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Land Cover Classification of the Indonesian Archipelago Using Digital Spectroscopy to Support Spatial Planning in Indonesia

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Abstract

In the context of urban and regional planning, this study aims to produce land classification products covering 230 paths/rows throughout Indonesia, which can serve as an important tool in supporting planning and research projects. The research method used combines remote sensing in Geographic Information Systems (GIS) with the utilization of spectroscopy through QGIS software with Dzetsaka plugins (semi-automatic classification tools). Land cover classifications, which include water bodies, vegetation canopies, green open spaces, bare grounds, settlements, and built-up areas, as well as additional classifications of cloud cover, provide a comprehensive overview of land conditions in Indonesia. Based on the results of the study, the average distribution of land classes reached 10,116. The standard deviation was 14,786, which shows the level of variation in the data against the average value, with the higher value indicating the most significant variation in land classification. This study offers a more potential alternative by using Landsat 8 OLI 2022 satellite imagery data from the USGS as a basis for a more in-depth and accurate analysis of land classification. Thus, the results of this study not only contribute to mapping and understanding land use in Indonesia but also provide useful tools for supporting natural resource planning and management, as well as infrastructure development and sustainable development policies in Indonesia.

1. Introduction

In an era of globalization characterized by rapid technological development, global issues such as climate change, rapid urbanization, and environmental degradation are becoming increasingly important to address within the context of regional and urban planning (Stevanović et al., 2023). Land cover change plays a crucial role in addressing these issues because it directly affects land use, environmental quality, and community welfare (Bongasie et al., 2024). For example, the conversion of green land to urban areas can increase local temperatures and reduce air quality, while deforestation exacerbates the effects of climate change and reduces biodiversity (Buchori et al., 2022). Therefore, a deep understanding of geospatial conditions and land cover is essential for formulating effective and sustainable policies. The use of accurate and up-to-date geospatial data, such as satellite imagery, is essential to support comprehensive analysis in urban and regional planning, ensuring that policies can effectively address these global challenges (Wiatkowska et al., 2021; Zaki et al., 2023).

Despite significant advancements in geospatial technologies and the availability of various data sources, a critical gap exists in the accessibility and resolution of geospatial data needed for detailed regional and urban planning (Yu & Fang, 2023). High-resolution data is often required to capture the complexities of land cover and land use changes accurately. However, many existing datasets either lack the necessary detail or are not readily accessible, posing a significant challenge for researchers, planners, and students engaged in planning studios (Buchori, 2007). Geospatial-based data, such as satellite imagery, land use maps, and building density maps, are critical to support urban and regional planning analysis. Spatial data forms the basis for establishing a spatial database system to produce geospatial information beneficial to government and society (Meidodga et al., 2023).

One area that receives special attention in this context is geomatics, a multidisciplinary discipline that integrates geospatial technologies for the analysis and mapping of territories. Geomatics utilizes geospatial-based data or data that has a specific coordinate system within a region or city (Padmini et al., 2023). Despite the availability of applications, including those developed by ESRI, that provide land cover data, there is criticism regarding the level of detail these applications offer, particularly for complex regional mapping. For example, applications using Sentinel-2 data with an accuracy of 10 meters still fall short in providing the high-resolution data needed for detailed analysis (Polyakova et al., 2023; Vanderhoof et al., 2023).

To address this gap, this study proposes using Landsat 8 OLI satellite imagery data from 2022 as a more suitable alternative. Landsat 8 OLI has proven to have adequate accuracy in remote sensing, especially in classifying land in the Indonesian region from Sabang to Merauke, and even on a global scale (Sitinjak et al., 2023). This study aims to evaluate the effectiveness of Landsat 8 OLI in providing the higher-resolution data necessary for detailed and accurate land cover analysis in Indonesia. By addressing the current limitations in data resolution and accessibility, this research seeks to enhance the precision of geospatial analyses and support the development of more effective and sustainable regional and urban planning policies.

Moreover, integrating spectroscopy technology with urban and regional planning offers a novel approach to overcoming these data challenges. Spectroscopy, which involves the measurement of the interaction between light and matter, can provide detailed information about the composition and properties of various materials, including soil, vegetation, and urban surfaces. By incorporating spectroscopic data, planners can achieve a more nuanced understanding of land cover and land use changes (Buchori & Tanjung, 2014; Sugiri et al., 2015). Spectroscopy can enhance the detection of pollutants, assess soil health, and monitor vegetation stress, thereby offering critical insights into environmental quality and sustainability (Wang et al., 2024).

The application of spectroscopic techniques in conjunction with satellite imagery can significantly improve the accuracy of geospatial analyses. For instance, hyperspectral imaging, which captures a wide spectrum of light across numerous bands, can identify specific materials and their conditions more precisely than traditional multi-spectral imaging. This capability is particularly valuable in urban areas where diverse materials and land covers coexist nearby. By integrating hyperspectral data with Landsat 8 OLI imagery, planners can refine their analyses, leading to more targeted and effective policy interventions (Li et al., 2023).

Furthermore, the synergy between geospatial data and spectroscopic analysis can enhance predictive modeling in urban and regional planning. By utilizing machine learning algorithms, planners can predict future land cover changes and assess their potential impacts on urban environments. This predictive capability is crucial for proactive planning and sustainable development, allowing planners to anticipate and mitigate adverse effects before they manifest (Srivastava & Maity, 2023).

In the context of Indonesia, where diverse ecological and urban challenges exist, the integration of spectroscopy and geospatial technologies can provide a robust framework for addressing these issues. Indonesia's varied landscapes, from dense urban centers to remote forested areas, require detailed and accurate data to inform planning decisions. The use of Landsat 8 OLI, supplemented with spectroscopic data, can offer a comprehensive view of land cover dynamics across the country. This integrated approach can support efforts to combat deforestation, manage urban sprawl, and protect biodiversity, aligning with national and global sustainability goals (Sitinjak et al., 2023).

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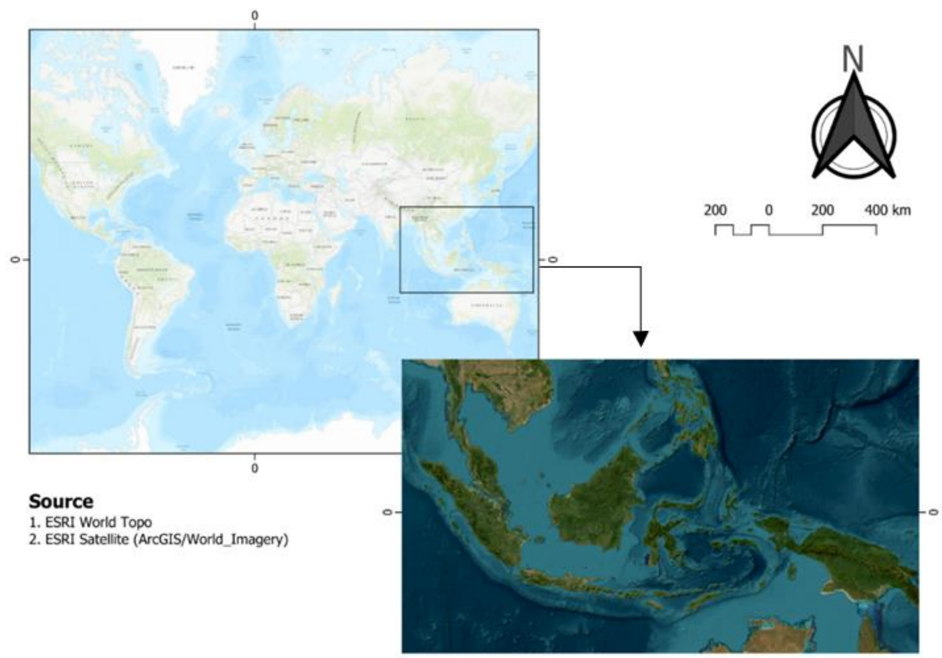
In conclusion, this study proposes a novel methodology that combines Landsat 8 OLI satellite imagery with spectroscopic analysis to enhance geospatial data resolution and accessibility for urban and regional planning in Indonesia. By leveraging the strengths of both technologies, this approach aims to fill existing data gaps, improve the precision of land cover analyses, and support the development of effective and sustainable planning policies. This integrated framework not only addresses current challenges but also provides a scalable solution that can be applied to other regions facing similar issues. Through this research, we aim to contribute to the advancement of geospatial science and its application in urban and regional planning, ultimately fostering more resilient and sustainable urban environments.

2. Data and Methods

2.1. Study Area

This research was conducted in a very wide and diverse area, namely the entire archipelago of the Republic of Indonesia, consisting of thousands of islands with various geographical, climatic, and ecosystem characteristics (Nunn et al., 2024). Indonesia is the largest archipelagic country in the world, consisting of five large islands: Sumatra, Kalimantan, Sulawesi, Papua, and Java, as well as thousands of small islands scattered between the Indian Ocean and the Pacific Ocean (Adnan, 2023; Simarmata et al., 2023). This study area covers 230 path/rows of Landsat 8 OLI imagery tracks, covering the entire land area of Indonesia, from the western border of Aceh to the eastern border of Papua.



Source: Author, 2024

Figure 1. Study Area in the Indonesian Archipelago

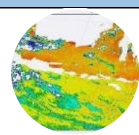
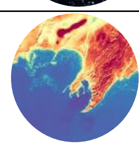
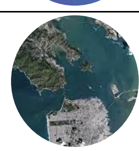
The research area in Figure 1 covers a wide range of ecosystems, including dense tropical rainforests, dense urban areas, large tracts of agricultural land, and coastal and marine areas rich in biodiversity (Dong, 2024). This diversity reflects a complex and varied array of land uses, which include water bodies, vegetation canopies, green open spaces, vacant land, settlements, and built-up areas. Each of these classes has different characteristics and requires a specific classification approach to obtain accurate results.

The study also considered geospatial factors affecting land classification, such as diverse topography ranging from high mountains to lowlands, as well as significant climate variability from island to island (Tenorio et al., 2023). This research uses satellite imagery with cutting-edge technology and sophisticated GIS software to process this large-scale data, address technical challenges such as high cloud cover, and ensure that land classification results can be used to support better planning and management of natural resources in Indonesia. With such a broad scope and detail, this research makes a significant contribution to mapping and understanding land use in Indonesia, which is important for a wide range of scientific and practical applications.

2.2. Remote Sensing

In essence, mapping requires a fairly long process, both from the aspect of observation in the field and using geospatial technology. One technology that is often used is remote sensing. In fact, since 1972, NASA has released satellite imagery data with the first Landsat model, Landsat-1 (Wulder et al., 2022; Crawford et al., 2023). Note that remote sensing has several components and types, as shown in Table 1.

Table 1. Satellite Imagery Data Types for Remote Sensing Surveys

No.	Name	Type	Model	Temporal Resolution	Spatial Resolution	Spectral Resolution	Cost	Source
1.	Modis	✓ Terra ✓ Aqua		Every 1–2 Days	✓ 250 m ✓ 500 m ✓ 1,000 m	36 Band	Free	NOAA
2.	Sentinel	✓ 1A, 1B ✓ 2A, 2B ✓ 3A ✓ 4A		Every 5 Days	✓ 10 m ✓ 20 m ✓ 60 m	13 Band	Free	ESA
3.	Landsat	✓ 5 TM ✓ 7ETM+ ✓ 8/9 OLI		Every 16 Days	✓ 15 m ✓ 300 m	7 Band (5 TM) 8 Band (7 ETM+) 11 Band (8/9 OLI)	Free	USGS
4.	Pleiades, Quickbird, Spot 6/7, Rapid Eye	Highest resolution		Everyday	5 m	5 Bands	At Cost	NASA LAPAN

2.3. Spectroscopy

Spectroscopy can be defined simply as the science of matter and its properties through the analysis of radiant energy, sound, and particles absorbed, emitted, or dispersed by observed substances. The science of spectroscopy has expanded to a wide range of electromagnetic spectra, from short-wavelength X-rays to long-wavelength microwaves (Mikheytsev & Korzhimanov, 2023). Spectroscopy is generally a science that can detect changes in soil quality and crop cover, and can predict soil classification based on various land use categories (Delcourt et al., 2023). This science studies the interaction of energy in the form of electromagnetic radiation with materials. This radiation interaction is a function of the wavelengths reflected (reflection), absorbed (emission), or emitted (scattered) by the material (Hede & Heriawan, 2020). The application of spectroscopy in remote sensing is associated with reflectance and hyperspectral imaging, which have shown accuracy in obtaining mineralogical information in inaccessible or remote areas or in situations where such information is difficult to obtain through alternative exploration methods (Falcioni et al., 2023). The spectroscopic method is highly efficient as a fast, reproducible, and relatively inexpensive method in remote sensing (Levi et al., 2022).

Spectroscopic techniques use electromagnetic waves with wavelengths visible to near-infrared (VNIR) 350–1,300 nm, short infrared (Shortwave Infrared / SWIR) 1,300–2,500 nm, and Long-Wave Infrared (LWIR) 8,000–14,000 nm (Hede et al., 2019). Most multi-spectral and hyperspectral optical sensor imagery belongs to the VNIR-SWIR spectrum, and reflectance information can be obtained from the digital amount of satellite imagery. Thus, spectroscopic imaging is currently evolving along with the development of optical sensor satellite imagery. Because reflectance data in the VNIR-SWIR range have been established for more than three decades for a wide range of geological mapping applications, they are widely used in terrestrial and space research and are considered an accurate technique with a variety of optical sensor images planned or developed, including images from Landsat 8, Sentinel-2, Hyperion, and EnMAP (Hede & Heriawan, 2020). According to Pedrotti et al (2017), spectroscopy is divided into three general types: absorption spectroscopy, emission spectroscopy, and scattering spectroscopy. In this study, a commonly used type is scattering or reflection spectroscopy, which, in theory, identifies the observed characteristics emitted through the analysis of the energy dispersed by the object. The scattering process is much faster than absorption and emission spectroscopy. It can be understood as a function of the wavelength/frequency and polarization of electromagnetic radiation that appears. Scattering spectroscopy is of great interest in exploring the characteristics of swamps, forests, and vegetation, which continuously return sunlight to the atmosphere.

2.4. Project-based Learning

In the context of the Urban and Regional Planning Study Program, Project-Based Learning (PBL) or Studio Planning plays a central role in shaping students' skills and knowledge. PBL is defined as a learning approach that provides practical experience through projects or case studies, creating an environment that allows direct integration between theory and practice. According to Safithri et al. (2021), PBL can be one solution to support students' problem-solving abilities.

PBL emphasizes active and collaborative learning, focusing on solving real-world problems. In planning studios, PBL includes the use of real projects that reflect the complexity of challenges in urban and regional planning. PBL aims to develop students' analytical, creative, and problem-solving skills. According to Nguyen et al. (2024), this approach can improve conceptual understanding, research skills, and the ability to communicate and work together in teams. PBL also creates a direct link between academic theory and real-world situations. According to Swandi et al. (2021), there is a Gold Standard PBL method that is implemented through seven steps: (1) Problem or Question Challenge, (2) Continuous Study, (3) Authenticity Test, (4) Student Role, (5) Reflection, (6) Criticism and Revision, (7) Product Publication.

The implementation of PBL in the planning studio involves several stages, including project identification, problem formulation, planning, implementation, and evaluation. Students work in groups to develop planning solutions that can be implemented in the field. In the digital age, technology integration is an important aspect of PBL. The use of planning and GIS software can increase efficiency in spatial data analysis, modeling, and presenting project outcomes. Although PBL has many benefits, some challenges arise, such as time management, group dynamics, and project sustainability. Effective strategies include active lecturer mentoring, collaborative mentoring, and structured reflection. Case studies of PBL implementation in the Urban and Regional Planning Study Program show an increase in student understanding of the complexity of planning problems (Ayerbe-López & Perales-Palacios, 2023). These projects also make a real contribution to the development of the region and the city. PBL or Studio Planning in the Urban and Regional Planning Study Program is a very effective learning approach to prepare students to face real-world challenges. PBL encourages understanding of concepts, practical skills, and professional attitudes, creating graduates who are ready to contribute to the planning and development of regions and cities.

2.5. Methodology

In Figure 2, the method used in this study is a remote sensing survey by obtaining Landsat-8 OLI satellite image data, which is a USGS product that has high accuracy in terms of land classification. The visualization provided by this image cannot be separated from the combination of bands as a diverse coloring source, often called multi-spectral (Carrasco et al., 2019). It should also be noted that the Landsat-8 OLI data acquisition technique uses the term path/rows (Ferdous et al., 2019). For the path/rows, Indonesia's coverage from Sabang to Merauke has been listed in Figure 3 and Table 2.

For analysis techniques, the dzetsaka plugin (Classification Tool) is used, which is available in QGIS (Sejati et al., 2019). Previously, the acquired Landsat-8 OLI satellite imagery combined multiple bands (1–7) to generate a Virtual Map of the area corresponding to the path/row. Then, the visualization result is modified according to the rules of composite coloring. Figure 4 below is a combination of bands (4, 3, 1) with path/row regions (113/66).

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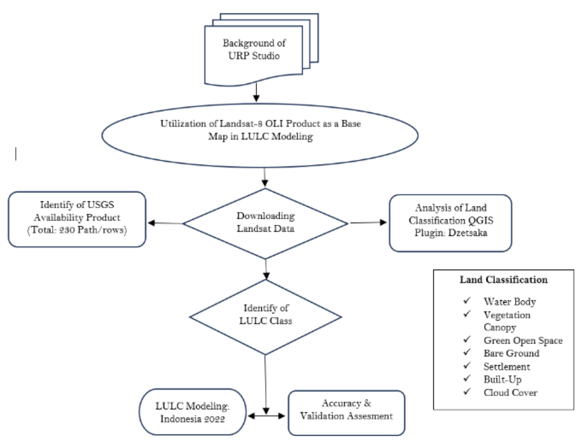

Figure 2. Research Framework

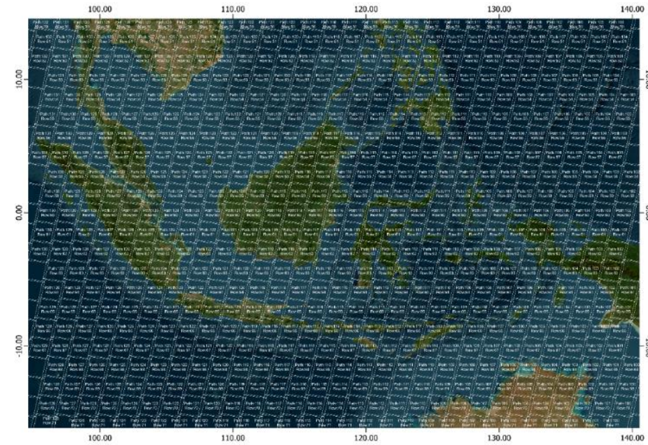

Figure 3. Path/rows Concept for Landsat 8 OLI Data Acquisition

Table 2. Path/rows of Provinces in Indonesia

No.	Province	Path/Row
1.	Nangroe Aceh Darussalam (NAD)	131–129/56–58
2.	North Sumatra	129–128/57–60
3.	West Sumatra	128–127/59–62
4.	Riau	128–125/58–61
5.	West Sumatra	128–126/59–62
6.	Bengkulu	126–124/62–64
7.	Jambi	126–125/61–62
8.	South Sumatra	126–123/63–61
9.	Riau Islands	125–124/59–60
10.	Bangka Belitung	124–122/61–62
11.	Lampung	124–123/63–64
12.	West Kalimantan	122–119/59–62
13.	Central Kalimantan	120–117/60–62
14.	North Kalimantan – East Kalimantan	118–116/62–57
15.	Banten	122–123/65–64
16.	Jakarta	122/64
17.	West Java	122–121/65–64
18.	Central Java	121–119/65–66
19.	Special Region of Yogyakarta	120–119/65–66
20.	East Java	119–117/66–65
21.	North Sulawesi	113–111/58–59
22.	Gorontalo	114–112/59–61
23.	Central Sulawesi	115–112/59–62
24.	West Sulawesi	115–114/61–62
25.	South Sulawesi	114–113/61–65
26.	Southeast Sulawesi	113–111/62–64
27.	Bali	117–116/66
28.	West Nusa Tenggara	116–114/66
29.	East Nusa Tenggara	114–110/66
30.	North Maluku	111–109/58–63
31.	Maluku	110–104/62–66
32.	West Papua	108–105/60–63
33.	Papua	105–102/61–63
34.	East Papua	102–100/61–66

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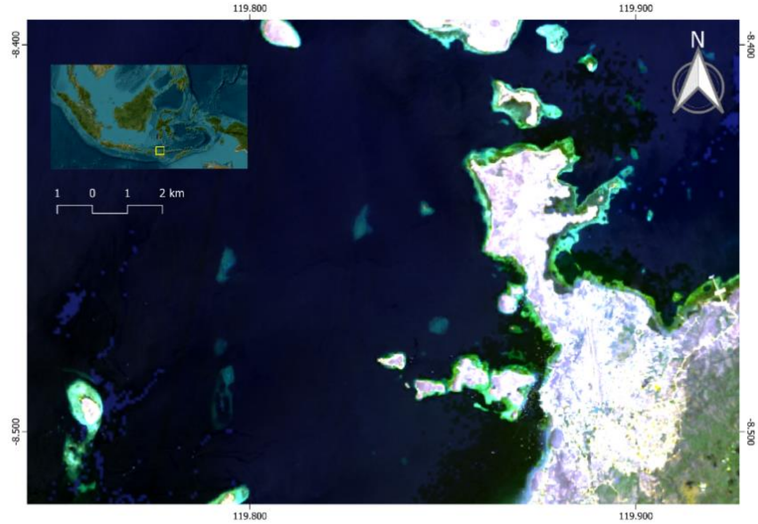

Figure 4. One of the Base Maps of Landsat 8 OLI, Band Combination 4, 3, 1, Path-113/Row-066

3. Results and Discussion

Spectroscopy is one of the most important analytical methods in chemistry and physics, involving the measurement of the interaction between matter and electromagnetic radiation (Prasad et al., 2024). The spectroscopic procedure, although it varies depending on the type of spectroscopy used (e.g., UV-Vis spectroscopy, infrared (IR), or nuclear magnetic resonance (NMR)), essentially involves several main stages. First, sample preparation is carried out to ensure that the sample is in suitable conditions for analysis. In UV-Vis spectroscopy, the sample is usually a clear solution, whereas in IR spectroscopy, the sample can be a solid, liquid, or gas placed in a specialized cell.

The second stage is sample irradiation, in which the sample is subjected to electromagnetic radiation at a specific wavelength. In UV-Vis spectroscopy, ultraviolet radiation or visible light is used, while in IR spectroscopy, infrared radiation is applied. Next, the detector measures the radiation emitted or absorbed by the sample, and this data is processed to produce a spectrum. This spectrum is a visual representation of the interaction between radiation and the sample, showing characteristic peaks related to electron transition energy or molecular vibration (Kuttruff et al., 2023).

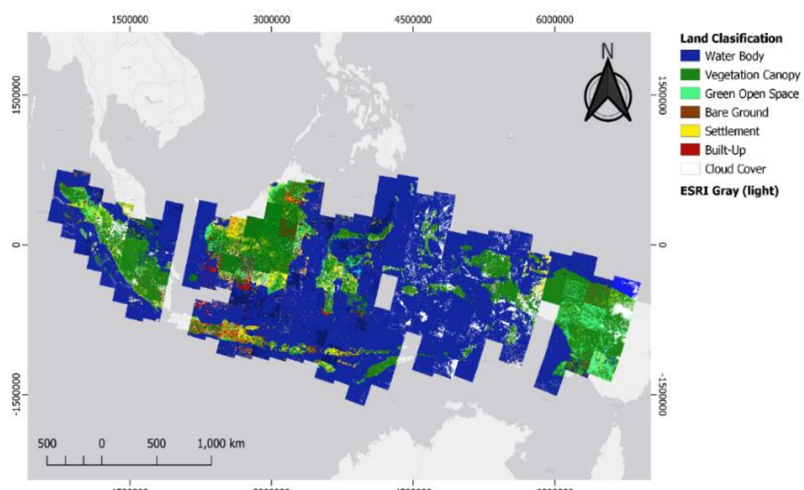

Figure 5. Results of Spectroscopic Analysis with GIS, Scope of All Islands in the Republic of Indonesia.

Analysis of spectral data is the final and critical stage in the spectroscopic procedure. These data are analyzed to determine the chemical or physical characteristics of the sample, such as the identification of functional groups in molecules, molecular structure, or concentration of components in mixtures (Karpukhina et al., 2023). For example, in IR spectroscopy, peaks in the spectrum may indicate the presence of functional groups such as hydroxyl (-OH) or carbonyl (C=O), which provide important information about the molecular structure of the sample. In this study, Figure 5 shows land classification, which is represented by characteristics in the form of color. Water bodies are blue, vegetation canopies are dark green, green open spaces are light green, bare grounds are brown, settlements are yellow, built-up areas are red, and cloud errors are white.

In a recent study, spectroscopy-based image processing technology was applied to land classification using Landsat 8 OLI imagery with acquisition in 2022 (Manetu et al., 2023; Yuan et al., 2023). The use of GIS (Geographic Information System) software with the dzetsaka plugin, a semi-automatic classification tool, allows for more accurate and detailed visualization of land classification. The research resulted in the classification of land into seven main classes: water bodies, vegetation canopy, green open spaces, vacant land, settlements, built-up areas (buildings), and cloud cover. The Landsat 8 OLI imagery used covers the entire archipelago of the Republic of Indonesia, consisting of 230 paths/rows, allowing comprehensive and extensive analysis.

The advantage of the GIS method with the dzetsaka plugin, compared to other methods, lies in several aspects. First, the accuracy and detail of the resulting classification are very high, allowing clear identification of different types of land use. Secondly, this method allows for a very wide scope of analysis, which is difficult to achieve with traditional methods. For example, manual analysis of land use for the entire territory of Indonesia would take an enormous amount of time and resources. Third, efficiency is another advantage of this method. The use of GIS software and semi-automated plugins speeds up the analysis process, saving valuable time and resources. This method has an important role in planning science. Accurate information about land use is essential for urban planning, infrastructure development, and natural resource management (Kalfas et al., 2023). For example, by knowing the distribution and extent of green open space areas, governments and urban planners can design strategies to improve the quality of the environment and public health. Environmental monitoring is also one of the main benefits of this method. Changes in land use, such as deforestation or urbanization, can be monitored in real-time, enabling faster and more effective prevention or mitigation actions (Singh et al., 2022).

Data-driven decision-making in spatial planning, disaster mitigation, and development planning becomes easier with this method (Carramiñana et al., 2024). Data generated from land classification can be used to identify disaster-prone areas, such as floods or landslides, and plan for safer and more sustainable infrastructure development. In addition, this information is also important in environmental conservation efforts and natural resource management, ensuring that the development carried out does not damage the existing ecosystem.In further discussion with related articles, this study describes the use of Landsat 8 OLI imagery and GIS software with the dzetsaka plugin for land classification throughout the archipelago of the Republic of Indonesia. The classification results shown in Figure 5 of the study provide a clear and comprehensive visualization of land use in the region. This provides invaluable information for a wide range of resource planning and management applications. However, on the disadvantage side, these results are less effective in terms of processing time, which takes quite a long time, making them less qualified in terms of quantity.

Overall, spectroscopic methods and GIS-based image processing technologies provide many advantages in accurate and efficient data analysis (Shaikh & Birajdar, 2024). With the ability to provide detailed information about the chemical and physical characteristics of samples, as well as land use on a large scale, the method plays an important role in research and practical applications. The application of this technology in land classification research shows how accurate and detailed data can be used to support better planning and more effective decision-making (Abdelkarim, 2023). It emphasizes the importance of technology in obtaining and analyzing data efficiently and accurately, as well as its application in various fields to improve the quality of life and environmental sustainability.

Figure 6 below presents a descriptive statistical graph of the results of land classification validation using Landsat 8 OLI data. The minimum value of the dataset is 0, while the maximum value reaches 249, which indicates that the data covers the full range of possible classification categories. A range of 249 reflects the difference between the highest and lowest values in the dataset, which can be an indicator of data variability. The total number of values in the dataset is 21,517,803,345, with a mean value of 10.116, showing the average distribution of land classes across the research area. A standard deviation of 14.786 indicates the degree of variation or dispersion of the data against the average value, with a higher value indicating a significant variation in land classification.

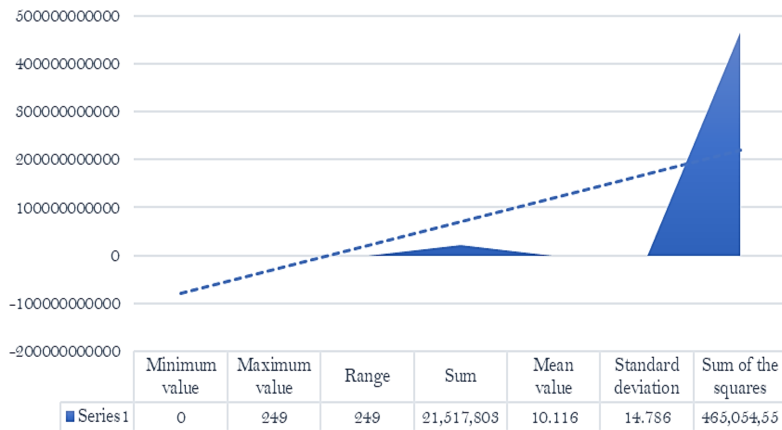

Figure 6. Descriptive Statistical Graph of the Results of Land Classification Validation Using Landsat 8 OLI Data and Spectroscopy Method-Based

In addition, the sum of the squares of 465,054,550,961.107 provides important information regarding the distribution of the data, which can be used for further analysis, such as variance and regression calculations. These values can help in assessing the extent to which the classification results are close to the actual land conditions in the field. This statistical data plays an important role in regional and urban planning, where understanding the distribution of land cover can be used for the development of spatial planning policies, identification of land use patterns, and data-based decision-making for sustainable development.

4. Conclusion

Research on land classification modeling using Landsat 8 OLI imagery across the archipelago of the Republic of Indonesia has provided important insights into land cover distribution, which contributes significantly to regional and urban planning. The main findings of this study are the identification of seven main classes of land cover, namely: water bodies, vegetation canopy, green open spaces, vacant land, settlements, built-up areas, and cloud cover. This classification serves as a very useful basic dataset for spatial planning, environmental monitoring, and sustainable development strategies. Although GIS software with the dzetsaka plugin is able to provide accurate and detailed visualizations, the study faces challenges, especially with cloud cover, which hinders the visibility of satellite imagery. These limitations impact the accuracy of the classification, particularly under suboptimal atmospheric conditions. In addition, the limitations of the temporal and spectral resolution of Landsat 8 imagery also affect the accuracy of land use analysis over time.

This research makes an important contribution to regional and urban planning by providing a reliable geospatial framework for decision-makers. Accurate land classification supports strategic planning initiatives, infrastructure development, and disaster risk management. Moreover, the study also highlights the importance of integrating advanced methodologies, such as cloud removal techniques and the use of radar data (e.g., Sentinel-1 from ESA), to improve the reliability of classification in challenging atmospheric conditions. For further research, it is recommended to explore the use of higher-resolution satellite data, such as Sentinel-2, to improve the level of detail and frequency of monitoring. Additionally, the application of advanced classification algorithms, such as machine learning and deep learning, is expected to further enhance the accuracy of land classification. Wider field validation is also needed to ensure consistency with conditions in the field, thereby improving the reliability and applicability of research results in practical planning contexts. The adoption of more advanced satellite image processing technologies will ultimately strengthen the capacity to monitor and manage land-use changes in real-time, thereby supporting more informed decision-making and driving sustainable urban development.

5. Acknowledgments

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