

2007). Several studies have shown that vegetation index-based mapping can help identify priority areas for green space conservation and evaluate the impact of land cover changes on urban environmental quality, including its relationship to air quality issues (Li et al., 2019; Chen et al., 2020; World Health Organization, 2021). However, the application of *NDVI* has limitations such as saturation in very dense vegetation and the influence of surface background, so the use of *FVC* and pre-processing controls are important to improve the comparability of results (Carlson & Ripley, 1997; Pettorelli et al., 2005). In addition, the O₂ production aspect in many studies is generally still derived indirectly from CO₂ absorption estimates, so that studies that explicitly map CO₂ absorption and O₂ production multi-temporally in a tropical urban context, especially in Papua, are still limited. This condition becomes a *gap* that underlies the need for multi-temporal mapping 2020–2024 in Abepura District to support evidence-based green space planning.

METHOD

This study uses a descriptive spatial analysis method based on Geographic Information Systems (GIS) and remote sensing with a multi-temporal approach for the 2020–2024 period in the Abepura District area. The analysis stages include: (1) determining the study area and compiling annual data, (2) pre-processing to maintain consistency across time (3) calculating *NDVI* to describe the density of vegetation greenery, (4) classifying vegetation density based on *NDVI* to facilitate ecological interpretation, (5) calculating *FVC* as the fraction of vegetation cover per pixel through normalizing *NDVI values* , and (6) estimating *NPP* based on *FVC* using reference values *NPP_{ref}*, which are then converted into CO₂ absorption and O₂ production using conversion factors used in this study. The final stage is the presentation of thematic maps and annual statistical summaries (minimum maximum values and class distribution) to assess the spatial-temporal dynamics of vegetation function in the study area. Stage 1. Location and data determination. The research location was determined in Abepura District with a time span of 2020–2024. The variables analyzed included *NDVI* (range -1 to 1), *FVC* (range 0–1), CO₂ absorption (kg/m²/year), and O₂ production (kg/m²/year). Stage 2. Pre-Processing. Pre-processing is carried out to ensure data consistency between years, including basic adjustment corrections as needed, cloud masking, and clipping *according* to the Abepura District boundaries.

NDVI calculation . *NDVI* is calculated to describe the level of greenness/vegetation density with the equation:

$$NDVI = \frac{NIR - Red}{NIR + Red} \tag{1}$$

In equation 1, *NIR* is the reflectance value in the *near-infrared spectrum* , while *Red* is the reflectance value in the red spectrum of *satellite imagery*. *NDVI* values range from -1 to +1; higher values indicate denser vegetation, while values closer to 0 or negative generally represent non-vegetation such as open land, water bodies, or built-up areas.

Stage 4. Classification of vegetation density based on *NDVI* . *NDVI* values are classified to facilitate interpretation of the ecological conditions of the study area.

Table 1. Vegetation density classification based on *NDVI*

NDVI Range	Density class	Ecological interpretation
< 0.20	Non-vegetation	Built-up areas, water bodies, open land
0.20–0.39	Low vegetation	Vegetation is sparse, undergrowth
0.40–0.59	Moderate vegetation	Mixed vegetation cover
≥ 0.60	Tall vegetation	Dense vegetation, forest area

Source: Analysis Results, 2026

Step 5. Calculation of *FVC* . *FVC* is calculated as the proportion of vegetation cover per pixel (0–1) using the equation:

$$FVC = \frac{NDVI - NDVimin}{NDVImax - NDVimin} \tag{2}$$

In equation 2, *FVC* represents the proportion of vegetation cover at each pixel with a value range of 0–1, where values close to 0 indicate very low vegetation cover (predominantly open, non-vegetated land) and values close to 1 indicate very high vegetation cover (dense vegetation). *NDVI* is the vegetation index value of the pixel calculated previously, while $NDVI_{min}$ and $NDVI_{max}$ are the minimum and maximum *NDVI* values used as a normalization reference. This formula normalizes *NDVI* to the cover fraction, making it easier to compare between areas/years and more representative for estimating derived parameters such as *NPP* and CO₂ uptake and O₂ production. Step 6. Estimation of *NPP*, CO₂ uptake, and O₂ production. *NPP* is estimated from *FVC* using reference values NPP_{ref} , then CO₂ uptake is calculated from *NPP* using conversion factors, and O₂ production is derived from CO₂ uptake according to the ratio used in this study. The equation used is:

$$NPP = FVC \times NPP_{ref} \quad 3$$

In equation 3, *NPP* (*Net Primary Productivity*) is the net primary productivity, namely the amount of net carbon biomass produced by vegetation after subtracting plant respiration in a certain period. *FVC* (*Fractional Vegetation Cover*) is the fraction of vegetation cover (0–1) in each pixel where the greater the *FVC* means the greater the proportion of vegetation in that pixel. NPP_{ref} is the reference *NPP* value that represents the productivity of saturated vegetation under certain conditions and the *NPP* at the pixel scale is proxied as the proportion of *FVC* vegetation multiplied by the reference *NPP*.

$$CO_2 = NPP \times 3.67 \quad 4$$

In equation 4, converting carbon (C) to carbon dioxide (CO₂) equivalents uses the molecular mass ratio. The factor 3.67 comes from the ratio of the molecular mass CO₂(44) to the atomic mass of C (12), which is 44/12 = 3,67. This means that if *NPP* is expressed in CO₂ units, then it is multiplied by 3.67 to obtain the equivalent in CO₂ units.

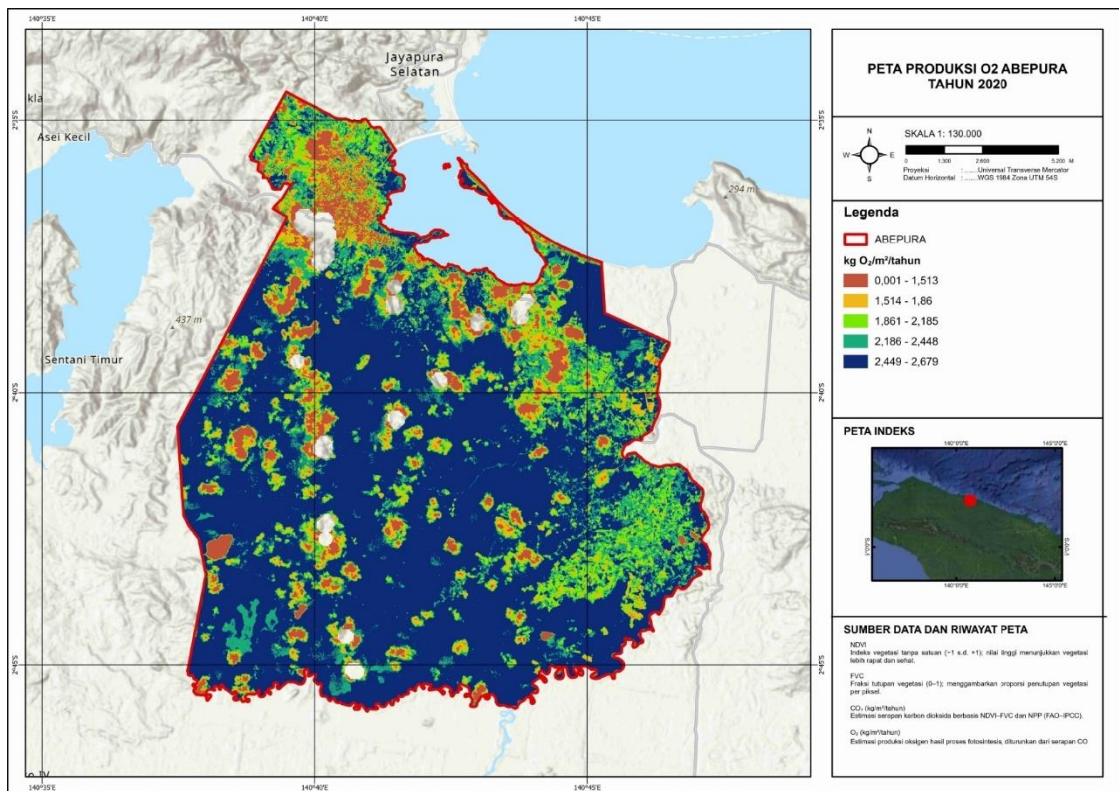
$$O_2 = CO_2 \times 0.73 \quad 5$$

This equation 5 derives O₂ production from CO₂ uptake using the ratio of the molecular masses of O₂ to CO₂. The factor 0.73 comes from 32/44 (molecular mass of O₂ = 32 and CO₂ = 44), so that 32/44 ≈ 0,73. Stage 7. Final processing and analysis. For each year (2020–2024), *NDVI*, *FVC*, CO₂, and O₂ rasters were extracted in the study area, then presented in a thematic map and summarized statistically in the form of minimum–maximum values and class distribution. The analysis was conducted descriptively spatially to understand distribution patterns between zones and descriptively temporally to compare changes between years to illustrate the dynamics of the ecological function of vegetation in Abepura District.

RESULTS AND DISCUSSION

This section presents the results of systematic mapping of O₂ production and CO₂ absorption in Abepura District for the 2020–2024 period based on the *NDVI FVC analysis output*, accompanied by a discussion to interpret spatial patterns and changes between years. The discussion is carried out by linking the findings on the map and the range of class legends to the concepts of vegetation density and health as represented by *NDVI* and its derivatives, as well as their implications for the ecological function of the study area.

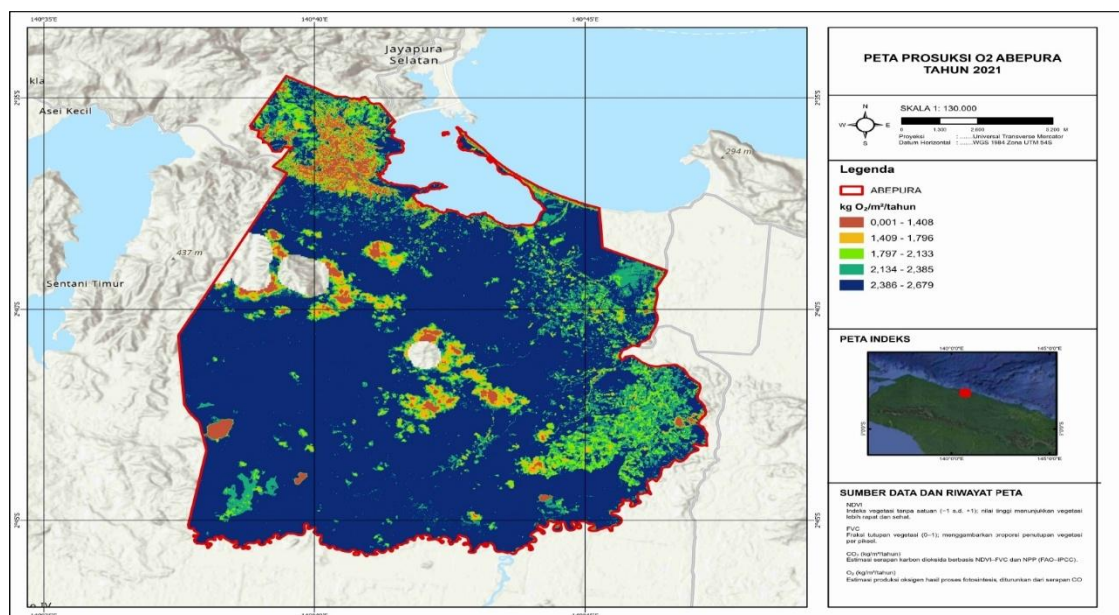
1. O₂ Production (2020–2024)
 - a. O₂ Production 2020



Gambar 1. Peta Produksi O₂ Tahun 2020

Figure 1 shows a range of values of 0.001–2.679 kg/m²/year with five legend classes (0.001–1.513; 1.514–1.86; 1.861–2.185; 2.186–2.448; 2.449–2.679). This class range illustrates the presence of low to high O₂ production zones that reflect variations in vegetation density in the study area.

b. O₂ Production 2021

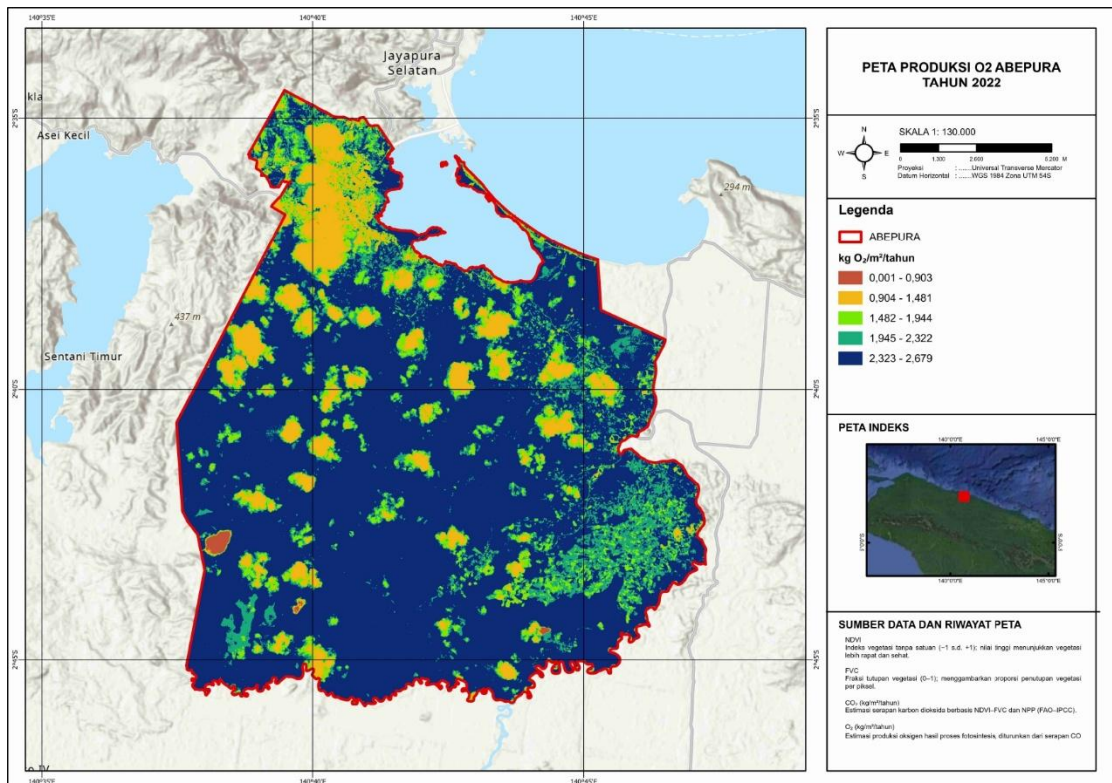


Gambar 2. Peta Produksi O₂ Tahun 2021

Figure 2. maintains the maximum value of 2.679 kg/m²/year but the lower class boundary changes to 0.001–1.408 in class 1, followed by classes 2–5 (1.409–1.796; 1.797–2.133; 2.134–2.385; 2.386–2.679). These changes in class boundaries indicate a shift in the distribution of O₂ production between years in the Abepura shaded area.

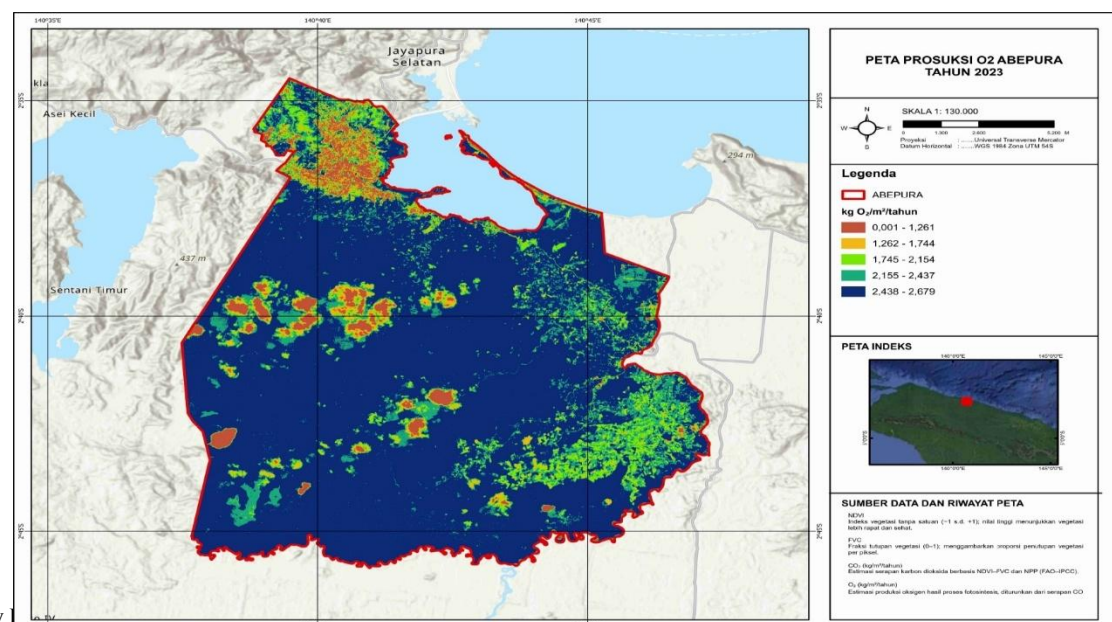
c. O₂ Production 2022

Figure 3. O₂ production in 2022 showed the most pronounced changes in the low classes, with class 1 being 0.001–0.903 kg/m²/year, followed by classes 2–5 (0.904–1.481; 1.482–1.944; 1.945–2.322; 2.323–2.679). Interpretatively, the widening range of the low classes may reflect an increase in areas with low or disturbed vegetation cover in that year, in line with the principle that lower NDVI indicates less dense vegetation.



Gambar 3. Peta Produksi O₂ Tahun 2022

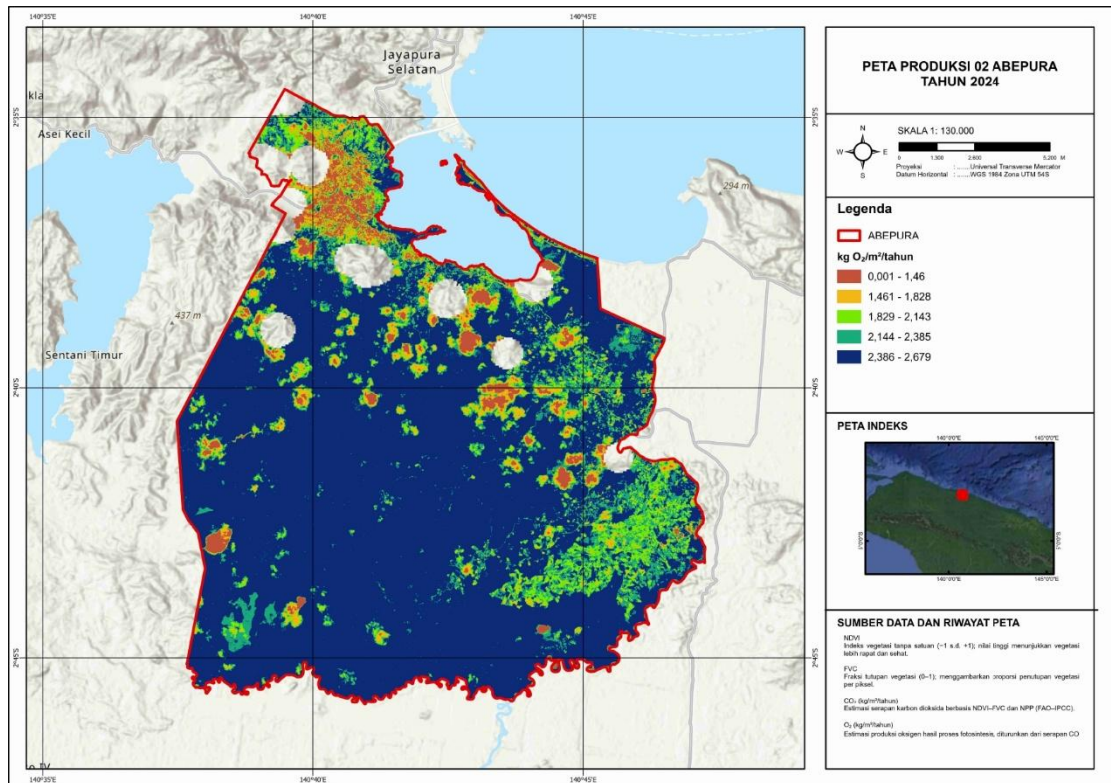
d. O₂ Production 2023



Gambar 4. Peta Produksi O₂ Tahun 2023

Figure 4. still has a maximum of 2.679 kg/m²/year with class 1 of 0.001–1.261, and classes 2–5 (1.262–1.744; 1.745–2.154; 2.155–2.437; 2.438–2.679). Compared to 2022, the class 1 limit has increased again, indicating a shift in the distribution of O₂ production towards higher values in some study areas.

e. O₂ Production 2024



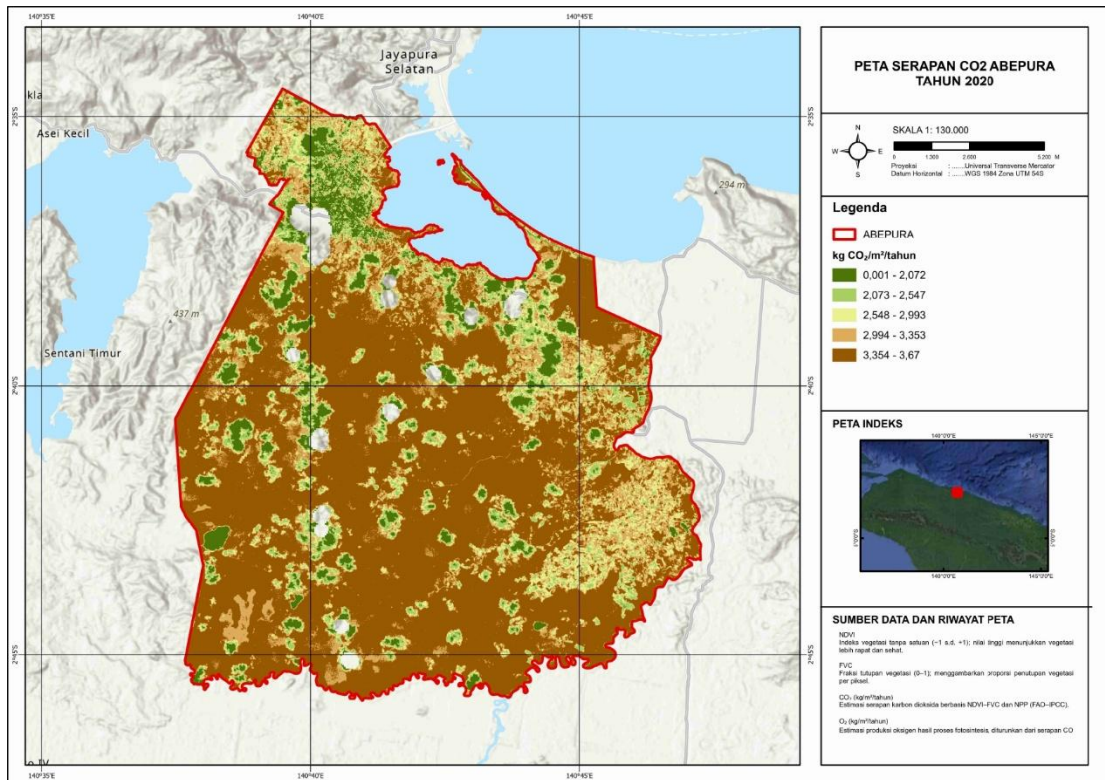
Gambar 5. Peta Produksi O₂ Tahun 2024

Figure 5 shows a range of 0.001–2.679 kg/m²/year with class 1 being 0.001–1.46 and classes 2–5 being (1.461–1.828; 1.829–2.143; 2.144–2.385; 2.386–2.679). In general, the stability of the maximum O₂ value and the change in the lower class limit between years indicate the existence of spatial-temporal dynamics of O₂ production related to changes in vegetation density resulting from the vegetation index.

2. CO₂ Absorption (2020-2024)

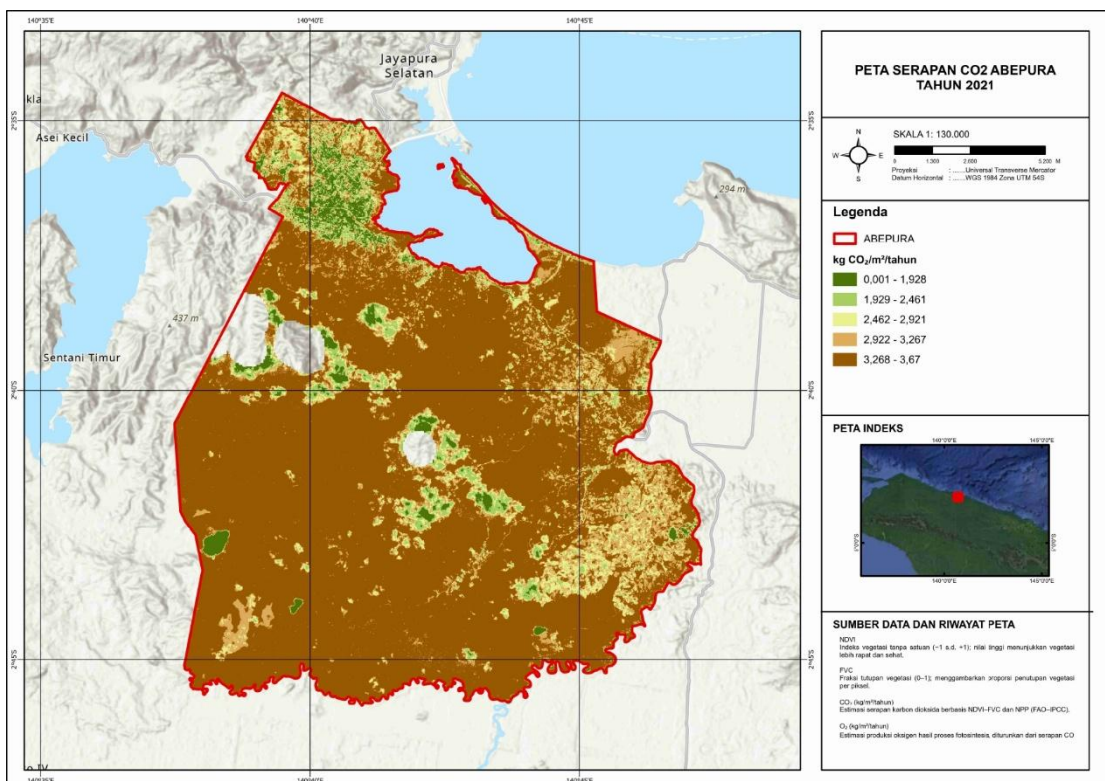
a. CO₂ Absorption 2020

Figure 6 shows a range of 0.001–3.67 kg/m²/year with five classes (0.001–2.072; 2.073–2.547; 2.548–2.993; 2.994–3.353; 3.354–3.67). The maximum value of 3.67 indicates the use of the carbon-to-CO₂ conversion factor (44/12) in *NPP-based calculations*, which is commonly used to convert C units to CO₂ equivalents.



Gambar 6. Peta Produksi CO₂ Tahun 2020

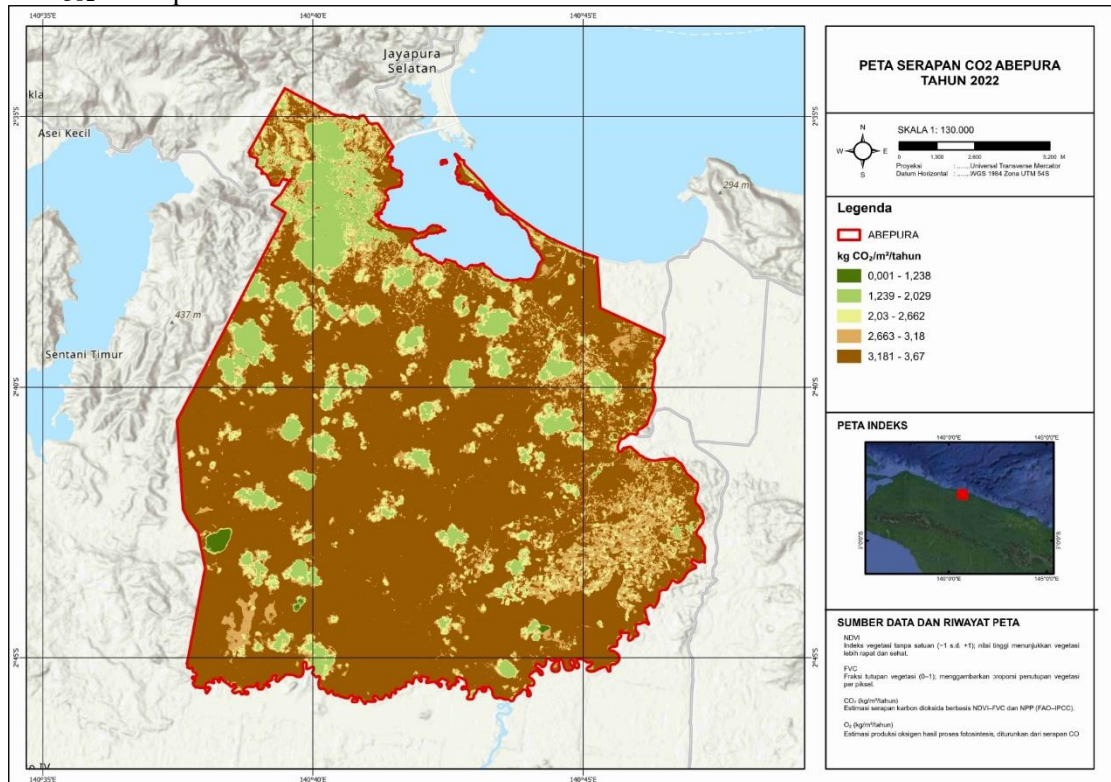
b. CO₂ Absorption 2021



Gambar 7. Peta Produksi CO₂ Tahun 2021

Figure 7. remains at a maximum of 3.67 but class 1 changes to 0.001–1.928, followed by classes 2–5 (1.929–2.461; 2.462–2.921; 2.922–3.267; 3.268–3.67). Changes in class thresholds illustrate the shift in the distribution of CO₂ absorption between years in the study area.

c. CO₂ Absorption 2022

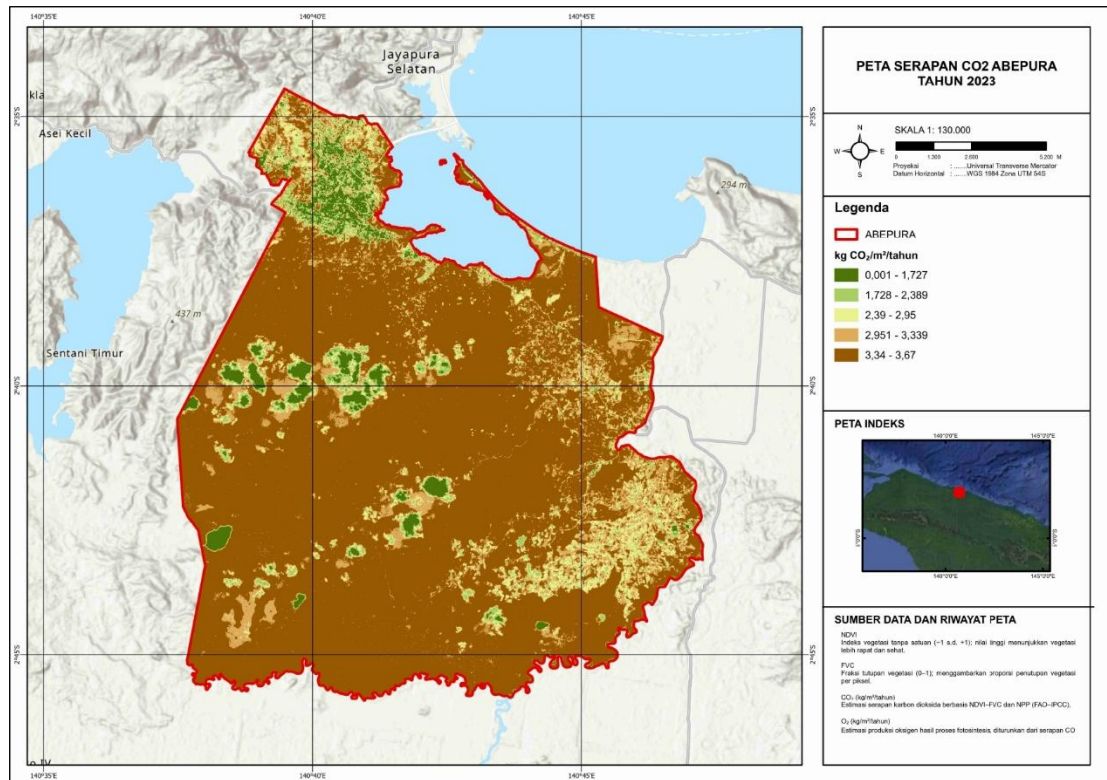


Gambar 8. Peta Produksi CO₂ Tahun 2022

Figure 8 shows a smaller low class (class 1 being 0.001–1.238), followed by classes 2–5 (1.239–2.029; 2.03–2.662; 2.663–3.18; 3.181–3.67). This pattern can be interpreted as a shift in the proportion of areas with low to moderate absorption capacity, which is conceptually related to variations in *NDVI* *FVC* as a proxy for vegetation density and photosynthetic productivity.

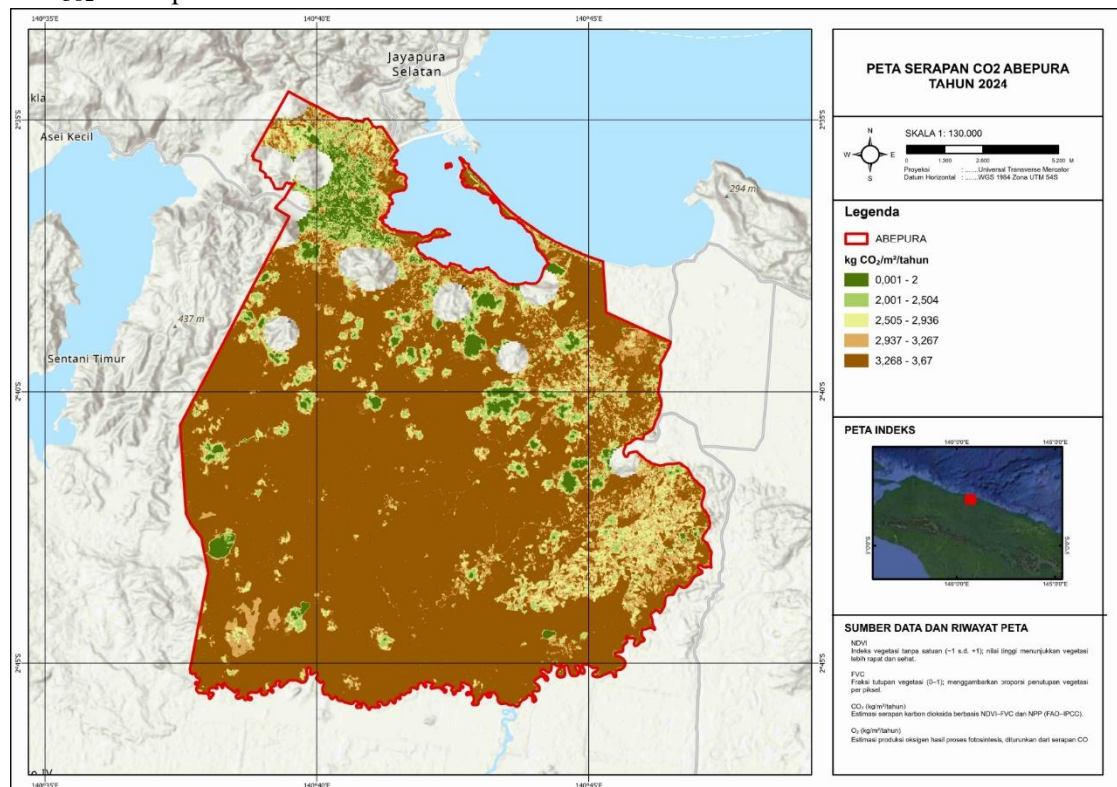
d. CO₂ Absorption 2023

CO₂ uptake in 2023 maintained a maximum of 3.67, with class 1 ranging from 0.001 to 1.727, and classes 2–5 ranging from 1.728 to 2.389; 2.39 to 2.95; 2.951 to 3.339; 3.34 to 3.67. Changes in class boundaries compared to 2022 indicate spatial-temporal dynamics of CO₂ uptake that may be related to changes in annual vegetation conditions.



Gambar 9. Peta Produksi CO₂ Tahun 2023

e. CO₂ Absorption 2024



Gambar 10. Peta Produksi CO₂ Tahun 2024

CO₂ absorption in 2024 shows a range of 0.001–3.67 with class 1 being 0.001–2.0 and classes 2–5 being (2.001–2.504; 2.505–2.936; 2.937–3.267; 3.268–3.67). In general, the stability of the maximum CO₂ value and the change in class thresholds between years indicate a shift in the distribution of CO₂ absorption in the study area consistent with the influence of vegetation variations. Mapping results show that O₂ production and CO₂ absorption in Abepura District for the 2020–2024 period have relatively stable maximum values, namely O₂ up to 2.679 kg/m²/year and CO₂ up to 3.67 kg/m²/year, but there are changes in the distribution of low to medium classes between years. Changes in class thresholds, especially in 2022, which show a low class range of O₂ production (0.001–0.903 kg/m²/year) and CO₂ absorption (0.001–1.238 kg/m²/year), indicate the spatial dynamics of vegetation related to variations in vegetation density and health as represented by NDVI and its derivative, FVC. Spatially, high values tend to be concentrated in areas with dense vegetation cover, while low values are more dominant in built-up areas and areas with sparse vegetation, so this difference shows the role of green space as an important provider of ecosystem services for the urban environment. Thus, high-value areas need to be prioritized for preservation, while low-value areas are targeted for rehabilitation/increased vegetation cover to maintain CO₂ absorption capacity and O₂ production.

CONCLUSION

This study produced a multi-temporal map (2020–2024) depicting the distribution of vegetation functions as a CO₂ absorber and O₂ producer in Abepura District based on the NDVI FVC approach and NPP-based estimation. The results show a relatively consistent maximum value of CO₂ absorption up to 3.67 kg/m²/year and O₂ production up to 2.679 kg/m²/year, while variations in distribution in the low-medium class between years indicate the spatial-temporal dynamics of vegetation regulation capacity in the study area. These results confirm that zones with higher vegetation density contribute more to ecosystem regulation, so that protection and improvement of vegetation cover quality are important in urban environmental mitigation. The limitations of this study are mainly related to the reliance on vegetation index proxies and the assumption of reference values in NPP estimation, so updates using higher-resolution imagery are recommended for field verification. Prospectively going forward, integration of map results with land use data and green open space policies is needed to prioritize vegetation management in zones that have the greatest influence on increasing CO₂ absorption and O₂ production.

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