12.57	2,466.48
Tawangsari	34.82	1,764.14
Kartasura	-290.98	-4,323.58
Weru	139.74	5,918.80
Total	-981.90	38,201.66

*) the productivity in wet conditions (Source: Data Processing 2023)

Even though the yield field area has been reduced, the productivity has increased**.** In a one-decade period, the paddy productivity had increased by 38,2 x 10^3 tons. The sub-district which had the highest productivity increase was Bendosari, 12.4 x 10^3 tons. Meanwhile, the sub-district with the greatest reduction in paddy productivity was the Kartasura Sub-district. The reduction in productivity is about 4.3 x 10^3 tons. Another sub-district that had occurred productivity reduction was Grogol. Both of these conditions were triggered by the convention of yield area to the built-up area. For more details, the distribution of Paddy productivity in Sukoharjo in 2013 and 2023 is shown in Figure 6.

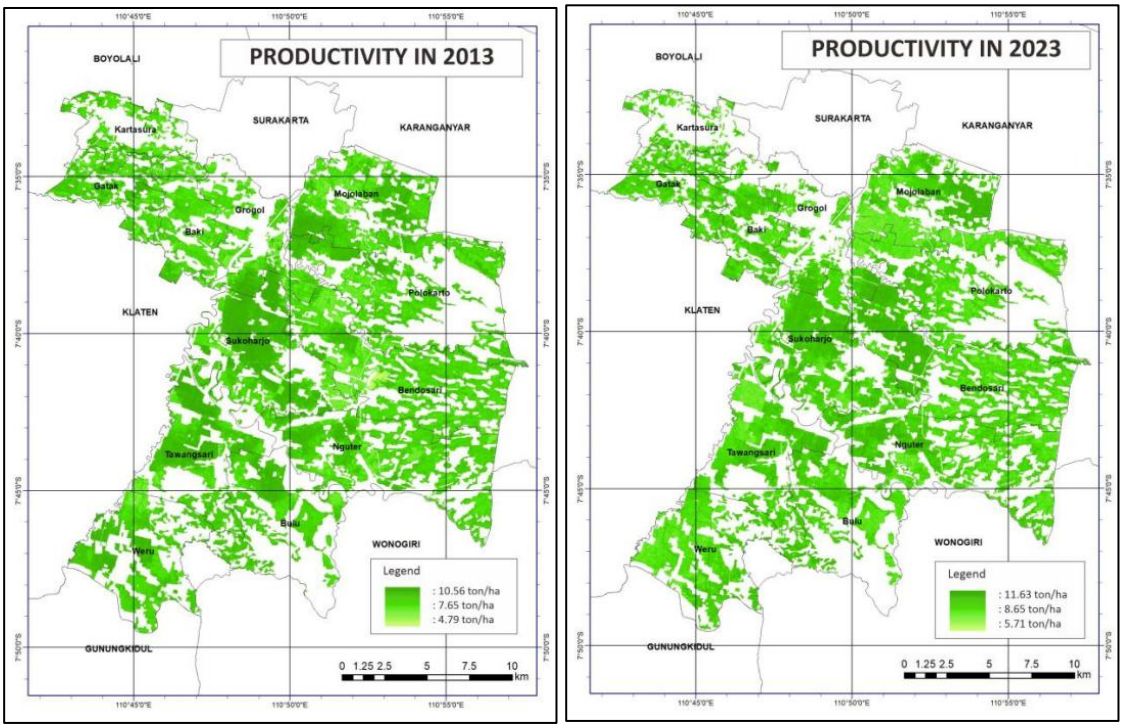

Figure 6. Paddy productivity in Sukoharjo District in 2013 and 2023 (Source: Data Processing 2023)

NDVI algorithm method was used to determine the age of paddy plants, which was then used to estimate paddy Productivity (Tian et al., 2023). In the Sustainable Development Goals SDGs, the availability of rice as the main staple food is the main requirement for realizing Indonesia's food security. Food security in Indonesia is influenced by the area of rice harvested and land productivity. With remote sensing technology, rice availability can be monitored accurately and continuously to achieve an Indonesia free from hunger and famine. By using this research, which is obtained from remote sensing data and ubinan data, the formula can be used to calculate the productivity in different years in Sukoharjo.

CONCLUSION

Within a decade (2013-2023), there was a change in land use from paddy yields to non-paddy yields in Sukoharjo District. Generally, there was a reduction in paddy's yield. It is about 981.90 Ha. During that period, there was an increase in paddy's productivity, around 38.2 x 10^3 tons. Almost all sub-districts in Sukoharjo's yield had been reduced except for Tawangsari and Weru. However, during this reduction in paddy's yield area, productivity had been increased. All sub-districts in Sukoharjo had been increased except Kartasura and Grogol. Kartasura and Grogol have been an intensive change in paddy's yields to non-paddy's yields. Intensive land use changes affected Paddy's productivity. By using remote sensing data, it can be done

efficiently and accurately. The ubinan data combined with multi-temporal imagery can be used as a tool to monitor paddy's productivity. The equation resulting from this method is y=6.2212x+6.7444 and the accuracy is around 86%. In which y is productivity, and x is NDVI value. The equation can be used as a reference for calculating productivity in different periods.

ACKNOWLEDGMENT

Thank you to the Geography Department, University of Amikom Yogyakarta, and all the staff who have accompanied and provided the best service for this research. Amikom University of Yogyakarta's Research Center and all its staff. Thank you also to the Sukoharjo Agriculture Service for providing information and permits for this research.

REFERENCE LIST

Al Hibbi, A., Harsono, D., & Lena Satlita, D. (2023). Analisis Karakteristik Gentrifikasi Pada Kawasan Solo Baru Sukoharjo: Tinjauan Dari Penyebab Dan Dampak Ruang-Fisik Gentrifikasi.

Armayani, C., Fauzi, A., & Sembiring, H. (2021). Implementasi Data Mining Pengelompokan Jumlah Data Produktivitas Ubinan Tanaman Pangan Berdasarkan Jenis Ubinan Dengan Metode Clustering Dikab Langkat (Studi Kasus : Badan Pusat Statistik Langkat). Jurnal Informatika Kaputama (JIK), 5(1), 185–196. https://doi.org/10.59697/jik.v5i1.318

Ban, H. Y., Kim, K. S., Park, N. W., & Lee, B. W. (2017). Using MODIS data to predict regional corn yields. Remote Sensing, 9(1). https://doi.org/10.3390/rs9010016

Berd, I., Ekaputra, E. G., Yanti, D., & Stiyanto, E. (2022). The Use of NDVI Algorithm in Predicting the Productivity of Rice Fields of Talang District of Solok Regency. IOP Conference Series: Earth and Environmental Science, 1059(1). https://doi.org/10.1088/1755-1315/1059/1/012004

BPS. (2022). Luas Panen dan Produksi Padi di Indonesia 2022. In Badan Pusat Statistik.

BPS. (2023). Kaputanten Sukoharjo Dalam Angka 2023. In Badan Pusat Statistik.

Brumbaugh, M. A., & Guilford, J. P. (1943). Fundamental Statistics in Psychology and Education. In Journal of the American Statistical Association (Vol. 38, Issue 222). https://doi.org/10.2307/2279562

DPP. (2023). Panen Raya Padi IP 400 bersama Menteri Pertanian dan Bupati Sukoharjo Gapoktan Krido Usodo di Desa Tegalsari, Kecamatan Weru, Kabupaten Sukoharjo. Dinas Pertanian Dan Perikanan Kabupaten Sukoharjo. https://dpp.sukoharjokab.go.id/berita/panen-raya-padi-ip-400-bersama-menteri-pertanian-dan-bupati-sukoharjo-gapoktan-krido-usodo-di-desa-tegalsari-kecamatan-weru-kabupaten-sukoharjo

Faisal, F. (2019). Pengaruh Perlakuan Varietas Berbeda Dan Konsentrasi Garam Terhadap Viabilitas Dan Vigor Benih Padi Sawah (Oryzae sativa). Jurnal Agrium, 16(1), 13–20. https://doi.org/https://doi.org/10.29103/agrium.v16i1.1337

FAO. (2023). Crop Prospects and Food Situation #2, July 2023. In Crop Prospects and Food Situation #2, July 2023 (Issue 2). https://doi.org/10.4060/cc6806en

Franch, B., San Bautista, A., Fita, D., Rubio, C., Tarrazó-Serrano, D., Sánchez, A., Skakun, S., Vermote, E., Becker-Reshef, I., & Uris, A. (2021). Within-field rice yield estimation based on sentinel-2 satellite data. Remote Sensing, 13(20). https://doi.org/10.3390/rs13204095

Hisyam, A. K., Supriatna, S., & Shidiq, I. P. A. (2022). Remote sensing-based vegetation indices for monitoring rice crop phenology and productivity in cikakak sub-district, sukabumi regency. IOP Conference Series: Earth and Environmental Science, 1089(1),

6–13. https://doi.org/10.1088/1755-1315/1089/1/012025

Inayah, A. N., Mudasirah, M., Salfiana, S., & Khalik, A. (2023). Technique Tiles Taken in the Frame Work of Increasing Agricultural Production in Panca Rijang District. 11(3), 298–306.

Indrasari, S. D., & Kristamtini, K. (2018). Biofortofokasi mineral Fe dan Zn pada beras: perbaikan mutu gizi bahan pangan melalui pemuliaan tanaman. Jurnal Litbang Peranian, 37, 9–16.

Islam, M. D., Di, L., Qamer, F. M., Shrestha, S., Guo, L., Lin, L., Mayer, T. J., & Phalke, A. R. (2023). Rapid Rice Yield Estimation Using Integrated Remote Sensing and Meteorological Data and Machine Learning. Remote Sensing, 15(9). https://doi.org/10.3390/rs15092374

Istiqomah, P., & Pramono, W. T. (2024). Population density analysis on the land use change in Kartasura District Sukoharjo between 2011 and 2021. IOP Conference Series: Earth and Environmental Science, 1314(1). https://doi.org/10.1088/1755-1315/1314/1/012118

Mardiansjah, F. H., Handayani, W., & Setyono, J. S. (2018). Pertumbuhan Penduduk Perkotaan dan Perkembangan Pola Distribusinya pada Kawasan Metropolitan Surakarta. Jurnal Wilayah Dan Lingkungan, 6(3), 215. https://doi.org/10.14710/jwl.6.3.215-233

Marques, A. C., Luís, I. C., Coelho, A. R. F., Pessoa, C. C., Daccak, D., Simões, M., Almeida, A. S., Campos, P. S., Ramalho, J. C., Semedo, J. M. N., Kullberg, J. C., Brito, M. G., Pessoa, M. F., Reboredo, F. H., Marques, P., Silva, M. M., Legoinha, P., Oliveira, K., Pais, I. P., & Lidon, F. C. (2022). Monitorization through NDVI of a Rice (Oryza sativa L.) Culture Production in Ribatejo Region. 3. https://doi.org/10.3390/iocag2022-12170

Nie, L., & Peng, S. (2017). Rice Production in China. In Rice Production Worldwide (pp. 33–52). https://doi.org/10.1007/978-3-319-47516-5_2

Panek, E., & Gozdowski, D. (2020). Analysis of relationship between cereal yield and NDVI for selected regions of Central Europe based on MODIS satellite data. Remote Sensing Applications: Society and Environment, 17(August 2019), 100286. https://doi.org/10.1016/j.rsase.2019.100286

Perbup. (2022). Peraturan Bupati Sukoharjo No 56 Tahun 2022 Tentang Pola Tanam dan Rencana Tata Tanam Pada Daerah Irigasi Tahun 2022-2023. Sekretaris Daerah Kabupaten Sukoharjo.

Putri, M. R., . S., DM Manessa, M., & Ristya, Y. (2019). The Spatial Pattern of Rice Productivity Using Sentinel-2A Image in Cariu and Tanjungsari District, Bogor Regency. KnE Engineering, 2019, 355–362. https://doi.org/10.18502/keg.v4i3.5883

Rifai, M. H., Nugroho, B. K., & Wijayanti, A. (2021). Changes in Agricultural Land Use To Non-Agricultural Land in Grogol District of Sukoharjo Regency in 2001 - 2018. Journal of Geography Science and Education, 3(1), 1. https://doi.org/10.32585/jgse.v3i1.1386

Ruslan, K. (2019). Memperbaiki Data Pangan Indonesia Lewat Metode Kerangka Sampel Area. In Center for Indonesian Policy Studies (Issue September).

Supriatna, Rokhmatuloh, Wibowo, A., & Ash Shidiq, I. P. (2020). Rice productivity estimation by Sentinel-2A imagery in Karawang Regency, West Java, Indonesia. International Journal of GEOMATE, 19(72), 49–53. https://doi.org/10.21660/2020.72.5622

Tian, J., Tian, Y., Cao, Y., Wan, W., & Liu, K. (2023). Research on Rice Fields

Extraction by NDVI Difference Method Based on Sentinel Data. Sensors, 23(13). https://doi.org/10.3390/s23135876

Wijdania, N., Rahayu, P., & Hardiana, A. (2023). Kawasan perdagangan-jasa Solo Baru sebagai Central Business District di Kabupaten Sukoharjo. Region : Jurnal Pembangunan Wilayah Dan Perencanaan Partisipatif, 18(1), 1. https://doi.org/10.20961/region.v18i1.47901

Yanti, D., Safitri, I., Rusnam, R., & Stiyanto, E. (2022). Rice Productivity Estimation Using Remote Sensing Method. Jurnal Teknik Pertanian Lampung (Journal of Agricultural Engineering), 11(3), 451. https://doi.org/10.23960/jtep-l.v11i3.451-465

Yogi, A. P., Samudro, B. R., Soesilo, A. M., & Pratama, Y. P. (2022). Land use and cover change (LUCC) and migration in Sukoharjo, Indonesia. International Journal of Ethics and Systems, 38(3), 465–483. https://doi.org/10.1108/IJOES-01-2021-0005

Yu, B., & Shang, S. (2018). Multi-year mapping of major crop yields in an irrigation district from high spatial and temporal resolution vegetation index. Sensors (Switzerland), 18(11), 1–15. https://doi.org/10.3390/s18113787

Zhai, Y., Wang, N., Zhang, L., Hao, L., & Hao, C. (2020). Automatic crop classification in northeastern china by improved nonlinear dimensionality reduction for satellite image time series. Remote Sensing, 12(17). https://doi.org/10.3390/RS12172726

Zhang, K., Chen, Y., Zhang, B., Hu, J., & Wang, W. (2022). A Multitemporal Mountain Rice Identification and Extraction Method Based on the Optimal Feature Combination and Machine Learning. Remote Sensing, 14(20). https://doi.org/10.3390/rs14205096

Zhang, K., Ge, X., Shen, P., Li, W., Liu, X., Cao, Q., Zhu, Y., Cao, W., & Tian, Y. (2019). Predicting rice grain yield based on dynamic changes in vegetation indexes during early to mid-growth stages. Remote Sensing, 11(4). https://doi.org/10.3390/rs11040387