Monitoring Changes in Ecological Quality of Land Cover Using Landsat-8 OLI Imagery in Semarang City

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Abstract
The establishment of industrial and trade areas has implications for economic growth, which is associated with an increase in population and creates larger urban areas. The urban expansion that results from this process will lead to ecological problems such as land degradation, pollution, and other ecological problems. Ecology can be defined as the combination of quality and quantity of ecological elements in the aspects of climate, land, and water that affect humans. Ecology, which can be assessed in terms of quality, is a complex relationship that is linked to social and economic sustainability. This research will assess RSEI-based ecological quality and its influence on land cover in Semarang City in 2013-2023. A total of four indicators, such as NDVI, WET, NDBSI, and LST, are used to assess ecological quality integrated with PCA, as well as land cover data with the acquisition of 9 classes to determine the dynamics of ecological quality on land cover. From this study, it can be seen that (1) the ecological quality in Semarang City in the span of 2013-2023 tends to decrease as evidenced by the mean value of 0.69 for 2013, 0.68 for 2018, and 0.66 for 2023. (2) In the green zone and built-up land zone, the area with stable ecological quality shows a higher value among other statuses, however, in the interval of 2013–2023, the area of degradation exceeds the area of improvement by more than 20%. In the water zone, especially coastal areas that tend to experience turbidity, the status of ecological quality improvement is higher, with the respective proportions of 76.04%, degradation 12.13%, and stable 11.84%.

Keywords: Ecological Changes, Land Cover, Landsat-8 OLI, RSEI

1. Introduction

Urbanization in Semarang City can be seen from the increase in population, which in 2019 was the year with the highest population increase of 0.69%. This was driven by various public facilities and infrastructure developments, especially in the urban center, which contributed to the formation of industrial and trade areas that had an impact on urban expansion [1][2] and [3].

The establishment of industrial and trade areas has implications for economic growth, which is associated with an increase in population and creates a larger urban area [4]. Urban expansion resulting from this process will lead to ecological problems such as land degradation, pollution, and other ecological problems. According to research by [5], urban expansion in Semarang City in the period 1998–2018 has reached 70%, which has resulted in a reduction in vegetation area of more than 30%, which has an impact on increasing air temperatures above 2°C.

Meanwhile, according to research by [6], the green zone in Semarang City decreased by around 7.07% in the period 2016 to 2019. This was triggered by increasing residential needs that urged the green zone to affect the ecological conditions formed.

Ecology can be defined as a combination of quality and quantity of ecological elements in the aspects of climate, land, and water that have an impact on humans. According to [7], ecology, which can be assessed in terms of quality, is a complex relationship that is related to social and economic sustainability. In recent years, remote sensing data, which has advantages in time efficiency and extensive data acquisition, has been a major plus in ecological quality monitoring [8]. RSEI is one of the remote sensing-based approaches for monitoring ecological conditions. RSEI was first introduced in 2013 and first applied to the study of ecological environmental change in Tzhangingchow, Fujian Province [9].

The purpose of RSEI is to obtain a rapid assessment of environmental ecology in an objective and visualizable manner. The ability of the RSEI-based index itself can be developed for monitoring urban environmental areas [10] and [11]. RSEI studies in urban areas with different characteristics have often been carried out because they have proven to produce stable outcomes, for example the research of [11] in several European cities and [12] in the Central Iran region. The four common variables that are often used to represent indicators of greenness, wetness, dryness, and surface temperature are NDVI, WET, NDBSI, and LST, respectively, which refer to several related studies belonging to [13][14][15] and [16] also use these indicators and are integrated using PCA on PC1 to assess ecological quality and are classified into 5 categories of poor, fair, moderate, good, and excellent. Departing from these conditions and approaches, this research has the main objective to determine changes in RSEI-based ecological quality and its dynamics for three zones representing land cover.

2. Method

2.1 Study Area

Semarang City is astronomically located between 6°50′ - 7°10′ N and 109°35′ - 110°50′ East. Semarang City is in the administrative area of Central Java Province as well as the capital city of Central Java Province. Semarang City is bordered to the north by the Java Sea, to the south by Semarang Regency, to the east by Demak Regency, and to the west by Kendal Regency. Through the results of land cover analysis in 2023, it is known that the built-up land zone has an area of 115.82 Km^2, the green zone is 245.46 Km^2, and the water zone is 25.15 Km^2. The research area presented in the Figure 1 is the location used in this study, the consideration of selecting the image uses the minimum percentage of cloud cover among all recording times in that year. The acquisition time also uses seasonal considerations, where the rainy season is chosen because in that season the ecological assessment becomes more objective. According to data (https://dataonline.bmkg.go.id/home) the rainfall formed at the recording time was 131 mm/month in 2013, 247 mm/month in 2018, and 269 mm/month in 2023, respectively. Semarang City is an area that offers attractiveness for industry and commerce, and this attractiveness has a favorable impact on the economic conditions of its residents. However, on the other hand, this condition also adds to environmental problems such as pollution that causes various diseases [17]. The expansion of urban areas in Semarang City has been more than 70%, with a decrease in the amount of vegetation of more than 35%, which has increased air temperatures by more than 2-5ºC in the period 1998–2018 [5].

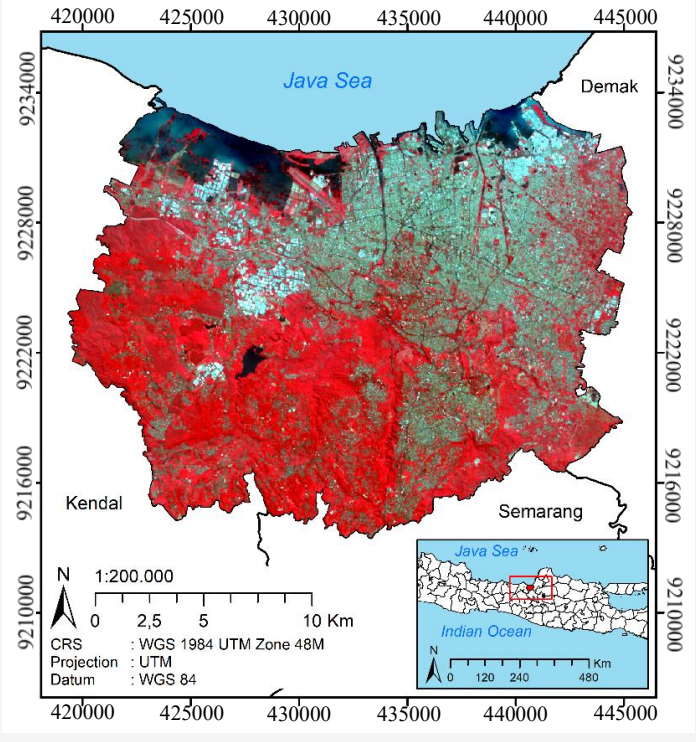

Figure 1: Semarang city. Cemtral Java, Indonesia

Meanwhile, research by [6] stated that the increase in housing needs caused a decrease in the green zone area in Semarang City from 26.03% in 2016 to 18.96% in 2019. As a result of these conditions, there is a degradation of environmental quality that correlates with public health.

2.2 RSEI Variable Extraction

RSEI is a comprehensive index for detecting environmental conditions [18]. The main component in RSEI is the extraction of variables such as greenness (NDVI), wetness (WET), dryness (NDBSI), and surface temperature (LST). The index-based indicators used in this study can be derived in various methods by considering the characteristics of the study area. The PCA transformation approach can calculate the RSEI. NDVI is a frequently used approach to monitor vegetation cover at different scales [19] and [20]. Most studies mentioned that NDVI is sensitive to low-density vegetation cover, especially in urban areas with a high density of built-up land [21] and [22]. In this study, NDVI utilizes the red band and NIR band, NDVI is used as an indicator that represents the greenery element to compile RSEI. The NDVI is determined using Equation 1:

$$NDVI = \frac{B5 - B4}{B5 + B4}$$

Equation 1

Wetness Index is an equation generated through the tasseled cap transform (TCT). TCT is a useful approach to minimize the loss of information in each band by using spectral compression methods [18]. TCT is often used for ecological monitoring that represents objects such as vegetation, water, and soil moisture and soil quality degradation [23] and [24]. In this study, the wetness indicator to compile RSEI utilizes the wetness index, Equation 2 is the wetness index equation using Landsat 8 imagery:

$$WET = 0.1511B2 + 0.0972B3 + 0.3283B4 + 0.3407B5 - 0.7117B6 - 0.4559B7$$

Equation 2

NDBSI is an index used to represent an indicator of the level of drought in urban areas due to urbanization and human activity factors. These factors will encourage surface hardening due to the displacement of natural ecosystems that make a place dry and deteriorate environmental quality [25]. NDBSI utilizes a combination of soil index (SI) and index-based built-up index (IBI) with Equations 3-5:

$$NDBSI = \frac{IBI + SI}{2}$$

Equation 3

$$SI = \frac{B6 + B4 - B5 + B2}{B6 + B4 + B5 - B2}$$

Equation 4

$$IBI = \frac{2B6/(B5+B6) - [B5/(B4+B5) + B3/(B3+B6)]}{2B6/(B5+B6) + [B5/(B4+B5) + B3/(B3+B6)]}$$

Equation 5

LST is obtained through processing the thermal band (band 10) on Landsat 8 OLI/TIRS imagery to represent surface temperature indicators. The first step is to convert the digital number (DN) into radian top of atmosphere (ToA) data. ToA data on Landsat 8 OLI/TIRS imagery can be determined from Equation 6.

$$L_\lambda = M_L Q_{cal} + AL - Oi$$

Equation 6

Where L_λ is ToA spectral radian, M_L is radiance multiplicative band, A_L is radiance add band, Q_{cal} is quantized and calibrated standard product pixel value (DN), and O_i is correction value band 10. The next step is to convert the radian spectral data into brightness temperature (*BT*) data. The process used to obtain *BT* values in units of degrees Celsius can utilize the thermal constant values *K1* and *K2*. Equation 7 is used to obtain the *BT* value.

$$BT = \frac{K2}{\ln\left(\frac{K1}{L_\lambda} + 1\right)} - 273.15$$

Equation 7

Where *K1* and *K2* are band constants in band 10 of Landsat OLI [26].

2.3 Normalization

The indicators that make up the RSEI data in the form of indices have different value units, which cause dimensional inconsistencies, to avoid these effects, a normalization step is needed. In this research, the minimum and maximum value normalization method is used to produce a value range of 0-1. Normalization calculations need to consider aspects of the function of indicators in compiling RSEI, where the greenness indicator (NDVI) and the wetness indicator (WET) are positively correlated with ecology so that Equation 8 is used to normalize the indices values, while the drought indicator (NDBSI) and temperature (LST) are negatively correlated with ecology, so the Equation 9 is used to normalize the indices values.

$$NI = \frac{I - I_{\min}}{I_{\max} - I_{\min}}$$

Equation 8

$$NI = \frac{I_{\max} - I}{I_{\max} - I_{\min}}$$

Equation 9

Where *NI* as the normalization value, *I* is the index value or index data calculated, I_{min} is the minimum value of the index, and I_{max} is the maximum value of the index [9].

2.4 Integration of RSEI Variable

Principal Component Analysis (PCA) analysis is used to integrate the 4 indicators after normalization and weighted based on the contribution of each index to PC1 [27]. PCA has a function as a relatively important variable identifier, PCA can eliminate the impact of co-linearity between 4 variables [20]. In some previous studies, RSEI will use the database on PC1 this is because PC1 has more comprehensive information content among other PCs. The results of further RSEI calculations need to be normalized again to produce values with a range of 0–1 to be further divided into 5 classes of ecological quality. Equation 10 is used to normalize teh RSEI index.

$$RSEI = \frac{RSEI_0 - RSEI_{0-\min}}{RSEI_{0-\max} - RSEI_{0-\min}}$$

Equation 10

2.5 Land Cover Extraction and Validation

Land cover was extracted through Landsat 8 OLI imagery by utilizing the support vector machine (SVM) classification method at a scale of 1:250,000. In validating the land cover data, Cohen's kappa was used. Cohen's kappa in this study was used to validate the 2023 land cover in Semarang City. The index is a method used to test the correctness between model data and actual data in the field [28]. This study used 100 validation samples sourced from field observations and Google Earth with a stratified random sampling system based on land cover class area. The kappa (*k*) illustrated in Equations 11 to 13 are used to assess the accuracy of the land cover classification.

$$k = \frac{P_{obs} - P_{\exp}}{1 - P_{\exp}}$$

Equation 11

$$P_{obs} = \frac{TP + TN}{N}$$

Equation 12

$$P_{\exp} = \frac{(TP + TN)(TP + FP) + (FP + TN)(FN + TN)}{N^2}$$

Equation 13

Where *N* is the number of field samples, while the value of *k* has a range between -1 to 1. The closer the value is to 1, the better the agreement [29][30] and [31].

3. Result

3.1 Result of RSEI

A total of four RSEI indicators combined using the PCA method seen in Table 1 shows that from PC1 to PC4 shows a decrease in contribution rate (%). Contribution rate on PC1 >70%, which indicates PC1 has higher information than other PCs, so PC1 can be used as the basis for building the RSEI index. RSEI is classified into 5 classes to see the ecological quality from poor to excellent. The results of the RSEI-based ecological quality assessment in Semarang City appear in the spatial distribution as shown in the Figure 2 and area coverage in units (%) as shown in the Figure 3. In terms of spatial distribution, good and excellent classes tend to be scattered in the southeast, south, and west areas, which are dominated by green zones in the form of hardwood plantations, mixed plantations, and agricultural land, moderate classes tend to form randomly throughout the area, and poor and fair classes tend to cluster in urban areas and northern areas of the research area which are fish ponds and waters.

In general, the ecological quality of Semarang City has decreased, as evidenced by the mean RSEI values in 2013, 2018, and 2023, which were 0.69; 0.68; and 0.66, respectively. Statistically, as shown in the Figure 3, the combined proportion of good and excellent area is higher than 50%. This is due to the higher proportion of green zones compared to built-up land zones and water zones with a total area in 2023 of 245.13 Km^2, 115.77 Km^2, and 25.08 Km^2, respectively. However, there are drastic changes in the moderate and excellent classes. Changes that occurred in the moderate and excellent classes, especially in 2013 - 2023, showed that the moderate class increased by 14.25% and the excellent class decreased by 15.26%. Meanwhile, the poor and fair classes tend to decrease, although only below 5% in each year interval.

Table 1: Result of PCA

PC	Year	NDVI	WET	NDBSI	LST	Contribution Rate (%)
	2013	0.53	0.05	0.82	0.21	79.78
PC1	2018	0.50	0.07	0.83	0.22	80.48
	2023	0.70	0.15	0.64	0.27	72.28
	2013	0.25	0.15	-0.39	0.87	14.56
PC2	2018	0.15	0.18	-0.34	0.91	13.73
	2023	-0.71	0.22	0.64	0.20	17.29
	2013	-0.80	0.12	0.42	0.40	4.98
PC3	2018	-0.86	0.12	0.43	0.28	4.99
	2023	-0.03	0.12	-0.37	0.92	9.46
	2013	0.03	0.98	-0.03	0.20	0.69
PC4	2018	0.04	0.98	-0.05	-0.21	0.80
	2023	0.06	0.96	-0.20	-0.20	0.99

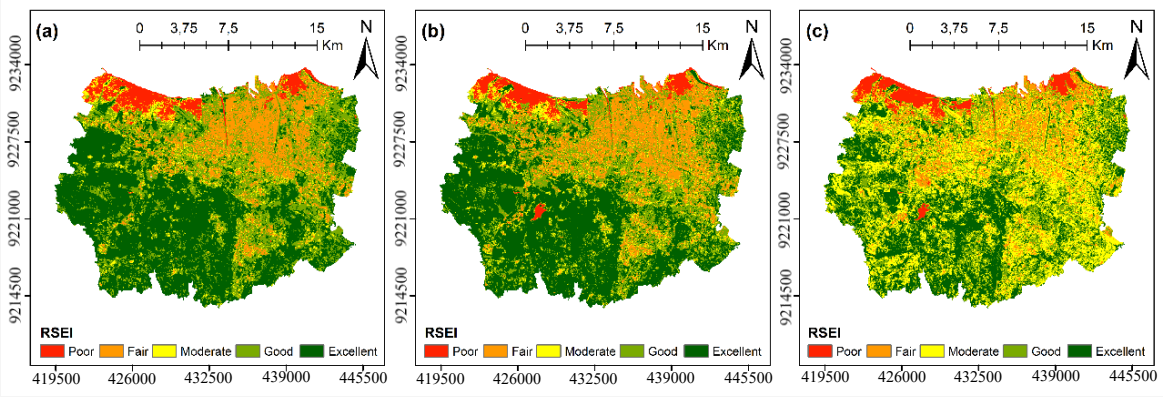

Figure 2: RSEI distribution (a) 2013 (b) 2018 (c) 2023

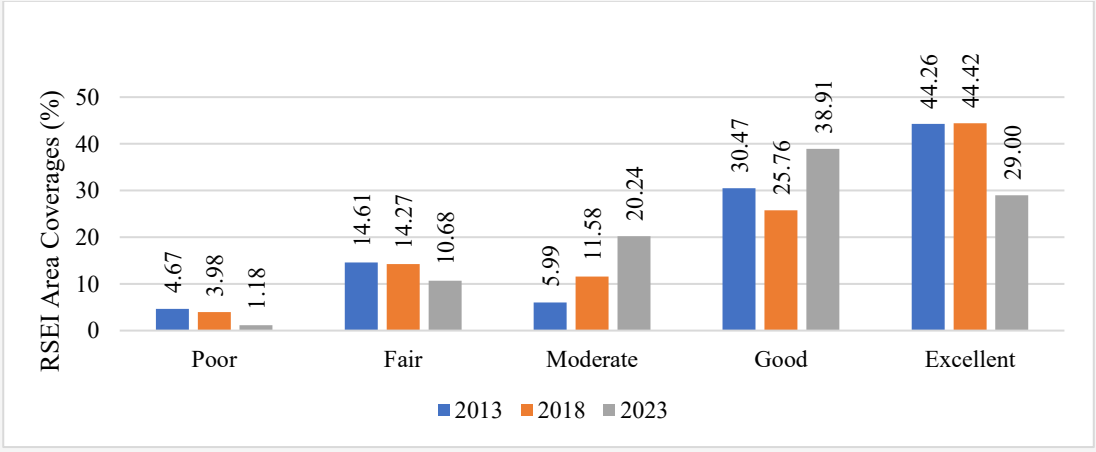

Figure 3: RSEI area proportion diagram

3.2 Ecological Changes of RSEI

The analysis of spatial-temporal changes in RSEI in Semarang City in 2013, 2018, and 2023 was conducted by dividing the RSEI class into 5 classes using the equal interval method. The identification of changes in environmental quality based on RSEI uses a value range of -4 to 4 with the following conditions: a value of -4 to -1 indicates a degraded; a value of 0 indicates no change or stable; and a value of 1 to 4 indicates an improved. The spatial distribution and statistics of the percentage of RSEI change area are presented in Figures 4 and 5, RSEI degradation in each year range slowly shows significant expansion, especially in vegetated areas that are evenly distributed in the research area.

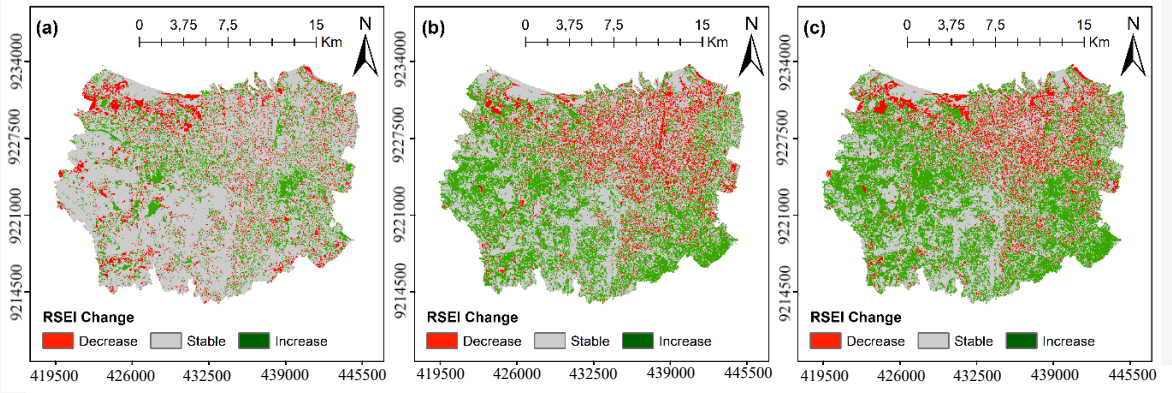

Figure 4: RSEI area change: s(a) 2013 to 2018 (b) 2018 to 2023 (c) 2013 to 2023

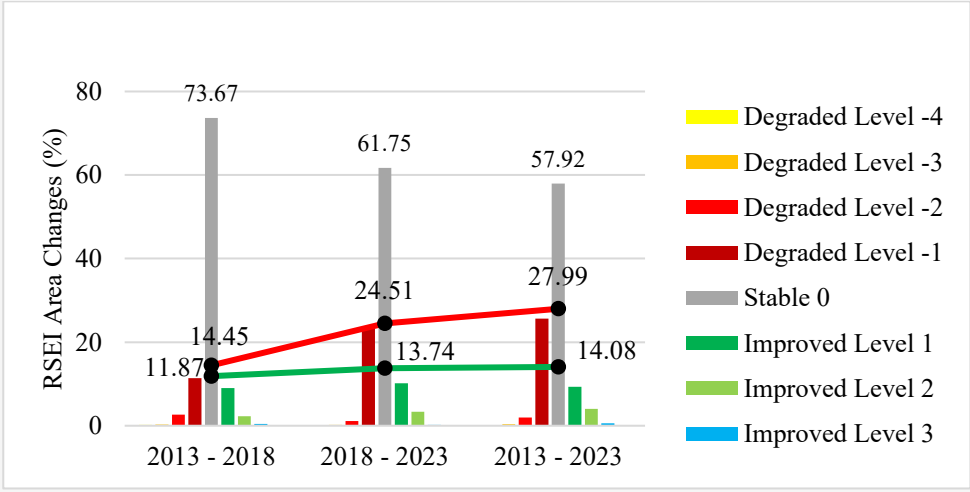

Figure 5: RSEI area changes statistics

Meanwhile, the quality improvement aspect tends to increase in the waters of the north side of the study area. Assessment of changes in ecological quality in terms of statistics on the aspect of degradation, level-1 degradation is the level that has the highest area in all year intervals. Level-1 degradation has an average area proportion of 25.60%, which always increases in each year interval. The year 2013-2023 is the interval that has the highest degradation area with an area proportion of 27.99%. In the aspect of improving ecological quality, improvement at level 1 is also the level that has the largest proportion of area in all year intervals, with an average area of 9.51%. Specifically, the pattern formed at level 1 improvement status shows an increasing graph and then falls back, although the difference is not much different with the highest proportion of area in the 2018-2023 interval of 10.16%. In the aspect of ecological quality that has not changed or is stable, at each year interval it always decreases, whereas in the intervals of 2013–2018, 2018–2023, and 2013–2023 it is 73.67%, 61.75%, and 57.92% respectively.

The ecological quality status is the status that has the highest proportion of area compared to all levels used, as well as indicating changes in ecological quality that are decreasing. Overall in the intervals of 2013–2018, 2018–2023, and 2013–2023, in the aspects of ecological quality degradation and improvement, although both increased the degradation aspect showed a higher total area than the total area of improvement in each year interval. Furthermore, the degradation of ecological quality is 14.45%, 24.51%, and 27.99% respectively; the improvement of ecological quality is 11.87%, 13.74%, and 14.08% respectively. Meanwhile, ecological quality in stable status shows a decreasing trend with a total area of 73.67%, 61.75%, and 57.92%, respectively.

3.3 RSEI Ecological Quality Change in Land Cover

In observing the RSEI changes to each land cover zone, Figure 6 shows the conversion of land cover data converted into 3 zones.

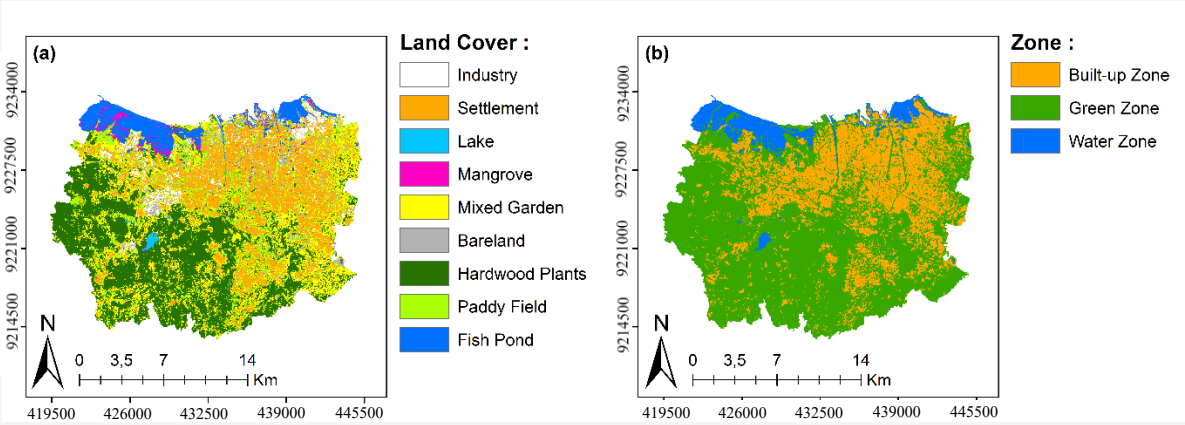

Figure 6: Conversion of land cover zone map of 2023 (a) land cover (b) zoning land cover

The 3 zones are built-up land zone, green zone, and water zone with a total area of 386 Km^2. The built-up land zone is composed of settlements, industries, and bareland, the green zone consists of mangrove, hardwood plantations, mixed garden, and paddy fields, while the water zone is composed of fish ponds, and lakes. The data used to construct these zones is 2023 land cover data sourced from Landsat 8 OLI imagery in 2023 and integrated with data on changes in ecological quality in the interval 2013–2023. To facilitate interpretation, each zone's total area was aggregated to 100%. The results of Cohen's kappa validation by utilizing 100 samples, found that the accuracy obtained was 0.851 or 85.1%. The built-up land zone with a total area of 115.77 Km^2 and the green zone with a total area of 245.13 Km^2 have a higher difference in degradation area than the improvement of ecological quality, with a difference of 5.63% and 19.62% respectively, but both zones from the aspect of ecological quality stability both show a higher proportion of ecological quality stability than the proportion of degradation and improvement, with a difference of 3.92% and 9.55% for the built-up land zone and 40.92% and 60.54% for the green zone respectively. The water zone with a total area of 25.08 Km^2 has different conditions compared to other zones, where there is a more significant improvement in ecological quality compared to degraded and stable ecological quality, although specifically the improvement formed is poor class to fair and moderate class. This condition is caused by changes in water conditions, especially in coastal areas, which tend to be turbid in the 2013–2023 timeframe, thus affecting the ecological index formed. In detail, the aspects of degradation, improvement, and stability of ecological quality are 11.84%, 76.04%, and 12.13%, respectively.

4. Discussion

This research has the main objective to assess changes in ecological quality based on RSEI using Landsat 8 OLI image data with recording years 2013, 2018, and 2023 and land cover data in 2023 in Semarang City. The analysis of changes in ecological quality was conducted because Semarang City experienced urban sprawl due to the high development of public facilities and infrastructure, especially in the urban center, which encouraged the creation of industrial and trade areas [2] and [3]. Ecological quality statistically tends to decline in all three years, indicating that Semarang City tends to experience a decline in ecological quality. In terms of spatial distribution, urban areas with a lot of built-up land tend to have poor quality, while green zones with a lot of vegetation tend to have good conditions. These findings are in accordance with the research of [15][32] and [33] where ecological quality will increase further away from the urban center, as seen in the Figure 7 Furthermore, areas classified as green zones tend to have better ecology, this is in accordance with [14] and [34], who state that green zones tend not to be much intervened by human activities.

The aspect of ecological quality changes to land cover as seen in Figure 8 shows that the built-up land zone and green zone tend to experience a higher proportion of ecological quality degradation than the improvement in RSEI. In line with this, research by [35] and [36] a decrease in the proportion of vegetation will have implications for a decrease in ecological quality, so that these conditions reflect that in the 2013-2023 period, Semarang City in the built-up land zone and green zone both experienced a decrease in vegetation area.

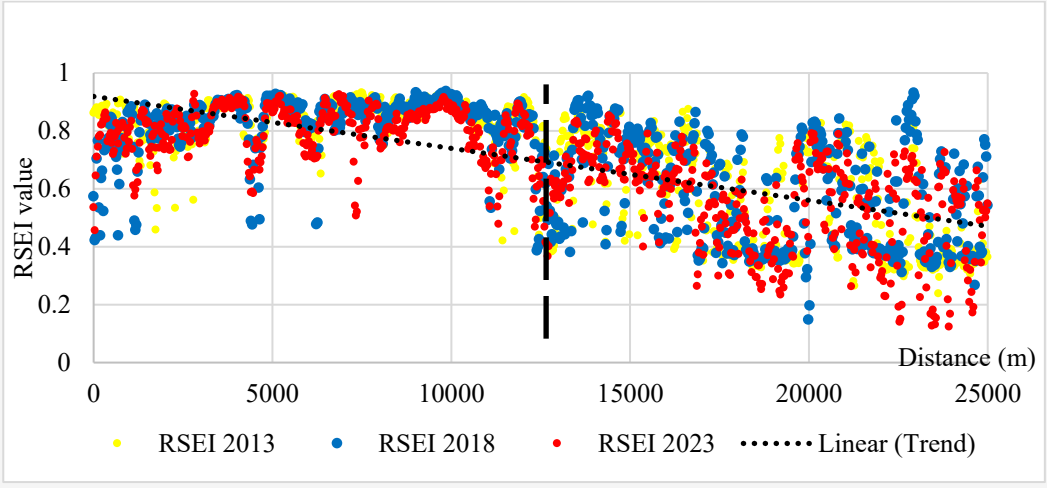

Figure 7: RSEI Cross Section

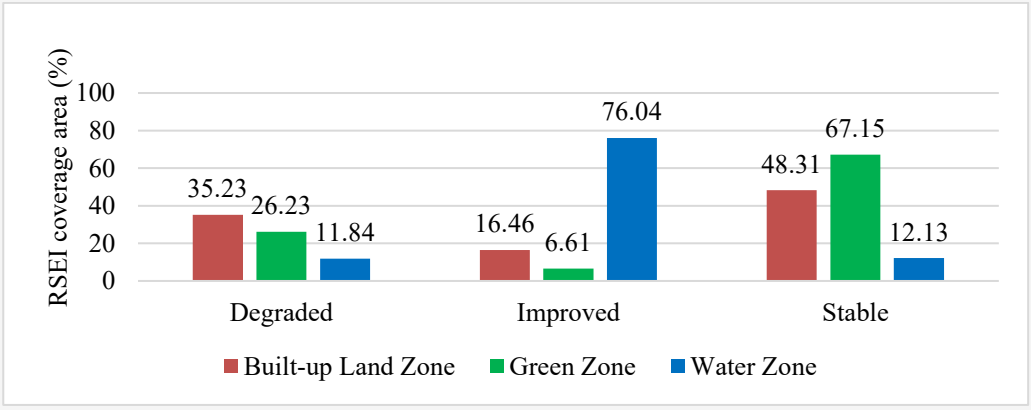

Figure 8: RSEI statistics on land cover zones

In addition, the condition of RSEI is also influenced by the season, research conducted by [37] on the ecological index in Bandung and Semarang City states that the rainy season will increase the contribution of greenness and humidity indicators that correlate with increasing ecological quality. This emphasizes the findings in this study, where even though image recording was carried out in the rainy season, the fact is that when compared between aspects of improvement and degradation, the built-up land zone and green zone show a higher proportion of degradation. Meanwhile, the increase in the water zone is more due to the process of turbidity, which affects the results that appear.

5. Conclusion

The analysis of changes in ecological quality based on RSEI is motivated by the condition of Semarang City, which has experienced urbanization in the last 10 years, causing green space degradation due to development pressure. This research has the main objective to determine the changes in ecological quality based on RSEI and its dynamics towards three zones representing land cover. The main data used are Landsat 8 OLI images in 2013, 2018, and 2023 to extract RSEI data and land cover data in 2023. Overall, this study found that: (1) ecological quality in Semarang City during 2013-2023 tends to decline, as evidenced by the mean RSEI value of 0.69 for 2013, 0.68 for 2018, and 0.66 for 2023; (2) although the area of ecological quality with stable status has a higher proportion than the status of improvement and degradation, especially in the green zone and built-up land zone, in both zones in the interval of 2013-2023, the proportion of degradation area is higher than the area of improvement, with coverage area above 20% in both zones.

Meanwhile, in the water zone, especially in coastal areas that tend to experience turbidity, the proportion of ecological quality improvement status is higher than the degradation and stable status with 11.84%, 76.04%, and 12.13% of stable, improvement and degradation status respectively.

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