The Impact of Land Use Land Cover Change (LULCC) On Runoff Coefficient at Upper Bengawan Solo Watershed, Central Java (Jawa Tengah) Province

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Abstract. Land use land cover change (LULCC) can cause hydrological impact. LULCC for economic activities can provide social and economic benefits, however, these changes often have an impact on decreasing environmental quality. This study aims to determine LULCC in the impact on hydrological conditions, especially on the runoff coefficient. The research location is in the Upper Solo Watershed which has an outlet in Jurug, which has an area of approximately 368,792.43 ha. Water discharge from 2013 to 2021 was obtained from the Bengawan Solo Water Resources Management Office, Ministry of Public Works and Public Housing (PUPR). LULCC data were analyzed from Landsat 8 Operational Land Imager (OLI) satellite imagery recorded in 2013, 2018 and 2021. Based on Landsat 8 OLI satellite imagery results, land cover/use has changed in 2013, 2018 and 2021. Some types of land use that have changed significantly are forest area, dry land agriculture, built-up areas and paddy fields. In the period 2013 - 2018, there was a reduction in the forest area of 0.22% of the watershed area, a reduction in the area of dry land agriculture by 7.16% and addition of a built-up area of 7.16% of the watershed area, an increase in the area of paddy fields by 2.87%. In the period 2018 - 2021, there was a reduction in a forest area of 2.82% of the watershed area, a reduction in water bodies of 0.47% addition of dry land agriculture of 1.51%, and addition of paddy fields of 1.45%. In 2013 the runoff coefficient was 0.41. In 2018, with the addition of a built-up area of 7.16% of the watershed area, the runoff coefficient increased to 0.54. In 2021 the runoff coefficient was decreased to 0.46. LULCC from 2013 to 2021 causes the runoff coefficient value to increase from 0.41 to 0.46.
Keyword : Land Use, Runoff coefficient, Upper Bengawan Solo Watershed, Central Java, Impact analysis.

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1 Introduction

A watershed is an area where the hydrological cycle occurs, functioning as a water catchment, storage, and release area [1]. Watersheds are fundamental units of ecosystems on the earth's surface, comprising various components, including agricultural areas, urban areas, forests, wetlands, lakes, and river ecosystems [2]. They form a complex system with complete functions, encompassing water resource, ecosystem, and socio-economic systems. Environmental management faces complex constraints due to the growing human population and increasing demand for natural resources. Healthy watershed conditions offer various ecosystem services, including nutrient circulation, water purification from waste, habitat protection, erosion/sedimentation control, flood control, and climate regulation [3]. According to [4], human activities in the upstream watershed have real impacts on people, land, and water in the downstream watershed. Environmental damage in watersheds is reflected in their hydrological conditions, making hydrological observations and measurements key parameters for determining watershed conditions [5].

Human activities, such as land cultivation and changes in land use within a watershed, can significantly affect water yields in terms of both quantity and quality [6]. The process of surface runoff and erosion is influenced by several factors, including land cover/use, rainfall, soil, and topography [7][8]. Surface runoff refers to water from rainfall that flows across the land surface, eventually reaching rivers, lakes, and oceans. It is influenced by two main factors: climatic conditions (rainfall) and characteristics of the watershed, including morphometry, topography, geology, and land use [6, 9]. The surface runoff coefficient is an indicator of the velocity and volume of surface runoff, providing valuable insights into the level of disturbance within a watershed. Changes in LULC serve as benchmarks for monitoring alterations in land ecosystems, which in turn have significant impacts on the hydrological regime [10].

Additionally, alterations in land use within a watershed can significantly impact various hydrological processes, including infiltration, groundwater infiltration, baseflow, and surface runoff. Given the rising demand for land and the expanding population, regular monitoring of LULC becomes crucial. The integration of remote sensing technology with Geographic Information Systems (GIS) proves to be extremely valuable and efficient for monitoring and managing dynamic objects on the earth's surface, such as LULC [11]. The objective of this study is to assess the impact of Land Use Land Cover Change (LULCC) on hydrological conditions, specifically focusing on the runoff coefficient.

2 Methodology

1.1 Research location

As mentioned in [12], the Bengawan Solo River holds the distinction of being the longest river on the island of Java, with a total length of 548 km. It flows through two provinces, namely Central Java and East Java, and traverses 17 districts along its course. However, several areas along the Bengawan Solo River often experience disasters such as floods and droughts [13]. The research location is in the Upper Solo Watershed which has outlet in Jurug. The Jurug Upper Bengawan Solo watershed has an area of approximately 368,792.43 ha, covering six regencies in Central Java Province, namely Klaten, Boyolali, Solo, Sukoharjo, Wonogiri and Karanganyar. Geographically, the study location is located in the coordinates 7o23’23” South – 8o09’23” South and 110o20’43” East – 111o22’48” East. Meanwhile, the location for measuring the water level and discharge at Jurug is located at the coordinates 7o33'59" south latitude and 110o51'39" east longitude. The research location is shown in Figure 1.

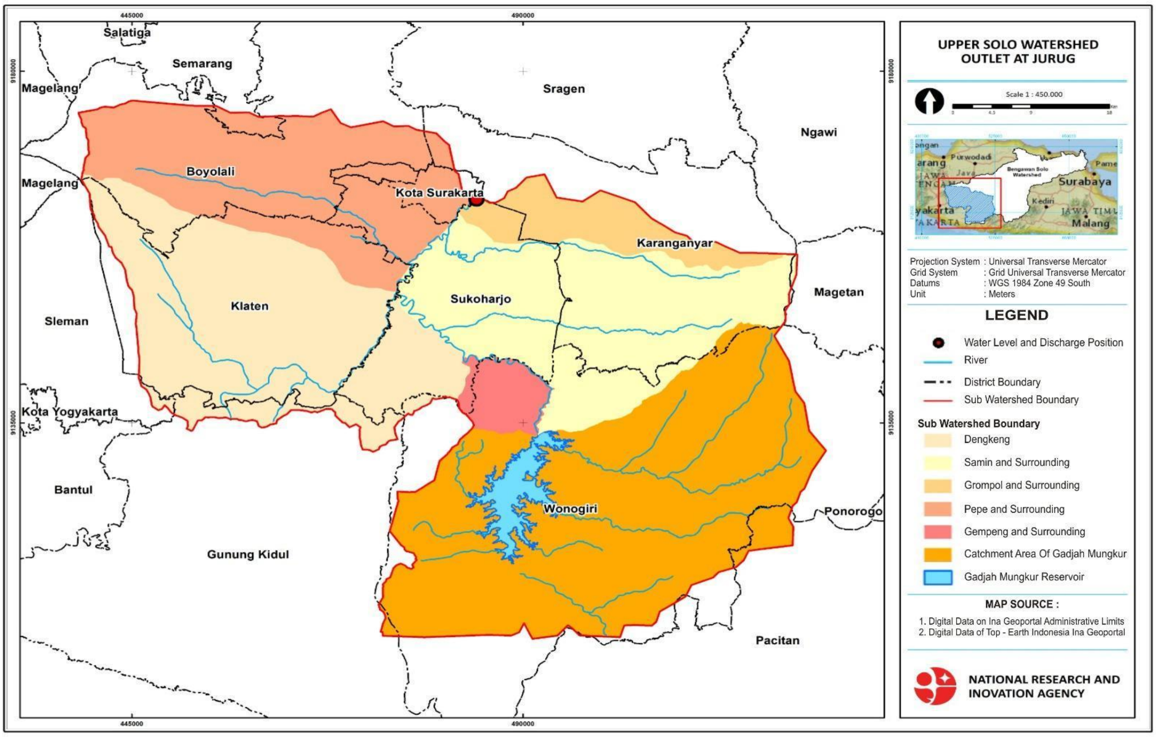

Fig. 1. Research Location

1.2 Materials and tools

The study employed various data sources, including water level and discharge data at Jurug from 2013 to 2021, obtained from the Bengawan Solo Water Resources Management Office (Balai Pengelolaan Sumber Daya Air Bengawan Solo), Ministry of Public Works and Public Housing (PUPR). For analyzing LULCC data, satellite imagery from Landsat 8 Operational Land Imager (OLI), recorded in 2013, 2018, and 2021, was utilized. Rainfall data for each sub-district from 2013 to 2021 were sourced from the Central Statistics Bureau (Biro Pusat Statistik/BPS). Additionally, thematic maps, created by the Geospatial Information Agency, derived from topographic maps of Indonesia, scaled 1:25,000, were utilized in the study. The equipment used included ArcGIS software version 10.2, Global Positioning System (GPS), and Microsoft Excel.

1.3 Methods

1.3.1 Calculating the runoff coefficient

Runoff coefficient is the comparison between runoff and rainfall. This figure can describe the ability of a watershed to store rainwater. The runoff coefficient numbers range from 0 to 1. A high runoff coefficient means that almost all of the rainfall becomes a stream or the watershed cannot store water. Conversely, if the runoff coefficient is low, it means that the watershed can store water during the rainy season and drain it during the dry season. The formula used is Runoff Coefficent (RC) = Total runoff/ Total precipitation [14].

This runoff coefficient is often used in describing watershed responses in instantaneous or annual units of time [15]. Runoff data was obtained from the results of recording the discharge carried out by BBWS Bengawan Solo from 2013 to 2021. The average rainfall data was obtained from BPS (Central Statistics Bureau) in Wonogiri, Klaten, Boyolali, and Karanganyar Regencies, which represent the upstream areas of the sub-watershed under study.

During smaller flood events, forested areas exhibit a lower runoff coefficient compared to non-forested areas, including disturbed forests and agricultural areas, when subjected to the same amount of rainfall. This difference is attributed to the forest's capacity for higher evapotranspiration and soil moisture retention, surpassing that of non-forested areas. As a result, forested areas tend to produce less runoff during smaller floods, making them beneficial for flood mitigation, particularly during more frequent flood occurrences. However, for larger flood events, the situation in the basin may vary, especially if the basin has high antecedent soil moisture or is approaching its saturation point. Forested areas are more effective at retaining antecedent soil moisture from previous storms compared to non-forested areas due to their deeper root zone and higher soil moisture holding capacity. Consequently, with ample antecedent soil moisture, forested areas require less water than non-forested areas to reach their soil saturation point. In such cases, the runoff coefficient in the forested area is found to be higher than that of the non-forested area. This study indicates that an increase in forested area leads to a higher runoff coefficient, while an increase in non-forested area results in a lower runoff coefficient [16].

1.3.2 Landsat Data Processing

Landsat data for one year is processed to become a free cloud mosaic. The processing is done by applying a cloud score to each pixel using the SimpleLandsatCloudScore algorithm. This algorithm will select the lowest cloud score at each point during the specified time range (in this case, for one year) and then calculate the percentile value of each band from the pixels received. In addition, the LandsatPathRowLimit algorithm is also used to select the least cloudy scene available. The cloud-free Landsat data is cut according to the area of interest boundaries (the Bengawan Solo sub-watershed that flows through the Jurug CA). Sample training consists of 8 classes, namely forest, field, paddy field, urban, open area, plantation, bush, and water classes class. The sample training is used to classify land use cover on previously cropped images. The method used for classification is using the Random Forest method. The result will be an image of the AoI area that has been graded. Figure 2. Shows Landsat data processing to produce LULC.

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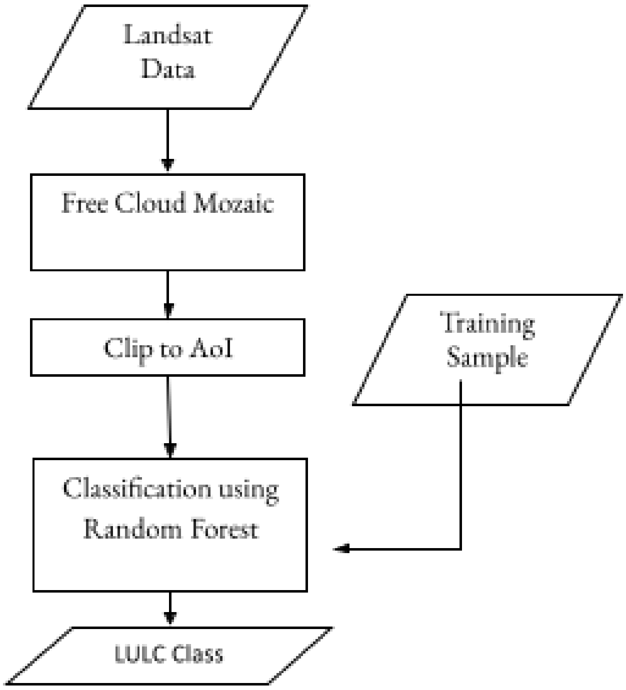

Fig. 2. Landsat data processing

2 Result and discussion

2.1 Monitoring lulcc with remote sensing

LULC at the study site were obtained from the analysis of Landsat imagery in 2013, 2018 and 2021. LULC are grouped into 8 classes, namely forest, field, rice field, urban, open area, platation, bush and water. LULC from Landsat imagery analysis results can be seen in Figures 3, 4 and 5. While the area of each class of LULC is presented in Table 1.

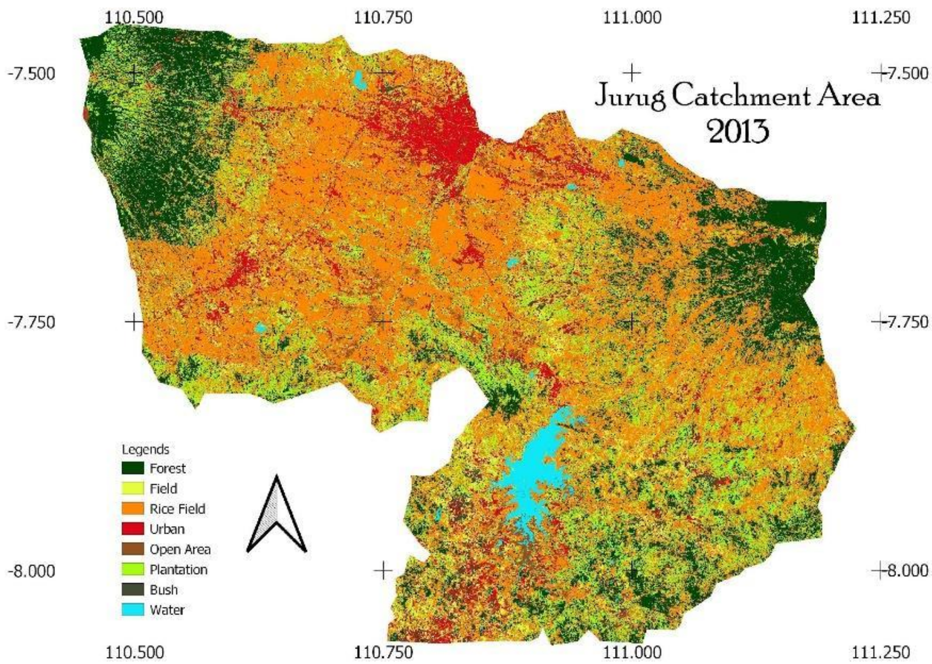

Fig. 3. LULC 2013, 2018, and 2022

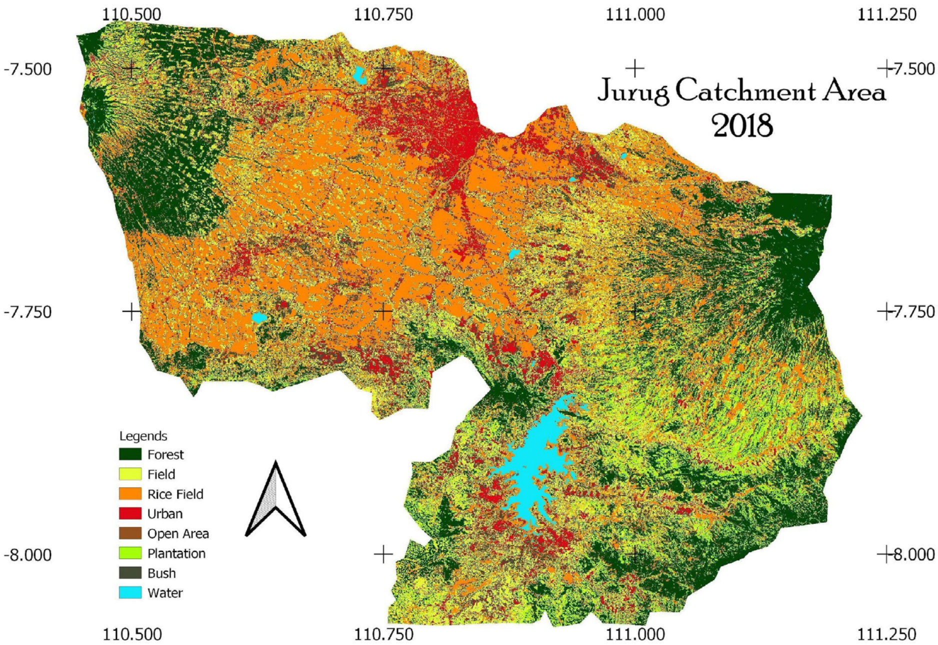

Fig. 4. LULC was classified by landsat recorded in 2013

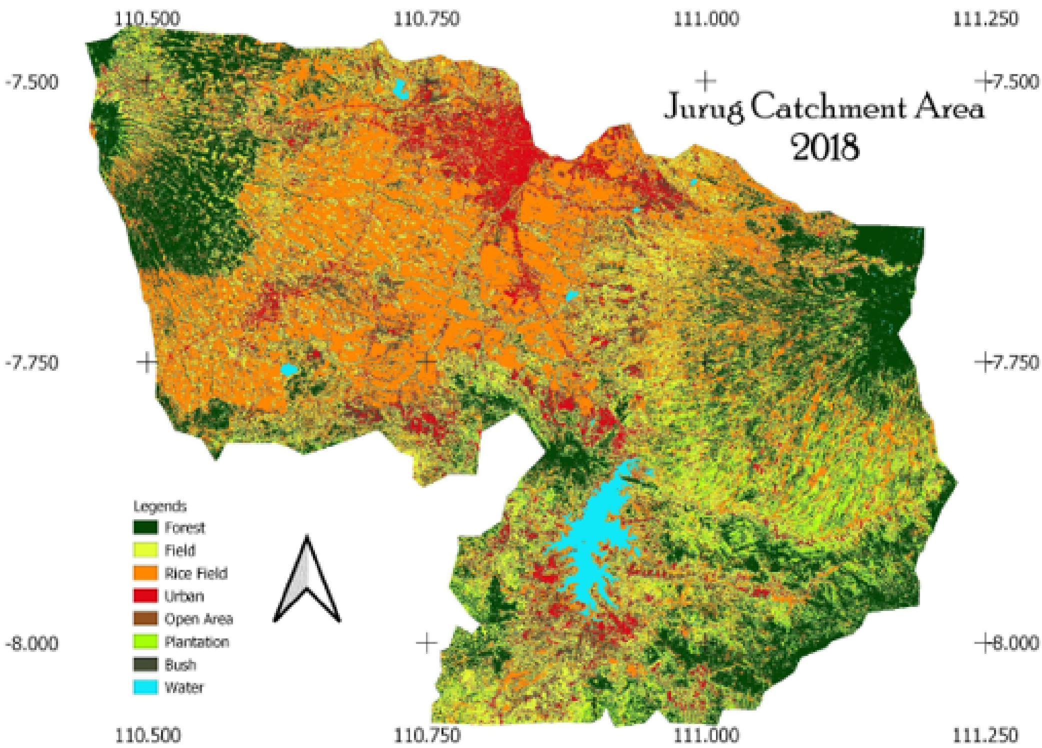

Fig. 5. LULC was classified by landsat recorded in 2018

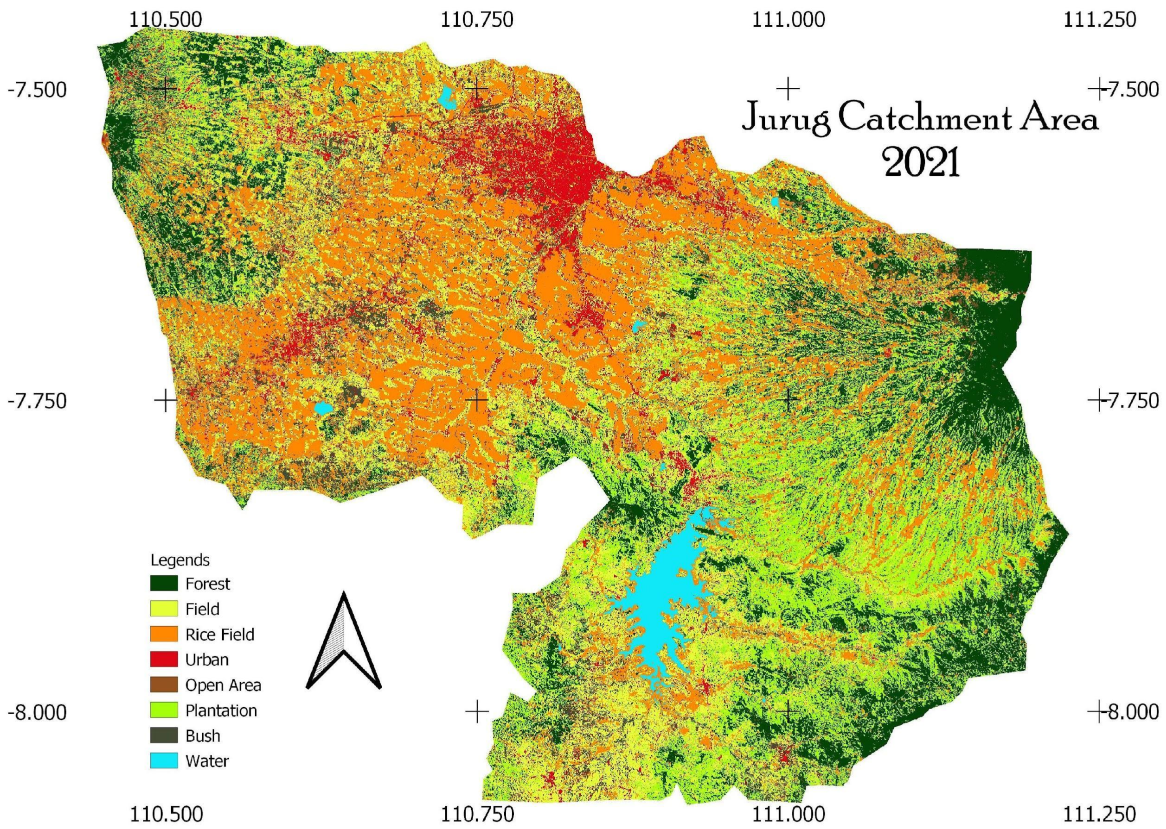

Fig. 6. LULC was classified by landsat recorded in 2021

The area of each class is shown in Figure 6

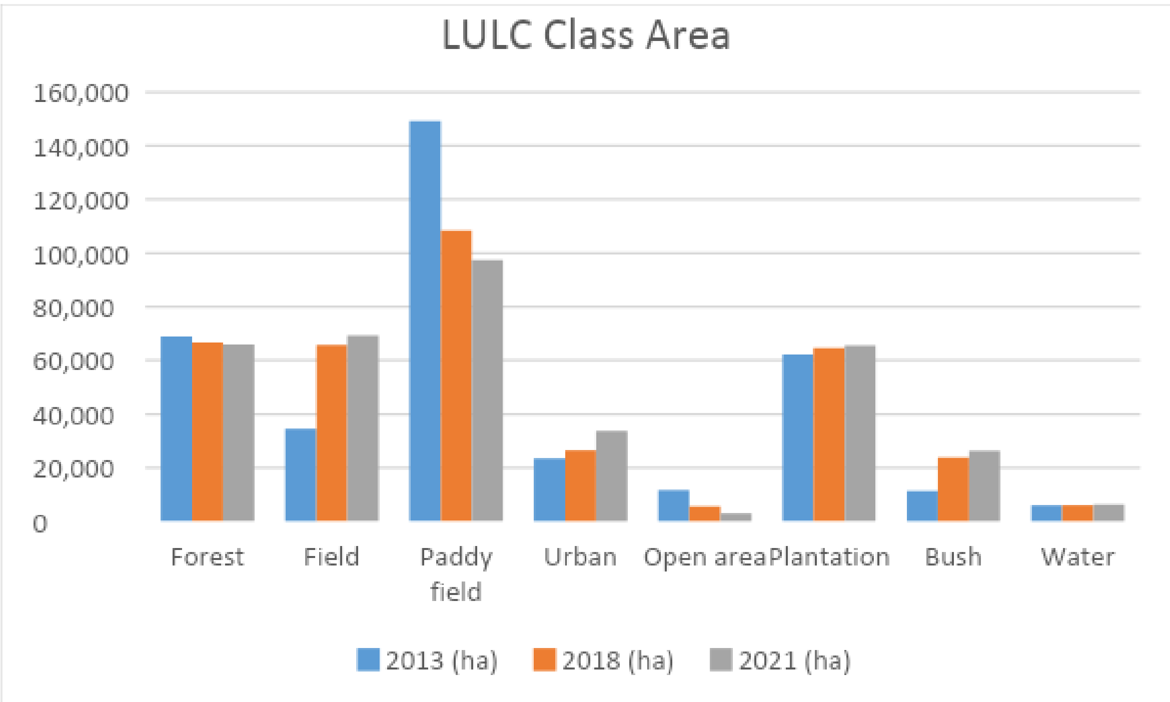

Fig. 7. LULC Class Area

From the class detection using the method used, it can be seen that from 2013 to 2021, there was a change in the LULC class, as shown in Table 1. Several classes that were detected experienced a decrease, namely the forest class, paddy field, and open area. In comparison, the detected classes have increased, namely field, urban, plantation, and bush classes. Several classes have experienced a decline, such as the forest class from 2013 to 2021, which has decreased by 2,878.59 ha (4.18%) from 68,832.79 ha to 65,954.20 ha. For paddy fields, there has been a decrease in the area of around 51,827 ha (34.73%); for open areas, it has decreased by about 8,600 ha (74.08%). In comparison, classes that experienced an increase in area, such as fields, were detected to experience a significant increase up to around 34,700 ha (100.98%). There has been an increase of around 10,200 ha (43.48%) for the urban class. The plantation and bush classes increased by approximately 3300 ha (5.24%) and 14800 ha (130.02%), respectively. And for the water class, it has increased by around 300 ha (5.30%).

The results generated from welding using machine learning are affected by various factors, mainly the sample and the data used as input. The remote sensing data used as input for machine learning is only a single mosaic of data with several channels. The mosaic used is also a one-year data mosaic where a selection of data can make it difficult to distinguish between one class and another. For example, in the paddy field class, there are times when the paddy fields in that area are not planted with rice but other crops such as crops and vegetables, so there is a possibility that the class is considered a field class. Apart from that, there is also a time when rice goes through a fallow phase where the land is in the form of empty land, which can cause it to enter the open land class. This case can happen to another class.

2.2 Runoff Coefficient in Upper Solo Watershed

The RC calculation results in the Upper Solo Watershed show that the RC in 2013, 2018 and 2021 is 0.42 each; 0.54; and 0.46 as shown in Table 1. The increase in RC values in 2018 is likely due to changes in land cover, reduced permanent vegetation or decreased annual rainfall. Annual rainfall in 2013, 2018 and 2021 is 2458 mm, 1719 mm and 2332 mm respectively.

Table 1. Runoff Coefficient at Upper Solo Watershedin 2013, 2018, and 2021

2013	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly
Runoff	271	207	83	128	50	111	24	21	8	11	34	65	1012
Rainfall	430	349	253	364	193	154	104	0	0	169	194	247	2458
RC	0.63	0.59	0.33	0.35	0.26	0.72	0.23	-	-	0.07	0.18	0.26	0.41
2018	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly
Runoff	217	185	125	80	35	36	35	34	35	33	44	63	923
Rainfall	434	354	248	164	22	26	0	0	11	6	223	231	1719
RC	0.50	0.52	0.51	0.49	1.59	1.38	-	-	3.08	5.74	0.20	0.27	0.54

2021	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Yearly
Runoff	95	141	167	121	85	32	27	33	52	66	95	161	1074
Rainfall	427	378	246	211	186	10	3	92	5	216	274	283	2332
RC	0.22	0.37	0.68	0.57	0.46	3.22	8.08	0.35	9.75	0.30	0.35	0.57	0.46

Based on Table 1. monthly RCs are various. It depends on rainfall in the month. During dry season where no or less rainfall the RC tend to higher. Therefore, annual RC is more representative to describe the watershed. Figure 7 is illustrated the RC during 2013 to 2021.

According to the study conducted by [15], the spatial distribution of the runoff coefficient showed a strong correlation with the average annual rainfall, but only a weak correlation with soil type and land use. The runoff coefficients tended to increase with higher event rainfall depth and prior rainfall, but the variations between different regions were more significant than the differences between events of various sizes. During light and moderate rainfall events, the runoff coefficient for forested areas was found to be lower than that of non-forested areas receiving the same amount of rainfall [16]. This is due to the greater infiltration capacity under forest cover than non-forest. In the event of heavy rains, the previous condition of soil moisture in forests is greater than in non-forests because forests have a higher ability to hold water in the soil. The conversion of forest land in the upstream part of the watershed into built-up areas such as settlements, trade, services has resulted in a decrease in the ability of land to hold water, resulting in rainwater being directly channeled into rivers and canals in the downstream part of the watershed [17]. With high humidity conditions, forest land requires little water to saturate the soil so that the runoff coefficient at high rainfall in the forest is greater than outside the forest [18]. Climatic factors, topography, land cover, soil properties, geology and other watershed characteristics are considered as the main drivers in producing runoff and provide insight into the spatial variation of runoff coefficients within the watershed. While the dominant control factors in the temporal variation of the runoff coefficient are rainfall, previous soil moisture, and rain intensity [19]. The runoff coefficient can be used as a parameter to see the condition of a watershed in moderate rainfall. In large rainfall the results will be biased. To avoid misinterpretation, it is better to use the annual runoff coefficient because the relationship between rainfall and runoff has settled and been observed for a long time. Land cover is not the only factor that influences the runoff coefficient, there are still many factors that influence it.

3 Conclusion

Based on Landsat Image analysis, LULC in the study area are grouped into 8 classes, namely forest, field, rice field, urban, open area, platation, bush and water**.** Several classes have experienced a decline, such as the forest class from 2013 to 2021, which has decreased by 2,878.59 ha from 68,832.79 ha to 65,954.20 ha. For paddy fields, there has been a decrease in the area of around 51,827 ha; for open areas, it has decreased by about 8,600 ha. In comparison, classes that experienced an increase in area, such as fields, were detected to experience a significant increase up to around 34,700 ha. There has been an increase of around 10,200 ha for the urban class. The plantation and bush classes increased by approximately 3,300 ha and 14,800 ha, respectively. The RC calculation results in the

Upper Solo Watershed show that the RC in 2013, 2018 and 2021 is 0.42 ; 0.54; and 0.46. The decrease in annual rainfall in 2018 and the decrease in the area of permanent vegetation may have contributed to the high RC in the study area. The runoff coefficient can be used as a parameter to see the condition of a watershed in moderate rainfall. To avoid misinterpretation, it is better to use the annual runoff coefficient because the relationship between rainfall and runoff has settled and been observed for a long time. Land cover is not the only factor that influences the runoff coefficient, there are still many factors that influence it.

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