Urban Dynamics and Carbon Stock Estimation in Salatiga City, Indonesia

N. M. Lakshita¹ and S. Rahayu¹

¹Diponegoro University, Indonesia

Email: nattayam98@gmail.com

Abstract. Previous research has not discussed about the prediction method of carbon stock changes using open-source software. This research aims to fill the gap by using QGIS as open-source software in. The method used is Support Vector Machine and Cellular Automata, which is only found in QGIS software, including QGIS 3.8.0 and QGIS 2.18.24 with Pip-Python 3. The results show that SVM and Cellular Automata algorithms in QGIS software successfully predicted land cover in the context of carbon stock change. This study shows the prediction of carbon stock changes due to land cover conversion in Salatiga City for the period 2019-2029 decreased by 9,202.77 tons C, where carbon emission was 10,313.47 tons C and carbon sequestration was 1,110.70 tons C. The prediction of carbon stock changes in Salatiga City is needed to reference local governments to formulate mitigation and adaptation efforts to global climate change.

Keywords: carbon stock changes, land cover conversion, open-source software

1. Introduction

Urbanization, climate change, and cities are intricately related as a change in any one will affect the others [1]. Cities are major contributors to greenhouse gas emissions. Half of the world's population lives in cities, a share that is likely to reach 70 percent in 2050. Most economic activity is concentrated in urban areas. Cities have a key role in climate change [2]. Therefore, cities are responsible for reducing GHG emissions, both emissions that have been generated and emissions that will come. Due to uncontrolled urbanization in Indonesia, particularly in Java, environmental degradation has been occurring very rapidly and causing many problems [3]. High development activities have placed Indonesia as one of the world's third emitting countries, especially emissions from deforestation and degradation of forests and peatlands [4–10].

Ecosystem services have an important role in human well-being. Because they are overexploited, environmental degradation occurs, which has a negative impact on humans and other living things for future generations. Today's most pressing environmental challenge is protecting ecosystems from the pressures of ongoing development [11–13]. Change in land cover means changes in carbon stocks. The higher the rate of change from forest land to non-forest land, the higher the rate of change in rainfall, while carbon stock decreases so that the chance of climate change due to increased CO2 content in the atmosphere is greater [14].
The achievement of international goals and national commitments related to forest conservation and management, climate change, and sustainable development requires credible, accurate, and reliable monitoring of stocks and changes in forest biomass and carbon. The estimation of biomass is important for quantifying and understanding the impacts of dynamic land-use or land-cover events such as encroachment of vegetation and biomass removal [15]. In Indonesia, the RAN-GRK mandate to develop action plans for GHG emission reduction at the provincial level including district/city was called Local Action Plan for Green House Gas Emission Reduction [16]. The estimated carbon storage of an urban area cannot be extrapolated to other urban areas due to the pattern of urbanization, spatial planning, and the type of vegetation as cover in fundamentally different conditions [17].

Salatiga is one of the cities located in the Kedungsepur National Strategic Area and has good potential from natural resources, facilities, infrastructure to provide opportunities for Salatiga City to grow and develop. The increasing population and the high level of development by indigenous people also migrants have made Salatiga City experience problems in terms of spatial use. It causes a bigger need for residential areas and other facilities. This is the factor that induces green area in Salatiga to change its function to be built-up land. This land use transformation has led to an increase in attraction in certain zones, due to the growth of new activity center that has a considerable attraction, such as education and commercial & services [18–20]. Previous studies show the implementation of a spatial plan for settlements in Salatiga City in 2017 is not under the Spatial Plan of Salatiga City 2010-2030. The occurrence of irregularities/ discrepancies in the RTRW based on the field results is because the community's land is privately owned, and the community lacks knowledge of the spatial plan [21].

Land cover change in an area can indicate the dynamics of carbon stocks. The quantification of land changes that occur over a period of time can be done by analyzing satellite images from different capture times [22]. Improvements in both the field estimates of biomass change and remote sensing technologies in the coming years could lead to such approaches becoming efficient and accurate for GHG inventory purposes [15]. Previous research also used the existing LULCC to calculate the carbon stock changes [23–26]. Some of these studies also still use paid software. Besides, there are still few studies that discuss the amount of carbon stock in the future.

Recent studies have demonstrated the use of cellular automata (CA) and artificial neural network (ANN) to predict land use and land cover [27–29]. The model results reveal that the CA-ANN can produce satisfactory results because the simulated situation is close to the observed situation [27]. The integrated CA-ANN model was one of the most efficient methods for simulating complex and non-linear LULC, specific for the research area [29]. CA-based models' advantages include their simplicity, flexibility, and intuitiveness, particularly their ability to incorporate the spatial and temporal dimensions [28].

The research to date focuses only on predicting LULCC and calculating only current carbon stock changes. In fact, spatial planning and development planning also requires planning for carbon stock changes in the future. To complement the previous studies, carbon stock changes were calculated using land cover changes using cellular automata. This research aims to study the prediction of carbon stock changes due to land cover conversion in Salatiga City for 2019-2029.

2. Data and Methods

2.1 Study Area

The research location was chosen in Salatiga City (Figure 1), which consists of 4 subdistricts and 23 villages in 5.595 hectares. Salatiga City is an education city with high accessibility and mobility due to its strategic location and adequate supporting infrastructure. In 2011, the Southern Ring Road of Salatiga City was completed, where the road section passes through the protected area of Kumpulrejo Village and Dukuh Village. Besides, the Semarang-Solo Toll exit had also been opened in Tingkir Tengah Village in 2018. There is an opportunity for settlements and trade services to develop and reduce green open land in Salatiga City in 2019-2029.
2.2 Land Cover Identification

In general, land cover identification consists of three processes, namely geometric and radiometric correction, image cropping, and image interpretation and classification. Image classification is carried out in a supervised classification using the Support Vector Machine method. The image cut with administrative boundaries is then taken 70-110 image samples showing all land cover classes to be used as a training set. Before classifying images with QGIS, it is necessary to install Pip-Python 3 on QGIS 3.8.0 to activate the SVM in the dzetzaka plugin.

Verification of the land cover classification results can be done using the existing land cover data of Salatiga City, obtained through observation activities. The kappa value is derived from r.kappa in QGIS with the help of a testing set. The testing set is a reference for determining the extent to which the researcher has succeeded in classifying. According to Altman (1991) in [30], the Kappa value of 0.81-1.00 shows very good results, 0.61-0.80 good, 0.41-0.60 moderate, 0.21-0.40 is less than moderate, and a value <0.21 is considered bad.

2.3 Analysis of Land Cover Prediction

The results of a land cover classification in 2009 and 2019 are the basis for the land cover classification for Salatiga City in 2029. The method used is Cellular Automata from the Molusce plugin on QGIS 2.18.24 software. Cellular Automata (CA) are raster-based tools used effectively to model cities and land-use change. Cellular Automata iteration is set to 1,000 with a sample size of 5,000 to produce the maximum predicted land cover. The driving factors used in predicting land cover are based on research [31] which has been modified according to the study area. Therefore, this study's driving factors are the distance from non-toll roads, distance from toll roads, distance from rivers, distance from the city center, slope, and population density.

2.4 Analysis of Carbon Stock Changes Prediction

First, the researchers analyzed land cover change. The calculation of the area of land cover conversion and carbon stock changes in Salatiga City uses a matrix. Carbon stocks for each land cover type are presented in Table 1 [32]. Furthermore, the researcher analyzes the input-output. The input-output analysis will produce the gain and loss graph based on calculating the previously done predicted carbon stock changes. This is necessary because the land has two possible carbon stock changes: carbon sequestration (sequestration) or carbon release (emissions).
Table 1. Carbon Stocks Based on Land Cover

| No. | Land Cover           | Carbon Stocks (Ton C/Ha) |
|-----|----------------------|--------------------------|
| 1.  | Primary Dry Forest   | 195                      |
| 2.  | Secondary Dry Forest | 169                      |
| 3.  | Primary Mangrove Forest | 170                |
| 4.  | Primary Swamp Forest | 196                      |
| 5.  | Plantation Forest    | 64                       |
| 6.  | Shrubs               | 30                       |
| 7.  | Plantation           | 63                       |
| 8.  | Settlements          | 4                        |
| 9.  | Open Ground          | 2.5                      |
| 10. | Grassland            | 4                        |
| 11. | Secondary Mangrove Forest | 120            |

| No. | Land Cover           | Carbon Stocks (Ton C/Ha) |
|-----|----------------------|--------------------------|
| 12. | Secondary Swamp Forest | 155               |
| 13. | Swampy Shrub         | 30                       |
| 14. | Agriculture          | 10                       |
| 15. | Mixed Agriculture    | 30                       |
| 16. | Rice Field           | 2                        |
| 17. | Fishponds            | 0                        |
| 18. | Airport/Port         | 0                        |
| 19. | Transmigration Area  | 10                       |
| 20. | Mining               | 0                        |
| 21. | Swamps               | 0                        |

3. Result and Analysis

Image classification results produce five land cover classes, including settlements, mixed agriculture, plantation, rice field, and open ground. Accuracy tests carried out on the 2019 Salatiga City image classification results have an accuracy rate of 97%. The kappa value in the image classification in 2009 was 0.9142 and in 2019 was 0.9428, meaning that the image classification showed excellent results.

Based on Table 2, mixed agriculture in Argomulyo Subdistrict in 2009 became the largest mixed agriculture compared to the other three subdistricts, reaching 1,122.75 hectares. The largest plantation area is located in Sidorejo Subdistrict, especially in the northern part of the subdistrict, a rubber tree plantation. Not only that, but Sidorejo Subdistrict also dominates the rice fields in Salatiga City. Despite having the largest plantation and rice fields, Sidorejo Subdistrict also has a large settlement area of 666.65 hectares. This is triggered by the geographical condition of Sidorejo Subdistrict, which is the entrance to Salatiga City from Semarang City's direction.

Table 2. Land Cover Area Each Subdistrict in Salatiga City, 2009

| No. | Subdistrict | Settlements | Mixed Agriculture | Plantation | Rice Field | Open Ground | Total |
|-----|-------------|-------------|-------------------|------------|------------|-------------|-------|
| 1   | Argomulyo   | 632.38      | 1,122.75          | 2.70       | 18.72      | 43.22       | 1,819.78 |
| 2   | Sidomukti   | 502.72      | 562.05            | 3.06       | 54.67      | 11.56       | 1,134.07 |
| 3   | Sidorejo    | 666.65      | 496.64            | 143.44     | 281.30     | 9.45        | 1,597.48 |
| 4   | Tingkir     | 421.99      | 349.47            | 9.86       | 254.79     | 7.85        | 1,043.96 |
|     | Total       | 2,223.75    | 2,530.92          | 159.07     | 609.48     | 72.09       | 5,595.30 |

In 2009, the largest settlement area was in Sidorejo Subdistrict, while in 2019, Argomulyo Subdistrict experienced rapid growth of settlements. This was driven by the construction of the Salatiga South Ring Road, which was inaugurated in 2011. Therefore, the largest area of settlements in 2019 is in Argomulyo Subdistrict, which is 838.89 hectares. Although the area of mixed agriculture has decreased, Argomulyo Subdistrict still dominates. In 2019, the widest plantation and rice fields are still in Sidorejo Subdistrict, just as the largest open ground area is still in Argomulyo Subdistrict.

Figure 2 and Figure 3 below show the map and percentage diagram of the land cover in Salatiga City in 2009 and 2019. The area of settlements increased by 10.01% in a period of 10 years. It is inversely proportional to the area of mixed agricultural land, which decreased by around 13.17%. Figure 4 shows the land cover changes that occurred in Salatiga City in 2009-2019. It can be seen that the Salatiga South Ring Road in 2009 has not been completed, resulting in a land cover change from
mixed agriculture and rice field to settlements in 2019. This has also stimulated the growth of settlements on the ring road, as seen in Argomulyo Subdistrict. Not only that, due to the construction of the Semarang-Solo Toll Road, the rice field in Sidorejo and Tingkir Subdistricts have turned into settlement areas.

Table 3. Land Cover Area Each Subdistrict in Salatiga City, 2019

| No. | Subdistrict | Settlements (Ha) | Mixed Agriculture (Ha) | Plantation (Ha) | Rice Field (Ha) | Open Ground (Ha) | Total (Ha) |
|-----|-------------|------------------|------------------------|----------------|----------------|------------------|------------|
| 1.  | Argomulyo   | 838.89           | 830.12                 | 16.36          | 56.41          | 78.01            | 1,819.78   |
| 2.  | Sidomukti   | 629.91           | 384.64                 | 15.44          | 78.48          | 25.60            | 1,134.07   |
| 3.  | Sidorejo    | 783.92           | 334.37                 | 144.99         | 285.98         | 48.22            | 1,597.48   |
| 4.  | Tingkir     | 531.18           | 244.82                 | 14.49          | 192.55         | 60.91            | 1,043.96   |
| Total|             | 2,223.75         | 2,783.90               | 1,793.95       | 191.28         | 613.42           | 212.74     |

Figure 2. (a) Land Cover of Salatiga City in 2009; (b) Land Cover of Salatiga City in 2019 (Author’s Analysis, 2020)

Figure 3. Percentage Diagram of The Land Cover Area in Salatiga City in 2009; (b) Percentage Diagram of The Land Cover Area in Salatiga City in 2019 (Author’s Analysis, 2020)
Figure 4. Map of Land Cover Change in 2009-2019 (Author’s Analysis, 2020)

Based on Table 4, it is known that mixed agriculture in each subdistrict has turned into settlements. This change is also the largest land cover change compared to other land cover changes. A total of 254.36 hectares of mixed agriculture in Argomulyo Subdistrict has turned into settlements. This shows that there has been a change in non-built-up to built-up area in Salatiga City for ten years.

Table 4. Matrix of Land Cover Change in 2009-2019

| Land Cover (Ha)       | Settlements | Mixed Agriculture | Plantation | Rice Field | Open Ground | Total 2009 |
|-----------------------|-------------|--------------------|------------|------------|-------------|------------|
| **Argomulyo Subdistrict** |             |                    |            |            |             |            |
| Settlements           | 553.39      | 62.92              | 1.64       | 9.27       | 15.17       | 632.38     |
| Mixed Agriculture     | 254.36      | 768.51             | 10.87      | 40.72      | 48.29       | 1,122.75   |
| Plantation            | 0.23        | 0.16               | 2.25       | 0.00       | 0.07        | 2.70       |
| Rice Field            | 8.62        | 3.51               | 0.22       | 4.23       | 2.14        | 18.72      |
| Open Ground           |             | 5.02               | 1.37       | 2.18       | 12.35       | 18.22      |
| **Total 2019**        | 838.89      | 830.12             | 16.36      | 56.41      | 78.01       | 1,819.78   |
| **Sidomukti Subdistrict** |         |                    |            |            |             |            |
| Settlements           | 460.83      | 22.37              | 0.59       | 11.95      | 7.00        | 502.72     |
| Mixed Agriculture     | 154.62      | 355.28             | 11.90      | 30.08      | 10.17       | 562.05     |
| Plantation            | 0.00        | 0.54               | 2.25       | 0.27       | 0.00        | 3.06       |
| Rice Field            | 11.20       | 5.85               | 0.63       | 45.55      | 1.44        | 54.67      |
| Open Ground           | 3.26        | 0.61               | 0.07       | 0.63       | 7.00        | 11.56      |
| **Total 2019**        | 629.91      | 384.64             | 15.44      | 78.48      | 25.60       | 1,134.07   |
| **Sidorejo Subdistrict** |           |                    |            |            |             |            |
| Settlements           | 595.26      | 22.21              | 0.40       | 31.57      | 13.61       | 666.65     |
| Mixed Agriculture     | 135.63      | 259.99             | 20.97      | 66.37      | 13.68       | 496.64     |
| Plantation            | 0.68        | 26.24              | 112.73     | 0.95       | 2.86        | 143.44     |
| Rice Field            | 49.97       | 25.67              | 3.73       | 186.64     | 15.28       | 281.30     |
| Open Ground           | 2.39        | 0.27               | 3.56       | 0.45       | 2.79        | 9.45       |
| **Total 2019**        | 783.92      | 334.37             | 144.99     | 285.98     | 48.22       | 1,597.48   |
| **Tingkir Subdistrict** |           |                    |            |            |             |            |
| Settlements           | 385.65      | 19.06              | 0.61       | 9.45       | 7.22        | 421.99     |
| Mixed Agriculture     | 105.97      | 190.33             | 8.84       | 29.97      | 14.36       | 349.47     |
| Plantation            | 0.32        | 4.03               | 2.45       | 1.62       | 1.44        | 9.86       |
| Rice Field            | 36.22       | 30.51              | 2.59       | 151.45     | 34.02       | 254.79     |
| Open Ground           | 3.01        | 0.90               | 0.00       | 0.07       | 3.87        | 7.85       |
| **Total 2019**        | 531.18      | 244.82             | 14.49      | 192.55     | 60.91       | 1,043.96   |

Yellow cells mean the value is fixed.
Furthermore, the Cellular Automata method from Molusce plugin is used to predict the land cover of Salatiga City in 2029. The driving factors used can be seen in Figure 5. Distance from non-toll roads, toll roads, rivers, and city centers using euclidean distance with a radius of 10,000 meters. The red color on the map shows the location closer to the road, river, or city center. Slope processed by reclassification flat (dark green) to very steep (red). The population density of each village is processed using kernel density with a radius of 2,500 km2. The red color on the map indicates the location is densely populated.

**Figure 5.** (a) The Distance Factor from The Non-Toll Road; (b) The Distance Factor from The Toll Road; (c) The Distance from The River; (d) The Distance Factor from The City Center; (e) Slope Factor; (f) Population Density Factor (Author's Analysis, 2020)

Based on Figure 6a, the increase in the settlement area in Salatiga City in the previous ten years is predicted to occur again in 2029. The settlement area, which was originally 49.75%, has increased to 57.74% of the total area of Salatiga City. Not only that, but the area of mixed agriculture has also decreased, as happened in 2009-2019. The area of mixed agriculture, which was originally 32.06%, is predicted to decrease to 26.81% of the total area of Salatiga City (see Figure 6b).
Figure 6. (a) Salatiga City Land Cover in 2029; (b) Diagram of The Percentage of Land Cover Area in Salatiga City in 2029 (Author's Analysis, 2020)

Figure 7 shows a map of land cover change for Salatiga City in 2019-2029. Most mixed agriculture, plantations, rice fields, and the open ground will turn to settlements. It is predicted that the growth of settlements in 2029 will follow road patterns and become denser in the city center. Based on Table 5, it is known that the area of mixed agriculture will decrease significantly and turn into settlements in 2029, which is an area of 299.38 Ha.

Changes in the area of each land cover class in Salatiga City in 2009-2019 and 2019-2029 have been identified through analyzes conducted by researchers. This data can show changes in the land cover area in 2009-2029. The following is Table 6 and Figure 8 to compare changes in the land cover area in Salatiga City in 2009-2019, 2019-2029, and 2009-2029.

Figure 7. Map of Land Cover Change in 2019-2029 (Author's Analysis, 2020)
Table 5. Matrix of Land Cover Change in 2019-2029

| Land Cover (Ha) | Settlemtns | Mixed Agriculture | Plantation | Rice Field | Open Ground | Total 2019 |
|----------------|------------|-------------------|------------|------------|-------------|------------|
| Argomulyo Subdistrict | 828.32 | 3.87 | 0.02 | 7.76 | 0.07 | 840.04 |
| | 115.13 | 710.27 | 0.00 | 2.07 | 5.40 | 832.87 |
| | 0.29 | 3.06 | 11.28 | 0.70 | 0.09 | 15.42 |
| | 26.14 | 0.92 | 0.02 | 27.08 | 1.42 | 55.58 |
| | 10.49 | 2.07 | 0.41 | 7.58 | 56.58 | 77.12 |
| Total 2029 | 980.37 | 720.19 | 11.73 | 45.19 | 63.55 | 1,821.04 |
| Sidomukti Subdistrict | 627.07 | 0.58 | 0.02 | 1.19 | 0.05 | 628.91 |
| | 69.77 | 299.78 | 0.00 | 2.27 | 12.33 | 384.15 |
| | 0.16 | 4.10 | 9.66 | 0.52 | 0.14 | 14.48 |
| | 25.09 | 0.94 | 0.00 | 48.11 | 3.47 | 77.61 |
| | 2.48 | 0.47 | 0.02 | 0.38 | 21.30 | 24.65 |
| Total 2029 | 724.56 | 305.79 | 9.71 | 52.48 | 37.27 | 1,129.81 |
| Sidorejo Subdistrict | 780.31 | 0.38 | 0.05 | 2.70 | 0.05 | 783.48 |
| | 57.12 | 262.92 | 0.00 | 5.49 | 9.74 | 335.57 |
| | 1.01 | 9.65 | 132.06 | 1.55 | 0.56 | 144.84 |
| | 65.23 | 4.61 | 0.02 | 209.66 | 6.91 | 286.43 |
| | 6.71 | 1.37 | 0.13 | 2.52 | 36.82 | 47.55 |
| Total 2029 | 810.67 | 278.94 | 132.26 | 221.92 | 54.08 | 1,597.88 |
| Tingkir Subdistrict | 528.51 | 1.01 | 0.00 | 3.87 | 0.09 | 531.48 |
| | 57.06 | 176.09 | 0.00 | 6.59 | 6.93 | 246.67 |
| | 0.11 | 7.29 | 6.17 | 0.31 | 0.04 | 13.93 |
| | 27.05 | 4.32 | 0.00 | 158.97 | 3.80 | 194.14 |
| | 4.54 | 6.59 | 0.56 | 6.73 | 41.92 | 60.35 |
| Total 2029 | 615.27 | 195.30 | 6.73 | 176.48 | 52.79 | 1,046.58 |

Yellow cells mean the value is fixed

Table 6. Changes in The Land Cover Area of Salatiga City in 2009-2029

| Land Cover | 2009-2019 | 2019-2029 | 2009-2029 |
|------------|-----------|-----------|-----------|
| Settlements | 560.15 | 446.96 | 1,007.11 |
| Mixed Agriculture | -736.96 | -299.05 | -1,036.01 |
| Plantation | 32.21 | -28.24 | 3.98 |
| Rice Field | 3.94 | -117.70 | -113.76 |
| Open Ground | 140.65 | -1.98 | 138.67 |
| Total | 0.00 | 0.00 | 0.00 |

Figure 8. Land cover area change diagram for Salatiga City, 2009-2029 (Author’s Analysis, 2020)
Based on the table 6 and figure 8, it is known that the growth of settlements is very fast. The settlement area will increase by around 1,007.11 Ha from 2009 to 2029. It is inversely proportional to the decreasing of mixed agriculture. The land area reduction has reached 1,036.01 Ha in the past ten years and the next ten years (2009-2029). This shows, under normal conditions and there is no action from the government to limit land-use change in Salatiga City (business as usual), the built-up land will continue to increase. In contrast, green space will continue to decrease.

### Table 7. Matrix of Carbon Stocks based on Land Cover Conversion

|                 | Settlements | Mixed Agriculture | Plantation | Rice Field | Open Ground |
|-----------------|-------------|-------------------|------------|------------|-------------|
| 2019 Carbon Stock (Ton C/Ha) | 0.00 | -26.00 | -59.00 | 2.00 | 1.50 |
| Mixed Agriculture | 26.00 | 0.00 | -33.00 | 28.00 | 27.50 |
| Plantation | 59.00 | 33.00 | 0.00 | 61.00 | 60.50 |
| Rice Field | -2.00 | -28.00 | -61.00 | 0.00 | -0.50 |
| Open Ground | -1.50 | -27.50 | -60.50 | 0.50 | 0.00 |

Yellow cells mean the value is fixed.

The land cover conversion area of Salatiga City in 2019-2029 multiplied by carbon stock will result in a stock difference in ton C, as shown in Table 8. Changes in mixed agriculture to settlements in 2029 have the most dominant effect in releasing reserves carbon. It is known that the release of 7,783.98 tons C or 75.47% of the total release of carbon reserves in Salatiga City in 2029. Although there has been a decrease in green space, green space has also occurred in 2029.

Most of the sequestration was obtained from the increase in the area of plantation and mixed agriculture. Sequestration occurs in every district, especially Tingkir Subdistrict. 395.72 tons of C was obtained from rice fields’ conversion and open ground to land with larger carbon reserves such as plantation and mixed agriculture.

### Table 8. Matrix of Carbon Stock Changes in Salatiga City 2019-2029

| Land Cover (Ha) | 2019 | Settlements | Mixed Agriculture | Plantation | Rice Field | Open Ground | Total 2019 |
|----------------|------|-------------|-------------------|------------|------------|-------------|-------------|
| Argomulyo Subdistrict | | | | | | | |
| Settlements | 0.00 | -100.62 | -1.34 | 15.53 | 0.10 | -86.33 |
| Mixed Agriculture | 2,993.46 | 0.00 | 0.00 | 57.95 | 148.51 | 3,199.92 |
| Plantation | 17.26 | 100.98 | 0.00 | 42.55 | 5.44 | 166.23 |
| Rice Field | -52.29 | -25.83 | -1.37 | 0.00 | -0.71 | -80.20 |
| Open Ground | -15.73 | -56.93 | -24.50 | 3.79 | 0.00 | -93.37 |
| Total 2019 | 2,942.70 | -82.40 | -27.21 | 119.82 | 153.34 | 3,106.26 |
| Sidomukti Subdistrict | | | | | | | |
| Settlements | 0.00 | -15.21 | -1.33 | 2.38 | 0.07 | -14.09 |
| Mixed Agriculture | 1,814.08 | 0.00 | 0.00 | 63.63 | 339.08 | 2,216.79 |
| Plantation | 9.30 | 132.22 | 0.00 | 31.58 | 8.17 | 181.26 |
| Rice Field | -50.18 | -26.46 | 0.00 | 0.00 | -1.73 | -78.37 |
| Open Ground | -3.71 | -13.00 | -1.36 | 0.19 | 0.00 | -17.88 |
| Total 2019 | 1,769.49 | 77.55 | -2.69 | 97.79 | 345.58 | 2,287.72 |
| Sidorejo Subdistrict | | | | | | | |
| Settlements | 0.00 | -9.94 | -2.68 | 5.40 | 0.07 | -7.15 |
| Mixed Agriculture | 1,492.91 | 0.00 | 0.00 | 153.72 | 267.92 | 1,914.55 |
| Plantation | 59.74 | 318.53 | 0.00 | 94.70 | 34.03 | 506.99 |
| Rice Field | -130.45 | -129.15 | -1.37 | 0.00 | -3.45 | -264.43 |
| Open Ground | -10.06 | -37.74 | -8.17 | 1.26 | 0.00 | -54.71 |
| Total 2019 | 1,412.13 | 141.69 | -12.22 | 255.08 | 298.56 | 2,095.25 |
| Tingkir Subdistrict | | | | | | | |
| Settlements | 0.00 | -26.33 | 0.00 | 7.74 | 0.14 | -18.45 |
| Mixed Agriculture | 1,483.53 | 0.00 | 0.00 | 184.59 | 190.57 | 1,858.69 |
| Plantation | 6.64 | 240.47 | 0.00 | 19.21 | 2.72 | 269.04 |
| Rice Field | -54.09 | -120.96 -0.00 | 0.00 | -1.90 | -176.95 |
| Open Ground | -6.82 | -181.29 | -34.03 | 3.36 | 0.00 | -218.77 |
| Total 2019 | 1,429.26 | -88.10 | -34.03 | 214.90 | 191.52 | 1,713.55 |

Yellow cells mean the value is fixed.
Figure 9 shows the prediction of carbon stock changes due to land cover conversion per subdistrict in Salatiga City in 2019-2029. The highest release of carbon stocks occurred in Argomulyo Subdistrict, amounting to 3,366.15 tons C. This occurred because the vast area of mixed agriculture in Argomulyo Subdistrict had turned into settlements. The highest sequestration occurred in Tingkir Subdistrict with 414.18 tons C.

Emissions and sequestration of each subdistrict are then added to determine the release and absorption of carbon stocks in Salatiga City. Based on Figure 10, 10,313.47 tons C will be released (emissions), and 1,110.70 tons of C will be absorbed (sequestration) in 2019-2029 in Salatiga City. Therefore, it can be said that the carbon stock released is 0.18 tons C / Ha.year, and the absorbed carbon stock is 0.02 tons C / Ha.year. This shows that the increase in the area of built-up land occurred faster than the addition of green space during 2019-2029.

The decrease in the amount of carbon stock in Salatiga City in 2019-2029 is not as big as the decline in 2009-2019. Changes in carbon stock in 2009-2019 amounted to 17,479.26 tons C, where there were 23,769.39 tons C of carbon emissions, and carbon sequestration of 6,290.13 tons C. If adjusted for the area of Salatiga City, carbon emissions that occurred were 0.42 tons C / Ha.year and carbon sequestration 0.11 tons C / Ha.year. Even though the decrease in the amount of carbon stock in the predicted year is lower than the decline in the existing year, the value of carbon emissions is still greater than the carbon sequestration.

![Figure 9](image9.png)

**Figure 9.** (a) Diagram of the number of emissions and sequestration for 2019-2029 in ton C in Argomulyo Subdistrict; (b) Sidomukti Subdistrict; (c) Sidorejo Subdistrict; (d) Tingkir Subdistrict (Author's Analysis, 2020)

![Figure 10](image10.png)

**Figure 10.** Diagram of the number of emissions and sequestration for Salatiga City in 2019-2029 in ton C (Author's Analysis, 2020)
Salatiga City is included in the Kedungsepur area, with Semarang City as the core city and several surrounding districts/cities as a buffer area. According to [33], Kedungsepur, as an Extended Metropolitan Region, will be one of the phenomena of a city that has an extremely fast population growth. Urbanization that occurs is not due to an increase in the power of innovation in society but because of an increase in society's consumerist style.

This study shows that the phenomenon of urbanization and urban development in Salatiga City is in line with the decrease in carbon stocks which will have an impact on global climate change. This is supported by several previous studies [3,14,34,35]. The researches reveal that the urbanization process occurs rapidly in the open space area and the dominance of new public infrastructure investment because the demand for land increases as a result of high population growth and development activities. Changes in non-built-up into built-up area due to urbanization cause changes in carbon stocks and lead to environmental degradation.

Similar research was conducted in Ciamis Regency, West Java, by [36]. resulted in a prediction of emissions of 105,823.95 tons C/year and sequestration of 671.57 tons C/year. If it is adjusted to the land area of Ciamis Regency, the emission is 0.27 ton C/Ha-year and sequestration of 0.0017 ton C/Ha-year. The AGB carbon stock released by Salatiga City is smaller than that of Ciamis Regency. However, the difference is not significant, namely, 0.09 tons C/Ha.year. The sequestration that occurred in Salatiga City was greater than that of Ciamis Regency with a difference of 0.0183 ton C/Ha.year.

Seeing that the release of carbon reserves is greater than absorption in the next ten years requires the role of various stakeholders to protect green land in Salatiga City. This can be done through the government's commitment to expanding green areas, tightening development permits, and preparing other regional action plans. This study's results can target the government in planning green development that prioritizes environmental aspects.

4. Conclusion

Several conclusions can be drawn from the results of the analysis conducted by the researcher. This research results that SVM and Cellular Automata algorithms in QGIS software successfully predicted land cover in the context of carbon stock change. Land cover change in Salatiga City from 2009-2019 occurred quite significantly. The area of settlement increased by 10.01% in 10 years. It is inversely proportional to the area of mixed agriculture, which decreased by around 13.17%. In the previous ten years, the increase of the settlement area and the decrease of mixed agriculture in Salatiga City is predicted to occur again in 2029.

The highest release of carbon reserves occurred in Argomulyo Subdistrict, which was 3,366.15 tons C. The highest sequestration occurred in Tingkir Subdistrict at 414.18 tons C. The conversion of green areas to the non-green area could affect the amount of carbon stock. The prediction of carbon stock changes due to land cover conversion in Salatiga City in 2019-2029 has decreased by 9,202.77 ton C, where carbon emissions are 10,313.47 ton C, and carbon sequestration is 1,110.70 ton C.

This research's limitation is predicting changes in carbon stocks above-ground biomass produced in a business-as-usual scenario. Future studies can predict changes in carbon stocks above-ground biomass in different scenarios, where the government has implemented efforts to mitigate greenhouse gas emissions. This study uses six driving factors, and further research can research with other factors. Also, classification based on pixels produces a pepper and salt effect.

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