Estimation of carbon stock in mixed garden tree stands in Jatigede Subdistrict, Sumedang Regency using NDVI (Normalized Difference Vegetation Index)

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Abstract. Carbon dioxide (CO2) is the most significant greenhouse gas causing global warming. Mixed gardens are one type of artificial vegetation in Indonesia that helps to mitigate global warming. The construction of Jatigede Reservoir leads to a reduction in agricultural area and plant cover, affecting tree stands' ability to absorb CO2 from the atmosphere. Remote sensing, GIS, and NDVI analysis were used in research to estimate stored carbon stocks in Jatigede District, Sumedang Regency. These methods can improve the accuracy and efficiency of carbon stock estimates by providing preliminary data on the role that tree stands possess in absorbing carbon in the atmosphere. The purpose of this study was to ascertain the potential for carbon storage in mixed plantation tree stands as well as the amount of carbon stored in each village within Sumedang Regency's Jatigede District. The Normalized Difference Vegetation Index (NDVI), a geographic information system, and non-destructive sampling were the quantitative methods used in the research. The research's findings indicated that the estimated carbon stock in Jatigede District, Sumedang Regency, are 55,680.17135 tons/ha. Of the 12 villages in Jatigede District, Karedok Village has the largest carbon stock, at 13,368.05 tons/ha, while Sukakersa Village has the smallest, at 156.90 tons/ha.

1 Introduction

Global warming has emerged as a significant concern in the modern era. It is an occurrence that is highly dreaded not only in Indonesia but also around the world [1-2]. The primary greenhouse gas responsible for global warming is carbon dioxide (CO2), which is released into the atmosphere as a result of human activity [3]. Reducing CO2 emissions may be accomplished by making use of land uses like rice fields, woodlands, and gardens. Because plants actively participate in photosynthesis, standing trees account for the greatest portion of the carbon absorbed and stored in biomass in the above-ground carbon category [4]. Mixed gardens are one type of artificial vegetation in Indonesia that helps to mitigate global warming [5]. Mixed gardens/agroforestry is a bioproduction system that resembles a forest. This is caused by the presence of perennial plants predominantly cultivated by humans [6&7].

Sumedang is renowned for its efficient use of land. Based on the daily lives of the villagers, who are farmers and farm laborers, the Jatigede Subdistrict, Sumedang Regency, is one of the subdistricts noted for being a provider of bioproduction in plantations, particularly in the field of wood production. The area that backs the agricultural industry attests to this. The 93,633 kmİ Jatigede District is made up of 12 settlements with 415.5 acres of heavily planted land.

The construction of the Jatigede Reservoir in Sumedang Regency several years ago seriously impacted the community. Farmers in the Jatigede District lost their jobs because some of the locations where the Jatigede Reservoir was inundated were productive agricultural land and were rice granaries for the people of Sumedang Regency, even West Java Province [8]. The reduction in agricultural land accompanied by reduced vegetation cover due to the construction of the Jatigede Reservoir has implications for the reduced ability of tree stands to absorb CO2 in the air. Apart from that, no research has been done on the estimation of stored carbon stocks in Jatigede District, Sumedang Regency using GIS and NDVI analysis or remote sensing to increase the efficacy and efficiency of carbon stock estimation; therefore, this research is essential to conduct to provide preliminary data on the role that tree stands play in atmospheric carbon sequestration. NDVI (Normalized Difference Vegetation Index) is an index of the 'greenness' of vegetation or photosynthetic activity of vegetation [9]. NDVI can show parameters, including green foliage biomass, which can be estimated for

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vegetation division [10]. Integrating remote sensing methods with field surveys to explore plot measurements over a wider coverage area can increase the effectiveness and efficiency of estimating carbon stocks in tree stands.

The purpose of this research is to determine the potential for carbon storage in mixed plantation tree stands and to determine carbon storage in each village in Jatigede District, Sumedang Regency. The purpose of this study is to obtain the total carbon stock in tree stands in mixed plantations and, using the NDVI value in Jatigede District, Sumedang Regency, to calculate the carbon stock for each village. In order to help development policymakers in Jatigede District continue to be aware of environmental conditions, it is hoped that this research will help provide information about the possibility of mixed plantation tree stands in the district to store carbon.

2 Materials and methods

2.1 Tools and materials

The tools and materials used in this research were stationery, a cellphone camera, GPS, a Laser Range Finder, a DBH Meter, a Worksheet, Arcgis Software, and Microsoft Excel.

2.2 Research methods

The research was carried out using exploration methods and satellite imagery with several stages, including determining the number and location of sample plots, collecting plant data using the census method, calculating tree biomass, and data analysis. Non-destructive sampling was the approach employed for data collection, and stratified random sampling based on NDVI class divides was the method utilized to create sample plots. NDVI class was determined based on the level of vegetation density in each area. In general, NDVI classes were divided into 5 classes [11]. Primary and secondary data were the kinds of information that were gathered. Field data were the source of primary data. Secondary data included government data, such as satellite imagery (Landsat 8), available through NASA, and spatial data utilized to compute NDVI (Normalized Difference Vegetation Index) values. The parameters measured include tree type, height, and diameter (DBH) using the census method.

2.3 Ground check

A Ground check was carried out to ensure that the area is a mixed plantation, to know the administrative boundaries of the area directly, and to find out land cover information. Land cover information was obtained from the BAPPEDA Sumedang Regency in 2020. Next, data collection techniques were determined based on the known and confirmed area size. Then a sampling technique was carried out to ensure that the data to be taken could represent the diversity of vegetation in the Jatigede District area, Sumedang Regency. The samples taken were representative of the entire region. The sampling method used was based on the sampling method [12], but an approach was created that could see the correlation between GIS (Geographic Information System) and Hairiah [12].

2.3.1 Pre-processing spatial data

The pre-processing stage consists of radiometric calibration and atmospheric correction [13]. All pre-processing stages were carried out in the Semi-automatic Classification (SCP) plugin which is integrated with ArcGIS 10.5 software. Landsat 8 OLI satellite imagery, which contains metadata (.MTL) is spatial data that will be used in the pre-processing stage. To produce complete image correction results, the "DOS1 atmospheric correction" option must be applied in the plugin.

2.3.2 Generated NDVI

Remote sensing was an appropriate method for describing the spatial mode of ecosystems. The NDVI was extracted from the raster using pre-calibrated Landsat 8 data to represent plant cover as pixel values. Every surface on Earth will reflect a particular kind of band when used for remote sensing. The majority of the red band (near-infrared reflectance) will be absorbed by vegetation that is actively engaged in photosynthesis [14]. Thus, the findings of the analysis of the red band and infrared band reflection in multispectral pictures may be used to observe the degree of green density from plant development [15]. The NDVI is obtained using equation (1) [16&17].

$$NDVI = \frac{NIR-Red}{NIR+Red} \quad (1)$$

2.3.3 Sample measurement

ArcGIS software with the compute geometry function was used to do sample measurements to calculate the size and number of plots. The utilized plot is a square that measures thirty by thirty meters. The term "plot size" describes the ~30 m pixel size of the Landsat 8 picture. The number of plots can reflect the whole diversity of plant life in the Jatigede District region and is defined as the area achieved after accounting for factors such as huge areas, challenging terrain, high rainfall, efficiency, and efficacy of data collection. Illustration of the Sample Plot Determination Technique:

- Total area of mixed gardens = 3552,829963 ha. The total area of mixed gardens according to BAPPEDA Kab. Sumedang in 2020
- Sample size = 1%. So, the sample size is 3552.829963 x 1% = 35.52829963 ha
- Size of 1 plot = 30 x 30 m
- The number of 30 x 30 m plots needed to cover 35.52829963 hectares, namely 395 plots

Determination of the number of distribution classes was carried out based on satellite imagery. The denser the vegetation canopy, the closer the vegetation value is to 1 [18].

The determination of plot distribution was carried out utilizing randomization or manually with the condition that the distance between plots was the same using the spatial information available. Class division is a reference for determining plot locations so that the plots to be sampled represent all classes.

2.3.4 Measurement of tree biomass in the field

Measurement Tree biomass measurements in the field in this study used non-destructive methods [19]. The census method was used to collect tree data, and the following steps were taken to measure the biomass of the trees:

- Identify the tree species using an identification book or software to identify plants, then record the local name and Latin name (if known) of the tree to be measured;
- Measure the Diameter at Breast Height (DBH); Measurement of diameter at breast height in various tree conditions in the field;
- Measure the height of the tree using a laser range finder;
- Record the tree species, DBH, and height data in the worksheet [20].

2.3.5 Calculation of tree biomass

Biomass measurements in the research area were grouped based on three categories of vegetation, including biomass in the categories of saplings, poles, and trees. Plants that fall into the sapling category are trees that have a diameter at breast height (DBH) of less than 10 cm and a tree height of more than 1.5 m. Plants that fall into the pole category are trees that have a diameter at breast height (DBH) between 10 and < 20 cm. Plants that fall into the pole category are trees that have a diameter at breast height (DBH) more than 20 cm [21].

Calculation of vegetation biomass was carried out using the allometric equation, which can be seen in equation (2).

$$(AGB)_{est} = 0{,}0509\ x\ \pi D^2 H \quad (2)$$

Where $(AGB)_{est}$ is the aboveground tree biomass (Kg/tree), π is the specific gravity of wood (g/cm^{-3}), D is DBH (cm), and H is tree height (m).

2.3.6 Calculation of carbon content

The carbon content was calculated using previously collected biomass data and then multiplied by the default value of 46%, allowing it to be finished using equation (3) [12].

$$\text{C Stock} = \text{biomass dry weight (Kg/ha)} \times 0{,}46 \quad (3)$$

2.3.7 Correlation analysis

Correlation analysis and regression analysis employing a basic linear regression equation were performed:

$$y = a + bx \quad (4)$$

Regression analysis was used to estimate the amount of influence brought about by changes in each unit of variable x, while correlation analysis was used to ascertain the degree of relationship between variable x, which contains vegetation index transformation data, and variable y, which contains field measurement results. Equation (5) may be used to solve the magnitude of the correlation coefficient (r), and equation (6) can be used to solve the coefficient of determination (r^2). These values were used to calculate the strength of the effect.

$$r = \frac{N\sum_{i=1}^{N}(x_i y_i) - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i}{\sqrt{\left[N\sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2\right]\left[\sum_{i=1}^{N} y_i^2 - \left(\sum_{i=1}^{N} y_i\right)^2\right]}} \quad (5)$$

$$r^2 = \left(\frac{N\sum_{i=1}^{N}(x_i y_i) - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i}{\sqrt{\left[N\sum_{i=1}^{N} x_i^2 - \left(\sum_{i=1}^{N} x_i\right)^2\right]\left[\sum_{i=1}^{N} y_i^2 - \left(\sum_{i=1}^{N} y_i\right)^2\right]}}\right)^2 \quad (6)$$

2.3.8 Extrapolate results

Extrapolation of carbon storage estimation results with the obtained regression model (with raster calculation). At this stage, the total value of carbon stock in Jatigede District, Sumedang Regency, was calculated by entering the data obtained from the field into the equation obtained at the correlation analysis stage. Furthermore, we can also find out the value of carbon stock in each village in Jatigede District, Sumedang Regency. The carbon stock value calculation was carried out using ArcGIS software.

3 Results and discussion

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3.1 Estimation of carbon stocks based on NDVI values in Jatigede District, Sumedang Regency

3.1.1 NDVI value

The vegetation index was an algorithm applied to digital images, intended to highlight aspects of vegetation. Such as aspects of density, type, age, or other aspects related to vegetation [22]. NDVI (Normalized Difference Vegetation Index) is a standard method for comparing the greenness of vegetation on satellites. Sulastri explains that a negative NDVI value indicates a low level of vegetation. Meanwhile, a positive NDVI value indicates a high level of green vegetation [23].

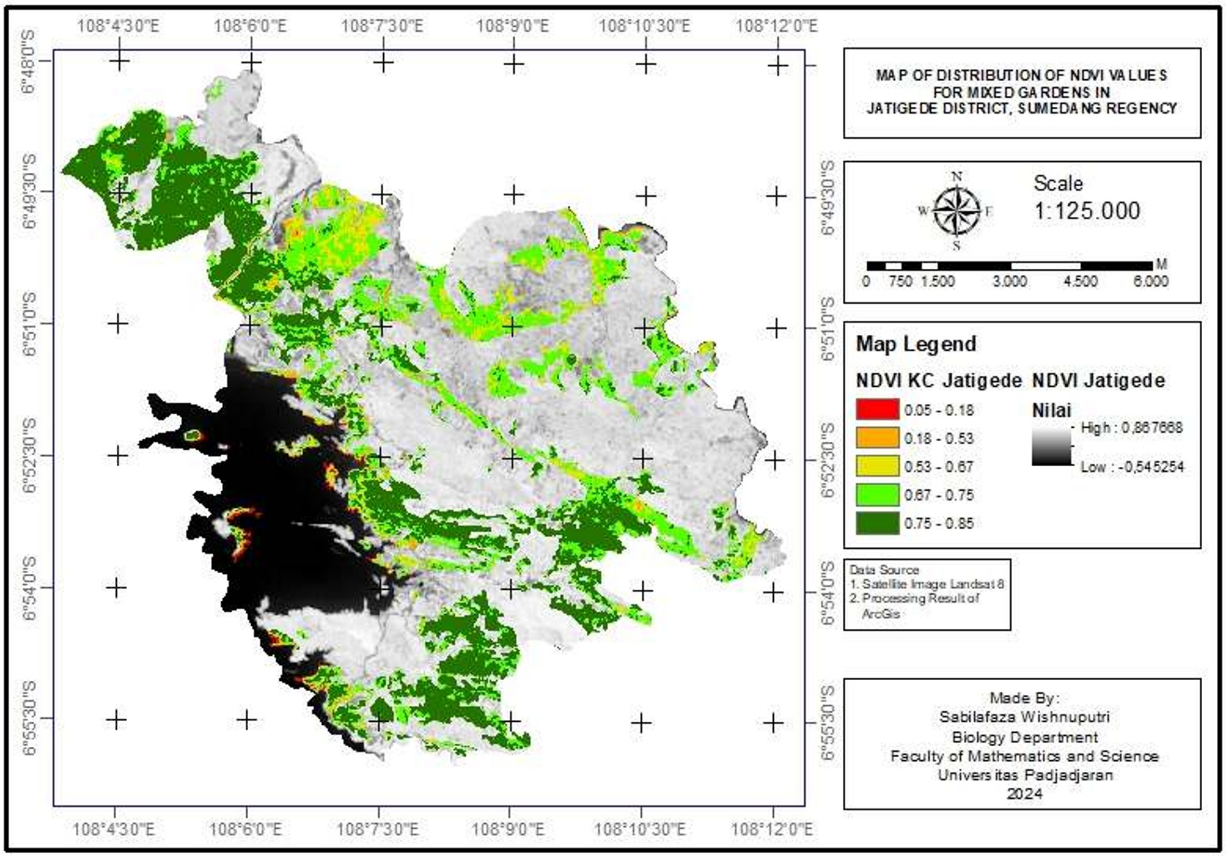

Fig. 1. Map of Distribution of NDVI Values for Mixed Gardens in Jatigede District, Sumedang Regency

The distribution of NDVI values for mixed gardens in Jatigede District, Sumedang Regency, can be seen on a map in Figure 1. Mixed gardens in Jatigede District, Sumedang Regency were, marked from red to green. NDVI values were divided into several classes according to the level of existing vegetation. Areas colored black to white indicate that the area was not a mixed plantation. The results of the NDVI class classification of mixed gardens can be seen in Table 1.

Table 1. NDVI Class

NDVI Class	Value Range	Information
1	0,05 – 0,18	Very Low
2	0,18 – 0,53	Low
3	0,53 – 0,67	Medium
4	0,67 – 0,75	High
5	0,75 – 0,85	Very High

The NDVI value of mixed gardens in Jatigede District, Sumedang Regency, has been affected by several factors, including land use modifications implemented by the local residents. Landowners who have recently felled trees on their mixed plantations to recoup their investment may have an impact on low vegetation density. In the next few years, areas that have high vegetation density are also likely to experience changes due to changes in land use or the felling of trees by plantation owners. Other land changes that can occur include development carried out by residents and the government. As happened during the construction of the Jatigede Reservoir in 2015, the mixed plantation area in Jatigede District was reduced because it was flooded by Jatigede Reservoir water. Continuously increasing global warming can also result in forest and mixed plantation fires, thereby reducing vegetation cover in the region.

The value representing vegetation is in the range of 0.1 to 0.7; if the NDVI value is above this value, it indicates a better level of vegetation cover health [24&25]. The Jatigede District in Sumedang Regency's mixed gardens has an NDVI value map with a maximum value of 0.85, indicating extremely high plant cover health.

The transformed image is used as a reference in determining sample points. The grouping of vegetation index values is visible, and samples are taken from each grouping of values to identify the parameters, namely type, stand density, and age of vegetation. The results of observations of sample points in the field are then expressed quantitatively and linked to vegetation index values at the same pixel position [22]. Based on the NDVI class that has been obtained, the plot composition is calculated. The composition of the carbon stock plot is calculated based on the area of each class in Jatigede.

Table 2 shows the composition of each NDVI class on the carbon plot. The ideal number of plots in total is 392 plots. The number of real plots obtained in the field was 60 plots. Reducing the number of plots was carried out by considering time, costs, and the location of plots that were difficult to reach. The number of real plots of 60 plots has been able to represent carbon stock

in Jatigeda District, Sumedang Regency because it has exceeded the minimum data required to carry out statistical tests (n > 30). Determining the sample coordinates in the field is carried out based on the NDVI values that have been analyzed previously. This determination is carried out randomly by considering locations that are easy to access.

Table 2. Composition of Each NDVI Class on Carbon Plots

NDVI Class	Area (ha)	Percentage	Number of Plot (Ideal)	Number of Plot (Real)
1	35.04	1%	3.87	0.59
2	28.05	1%	3.10	0.47
3	118.29	3%	13.0	2.00
4	1549.47	44%	171.44	26.24
5	1812.02	51%	200.48	30.68
Total	**3542.88**	**100%**	**392**	**60**

Before removing numerical extracts (descriptive statistics) from data, first check whether there are extreme values or outliers in the data. If there is an outlier, then the datum (extreme value) of the outlier must be removed before carrying out further data analysis. This outlier is one of the causes that can influence abnormal data distribution. Samples obtained from a normally distributed population will make it easier to describe the distribution of the data. Armed with a few statistics, such as the sample mean and standard deviation, we can get a picture of the distribution of the population data. This is one of the advantages of processing normally distributed data [26]. Plot elimination was carried out because the 5-plot data were upper-extreme and lower-extreme outlier data. The emergence of outlier data causes all data to not be normally distributed, so it cannot pass the statistical analysis stage.

3.1.2 Correlation and regression analysis

The statistical analyses used are correlation analysis and regression analysis. Correlation analysis is used to measure the closeness of the relationship between variables. In this study, the variables used are the vegetation index (NDVI) value and the carbon content value in each sample. The magnitude of the correlation coefficient moves between -1 to 1. Meanwhile, regression analysis is used to measure how much the independent variable can explain the dependent variable, where the independent variable is the value of the vegetation index used and the dependent variable is the value of the carbon content in each sample [27]

Field data was obtained in the form of tree height and tree diameter. Next, the tree biomass is calculated using the formula stated in equation (2). The tree biomass data is then processed using the allometric formula stated in equation (3) and the carbon value results for each plot are obtained. This is because it follows the rules of SNI 7724:2011 that 47% of biomass is carbon [27]. Based on the field data obtained, a regression equation formula was obtained which was calculated based on equation (4). Field observations were carried out to double-check whether the conditions in the field were by the NDVI values that had been analyzed and to determine the X (NDVI) and Y (Carbon) values in the equation. Based on field observations, the NDVI values that have been analyzed can be classified according to the type of vegetation density. Classification of NDVI values is necessary because NDVI values have subjective values, so a field observation process is needed.

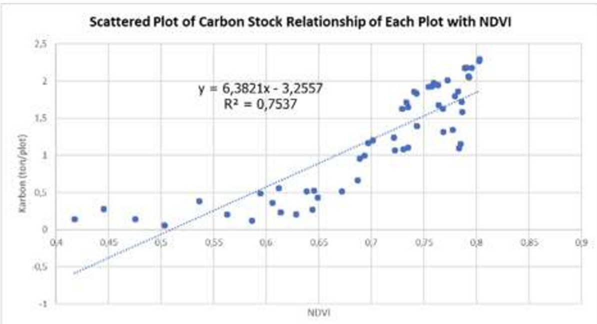

Fig. 2. Scattered Plot of Carbon Stock Relationship of Each Plot with NDVI

Figure 2 shows the relationship between carbon for each plot and NDVI. The results of calculating the regression equation and the relationship between the NDVI value and the carbon stock value can be depicted graphically which results in the calculation of the correlation coefficient Rİ = 0.7537 and the regression equation $y = 6.3821x - 3.2557$. This means that 75% of the carbon stock value at the research location can be determined by the NDVI variable. Meanwhile, 25% is determined by other unknown variables. Thus, the greater Rİ value indicates that the correlation between the vegetation index and the carbon value is better. Rakhmawati stated that the relationship is strong if the Rİ coefficient value is ≥ 0.4 [28].

3.1.3 Estimated carbon stock for Jatigede District, Sumedang Regency

The results of the regression equation that have been obtained are entered into the raster calculator in ArcGIS Software and the results obtained are a carbon distribution map of mixed plantations based on NDVI class in Jatigede District, Sumedang Regency and the total amount of mixed plantation carbon stock in Jatigede District, Sumedang Regency.

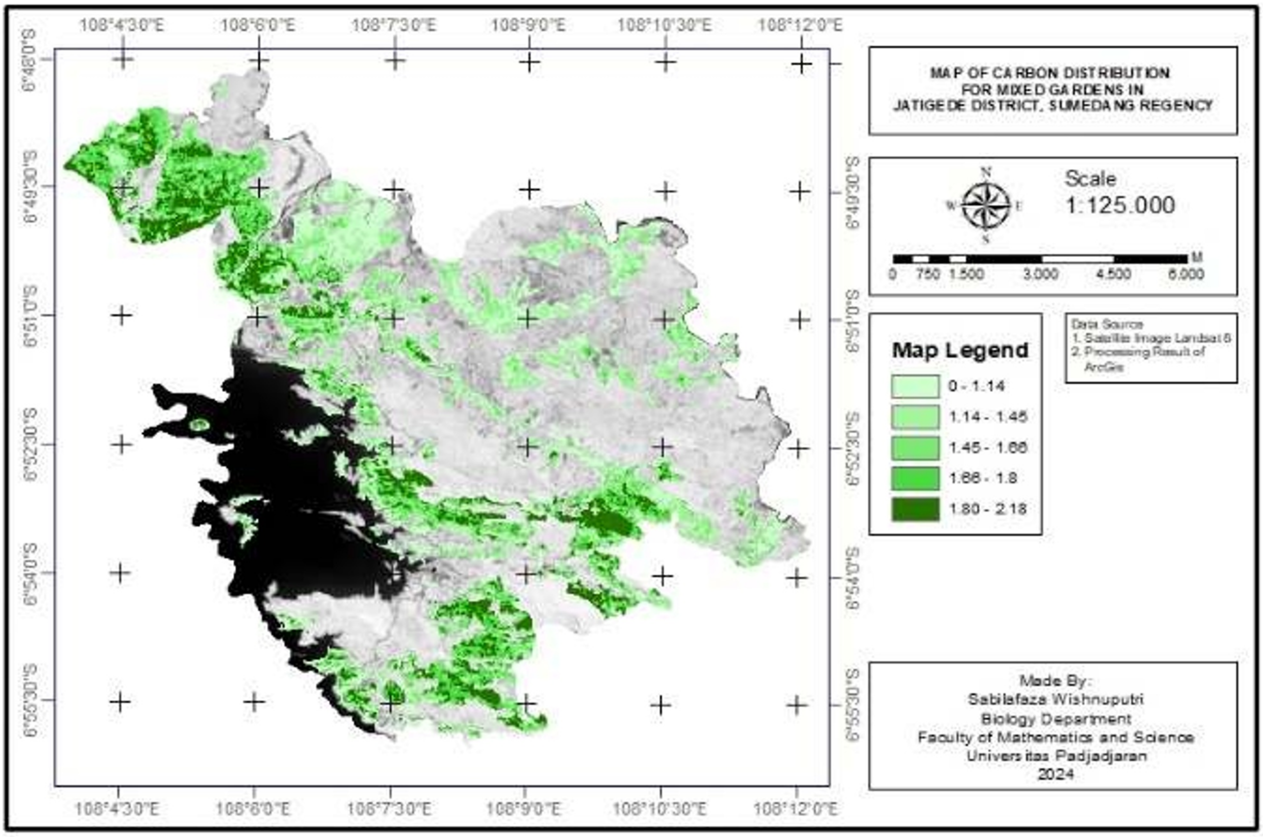

Fig. 3. Map of Carbon Distribution for Mixed Gardens in Jatigede District, Sumedang Regency.

In Figure 3 you can see a map of the carbon distribution of mixed gardens in Jatigede District, Sumedang Regency. On the right, there is a description of the color and class of mixed gardens in Jatigede District, Sumedang Regency. The most common classes in mixed gardens in Jatigede District, Sumedang Regency are classes 4 and 5 with an NDVI value range of 1.66 − 2.18. It can be interpreted that the level of mixed garden vegetation density in Jatigede District, Sumedang Regency is quite high. The estimated carbon stock in mixed plantations in Jatigede District is 55,680.17135 tons/ha. Dahlan explained that the total carbon content is greatly influenced by tree diameter and density, but the density factor does not provide total carbon if the tree diameter is small [29&30]. The mixed garden in Jatigede District, Sumedang Regency is dominated by teak trees (*Tectona grandis*) and Mahogany (*Swietenia mahagony*).

3.2 Estimated Carbon Stocks for Each Village in Jatigede District, Sumedang Regency

Jatigede District consists of 12 villages, including Cijeungjing Village, Cintajaya Village, Cipicung Village, Ciranggem Village, Cisampih Village, Jemah Village, Kadu Village, Kadujaya Village, Karedok Village, Lebaksiuh Village, Mekarasih Village, and Sukakersa Village. The results were obtained in the form of a map showing the distribution of mixed gardens based on NDVI class in each village in Jatigede District, Sumedang Regency, and the total carbon stock of mixed gardens in each village by applying the same method and adding the village administrative boundaries in Jatigede District, Sumedang Regency.

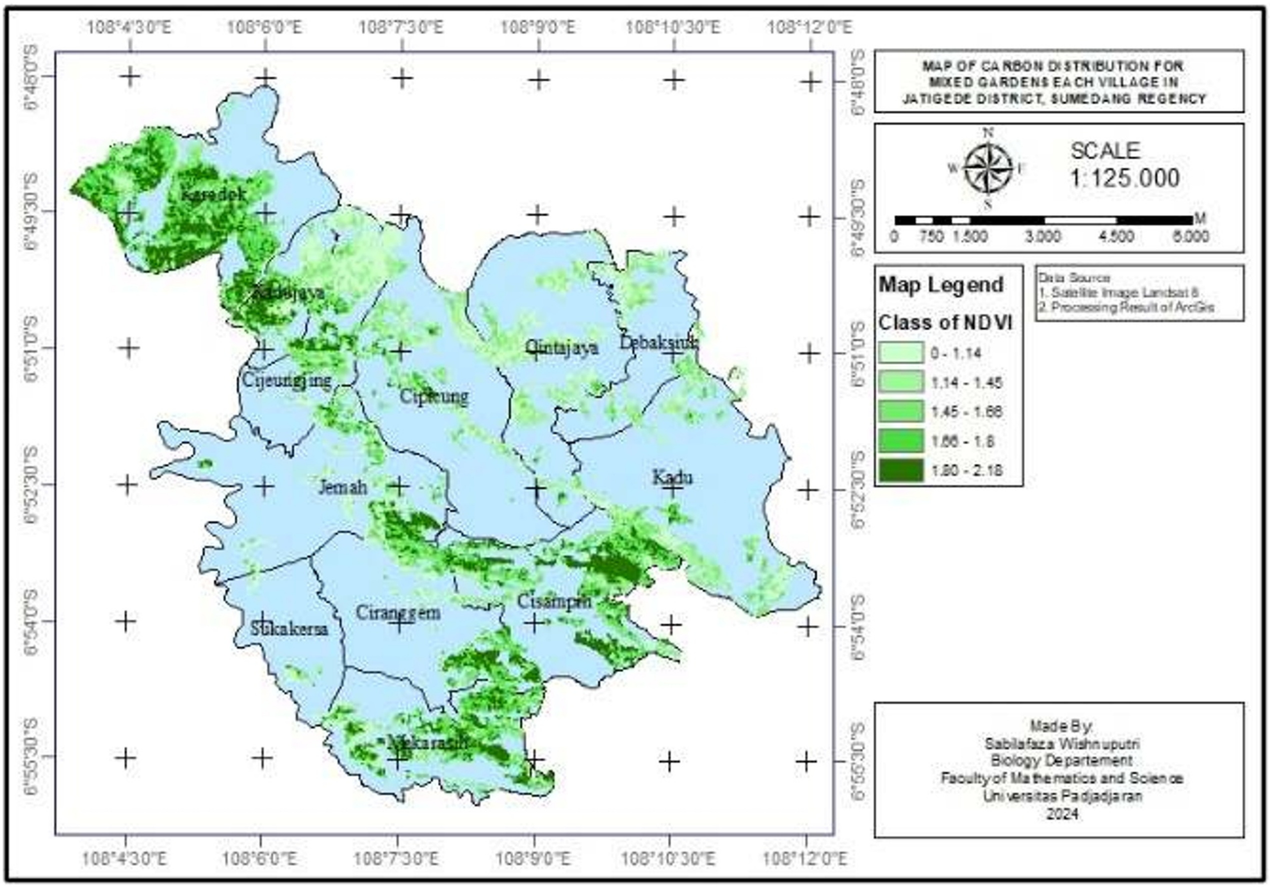

Fig. 4. Map of Carbon Distribution for Mixed Gardens Each Village in Jatigede District, Sumedang Regency.

Figure 4 shows the NDVI map of mixed gardens in each village in Jatigede District, Sumedang Regency. On the right, there is a description of the color and class of mixed gardens in Jatigede District, Sumedang Regency.

Table 3. Carbon Stock for Each Village

No	Village	Carbon Stock (ton/ha)
1	Mekarasih	6875,17
2	Cintajaya	3368,81
3	Lebaksiuh	1932,04
4	Cisampih	8878,90
5	Kadu	3790,77
6	Cijeungjing	4267,51
7	Sukakersa	156,90
8	Karedok	13368,05
9	Jemah	2504,68
10	Ciranggem	3446,36
11	Cipicung	3875,43
12	Kadujaya	3215,50
Total		55680,17

In Table 3 it can be seen that Karedok Village is the village that has the largest carbon stock, namely 13,368.05 tonnes/ha. Karedok Village has a huge plantation area because in Karedok Village there is not much development and settlement so most of the land in Karedok Village is used by the community for gardening. The majority of Karedok Village residents are farmers. Sukakersa Village has the smallest carbon stock, namely 156.90 tonnes/ha. This is because most of the Sukakersa Village area has been inundated by water due to the construction of the Jatigede Reservoir since 2015. So a lot of mixed garden land has been lost.

The construction of the Jatigede Reservoir provides an opportunity to make Jatigede District a tourist location for the Jatigede Reservoir. A rapid increase in development will occur in Jatigede District, Sumedang Regency. Changing the use of mixed plantation land into building infrastructure and residential areas is not impossible. Changes in land use have resulted in a reduction in mixed plantation land in the area. The rapid reduction in mixed plantation land has an impact on the amount of carbon stock in Jatigede District. Currently, the estimated carbon stock in Jatigede District are quite large so the ecosystem in the area is still maintained in balance even though several areas have been covered by standing water from the construction of the Jatigede Reservoir.

4 Conclusion

According to the findings of the study and the conversations that have taken place, the estimated amount of carbon stock in Jatigede District, Sumedang Regency, was 55,680.17135 tons/ha. Karedok Village has the highest carbon stores of any of the 12 villages in Jatigede District, at 13,368.05 tons/ha, while Sukakersa Village has the lowest carbon stock, at 156.90 tons/ha.

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