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REMOTE SENSING ANALYSIS OF NITROGEN DIOXIDE GHG EMISSIONS SUPPORTS RAP FOR MITIGATING CLIMATE CHANGE IMPACTS IN SITUBONDO REGENCY

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Abstracts

The study aims to inventory and analyse GHG Nitrogen Dioxide (NO_2) emissions to support regional action plans (RAP in the mitigation and adaptation of PI (climate change) in Situbondo Regency. It is hoped that the research output can be used by regional governments to implement mitigation and adaptation actions. The research area in Situbondo Regency was carried out for five months. The analysis method uses a remote sensing system through exploration of Sentinel- 5P satellite data for GHG NO_2 gas numerical spatial data on a cloud-based digital platform, JavaScript Google Earth Engine (GEE) and Google Colaboratory Research (GColab) 2023, image digitization and outlasting in QGIS software. Research data is remote sensing data access to the NO_2 gas datasets Sentinel_5P OFFL_ NO_2 Offline, MOD 11A1.061_Terra LST, and EDG 1km. Statistical data analysis using SAS v.jmp and Genstat v.18. The results show that the highest NO_2 density variable in 2017 was 0,66 – 2,12 g/m^2, then decreased to 0,65 – 2,01 g/m^2 in 2019 and to 0,63 – 1,94 g/m^2 in 2021, with the highest NO_2 density in the Banyuglugur sub-district. The highest range of LST variables in 2017 was 19 – 39 0C, then increased to 21 – 40 0C in 2019, and in 2021 decreased again to 18 – 38 0C. Regional variables The highest LST distribution in 2017 and 2019 was relatively the same in each sub-district, namely Situbondo, Panarukan, Panji, Kapongan and Jangkar. NO_2 and LST density variables in 2017 and 2019 were lowly correlated (r = 0.55), but in 2021, they were not correlated.
Keywords: lst, mitigation, NO_2, rap

INTRODUCTION

Estimating nitrogen oxide (NOx) gas emissions is becoming more important due to the fast growth of emissions in many developing districts (Jiang et al., 2016). High levels of NOx emissions directly and indirectly contribute to serious environmental issues, including smog, acid rain, and climate deviation, affecting both local and global ecosystems through the N flow (Erisman et al., 2011; Zien et al., 2014). According to Hilboll et al. (2013), NOx emissions in Asia and the Middle East rose by 5% to 10% due to hydrocarbon deposit ignition for power plants, thermoelectricity, and industrial activities. According to the IPCC (2013) and Klimont et al. (2013), the growth rate of NOx is increasing significantly faster than that of direct greenhouse gases like CO_2 and CH_4, as well as other atmospheric contaminants such as SO_2. This highlights the urgent need to address and mitigate NOx emissions worldwide.

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One source of nitrogen greenhouse gas (GHG) emissions that cause global warming includes NO, NOx, N_2O, and NO_2. According to Panwar et al. (2011), global warming is the phenomenon of increasing global temperatures due to the GHG effect from rising emissions of nitrogen gases such as NOx, NO_2, and N_2O. Some gases classified as GHGs (Mackay, 2008), such as CH_4, CO_2, NO, NOx, NO_2, N_2O, and other gases fluorinated (F-gas), such as perfluorocarbons (PFCs), a group of hydrofluorocarbons (HFCs) like SF6 (Sulphur hexafluoride), and compounds, will destroy the ozone layer. According to Damayanti and Lestari (2013), releasing solar thermal energy trapped by GHG will increase temperatures. The mean increase in global temperature of the Earth is 0.74 ± 0.18 ºC in the last 100 years. Furthermore, Numberi (2009) adds that two factors cause global warming: 1) burning fossil energy for industry, motor vehicles, and power plants; and 2) emissions of various gases from industrial activities such as the use and manufacture of CFCs. Humans contribute to global warming as the highest contributor of GHGs.

GHG emission, according to the rule of physics (Wahyono, 2008), occurs because the wavelength of light emitted by the entity will depend on the temperature of the entity.The higher temperature entity makes the small wavelength. The high temperature of the sun emits short-wave rays. The low temperature of the Earth's surface will emit long-wave infrared rays. Infrared rays in the atmosphere will be absorbed by certain gases, so they are not released into space. Heat surface, causing the air temperature to rise in the troposphere. If the trend of phenomena like this continues, the earth's surface air temperature (LST: Land Surface Temperature) in the future will rise by $\pm$ 2.30 ^{0}C. Climate change has encouraged the Republik Indonesia Government to commit to an active role in efforts to reduce the emission of GHGs through a RAN (National Action Plan, NAP) or RAD (Regional Action Plan, RAP). Based on PP No. 61/2011, concerned with the RAN for Reducing GRK emissions, and PP. RI No. 71 of 2011 about the National GHG inventory, provincial and district or city governments facilitate mitigation of GHG emission reduction through RAN for Reducing GHG Emissions (RAN-GRK), then provinces, and districts or cities throughout Indonesia (RAD-GRK). French (1998), mitigation is an effort to prevent, restrain the release of carbon, increase C absorption into forests or other C sinks, and reducing impact of GHGs that cause global heating. Setiawan (2010), adaptation is an important response strategy approach in efforts to minimise the dangers caused by the climate crisis. Adaptation has a role in reducing the impacts that immediately arise due to climate change that cannot be done by mitigation. The Indonesian government is trying to adapt through the RAN for Adaptation to climate change (PI). Slamet (2015), PI adaptation strategy: reducing socio-economic and environmental vulnerability originating from climate change; increasing community and ecosystem resilience; and improving the welfare of local communities through poverty alleviation. Mitigation and Adaptation to the PI impacts have been carried out nationally through NAP (National Action Plans) and regionally through RAD (Regional Action Plans). The nitrogen dioxide GHG emissions analysis study was carried out to provide a baseline description of NO_2 GHG producers and their potential for mitigation and adaptation to climate crisis impacts as a reference for RAD. It is hoped that the research results will be used by the Regional Government in designing and implementing climate change (PI) mitigation and adaptation actions. The research aims to reveal and analyse nitrogen dioxide (NO_2) GHG emissions supports RAP mitigation impacts of PI in Situbondo Regency.

METHOD

The research was conducted in the Situbondo Regency area at the astronomical line 7°35'–7°44' LS, and 113°30'–114°42'BT. The research period was six months, from May to October 2023. The scope of the research is a remote sensing system through the exploration of Sentinel-5P satellite data. The research method uses remote sensing analysis of NO^2 GHG projections through access to the Sentinel-5P OFFL NO_2: Nitrogen Dioxide Offline satellite dataset, and MOD 11A1.061 Terra LST (Land Surface Temperature)_and EDG (Emission Daily Global) 1km, then analysed using G_Colaboratory Research (Google Colab). Numerical spatial analysis via remote sensing and five-year projections were carried out on the cloud-based digital platform JavaScript Google Earth Engine (GEE), Google Colab, and distributed on Quantum Geographic Information System (QGIS) software. According to Voogt and Oke (2003), the application of remote sensing methods based on satellite thermal spectral sensors on earth colum layer provides insight into engineering technology and representative zone spatial and climate mapping capabilities. This method is a low-cost, high-resolution, more detailed, and inexpensive portable thermal scanning method for now and in the future. The following is an overview of the conceptual framework for the flow of stages in implementing remote sensing research.

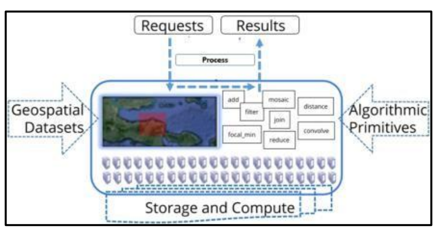

Figure 1. Flow charts of Implementation Stages of Remote Sensing Analysis of NO2 Emissions on the GEE and Google Colaboratory Platforms.

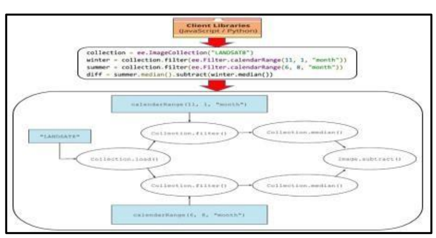

Figure 2. Accessing The NO2 Emissions Data Set

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(Source : Gorelick, N., Matt, H. et al. 2017).

Furthermore, used regression and correlation analysis to determine the relationship and closeness of the model between NO2 density variables and LST, and multivariate PCA biplot to determine the relative position of the variables using SAS v.jmp 16, and Genstat v.18 software.

RESULTS AND DISCUSSION

Nitrogen GHGs Emission

Nitrogen oxide (NOx) consists of 2 gases, namely nitric oxide (NO), as an uncoloured and smelless gas, and NO_2, as a reddish-brown gas with an extreme smell. Nitrogen oxides will react with O_2 or O_3 in the atmosphere to form NO_2. The other nitrogen oxides are NO_3, N_2O, N_2O_4, and N_2O_5. NOx is a powerful GHG that causes damage to the ozone layer.

Several forms of nitrogen gas are GHGs that contribute to the climate crisis. Wang et al. (2019), NOx is a general term given to many active gases, such as NO, N_2O, and NO_2. It's one of the main atmospheric contaminants from power plants and industrial boilers (mobile sources). Furthermore, Guo et al. (2009) state that apart from being directly toxic to humans, it also causes acid deposition and photoreaction fog, and can affect global tropospheric chemistry. Paraschiv et al. (2020) noted that burning hydrocarbon deposits, including biomass, to generate energy and warmth for industrial purposes is the primary human-made source of nitrogen oxides, NOx = NO + NO_2. Notably, nitrogendioxide, NO_2, is a precursor in the formation of greenhouse gases, such as Ozonosphere.

The increasing use of energy by hydrocarbon deposits for various human activities, especially in transportation, industrial and various processes related to development. Thus, an increase in the emission charge causes the concentration of GHG in the atmosphere to increase over time.

Mitigation and Reduction Strategies

The increase in population is directly proportional to the rise in energy consumption, making the energy supply sector an increasingly major contributor to world GHG emissions. The large GHG emissions in this sector occur due to the large amount of fossil energy used to provide power plants. Recorded 75% of Energy needs come from energy conversion non-renewables such as oil, coal, and natural gas (Ministry ESDM, 2010).

Nitrogen emissions from open burning significantly contribute to the change of the ozone layer and secondary aerosols in the troposphere. This includes the production of nitrogen oxides (Gao et al., 2015). Moreover, the NOx are formed by NO+NO_2, as the main atmospheric contaminant in the formation of greenhouse gases (Shen et al., 2021).

Shen et al. (2021) highlight that agriculture is a significant source of air contaminants. Agricultural contaminants primarily consist of contaminants from nitrogen-rich fertilisers, natural contaminants from plants, and contaminant resulted from the open flaring of plant trash.

For industrial sectors that use fossil energy, both for energy and non-energy purposes, the largest contribution from the NO_2 GHG emissions sector is 1) industries that consume large amounts of energy such as the metal, fertilizer, chemical, oil refinery, cement industries, and paper; 2) the process of burning agricultural waste and the aerobic decomposition process of organic material (Smith & Olesen, 2010); 3) waste/garbage management by traditional waste burning or by incinerators; 4) forestry, calculated based on the loss of the forest's ability to absorb and bind CO_2 (carbon stock).

Meanwhile, potential climate change mitigation and adaptation actions are carried out through policy reviews and document studies. Action potential refers to GHG emissions after mitigation actions, namely, reducing base year emissions by the amount of emissions after mitigation actions for each sector. Implementation of potential mitigation actions in Situbondo Regency through document studies. Farmers can determine the implementation of mitigation actions in the work area by considering costs, ease of work, and opportunities for facilitation by other parties.

GHG mitigation is a form of targeted human intervention reduce or increase the ability to absorb and change GHGs, so they are useful in environmental, social, and economic aspects. Simpson et al. (2008), four main implementation strategies mitigation of GHG emissions, 1) Elimination, avoidance of activities and the use of available tools produces GHG emissions, for example (Levermore, 1985), turning off lights when they are not in use; 2) Subtraction, done with carry out energy efficiency in each activity, for example (Ma et al., 2011), in purchasing equipment electronics, electricity savings indicators are not considered, but brand and price are the main ones, as is the result of research in China; 3) Substitution, strategy for replacing technology or change causes behavior large GHG emissions with technology or change to lower behavior emission, For example, the use of biogas to replace fossil energy or biomass energy.

Laramee and Davis (2013), the use of firewood, charcoal, kerosene, and LPG for biogas in Tanzania is able to prevent GHG emissions of 5,825 kg CO_2-eq/year/family; and 4) compensation, absorb strategy GHG concentration thereby reducing GHG emissions that arise, for example, Putri and Wulandari (2015), that reforestation with resin plants cat's eye (*Shorea javanica* L) is capable absorbs CO_2 emissions of 124.86 tons.ha-^{1}.

NO_2 Density (Total Density and Distribution Area)

The analysis results show the highest NO_2 density variable in 2017 was 0,66 – 2,12 g/m^2, then decreased to 0,65 – 2,01 g/m^2 in 2019, and to 0,63 – 1,94 g/m^2 in 2021, as in Figures 3, 4, and 5 below.

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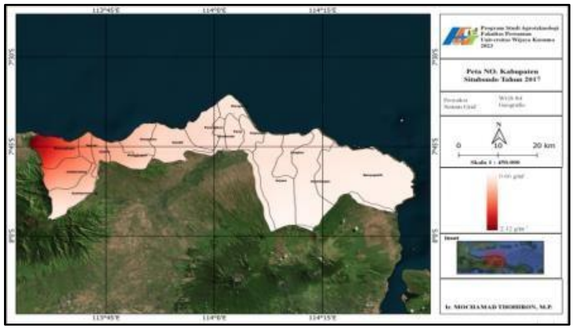

Figure 3. GHG NO2 Distribution Map (g/m^2) Based on District in Situbondo Regency in 2017 (source: analysis results)

Figure 4. GHG NO2 Distribution Map (g/ m^2) Based on District in Situbondo Regency in 2019 (source: analysis results)

Figure 5. GHG NO2 Distribution Map (g/ m^2) Based on District in Situbondo Regency in 2021 (source: analysis results)

For regional distribution variables, the highest NO_2 density in 2017 and 2019 in each sub-district was Besuki, Suboh, Banyuglugur, Panarukan, and Situbondo; then, in 2021, it would be Banyuglugur, Besuki, Suboh, and Kendit.

The NO_2 distribution map for 2017, 2019 and 2021 shows a decrease in density or change in density due to the dynamic nature of NO_2 in the atmosphere.

According to Shen et al. (2021), the concentration of NO_2 is closely linked to factors such as emission strength, meteorological conditions, atmospheric chemistry, and various sources of combustion residues.

Most of the NO_2 found in the atmosphere primarily originates from non-agricultural contaminant sources, including traffic density, power plants, and industry.

Additionally, Nitrogen dioxide is one of the very significant air contaminants, playing a critical role in the shift of secondary microparticles and Ozonosphere. Research to reveal hourly NO_2 concentrations across China and 12 urban agglomerations indicates that there are spatiotemporal variations in NO_2 concentrations.

This study also highlights that both anthropogenic and meteorological factors significantly influence inter-annual variations (IAV) in NO_2 levels. Weather conditions significantly influence the interannual variation (IAV) of NO2 concentrations. The increase in NO2 levels in several cities in China this winter is attributed to unfavourable weather conditions, which, in turn, may lead to a decrease in NO2 levels the following winter. Conversely, favourable weather conditions are the primary factors that contribute positively to NO_2 variations. Nitrogen dioxide, NO2, is a significant air contaminant that plays an essential part in atmospheric chemistry and poses risks to wellness (Tiwari et al., 2015).

It is the primary precursor for the formation of alternate particulate matter and ozone, contributing to various environmental issues (Carmona-Cabezas et al., 2020). Furthermore, Nitrogen dioxide is associated with several health problems, including heart diseases (Chen et al., 2018; Wang et al., 2022), impaired or alveolar dysfunction (Jiang et al., 2021), mental disorders (Fan et al., 2020), and shift bloodlipide sizes (Mao et al., 2020a; Mao et al., 2020b).

Higher concentrations of nitrogendioxides typically linked to a decrease in planetary boundary layer height (PBLH), wind velocity, and temperatures, but increased moistness (Zhang et al., 2020). Most nitrogendioxide emissions come from anthropogenic sources, especially internal combustion engines by automotive vehicles in municipal regions (Li et al., 2023).

NO_2 is one of the reactive nitrogen species (RNS), also referred to as reactive nitrogen (Nr) or NO_y. It is a free radical molecule that acts as an important signalling agent produced during various stress conditions. NO_y plays a crucial role in controlling the abundance of ozonosphere (Saddhe et al., 2018; Ali et al., 2021).

The most reactive form of NO_y is NO_x, which contributes to the accelerated damage of the stratospheric ozone layer through catalytic destruction mechanisms. This occurs when it interacts with other free radicals, particularly during photochemical processes (Kondo, 2003). Furthermore, Kondo (2003) stated that nitrogen dioxide (NO_2) and nitric oxide (NO), as components of reactive nitrogen (N_r) or RNS in the stratosphere, can be expressed as total nitrogen (NO_y). The equation for NO_y is: $NO_y = NO + NO_2 + NO_3 + 2N_2O + HNO_3$.

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According to Paraschiv et al. (2020), burning fuel for energy and heat in industrial processes releases anthropogenic nitrogen dioxide ($NO_x = NO + NO_2$), making NO_2 a precursor for greenhouse gas formation. In this case, Kondo (2003) stated that reactions between species of NO_y components did not cause changes in the total abundance of NO_y. Soil bacteria produce N_2O, which is released into the atmosphere and serves as the primary source of NO_y in the stratosphere. In the troposphere, nitrogen dioxide is the most stable form and is transported to the stratosphere via the tropical tropopause.

According to the US EPA (2021), the impact of gases on climate change depends on three main factors: (1) Gas density in the atmosphere (How Much). This refers to the concentration of a certain gas in the air. Higher emissions of GHGs result in greater concentrations in the atmosphere, (2) Survival time (How Long). Different types of GHGs have varying lifespans in the atmosphere, ranging from several years to thousands of years, and (3) strength of Influence (How Strong). Some gases have a more significant impact on the Earth's climate than others. Each greenhouse gas has a GWP, which measures both how long the gas persists in the atmosphere and how effectively it absorbs energy. Gases with higher GWPs absorb more power and contribute more to global warming compared to those with lower GWPs.

Furthermore, Erisman et al. (2011) state that the impact of climate warming due to GHGs is expressed in global warming potential (GWP), measured by CO_2 equivalent (CO_2 eq), because CO_2 is a reference chemical for determining a GWP value of 1. The nitrogen greenhouse gas group has a GWP value of 298, which means that the GWP is 298 times stronger and has a shelf life in the atmosphere for 144 years, while CH_4 has a GWP of 26 for a period of 100 years.

LST (Distribution Area, Monthly Distribution Pattern)

According to the results of previous research (Thohiron et al., 2023), the range of land surface temperature (LST) variables in 2017 was between 19°C and 39°C. This range increased to 21°C to 40°C in 2019 but then decreased again to 18°C to 38°C in 2021.

In the weather variable, the highest Land Surface Temperature (LST) distribution in 2017 and 2019 was relatively consistent across each sub-district: Situbondo, Panarukan, Panji, Kapongan, and Jangkar. However, in 2021, the area of distribution expanded to include Situbondo, Panarukan, Panji, Kapongan, Jangkar, Mangaran, Arjasa, and Asembagus, as illustrated in Figures 6, 7, and 8 below.

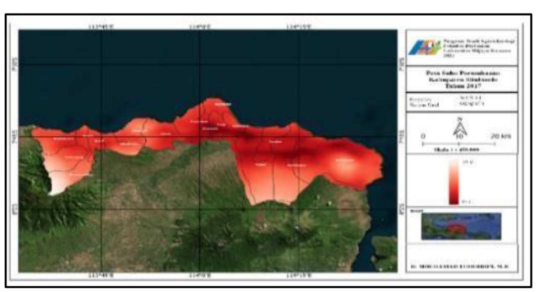

Figure 6. The LST Distribution Map (^{O}C) Based on District in Situbondo Regency in 2017

(Source: analysis results, 2023)

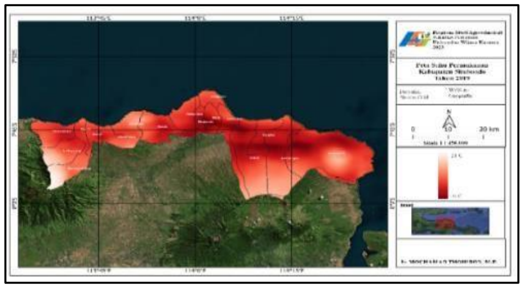

Figure 7. The LST Distribution Map (^{O}C) Based on District in Situbondo Regency in 2019

(Source: analysis results, 2023)

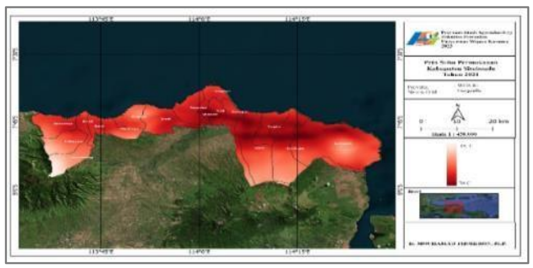

Figure 8. The LST Distribution Map (^{O}C) Based on District in Situbondo Regency in 2021

(Source: analysis results, 2023)

Furthermore, from the analysis of monthly LST distribution pattern variables, the highest LST in 2017 occurred in November and early December, and in 2019 it happened in November, then in 2021 in May and November, as in Figure 9 below.

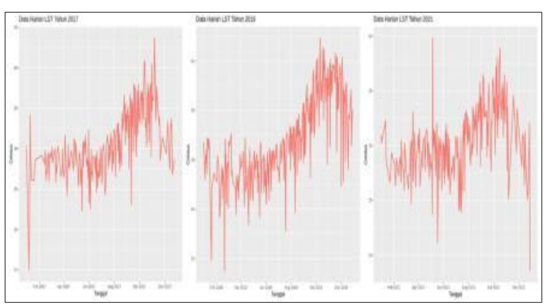

Figure 9. Monthly Distribution Pattern of LST in Situbondo Regency in 2017, 2019 and 2021

(Source: analysis results 2023).

LST is a measure of "how hot" the soil is to the touch. This temperature is different from air temperature because land heats and cools faster than air. This image shows the monthly average land surface temperatures (°C) measured by the MODIS on NASA's Terrasatellite (NEO, 2024a).

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In 2017 and 2019, the LST distribution map shows the same distribution pattern, which increases but decreases in 2021, even though the distribution area was wider. This has an impact on the extent of land exposed to maximum LST distribution because the land will heat up more quickly (NEO, 2024a). The large distribution of land areas exposed to maximum LST causes land temperatures to increase rapidly, thus having an impact on the ecological aspects of the land and the life on it (crops, livestock, and human beings).

Meanwhile, the maximum monthly and annual LST distribution pattern occurs until October-November, then decreases as we enter December. The occurrence of changes in LST will affect land temperature, which has a broad impact on the regional warming of local land.

Analysis of the NO_2 density distribution pattern with LST in 2017, 2019, and 2021 shows variations in the pattern of increase with the highest peak in 2019, then decreasing in 2021, as presented in Figure 10 below.

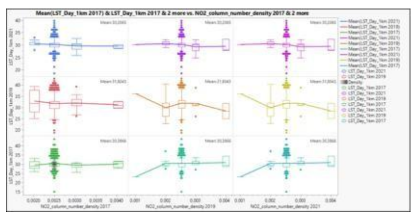

Figure 10. Description of the Distribution Pattern of NO2 Density on LST in Situbondo Regency in 2017, 2019 and 2021 (source: analysis results, 2023)

Furthermore, as NEO (2024b), the LST map shows the temperature of the Earth's land during the day as a measure of how warm or cold an object is, which will influence weather and climate patterns and impact plant life. The implication for plants, as results of previous research by Suryaningsih et al. (2023), is that temperature is closely correlated with the variable quantity and quality of potato yields (*Solanum tuberosum*) at $R2 > 0.8$. Eventually, worldwide LST (LST) measurements can be made from space via satellite instruments (NEO, 2024b).

Relationship Between Variables

To find out the extent of the relationship pattern between NO_2 density in 2017, 2019, and 2021 as an independent variable with a fixed variable (response) of LST in 2021, a regression analysis was carried out. The analysis results show that the model is insignificant with a relatively low correlation coefficient (r). This indicates that the relationship between these two variables does not stop. Results of the 2021 LST (LST) response variable regression model are $Y = 33{,}704 – 664{,}71*(NO_2\_density\ 2017) – 720{,}41*(NO_2\_density\ g/m^2\_2019) + 0.00*(NO_2\_density\ g/m^2\_2021)$.

The overall model estimation plot is presented in Figure 11 below.

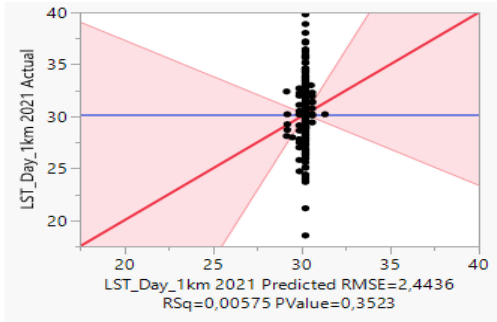

Figure 11. Actual Whole Model of LST by NO2 Predict Plot in Situbondo Regency Series 2017, 2019, and 2021 (source: analysis results, 2023)

Periodically, the results of the analysis in 2017, 2019, and 2021 show a decrease in the NO2 density variable, while the LST variable experiences fluctuations. In 2019, NO2 density reached its highest density. NO2 and LST density variables in 2017 and 2019 were lowly correlated (r = 0.55), but in 2021, they were not correlated (r = - 0.098), as presented in Figure 12 below.

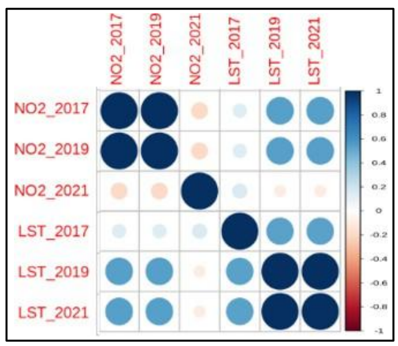

Figure 12. Correlation Matrix Map of the GHG NO2 Density Variable on LST in Situbondo Regency in 2017, 2019 and 2021 (source: analysis results, 2023).

Relative position of variables

Multivariate analysis was used to determine the relative position of variables through principal component analysis (PCA), AMMI (Additive Main Effect of Multiplication Interaction) Biplot. An overview of the analysis results is presented in Figure 13 below.

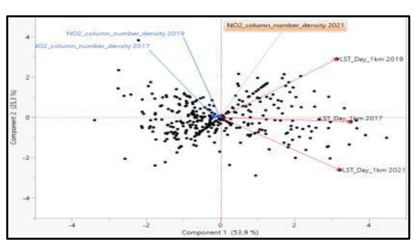

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Figure 13. Multivariate Analysis of the Main Components of the AMMI Biplot Graph for the NO2 Density Variable and LST in Situbondo Regency in 2017, 2019 and 2021
(Source: analysis results, 2023).

The figure above explains that the value of the suitability measure for the two-dimensional biplot graph is 53.9% (not too high); however, the biplot results obtained are considered quite representative. The independent variable (NO_2 density) is not correlated with LST in 2017, 2019, and 2021, but the periodic NO_2 density variables in 2017, 2019, and 2021 are all correlated. The periodic LST variables for 2017, 2019, and 2021 show the same variations, none of which are higher and uncorrelated.

Based on the regression analysis results, shows that regression analysis of NO_2 density (2017, 2019, and 2021) on LST in 2021 not significan, and it was seen that intercept (β0) was positive but the regression coefficients (β1), (β2), and (β3) of NO_2 density during 2017, 2019, and 2021 is negative so the LST prediction for 2021 will also decrease. There is a similar pattern in the regression results and the remote sensing LST analysis results in 2021. According to NEO (2024a), land affected by the maximum LST distribution will experience warming more quickly. The large distribution of land areas exposed to maximum LST causes land temperatures to increase rapidly.

CONCLUSION

Of all the variables analysed, the research results concluded that 1) there were differences in NO2 density in terms of quantity, distribution area, and monthly patterns throughout the year, where in 2017 - 2019 there was an increase, then a decrease in 2021.

2) there are differences in LST in terms of temperature, LST distribution area, and monthly patterns throughout the year, where there was an increase in 2017 and 2019, then a decrease in 2021; 3) The regression model is not significantly different and does not correlate between NO2 density in 2017, 2019 and 2021 and LST in 2021, which shows a decrease in LST in 2021 because the results obtained are the same as the results of remote sensing analysis; 4) The LST variables are not correlated and the variations are the same, but the NO2 density variables during 2017, 2019 and 2021 are correlated; 5) The chosen NO2 GHG reduction mitigation strategy is by implementing; Energy efficiency and conservation, Fuel switching, CCS, Changes in Land Use, also Land Management Practices.

Further research is needed to calculate the potential for reducing kind of nitrogen GHG emissions through several mitigation options that are most likely to be carried out, so that mitigation actions can be obtained and implemented for consideration by several interested parties. Community understanding and institutional operational steps are very necessary for socialising the impact of climate change (PI).

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